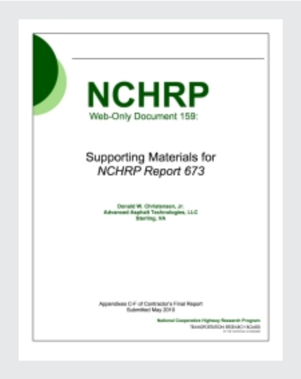

Supporting Materials for NCHRP Report 673

DETAILS

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NCHRP PROJECT 9-33:
A MIX DESIGN MANUAL FOR HOT MIX ASPHALT

REVISED FINAL REPORT

APPENDIX C:
COURSE MANUAL
FOR INSTRUCTORS AND PARTICIPANTS

May 13, 2010

Advanced Asphalt Technologies, LLC

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ACKNOWLEDGEMENT

This Course Manual was developed as part of NCHRP Project 9-33: A Mix Design Manual for Hot Mix Asphalt. The primary author of this Manual is Dr. Donald Christensen, who developed the slides for the course and compiled the manuals. Contributing authors for the Course Manual are Dr. Ramon Bonaquist and Dr. Allen Cooley, who contributed indirectly by providing some of the technical input upon which this course is based. This Course Manual is meant to accompany the *NCHRP Project 9-33 Mix Design Manual for Hot Mix Asphalt*.

INTRODUCTION

This Course Manual has been compiled for both Instructors and Participants for a one-day short course on the NCHRP 9-33 Mix Design Manual. The manual consists of copies of the slides used in the short course, along with several printed pages of data and a course evaluation sheet. The course itself consists entirely of Microsoft PowerPoint slides; this format was selected to make the course easy for Instructors to teach. Students and Instructors should review the Course Manual before the course, especially the front material so they are familiar with the objectives of the course and the course structure.

Although designed as a one-day course, shorter versions of the course can be delivered by eliminating some of the nine instructional units. A second version of the course is a half-day course which eliminates detailed coverage of RAP. A third version is only two hours long, presenting a short overview of the Mix Design Manual and HMA Tools for managers and executives. Schedules for all three versions of the course are given below. Instructors should modify the schedule given in Unit 1 if they are presenting one of the abbreviated versions of the course.

OBJECTIVES FOR THE COURSE

The main objective of this course is to provide the participants with a basic working knowledge of the mix design procedure for dense-graded HMA as outlined in the NCHRP 9-33 Mix Design Manual. Participants should be able to prepare an HMA mix design following the procedure described in the manual. Participants should be able to use the HMA Tools spreadsheet in preparing a typical HMA mix design, although some may wish to use other programs or spreadsheets in doing mix design work. At the conclusion of the course, participants should be able to explain the basic steps in the mix design process, and the differences between the procedure in the NCHRP 9-33 Mix Design Manual and the Superpave System of Mix Design. The participants should be able to explain in general terms how to incorporate RAP into a mix design, including RAP binder grade analysis and RAP variability analysis. Course participants should be able to describe the capabilities of the HMA Tools spreadsheet, and should also be able to use the spreadsheet in preparing a typical HMA mix design, including the incorporation of RAP.

DESCRIPTION OF THE COURSE MATERIALS

The course materials include the Instructor's Manual, the Participant's Manual, and the course slides. The table below outlines the slides used in the course. The Instructor's Manual and Participant's Manual are identical. The Course Instructor may wish to delete the notes on the slides in the manual—this would leave more room for the participants to take notes. These notes were primarily intended for the Instructor, but participants might also find them useful. At the end of this section of front material is an evaluation form that participants should be encouraged to fill out and return to the Instructor at the conclusion of the course.

OUTLINE OF COURSE SLIDES

Unit	Topic	Number of Slides
1	Welcome, Orientation and Announcements	3
2	Introduction/Frequently Asked Questions	27
3	Overview of Dense-Graded HMA Mix Design	16
4	Overview of HMA Tools	21
5	Mix Design Example Problem, Part 1	34
6	Quiz on Part 1 of the Mix Design Example Problem	21
7	Mix Design Example Problem, Part 2	36
8	Mix Design Example Problem, Part 3: Working with RAP	43
9	Quiz on Part 3 of the Example Problem—Mix Design with RAP	17

PREPARING TO TEACH THE COURSE

The course instructor should be experienced pavement engineers or technicians with a reasonable amount of experience in both HMA mix design and public speaking. The instructor should first do the Tutorial included in the CD that contains this manual and make sure they understand the material presented in it. It is a good idea to read Chapters 8 and 9 in the Mix Design Manual prior to teaching the course. He/she should then thoroughly review the Course Manual and make sure they understand the schedule and the content of each unit. If at all possible, the instructor should make a practice run through the course—if not every unit, then the most important ones—Units 5, 7 and 8. Print out the Participant Manuals for the course, allowing a few extra for visitors or for last minute attendees. Make sure the room that the course is scheduled in is large enough to comfortably fit all participants and that the facilities include a screen and a computer and projector. Inspect the room and facilities the evening before the course, or if that is not possible, early in the morning the day of the course. The Instructor should make sure the computer and projector are working properly and that he/she is comfortable with the room setup and any other equipment he/she will be using during the course.

PREPARING TO TAKE THE COURSE

Technicians and engineers taking this course should review the manual so they know what to expect. If possible, they should go over the Tutorial on the CD before taking the course. If this is not possible, the Tutorial can be done a week or two after taking the course as a review. Since many of the slides used in the course deal with HMA Tools, it would be helpful for participants to take a few minutes to familiarize themselves with this spreadsheet.

TAILORING THE COURSE TO SPECIFIC AGENCIES

The Course Manual, slides and HMA Tools spreadsheet have all been designed around the NCHRP 9-33 Mix Design Manual. A large degree of flexibility has been built into all of these materials, so that if desired they can be tailored to individual agencies. For example, the mix design method allows specifying agencies to maintain current levels of minimum VMA, or to increase these values by up to 1.0 % for improved durability. There is also some flexibility in dust:binder ratio and aggregate specifications. An important question for Instructors is how to tailor the course to individual agencies.

The first issue that must be addressed is HMA Tools; this spreadsheet can easily be customized by changing values in worksheet “Specifications.” Virtually any specification property can be changed by simply altering appropriate values in this worksheet. Furthermore, there is room for up to two additional coarse aggregate specification properties and two additional fine aggregate properties. Ideally, if you are teaching a course tailored to a specific state highway agency, HMA Tools should first be modified to reflect the specifications in effect for that agency. The course slides and the manual ideally should then be modified to reflect these specification changes. The procedure for doing this is straightforward. The Instructor should enter the data for the example problems into the modified version of HMA tools, and then go through the Course Manual and replace slides showing HMA Tools screens that have changes as a result of the modified specifications. This is done simply by deleting the existing slide from the Word Perfect file, copying the slide from Power Point and then using the “paste special” command and pasting the slide into the Course Manual as an “enhanced metafile.” Some Instructors comments may need to be modified.

Alternately—and perhaps more simply—the Instructor could go through the manual and produce a custom version of the participant manual that includes additional notes describing differences between what is in the course slides and the local specification and practice. A similar option would be to add an additional unit describing the specifications and practice of the local agency, and, if desired, showing a few slides of the HMA Tools spreadsheet with the appropriate modifications.

TIPS FOR TEACHING A SUCCESFUL COURSE

- Be well prepared—go through the Tutorial and review the Course Manual
- Read Chapters 8 and 9 of the Mix Design Manual carefully prior to teaching the course
- Practice delivering the course materials—especially units 5, 7 and 8.
- Inspect the room before the course begins and make sure all equipment is working properly.
- The course schedule is only a guideline. Be flexible.
- The scheduled breaks should be considered a minimum. Give more breaks if possible. Most people find it hard to focus on a technical slide presentation for longer than about 30 minutes.
- Answer questions that you can, and if you can't, admit it and refer the participant to someone who can answer the question or get back to the participant later with the answer.
- Encourage participants to fill out and turn in the evaluation form that appears at the end of this section. They should be reminded throughout the course to note any suggestions after each unit while their ideas are fresh in their minds. The forms are meant to be anonymous.

If the Course is Going too Slowly...

- Keep the breaks to the minimum—scheduled breaks only. Don't extend the breaks.
- If there are too many questions during the units, ask participants to hold their questions till the end of the unit. Limit the questions to a reasonable number and tell the students they can meet with you during break, lunch or after the class if they have additional questions.
- Don't spend time during the units on non-essential details—emphasize the important points.
- Remember that many participants have busy schedules and may have commitments after the course is over. Try as much as possible to finish the course on time.

If the Course is Going too Quickly…

- Give additional breaks during the presentation. Give slightly longer breaks.
- Encourage questions and discussions during the units
- Take additional time to discuss details on the slides.
- It's OK to finish early—many participants have busy schedules and will be happy to finish earlier than scheduled.

COURSE SCHEDULES

ONE-DAY COURSE

Time	Activity
8:30 am	Welcome, Orientation and Announcements
8:45 am	Introduction/Frequently Asked Questions
9:30 am	Overview of Dense Graded HMA Mix Design
10:00 am	Overview of HMA Tools
10:30 am	Break
10:45 am	Example Mix Design Problem, Part 1
11:45 am	Quiz 1
12:00 noon	Lunch
1:00 pm	Example Mix Design Problem, Part 2
2:00 pm	Break
2:15 pm	Example Mix Design Problem, Part 3: Working with RAP
3:45 pm	Break
4:00	Quiz 2
4:15 pm	Questions/Evaluations
4:30 pm	Adjourn

HALF-DAY COURSE

This version does not cover the use of RAP in detail.

Time	Activity
8:30 am	Welcome, Orientation and Announcements
8:45 am	Overview of Dense Graded HMA Mix Design
9:15 am	Example Mix Design Problem, Part 1
10:15 am	Break
10:30 am	Quiz 1
10:45 am	Example Mix Design Problem, Part 1
11:45 am	Questions/Evaluations
12:00 noon	Adjourn

TWO-HOUR COURSE

This version is a short overview for executives and managers.

Time	Activity
8:30 am	Welcome, Orientation and Announcements
8:45 am	Introduction/Frequently Asked Questions
9:15 am	Overview of Dense Graded HMA Mix Design
9:45 am	Overview of HMA Tools
10:15 am	Questions/Evaluations
10:30 am	Adjourn

NOTE: The course Instructor should modify the outline given in the slides in Unit 1 of the course if he/she is presenting an abbreviated version.

NCHRP Project 9-33: A Mix Design Manual for Hot Mix Asphalt

COURSE EVALUATION FORM

1. Which version of the course did you participate in? (circle one)

• Full-day • Half-day • Two-hour

2. Rate the overall effectiveness of the Instructor (circle one):

1	**2**	**3**	**4**	**5**	**6**	**7**
unacceptable			average/fair			excellent

3. Rate the overall effectiveness of the course (circle one):

1	**2**	**3**	**4**	**5**	**6**	**7**
unacceptable			average/fair			excellent

SUGGESTIONS

Please use the space below to provide suggestions to improve the course content or structure. Please be specific and include the unit that your suggestion deals with. You may use the back of the page if necessary.

NCHRP Project 9-33: A Mix Design Manual for Hot Mix Asphalt

UNIT 1: WELCOME, ORIENTATION AND ANNOUNCEMENTS

Number of Slides: 3

Approximate Time Required: 15 minutes

Purpose of Unit: to go over the course schedule, make any needed announcements and give participants information on layout of facility—where bathrooms are, where lunch will be held, etc...

Important Concepts

- The course schedule is approximate and flexible. Some units might be longer than scheduled, some might be shorter.
- The manuals have printouts of all the slides with room for a few notes in the margins and underneath each slide.
- There are several sheets in the front of the manual for doing course evaluations and making suggestions. Encourage the participants to right down suggestions as we go through the course and to take a few minutes at the end of the course to complete the evaluation and hand it in. No names—these are meant to be anonymous.
- You should make every reasonable effort to make sure that you do not finish later than scheduled.

Description of Slides: There are only three slides which give the course schedule.

Instructor's Notes

Course Schedule

Time	Activity
8:30 am	Welcome, announcements
8:45 am	Introduction
9:30 am	Dense-graded mix Design Overview
10:00 am	Overview of HMA Tools
10:30 am	Break
10:45 am	Example Mix Design, Part 1

1

Slide 1-1

The schedule is only approximate. You can give additional breaks if you want. Remember—it is difficult to stay focused for more than about 30 minutes during a slide presentation.

Course Schedule

Time	Activity
11:45 am	Quiz 1
12:00 noon	Lunch
1:00 pm	Example Mix Design, Part 2
2:00 pm	Break
2:15 pm	Example Mix Design, Part 3: Working with RAP

2

Slide 1-2

Course Schedule

Time	Activity
3:45 pm	Break
4:00 pm	Quiz 2
4:15 pm	Questions/Evaluations
4:30 pm	Adjourn

3

Slide 1-3

NCHRP Project 9-33: A Mix Design Manual for Hot Mix Asphalt

UNIT 2: INTRODUCTION/FREQUENTLY ASKED QUESTIONS

Number of Slides: 27

Approximate Time Required: 45 minutes

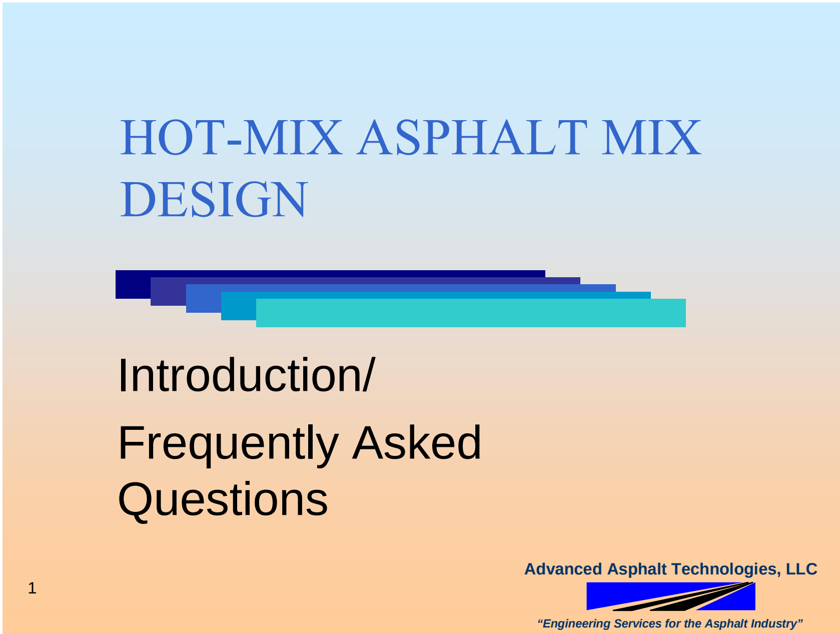
Purpose of Unit: To provide an introduction to the materials on the CD, including the Mix Design Manual, the Commentary and the HMA Tools Spreadsheet.

Important Concepts

- Most technicians and engineers don't need to read the Commentary—it's meant for researchers
- Experienced technicians and engineers don't need to read the whole manual. Chapter 8 is the most important—it describes how to do dense graded HMA mix designs. Chapter 9 on recycled asphalt pavement (RAP) is also important.
- HMA Tools is a comprehensive spreadsheet for doing dense-graded HMA mix designs. We will be referring to HMA Tools frequently throughout the course. If you have another spreadsheet or program you like to use for mix design work, you can use it as long as mix design requirements are meant.
- The requirements for dense-graded HMA are very similar to those in Superpave, but there are a few differences. The most important are that the aggregate specifications are slightly less restrictive.
- The new mix design method requires rut resistance testing for mixes designed for 3 million ESALs or more. Any one of six widely used performance tests can be used.

Description of Slides: These slides are in the form of frequently asked questions (FAQ). A slide poses a question concerning materials on the CD, and the following slide (or sometimes several) gives the answer to the question. This set of slides is included on the CD and some of the participants might have already gone over them. The instructor should ask that those who have already reviewed these slides be patient while they are reviewed for those who haven't yet read them.

Instructor's Notes

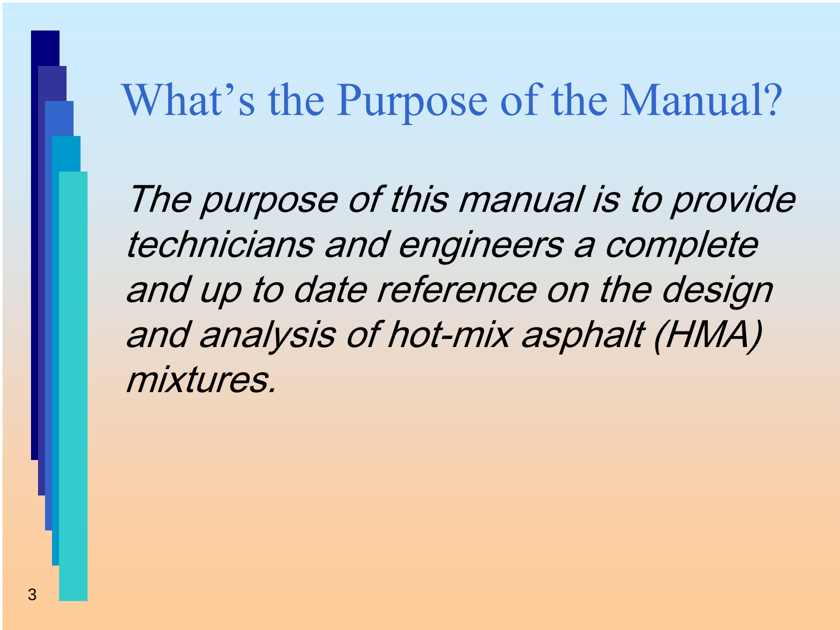


Slide 2-1

This unit is an introduction to the material that's on the CD. These slides are included on the CD and some of the participants might have gone over them already on their own. They need to be patient while they are reviewed for those who haven't seen them yet.

Slide 2-2

The participants don't need to read the Commentary—it is very technical and meant for research engineers. Doing the tutorial will help learning about the manual and HMA Tools. Participants could go through this after finishing the course as a review if they haven't done it already.



Slide 2-3

Slide 2-4

What’s in the Mix Design Manual isn’t a big change from Superpave. It includes a lot of information from different places that is now all in one document.

What's in the Manual?

Chapter 1	Introduction
Chapter 2	Background
Chapter 3	Asphalt Binders
Chapter 4	Aggregates

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Slide 2-5

Make sure the participants know that they don't need to read the entire manual. Experienced technicians will only need to read one or two chapters carefully.

What's in the Manual? (continued)

Chapter 5	Mixture Volumetric Composition
Chapter 6	Evaluating the Performance of Asphalt Concrete Mixtures
Chapter 7	Selection of Asphalt Concrete Mix Type
Chapter 8	Design of Dense-Graded HMA Mixtures

6

Slide 2-6

What's in the Manual? (continued)

Chapter 9	Reclaimed Asphalt Pavement
Chapter 10	Design of Gap-Graded HMA Mixtures
Chapter 11	Design of Open-Graded Mixtures
Chapter 12	Field Adjustments and Quality Control of HMA Mixtures

7

Slide 2-7

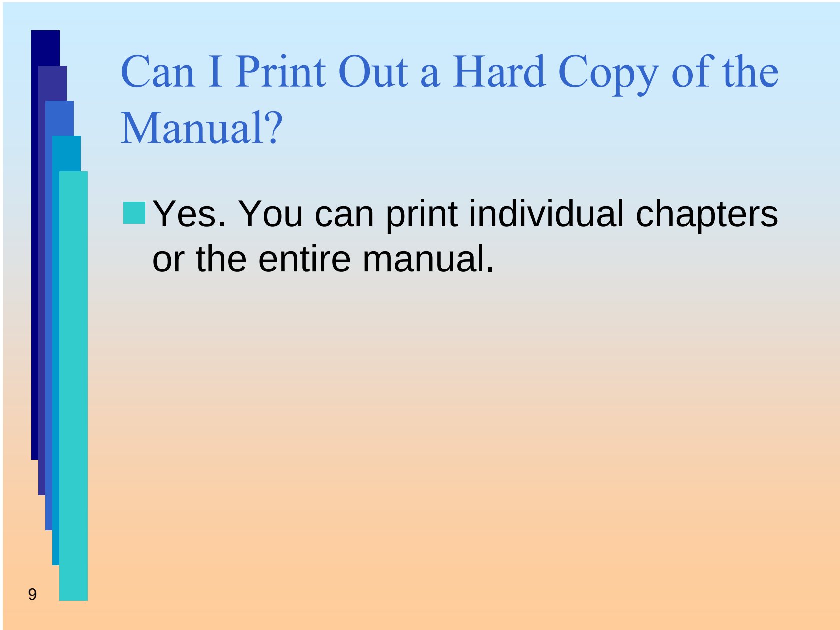
The Manual is Really Long. What Are the Most Important Parts?

- Chapter 8: Design of Dense-Graded HMA Mixtures
- Chapter 9: Reclaimed Asphalt Pavement
- Technicians and engineers with little or no experience may also find Chapters 1 through 6 useful.

8

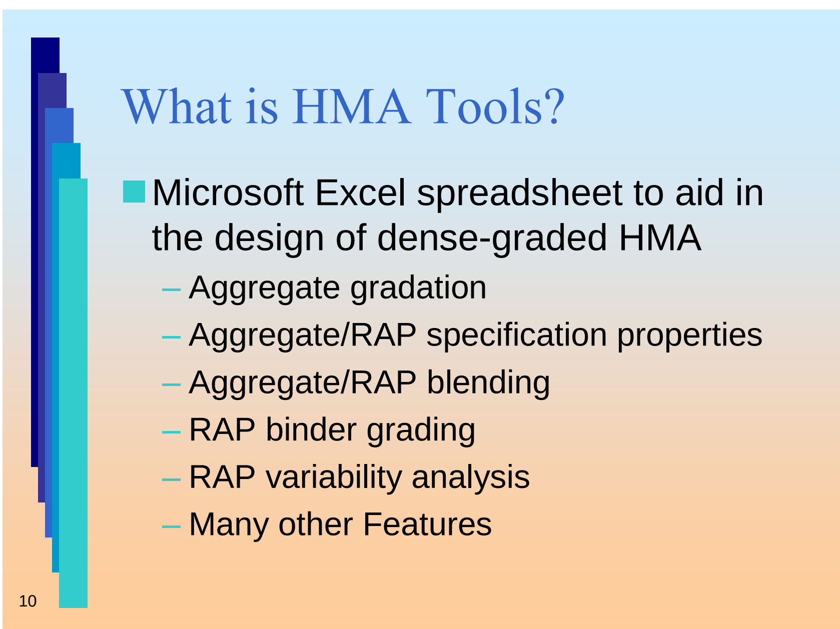
Slide 2-8

Chapter 8 and 9 are the most critical. Chapters 1 through 6 given useful background information for inexperienced engineers and technicians.



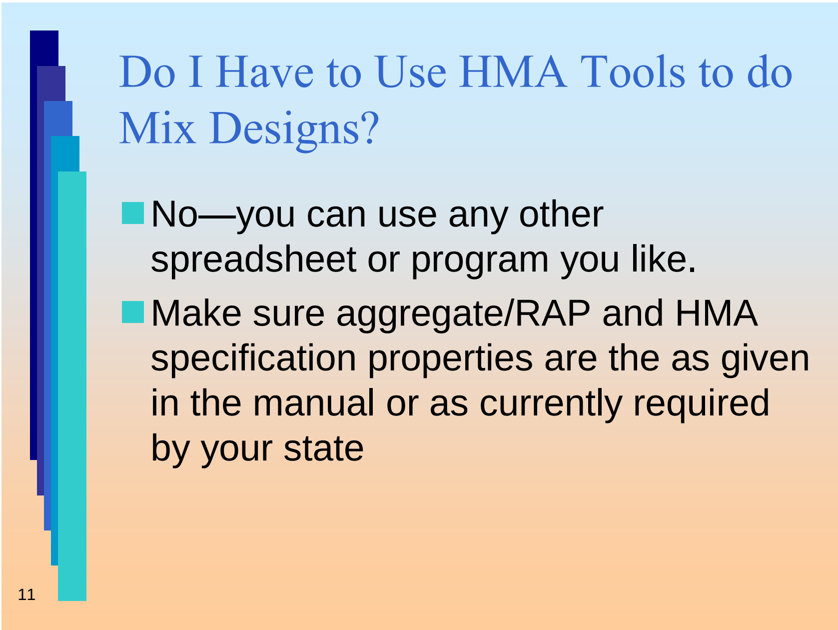
Slide 2-9

Most participants will probably find a hard copy of Chapter 8 especially useful. They probably will not need to print out the other chapters.

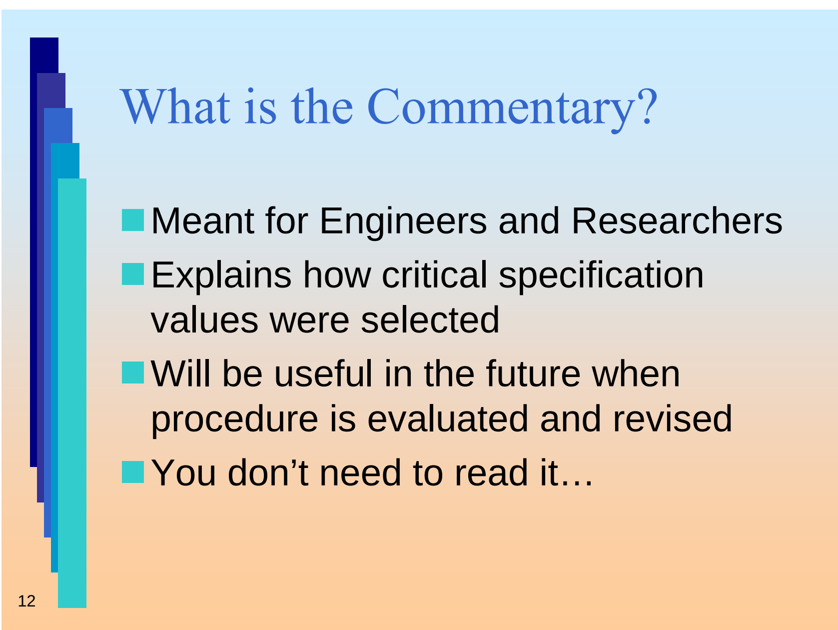


Slide 2-10

HMA Tools is covered in more detail later in the course.

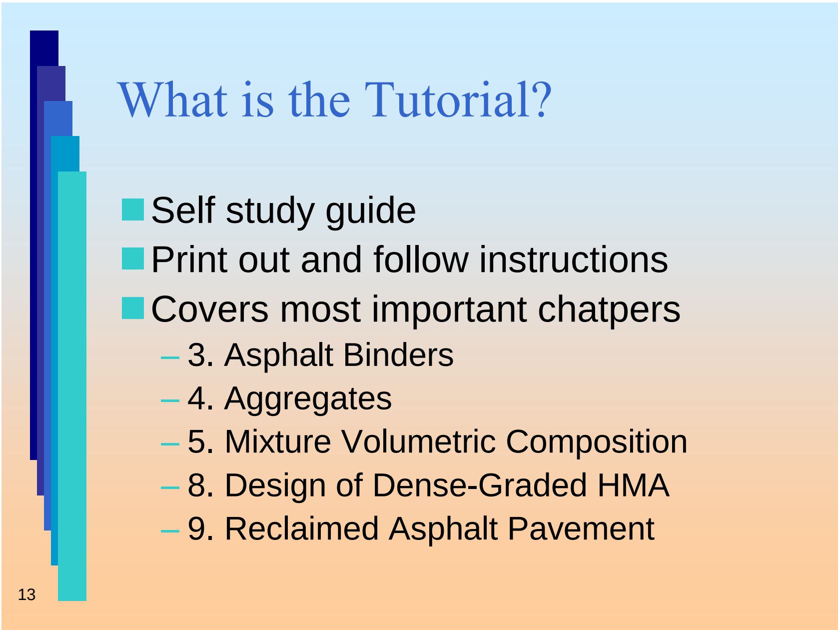


Slide 2-11



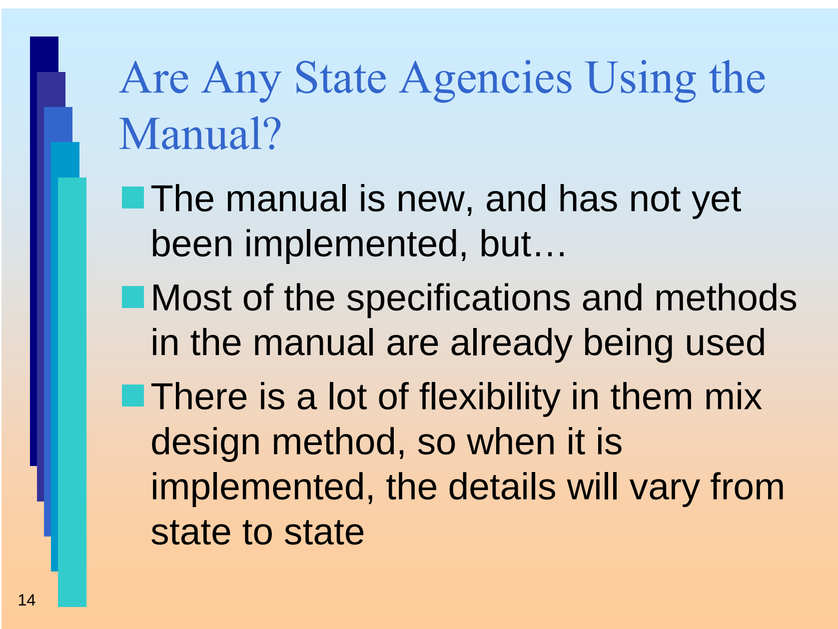
Slide 2-12

The Commentary is very technical and not meant for routine use. That's why it's a separate document.

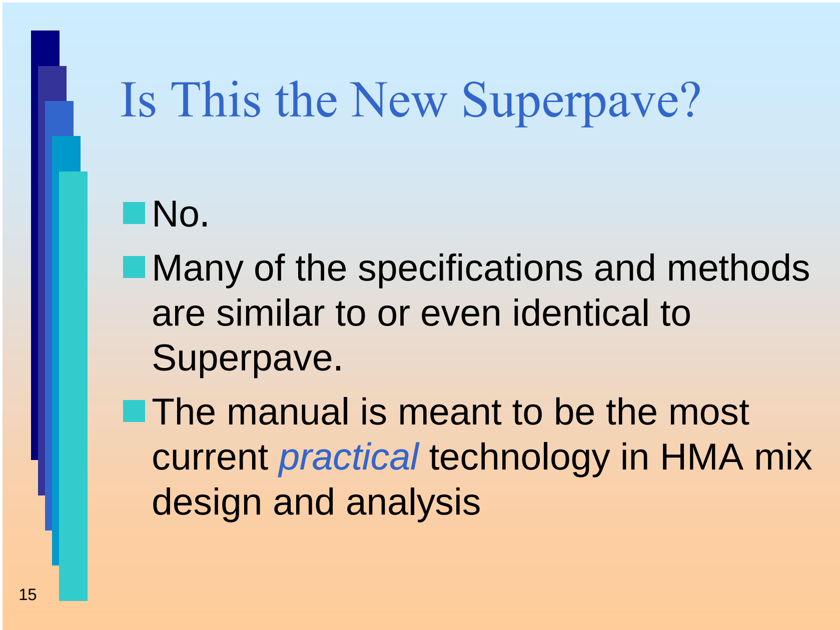


Slide 2-13

Again, participants may find this a good exercise for review after completing the course.

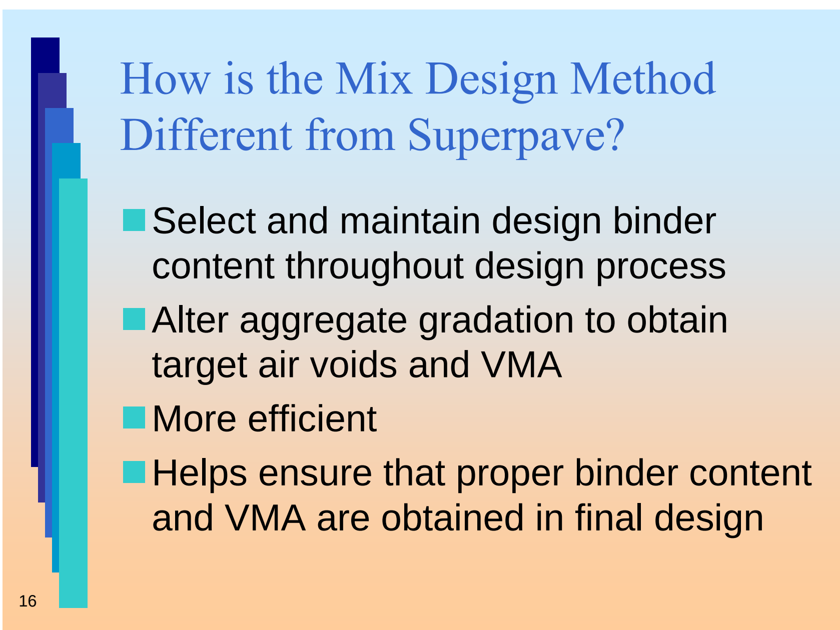


Slide 2-14

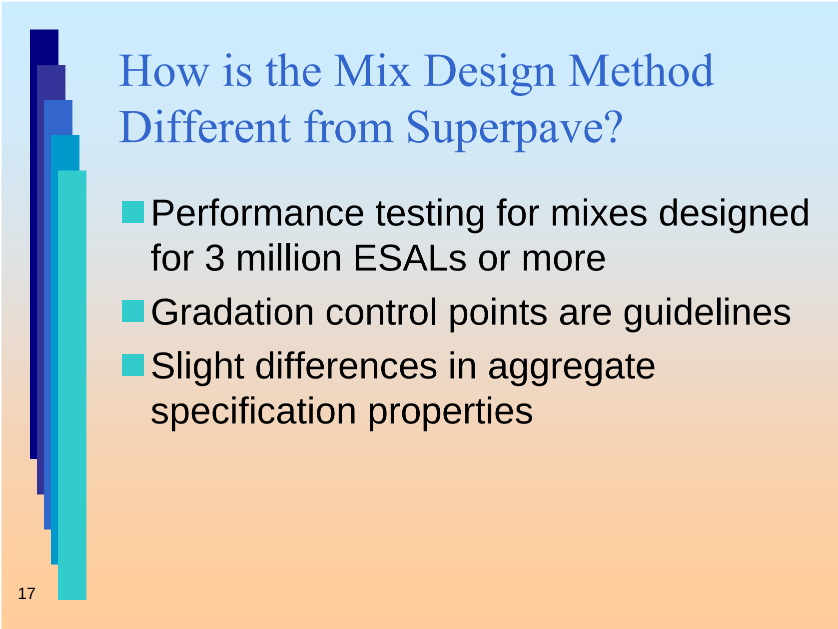


Slide 2-15

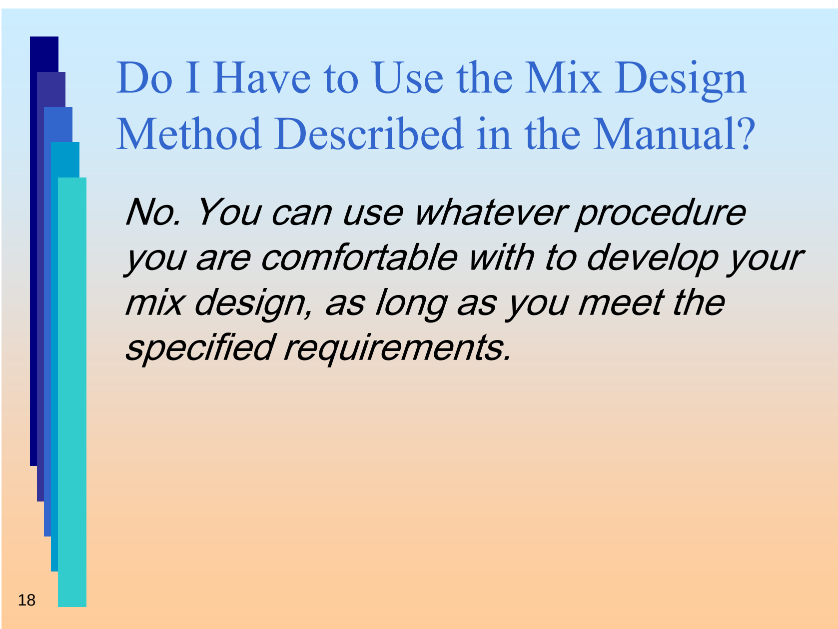
It is very similar to Superpave, but there are a few differences.



Slide 2-16



Slide 2-17



Slide 2-18

You should emphasize the difference between a mix design procedure and mix design requirements. The procedure is the steps you take in the laboratory to develop a mix design, which then must meet specific requirements. You can use any procedure you like, but you must in the end meet the requirements for VMA, air voids and so forth.

What Specifications are Different in the Manual Compared to Superpave?

- Coarse aggregate angularity (now called fractured faces)
- Fine aggregate angularity
- Aggregate gradation control points
- Mix performance testing (rut tests)

19

Slide 2-19

What are the New Requirements for Fractured Faces?

Design ESALs (millions)	Percentage of Particles with at Least One/Two Fractured Faces for Depth of Pavement Layer[A]	
	0 to 100 mm	> 100 mm
< 0.30	55 / ---	--- / ---
0.3 to < 3	75 / ---	50 / ---
3 to < 10	85 / 80	60 / ---
10 to < 30	95 / 90	80 / ---
30 or more	98 / 98[B]	98 / 98[B]

Note A: *Depth of pavement layer is measured from the pavement surface to top of the layer containing the given mixture.*
Note B: *The CAFF requirement for design traffic levels of 30 million ESALs or more may be reduced to 95/95 if experience with local conditions and materials indicate that this would provide HMA mixtures with adequate rut resistance under very heavy traffic.*

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Slide 2-20

The aggregate specifications in the manual are slightly less restrictive than in Superpave.

What are the New Requirements for Fine Aggregate Angularity?

Design ESALs (millions)	Depth to Top of Pavement Layer from Pavement Surface[A]	
	0 to 100 mm	Below 100 mm
< 0.30	---[B]	---
0.30 to < 3	40	---
3 to < 10	45[C]	40
10 to < 30	45[C]	45[C]
30 or more	45[C]	45[C]

***Note B:** Although there is no FAA requirement for design traffic levels < 0.30 million ESALs, consideration should be given to requiring a minimum uncompacted void content of 40 % for 4.75 mm nominal maximum aggregate size mixes.*

***Note C:** The FAA requirement of 45 may be reduced to 43 if experience with local conditions and materials indicate that this would produce HMA mixtures with adequate rut resistance under the given design traffic level*

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Slide 2-21

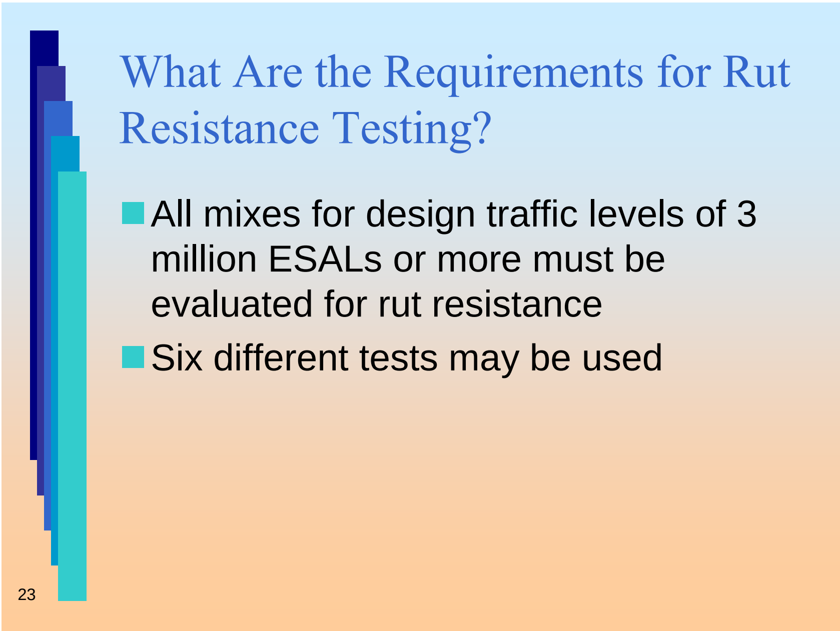
What Are the New Requirements for Aggregate Gradation?

- The control points for aggregate gradation have not changed
- The control points are guidelines, and not a requirement
- This will make it easier to meet VMA and other requirements

22

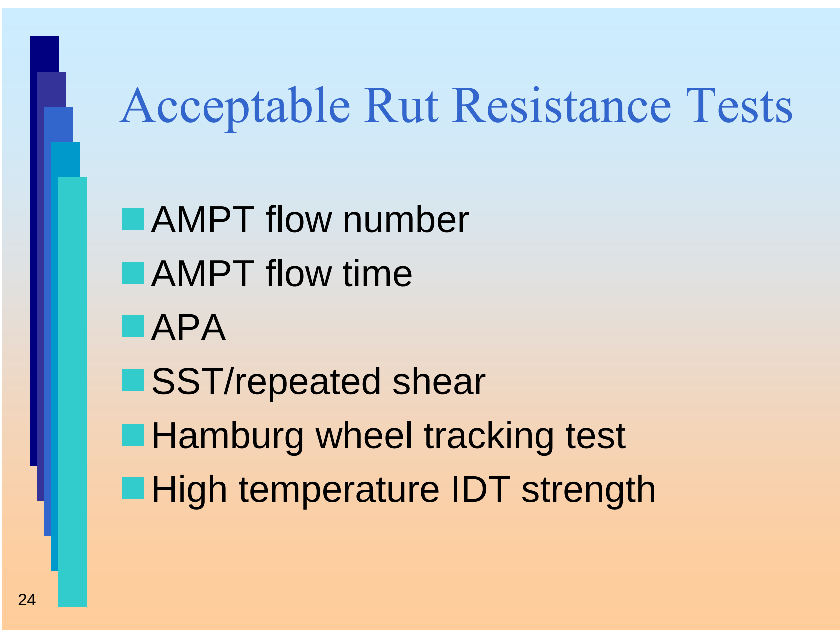
Slide 2-22

You should try to stay within the control points, but you can go outside them if you need to meet VMA and air void requirements.

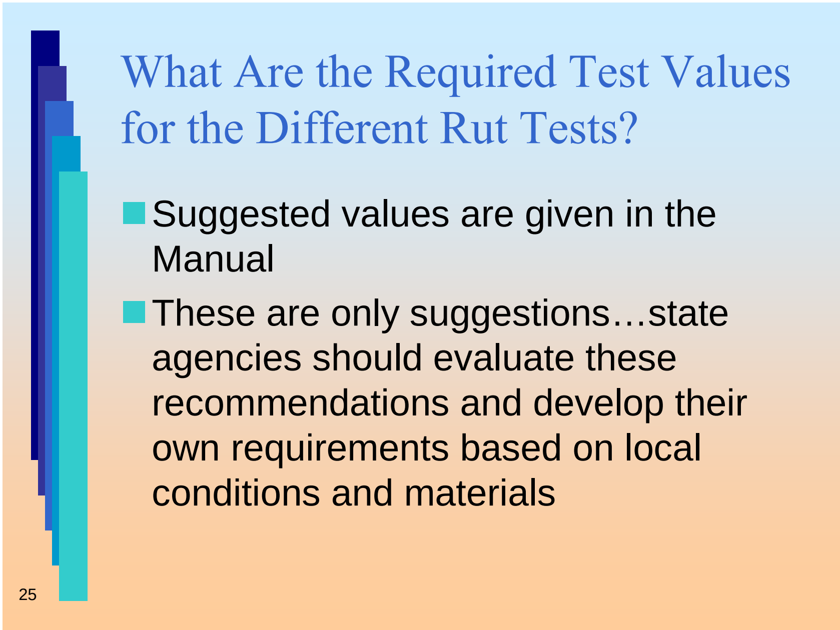


Slide 2-23

Many states already have performance test requirements. Point out to participants that they normally should be following their state's requirements for performance testing.

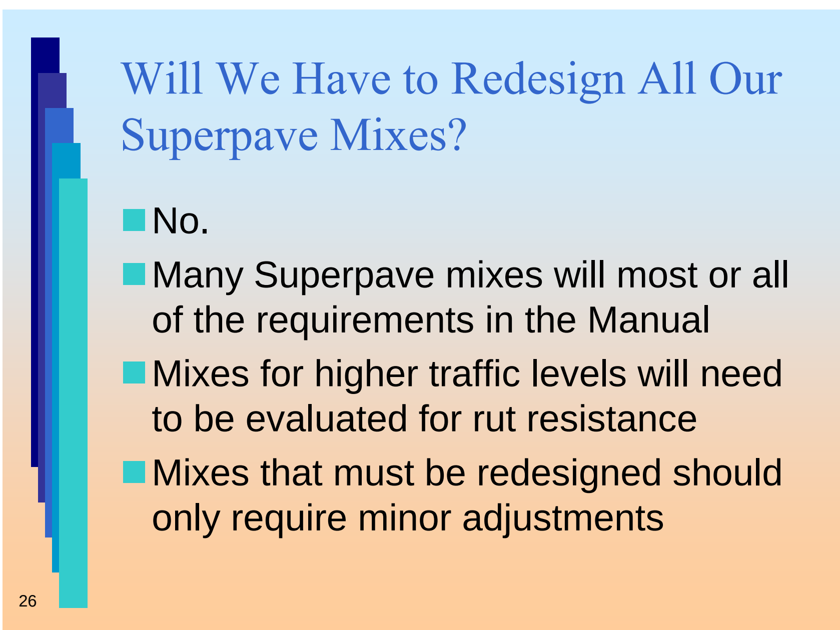


Slide 2-24

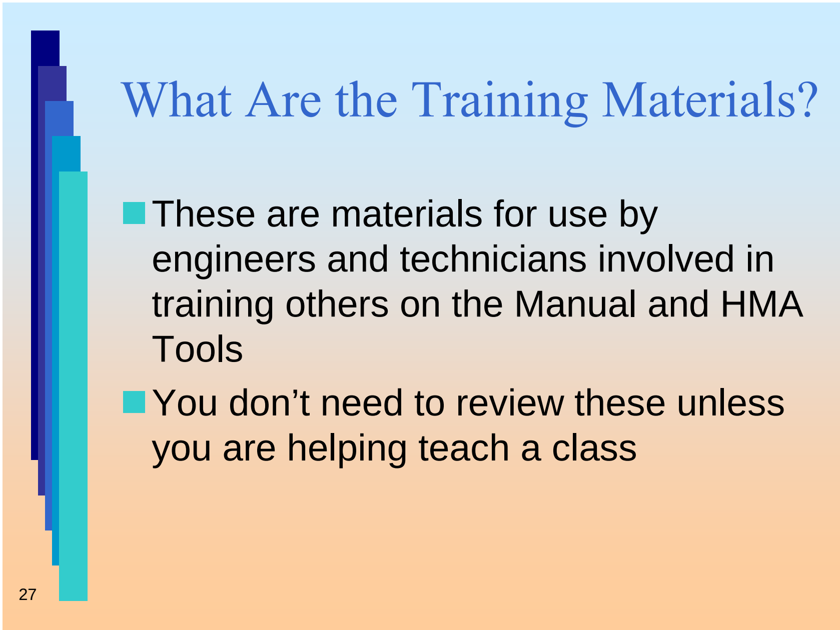


Slide 2-25

It will probably take some time before many states work out specifics of test method and required test values.



Slide 2-26



Slide 2-27

The course manual has all the slides we are using today.

NCHRP Project 9-33: A Mix Design Manual for Hot Mix Asphalt

UNIT 3: OVERVIEW OF DENSE-GRADED HMA MIX DESIGN

Number of Slides: 16

Approximate Time Required: 30 minutes

Purpose of Unit: To give an overview of the procedure described in the Mix Design Manual for doing mix designs for dense-graded HMA.

Important Concepts

- There are only a few differences between the recommended mix design procedure and the Superpave system.
- One big difference is that performance (rut resistance) testing is done for all mixes designed for 3 million or more ESALs
- The selection of binder content is done in a slightly different way. The volumetric binder content is calculated by subtracting the design air void content from the VMA. The volumetric binder content is then converted to a content by weight percentage. The target binder content is selected early in the mix design procedure and maintained throughout. This helps ensure that the final mix will have the proper binder content.

Description of Slides: These slides only give a quick overview of the mix design process. Most of the details are left out—these are covered later in a detailed, three-part example mix design which makes up most of the course.

Instructor's Notes

Dense-Graded HMA Mix Design: Overview

NCHRP 9-33

A Mix Design Manual for Hot Mix Asphalt

Advanced Asphalt Technologies, LLC

"Engineering Services for the Asphalt Industry"

1

Slide 3-1

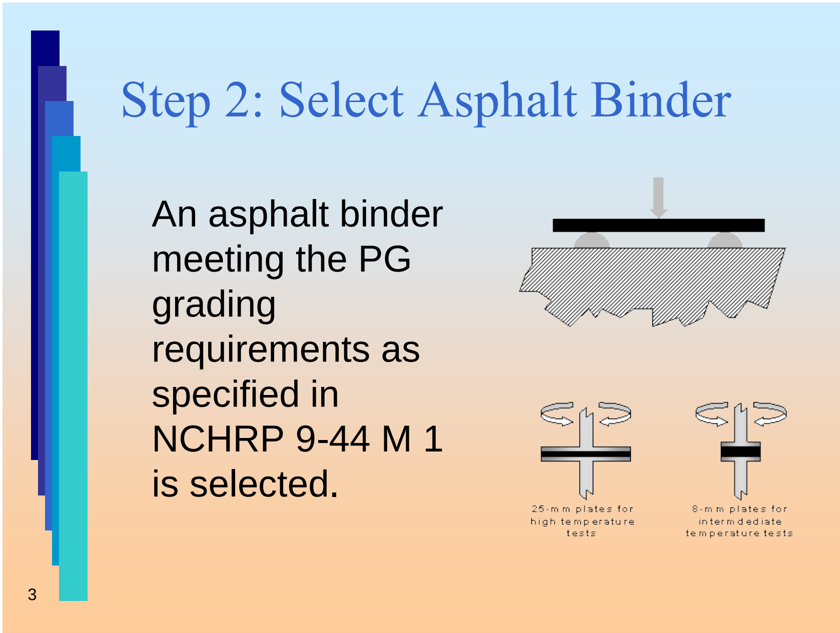
This unit is a short overview of the design of dense-graded HMA mixes. Much of the later part of the course is a detailed example mix design. If there are a large number of questions on details of the procedure, emphasize that this is an overview and that the details will be covered later in the course.

Step 1: Gather Information

All pertinent information concerning the paving project and mix design are gathered and organized. This should include information on potential binders, aggregates and RAP stockpiles

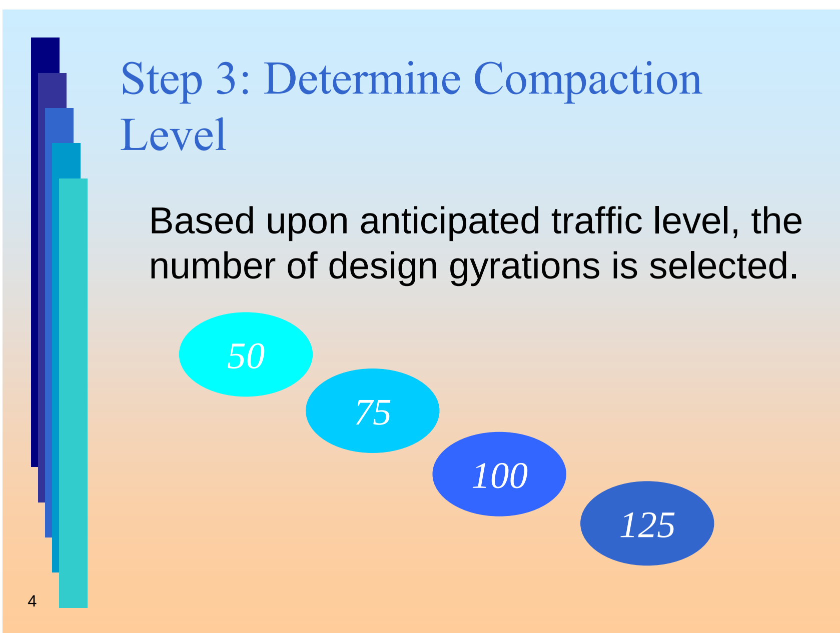
2

Slide 3-2



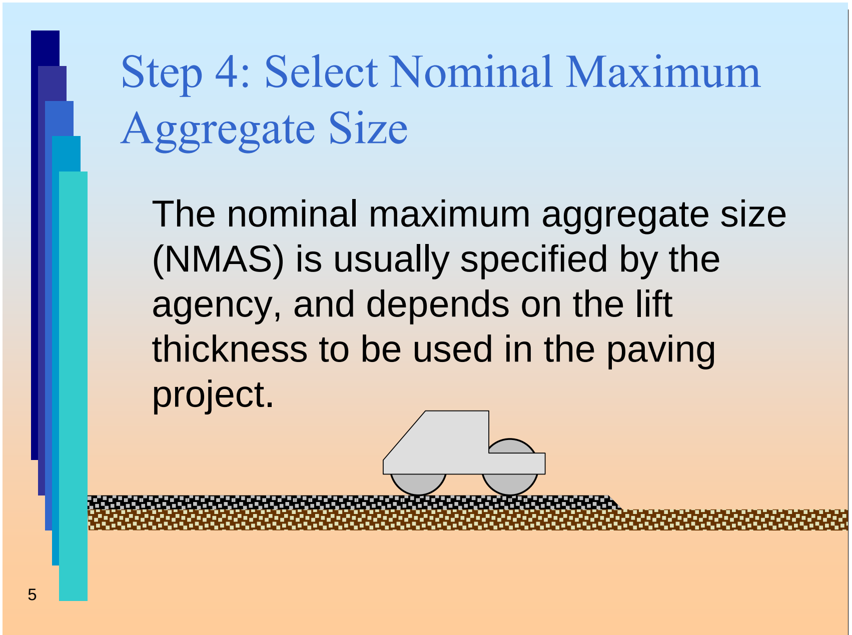
Slide 3-3

Binder requirements are the same as for Superpave.



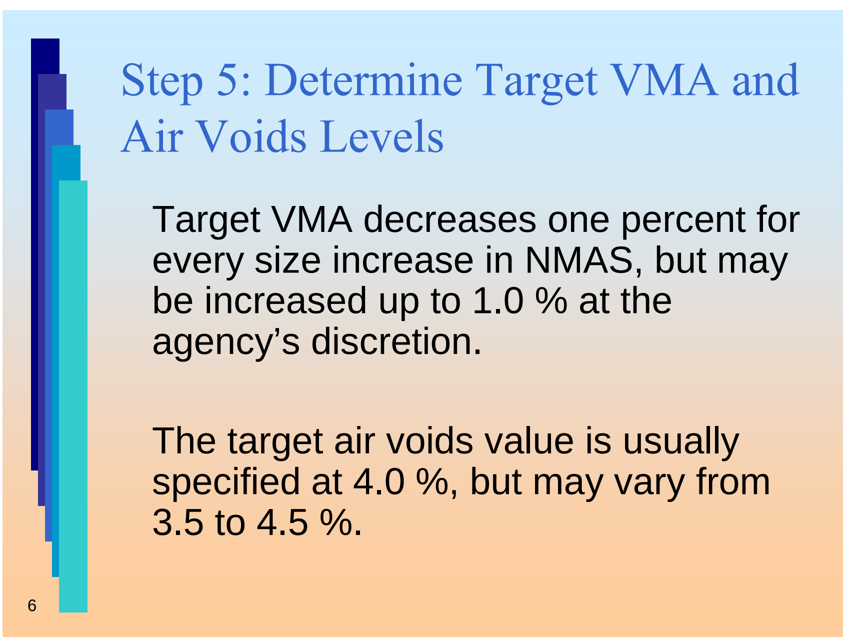
Slide 3-4

Compaction levels are also the same, although some engineers have proposed changes, and a few states use slightly different compaction levels.



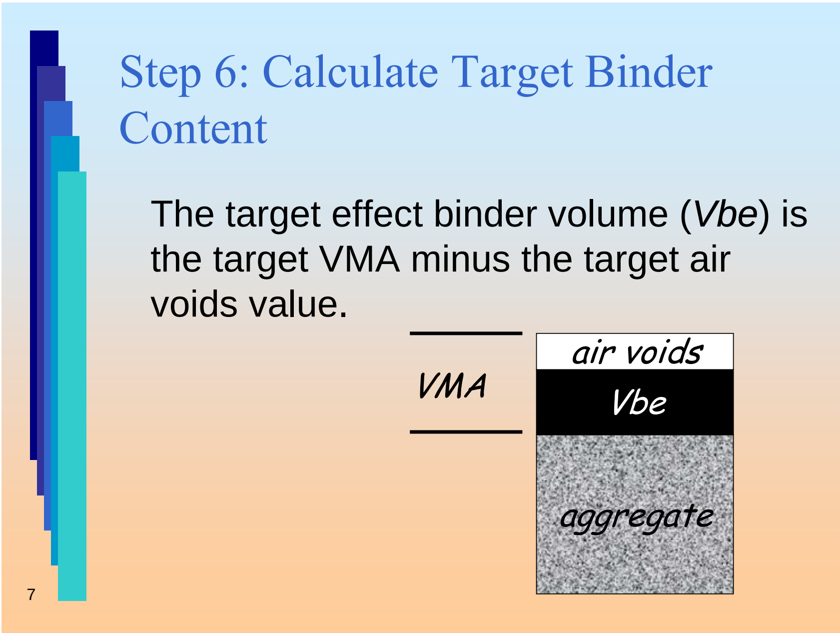
Slide 3-5

NMAS is usually given to the technician doing the mix design work.



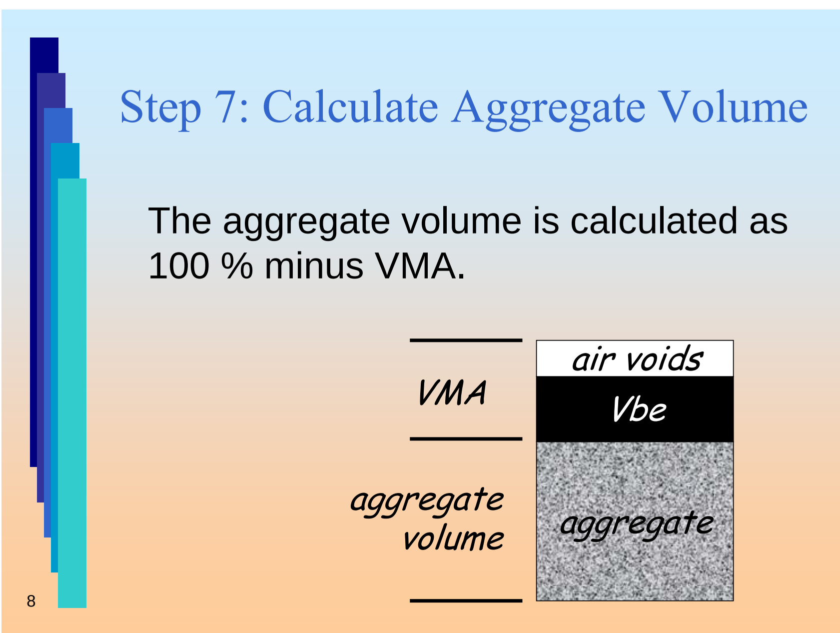
Slide 3-6

This is a bit different from Superpave—there is some built in flexibility allowing highway departments to increase VMA (and binder content) if they feel they need it. Some states will probably take advantage of this, others feel that VMA and binder content are about where they should be.



Slide 3-7

This is a little different from Superpave, but should produce similar results. The reason for this change is to emphasize the importance of selecting and maintaining the right binder content throughout the mix design process.



Slide 3-8

These calculations are done by the HMA Tools spreadsheet.

Slide 3-9

This is the same as in Superpave and other mix design systems. HMA Tools is set up to do aggregate blending using a graphical/trial-and-error procedure.

Slide 3-10

The are what were called "source properties" in Superpave.

Step 8: Proportion Aggregate Blends for Trial Mixtures

Prepare aggregate blends for three trial mixtures by proportioning selected aggregates and RAP to create coarse, dense and fine aggregate gradations.

11

Slide 3-11

Step 9: Calculate Mix Proportions by Weight and Check D/B Ratio

The volumetric mix proportions are used to calculate mix proportions by weight and batch weights for trial mixes.

12

Slide 3-12

Again, nothing new here.

Step 10: Evaluate and Refine Trial Mixtures

For each trial mixture, specimens are prepared using the Superpave gyratory compactor. Determine bulk specific gravity and theoretical maximum specific gravity of the loose mixture.

13

Slide 3-13

Just like in Superpave and Marshall mix design.

Step 10: Evaluate and Refine Trial Mixtures

From these data, VMA, air voids and dust to binder ratio are calculated and evaluated to determine if they meet the specified requirements. If one of the trial mixtures meets all aggregate specifications and mixture volumetric requirements, it is evaluated for moisture resistance—otherwise, modify mix and try again.

14

Slide 3-14

Slide 3-15

Performance testing is something new. Mixes designed for 3 million ESALs or more must be tested for rut resistance using one of six widely used tests, such as the Asphalt Pavement Analyzer (APA) or the Asphalt Mixture Performance Tester (AMPT).

Slide 3-16

NCHRP Project 9-33: A Mix Design Manual for Hot Mix Asphalt

UNIT 4: OVERVIEW OF HMA TOOLS

Number of Slides: 21

Approximate Time Required: 30 minutes

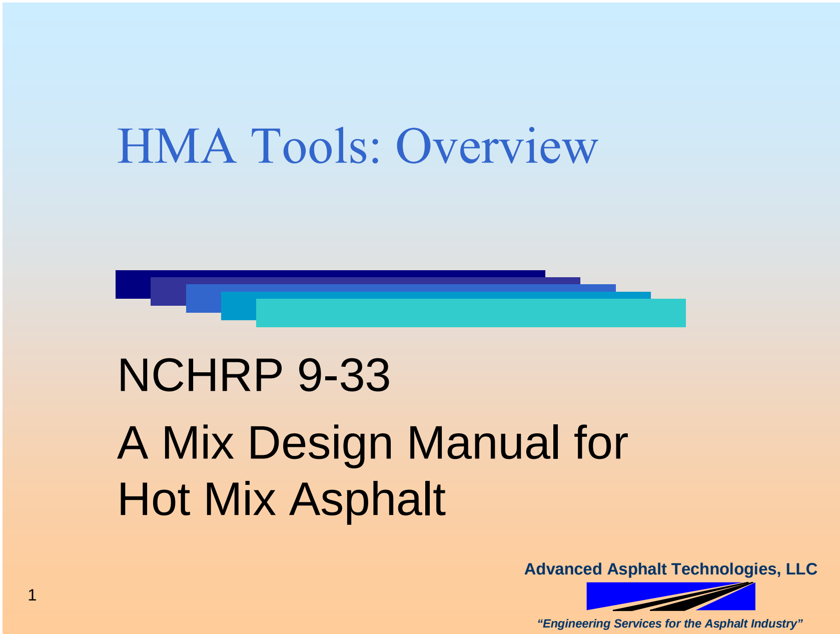
Purpose of Unit: To provide an overview of the most important parts of the HMA Tools spreadsheet.

Important Concepts

- HMA Tools is a comprehensive spreadsheet that helps to prepare dense-graded HMA mix designs.
- You don't have to use HMA Tools to do mix designs as they are described in the manual; you can use other spreadsheets or programs as long as the final mix meets the specified requirements.
- There are 17 worksheets in HMA Tools—the large number is needed because HMA Tools was designed to do almost all calculations you might need to do a mix design, including binder grade calculations in mixes with RAP, variability analysis of mixtures with RAP, and preparing comprehensive reports for selected mixtures.
- You normally won't have to use many of the worksheets. This is especially true if you aren't designing mixes with more than 15 % RAP.

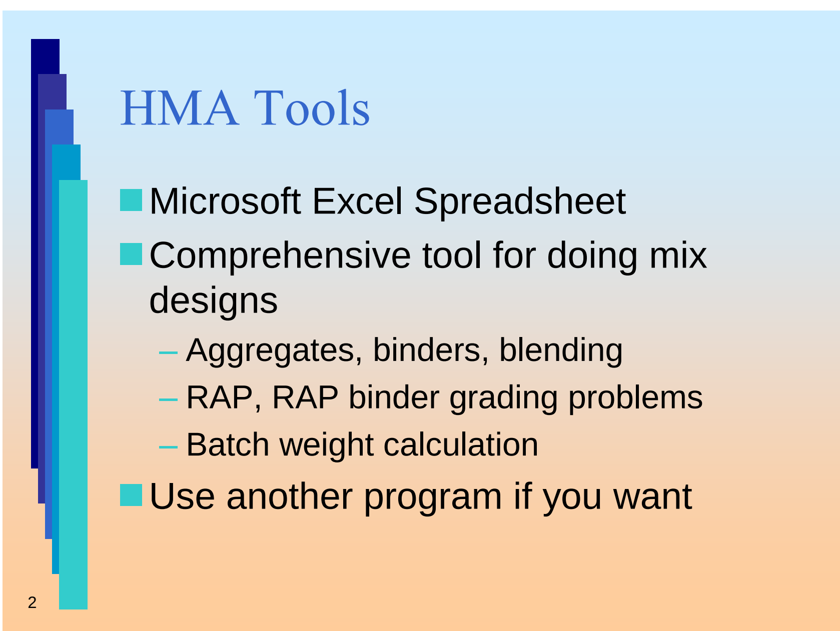
Description of Slides: The first few slides describe the HMA Tools spreadsheet. These are followed by slides showing parts of the most important worksheets in HMA Tools. This is meant to be a quick overview to give participants an idea of what HMA Tools looks like. Details are covered in the example mix design that takes up most of the later part of the course.

Instructor's Notes



Slide 4-1

This unit gives an overview of the HMA Tools Spreadsheet. The example problem goes over HMA Tools in more detail.



Slide 4-2

HMA Tools Worksheets

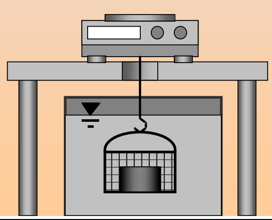
- Intro
- Abbreviations
- Specifications
- General
- Aggregates
- RAP_Aggregates

3

Slide 4-3

HMA Tools Worksheets

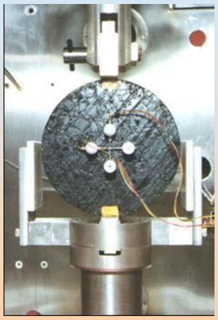
- Binders
- RAP_Binders
- Blended Binders
- RAP_Variability
- Trial_Blends
- Batch



4

Slide 4-4

HMA Tools Worksheets



- Specific_Gravity
- T_283
- Performance
- Short_Report
- Complete_Report
- Modulus

5

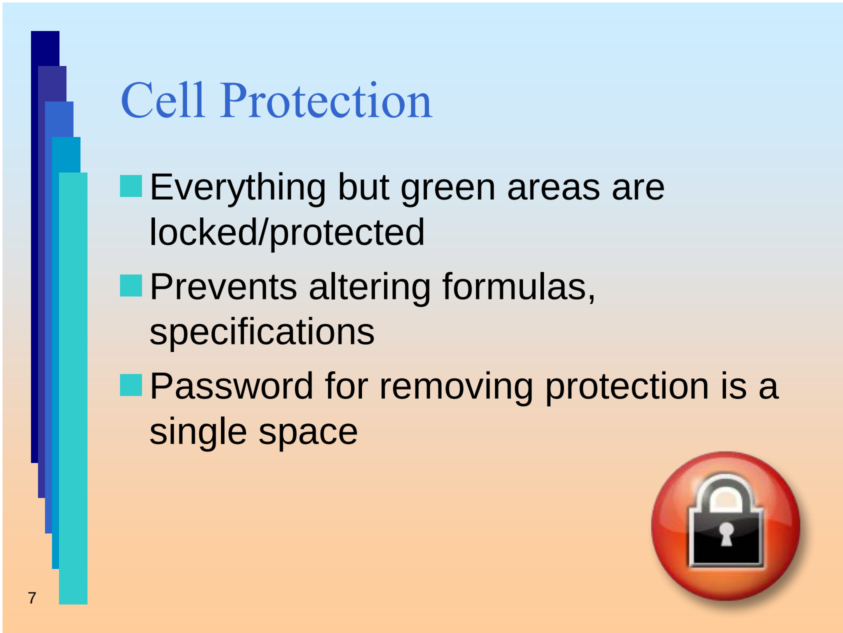
Slide 4-5

Color Coding

- Green = data entry
  - Everything else is locked
- Gold = main titles (usually)
- White = labels, formulas you probably want to see
- Pink = calculations that you probably don't need to see

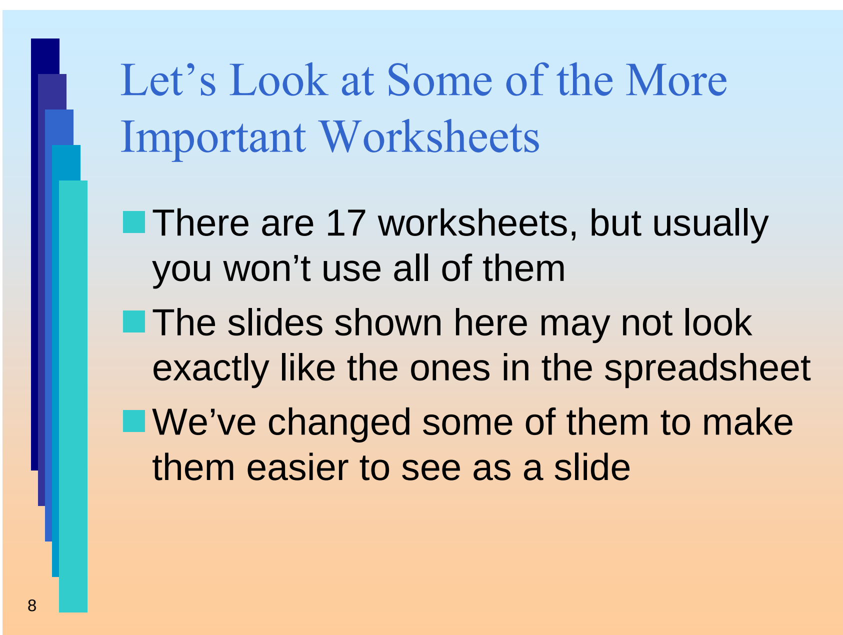
6

Slide 4-6

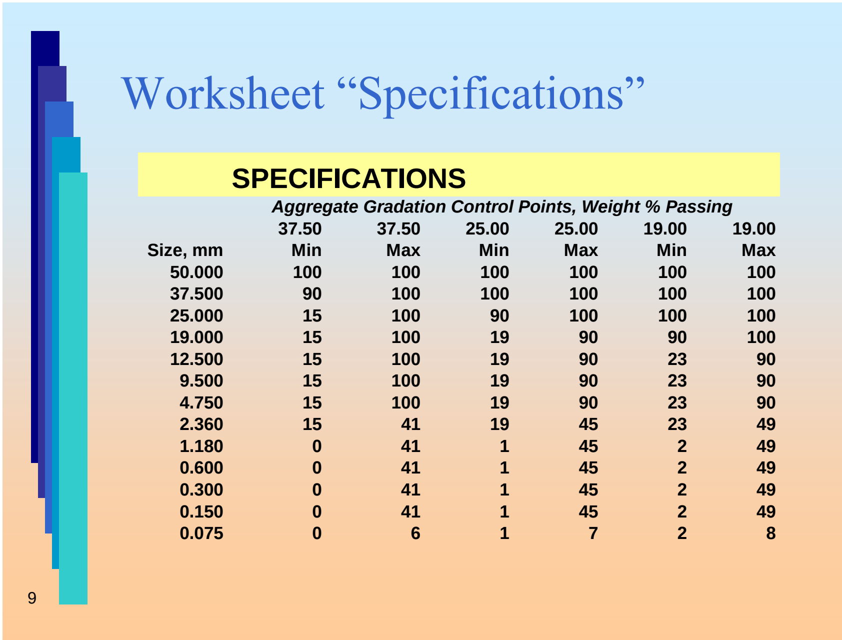


Slide 4-7

Save a backup copy of HMA Tools before you start working with it, in case you accidentally change formulas.

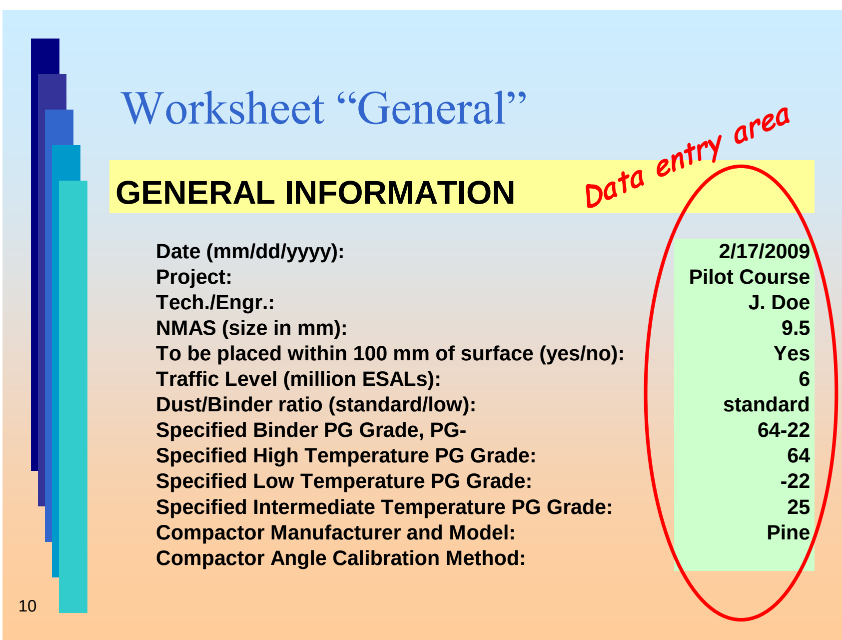


Slide 4-8



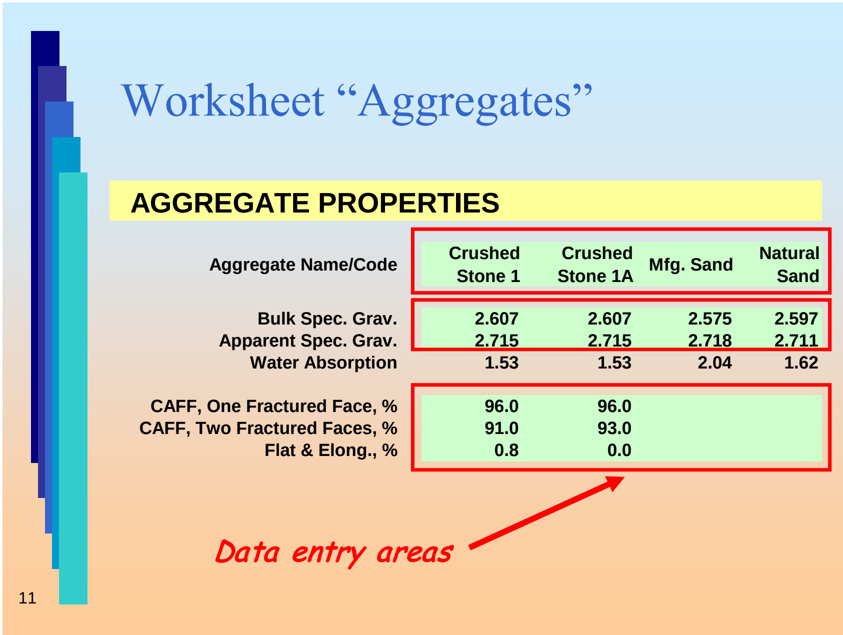
Slide 4-9

This slide shows data used in plotting control points for aggregate gradation. The reason there are data for each sieve size is for plotting the limits in other worksheets.



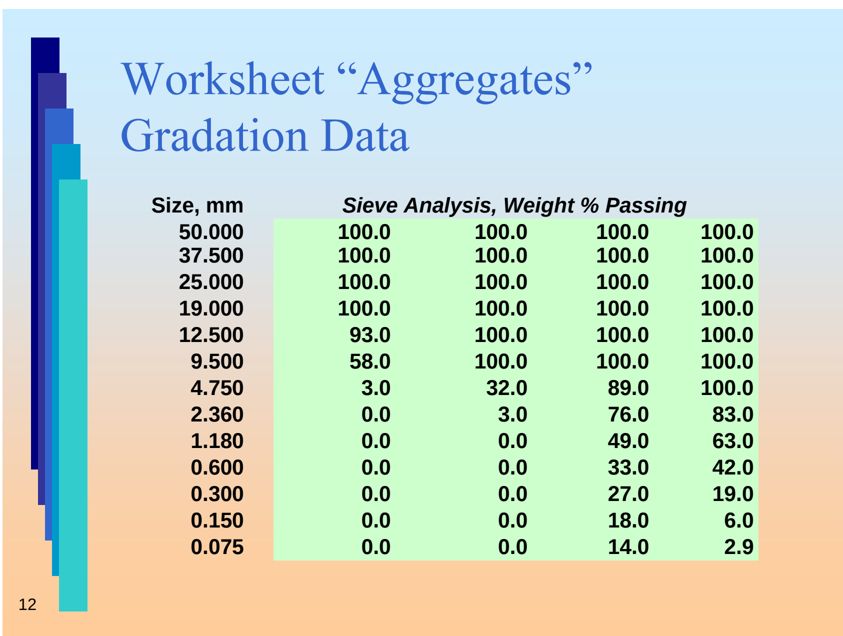
Slide 4-10

Worksheet “General” is used to enter the general project information for the mix design. Note that in HMA Tools green shaded cells are for data entry. All other cells are normally locked to prevent accidentally writing over important parts of the spreadsheet.

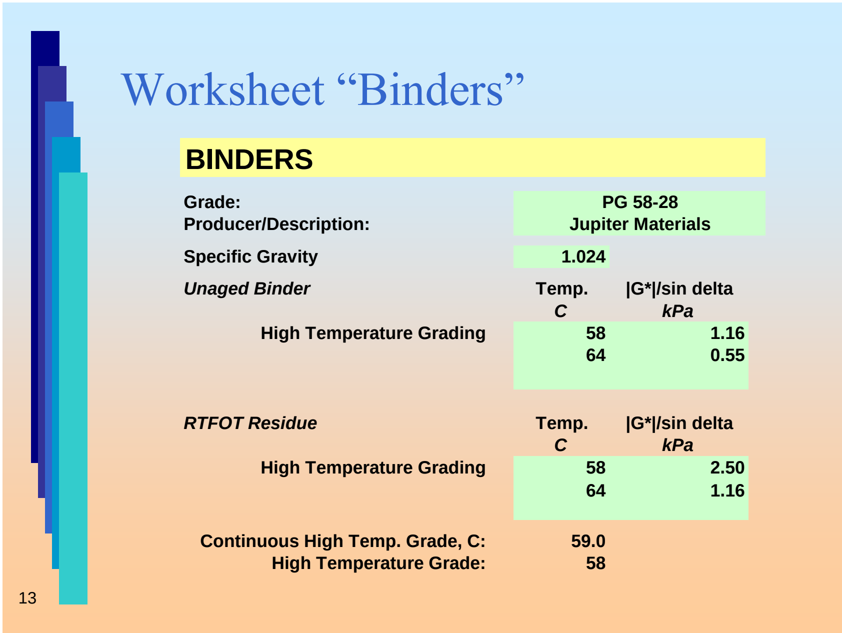


Slide 4-11

HMA Tools has space for up to seven different aggregates, and four RAP stockpiles. There is no separate place for entering information on hydrated lime and similar additives, so these are treated like aggregate.

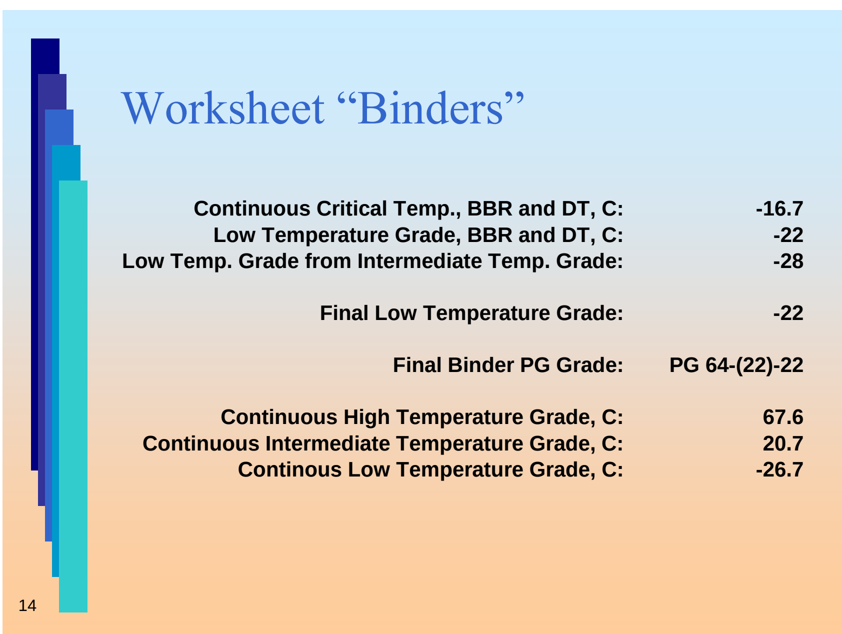


Slide 4-12



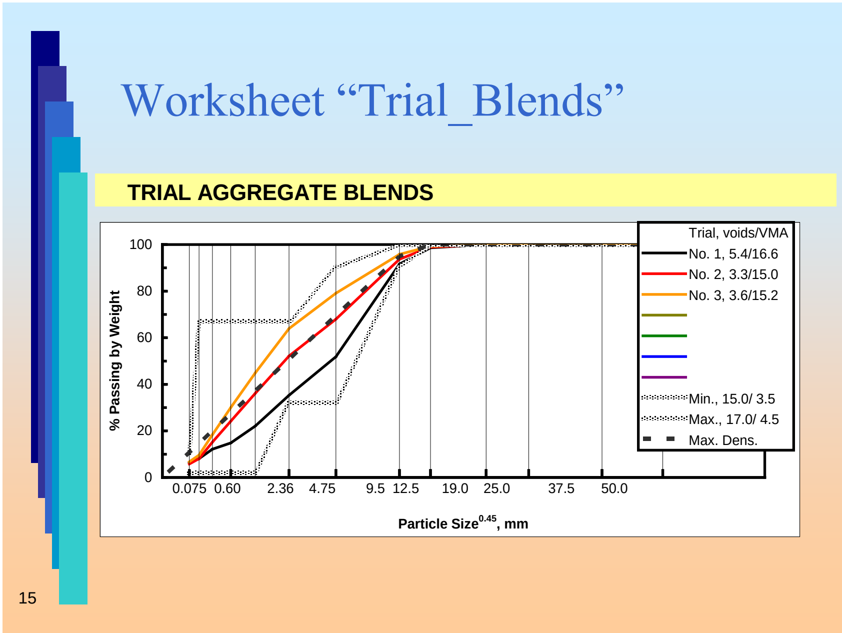
Slide 4-13

You don't need to enter binder data unless you are using more than 15 % RAP, or if you want modulus (|e*|) estimates.



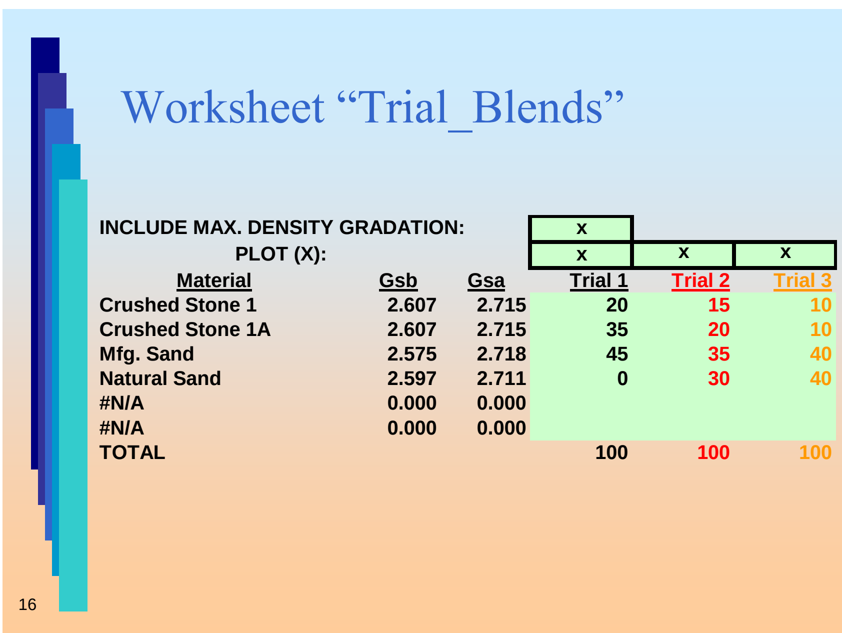
Slide 4-14

The "Binders" worksheet will do the grading calculations for you once you enter the appropriate test data.



Slide 4-15

Worksheet “Trial_Blends” is where you blend aggregates and develop the proportions for your trial mixes.

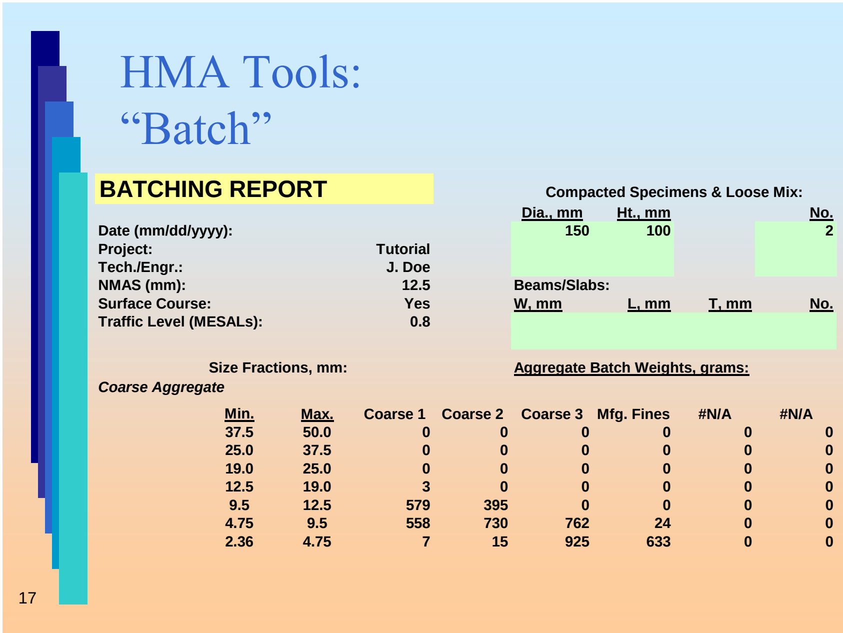


INCLUDE MAX. DENSITY GRADATION: x

PLOT (X):			x	x	x
Material	Gsb	Gsa	Trial 1	Trial 2	Trial 3
Crushed Stone 1	2.607	2.715	20	15	10
Crushed Stone 1A	2.607	2.715	35	20	10
Mfg. Sand	2.575	2.718	45	35	40
Natural Sand	2.597	2.711	0	30	40
#N/A	0.000	0.000			
#N/A	0.000	0.000			
TOTAL			100	100	100

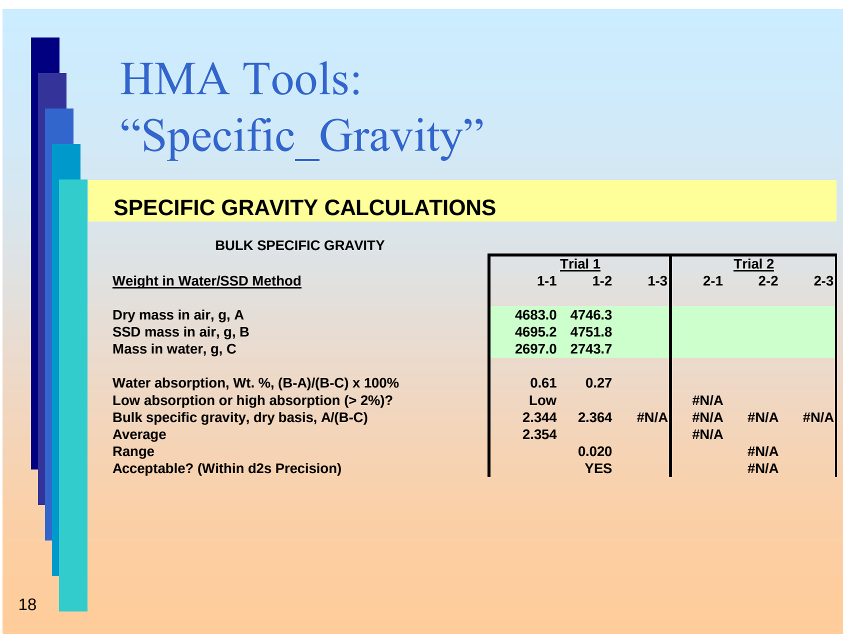
Slide 4-16

You proportion aggregates using a trial-and-error procedure—HMA Tools will plot the gradations and show other estimated properties for the aggregate blend and the mixture.



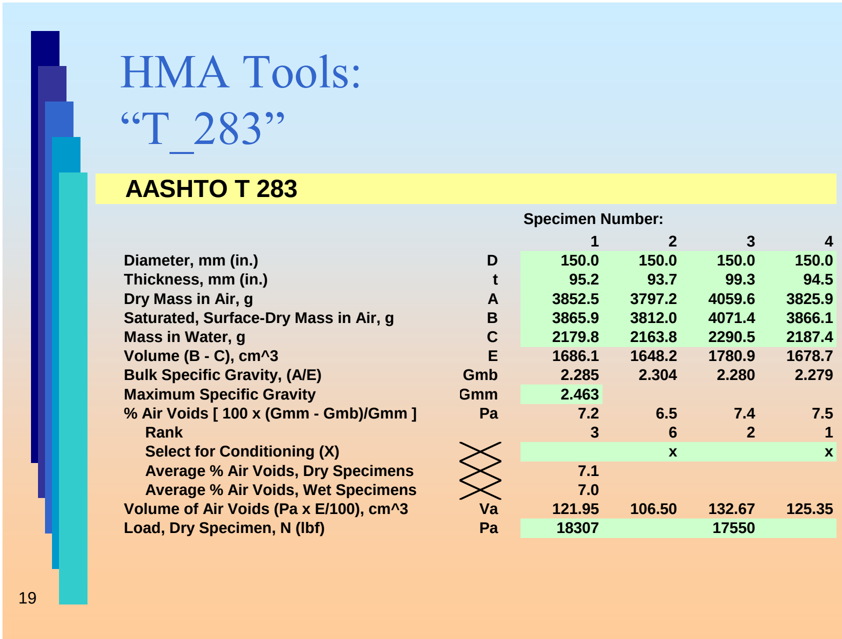
Slide 4-17

Worksheet “Batch” can be used to calculate batch weights for preparing specimens and/or loose mix in the laboratory.



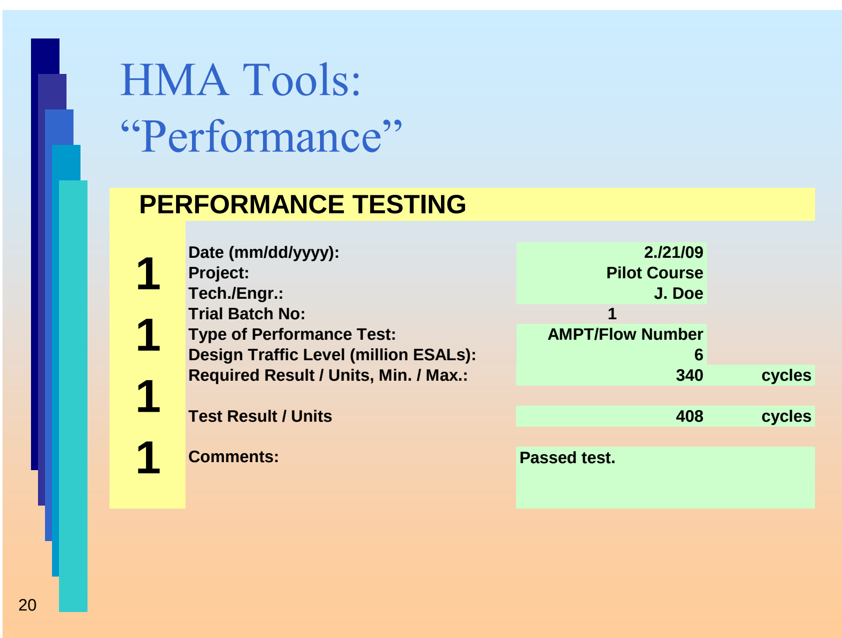
Slide 4-18

Worksheet “Specific_Gravity” is used to perform specific gravity calculations on the mix—both bulk and maximums, using a variety of different methods.



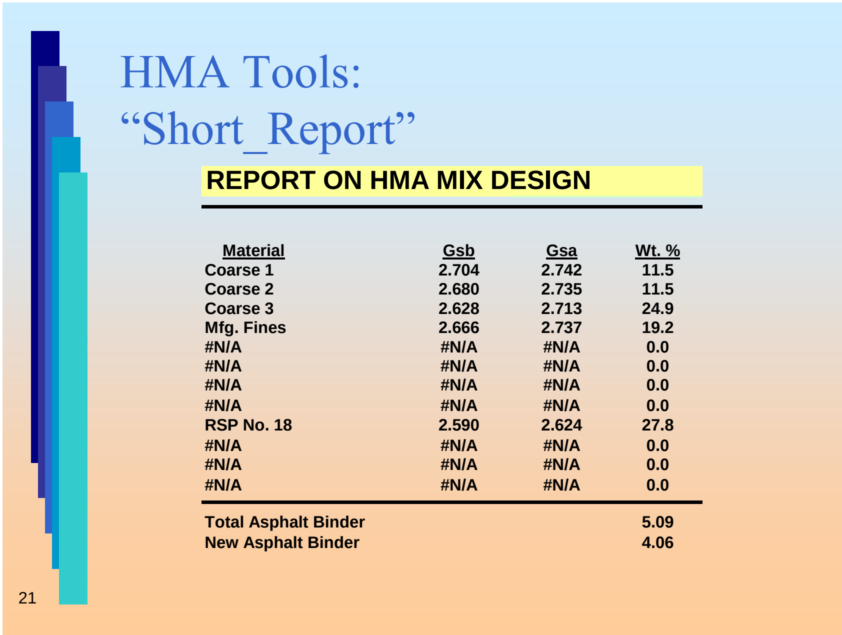
		Specimen Number: 1	2	3	4
Diameter, mm (in.)	D	150.0	150.0	150.0	150.0
Thickness, mm (in.)	t	95.2	93.7	99.3	94.5
Dry Mass in Air, g	A	3852.5	3797.2	4059.6	3825.9
Saturated, Surface-Dry Mass in Air, g	B	3865.9	3812.0	4071.4	3866.1
Mass in Water, g	C	2179.8	2163.8	2290.5	2187.4
Volume (B - C), cm^3	E	1686.1	1648.2	1780.9	1678.7
Bulk Specific Gravity, (A/E)	Gmb	2.285	2.304	2.280	2.279
Maximum Specific Gravity	Gmm	2.463			
% Air Voids [100 x (Gmm - Gmb)/Gmm]	Pa	7.2	6.5	7.4	7.5
Rank		3	6	2	1
Select for Conditioning (X)			x		x
Average % Air Voids, Dry Specimens		7.1			
Average % Air Voids, Wet Specimens		7.0			
Volume of Air Voids (Pa x E/100), cm^3	Va	121.95	106.50	132.67	125.35
Load, Dry Specimen, N (lbf)	Pa	18307		17550	

Slide 4-19



Slide 4-20

Performance test results are recorded in worksheet “Performance.”



Slide 4-21

HMA Tools includes two different reports—worksheet "Short_Report" gives a one page report on a single selected mix, while worksheet "Complete_Report" gives a longer report with information on any number of up to seven trial mixes.

NCHRP Project 9-33: A Mix Design Manual for Hot Mix Asphalt (HMA)

DATA FOR MIX DESIGN EXAMPLE PROBLEM, PARTS 1 AND 2

General Information

Design traffic level...6 million ESALs
Binder PG Grade..PG 64-22
Aggregate NMAS ....9.5 mm
Dust/binder ratio ....standard
Location within pavement...................................surface course (within 100 mm of surface)

Aggregate Gradation Data

	Wt. Percent Passing for Aggregate			
Sieve Size, mm	**Crushed Stone No. 1**	**Crushed Stone No. 1A**	**Mfg. Sand**	**Natural Sand**
50	100.0	100.0	100.0	100.0
37.5	100.0	100.0	100.0	100.0
25	100.0	100.0	100.0	100.0
19	100.0	100.0	100.0	100.0
12.5	93.0	100.0	100.0	100.0
9.5	58.0	100.0	100.0	100.0
4.75	3.0	32.0	89.0	100.0
2.36	0.0	3.0	76.0	83.0
1.18	0.0	0.0	49.0	63.0
0.600	0.0	0.0	33.0	42.0
0.300	0.0	0.0	27.0	19.0
0.150	0.0	0.0	18.0	6.0
0.075	0.0	0.0	14.0	2.9

Aggregate Specific Gravity Values and Specification Property Data

Specific Gravity Values				
Bulk specific gravity	2.607	2.607	2.575	2.597
Apparent specific gravity	2.715	2.715	2.718	2.711
Aggregate Specification Property Data				
C.A. fractured faces, Wt. % particles with one fractured face	96.0	96.0		
C.A. fractured faces, Wt. % particles with at least two fractured faces	91.0	93.0		
C.A. flat & elongated particles, Wt. %	0.8	0.0		
F.A. angularity, Vol. % uncompacted voids			48.0	43.0
F.A., clay content, sand equivalent value, %			58.0	89.0

Asphalt Binder Test Data

Property	**PG 58-28**	**PG 64-22**
Supplier	Jupiter Materials	Jupiter Materials
Specific Gravity	1.024	1.026
Grading Test Data		
Temperature, °C	*Unaged Binder, G*/sin δ, kPa*	
58	1.16	
64	0.55	1.54
70		0.76
	RTFOT Residue, G/sin δ, kPa*	
58	2.50	
64	1.16	3.46
70		1.62
	PAV Residue, G Sin δ, kPa*	
13	4,990	
16	3,647	
19	2,635	7,183
22		4,819
25		3,145
	PAV Residue, S, MPa (m-value)	
–12		214 (0.359)
–18	216 (0.373)	507 (0.275)
–24	548 (0.278)	

NCHRP Project 9-33: A Mix Design Manual for Hot Mix Asphalt

UNIT 5: MIX DESIGN EXAMPLE PROBLEM, PART 1

Number of Slides: 34

Approximate Time Required: 60 minutes

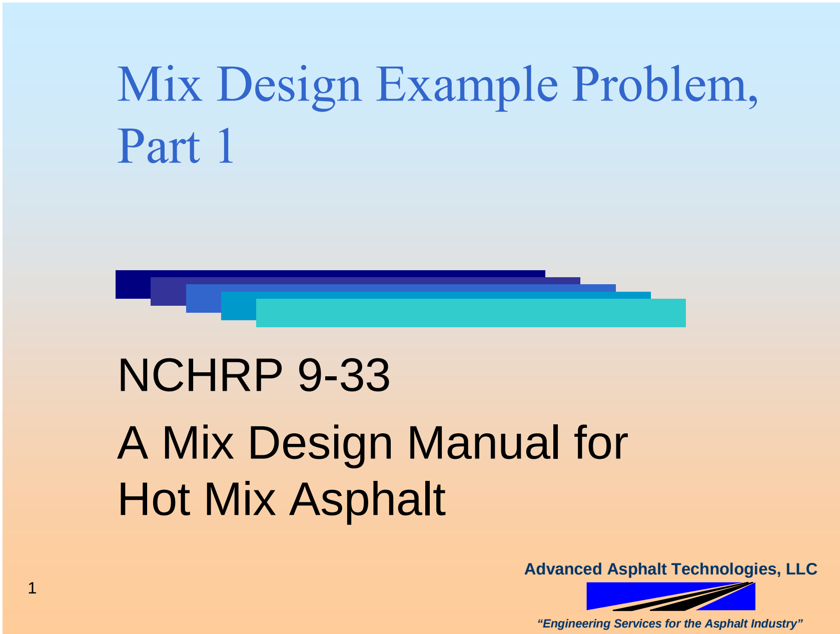
Purpose of Unit: This unit is the first part of a long mix design example that demonstrates in detail the mix design system and the HMA Tools spreadsheet.

Important Concepts

- The general procedure for doing a mix design follows the same general order as in Superpave and Marshall mix design: enter data, determine aggregate blends for trial batches, prepare trial batches and compact specimens, determine specific gravity, etc.
- Data should be entered in worksheet "General," worksheet "Aggregates," and worksheet "Trial_Blends."
- The binder specific gravity should be entered in worksheet "Binders." No other data needs to be entered on this worksheet unless you have a mix design with more than 15 % RAP, or if you want modulus (|E*| or "E-star") estimates.
- Volumetric data for the trial mixes will not appear in worksheet "Trial_Blends" until specific gravity data is entered in worksheet "Specific_Gravity."

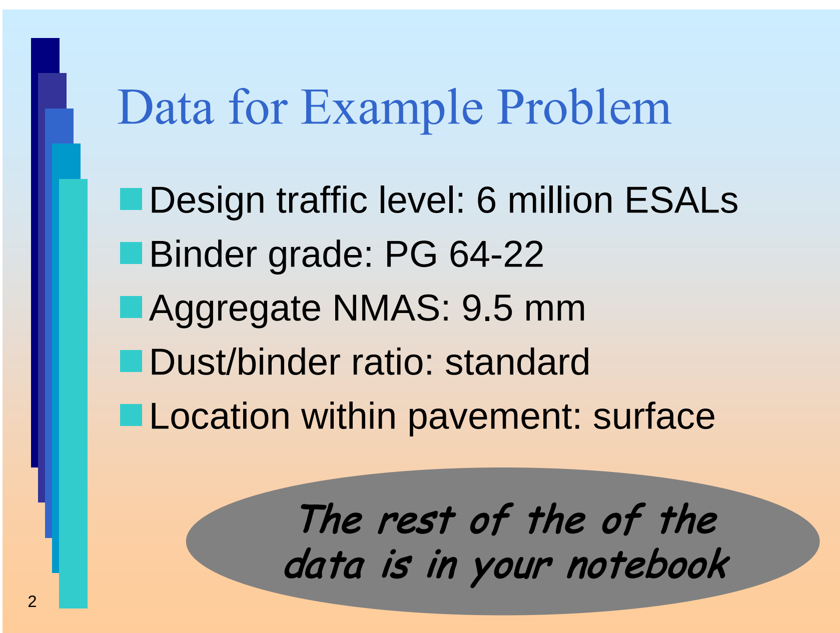
Description of Slides: The slides take the participants through a realistic mix design example problem, beginning with entering data for the problem. Some of the initial data entry slides first show a blank worksheet, and then the spreadsheet filled in with data from the example problem. Most of the slides are taken from HMA Tools, although they have been modified in many cases to make them easier to read as slides. Important parts of the various worksheets have been highlighted in read, in some cases with explanatory text. These slides only go through calculation of proportions for the initial three trial batches and specific gravity measurements on specimens for the mixtures.

Instructor's Notes



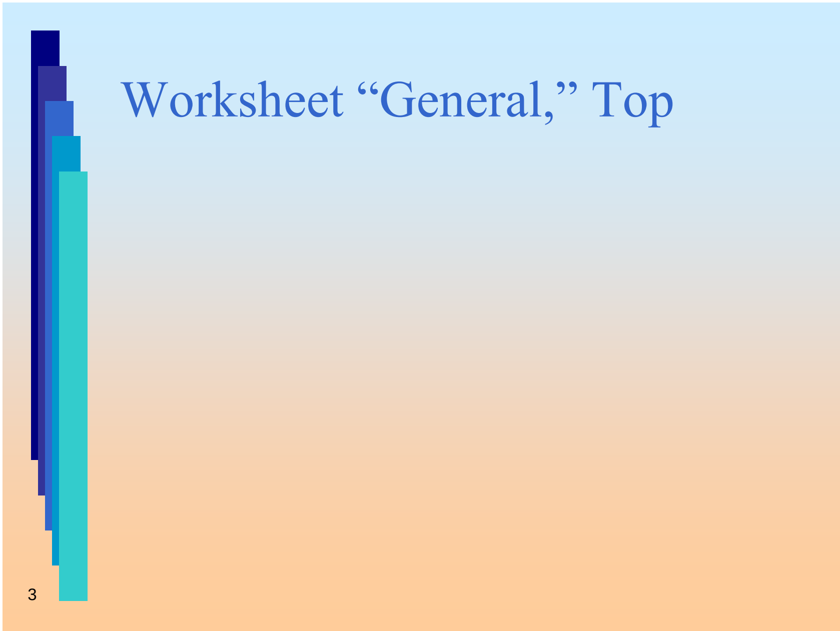
Slide 5-1

This is a fairly long unit and important to understanding the mix design procedure and HMA Tools. The slides describe an example mix design problem, going through the various steps in more or less the same order it would be done in a laboratory. Students can follow along in their notebooks.



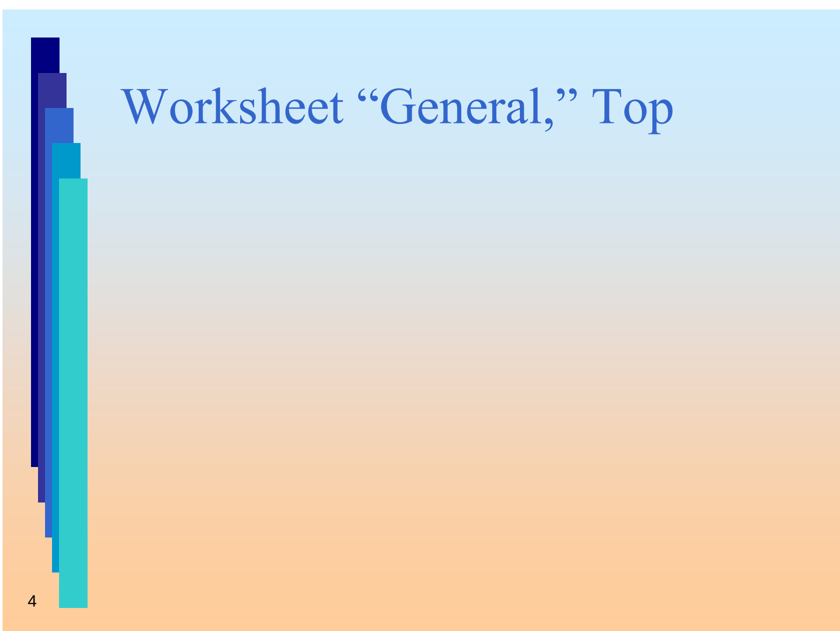
Slide 5-2

The participants have sheets in their notebooks with all data for parts 1 and 2 of the Example.



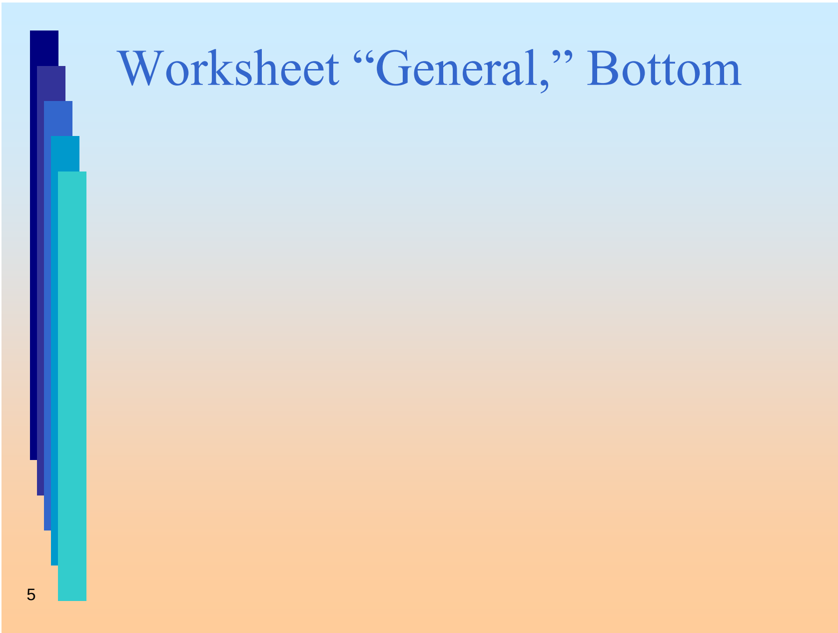
Slide 5-3

This is what the top part of worksheet “Genera” looks like before being filled.



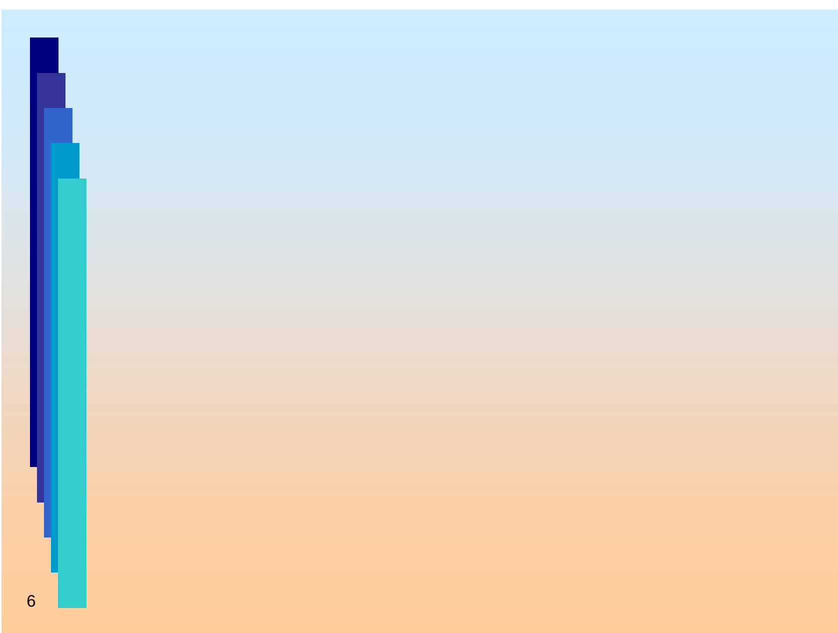
Slide 5-4

This is worksheet “General” after we fill it in with data for the example problem.



Slide 5-5

This is the lower part of worksheet General. The only data that needs to be filled in here is the target VMA, target air voids and the maximum allowable RAP. Parts 1 and 2 of the example mix design don not use RAP, so nothing is entered in that space. Part 3 of the example, covered towards the end of the day, shows how RAP is handled in the mix design procedure.



Slide 5-6

This is the top part of worksheet "Aggregates" before being filled in.

Slide 5-7

Here is what it looks like filled out.

Slide 5-8

The lower part of worksheet “Aggregates” is where you enter gradation data.

9

Slide 5-9

This is the gradation data for the four aggregates used in the example problem.

Trial Aggregate Blends

- Developing aggregate blends is mostly done on worksheet "Trial_Aggregate_Blends"
- This worksheet is very large
- These slides show the worksheet in separate sections
- Remember—green areas are for data entry

10

Slide 5-10

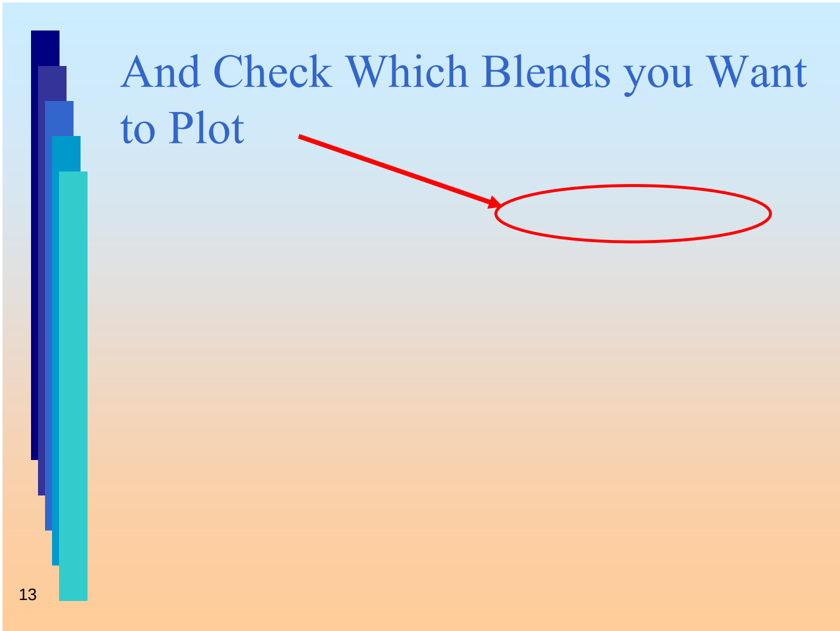
HMA Tools is very useful for developing trial blends in the mix design process.

Slide 5-11

Aggregate proportions are entered immediately below the plot. You mark an “x” above the trial if you want to plot it—otherwise leave it blank. This allows the user to plot only one or two aggregate blends at a time if desired. The air voids and VMA values will appear in the plot legend once specific gravity data is entered and volumetric data can be calculated.

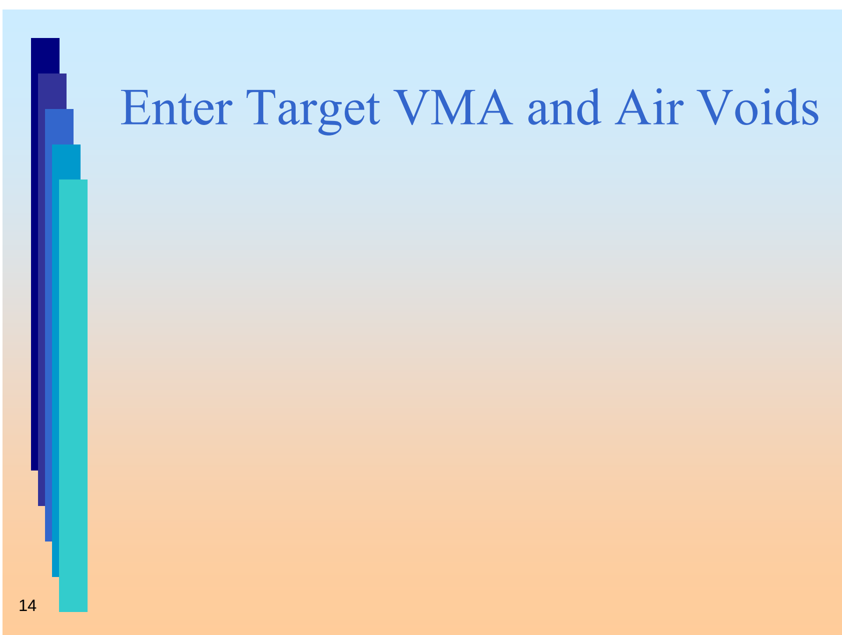
Slide 5-12

There is space for up to seven aggregate and four RAP stockpiles. Hydrated lime is treated as an aggregate. This is what the proportioning area looks like before being filled out.



Slide 5-13

Completed aggregate proportions for the example problem. We are plotting data for all three trials and the maximum density gradation.

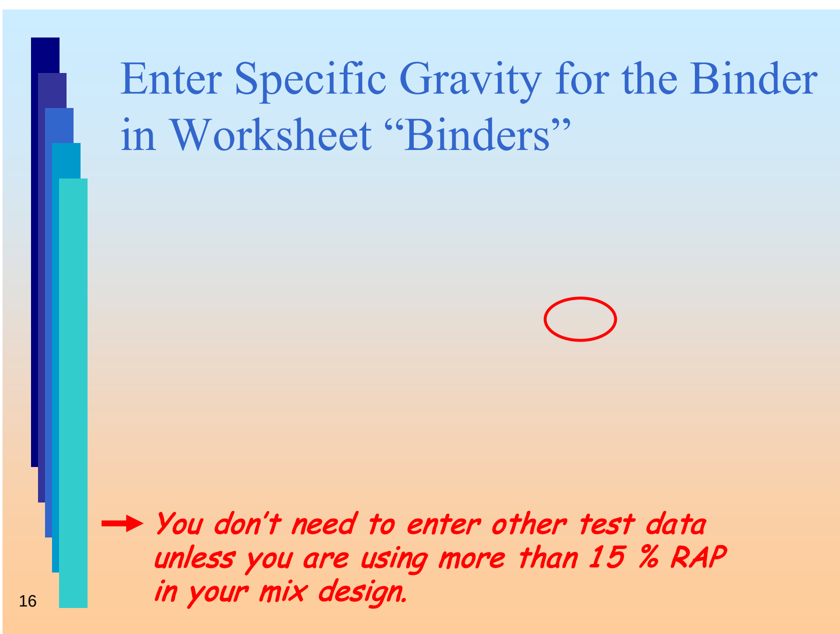


Slide 5-14

HMA tools lists the target VMA and air voids (15.0 and 4.0), but allows the user to enter other values. It might be necessary in some cases to design the mix with VMA and/or air voids values slightly above or below the target values. Note that HMA tools is estimating the dust:binder ratio for you.

Slide 5-15

Here we have filled in the target VMA and air voids values for each of three trial mixes.

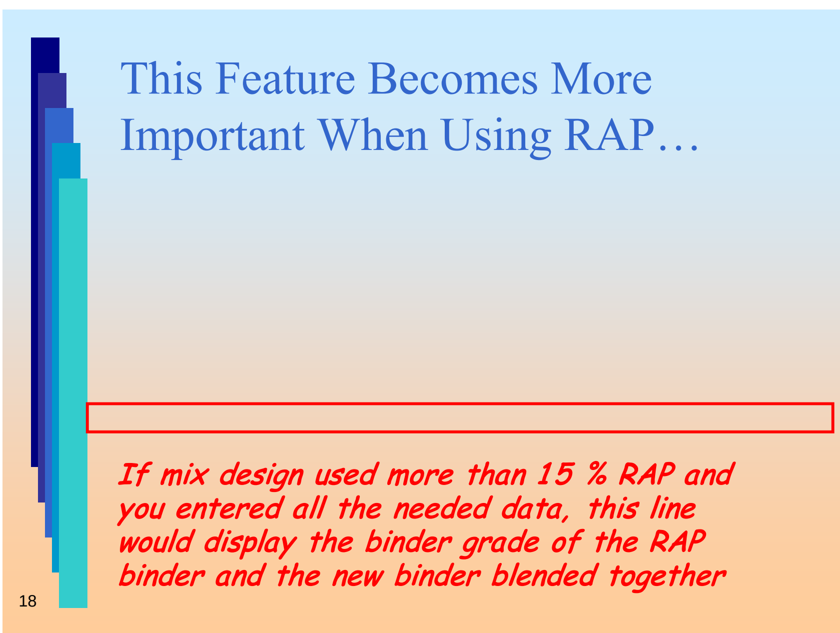


Slide 5-16

If you don’t enter specific gravity data, HMA Tools will assume a value of 1.03.

Slide 5-17

You should still mark the binder



Slide 5-18

If you don't check a binder, HMA Tools will assume a specific gravity of 1.03 for the binder.

Gradation data for the aggregate blends appear further down the "Trial_Blends" worksheet.

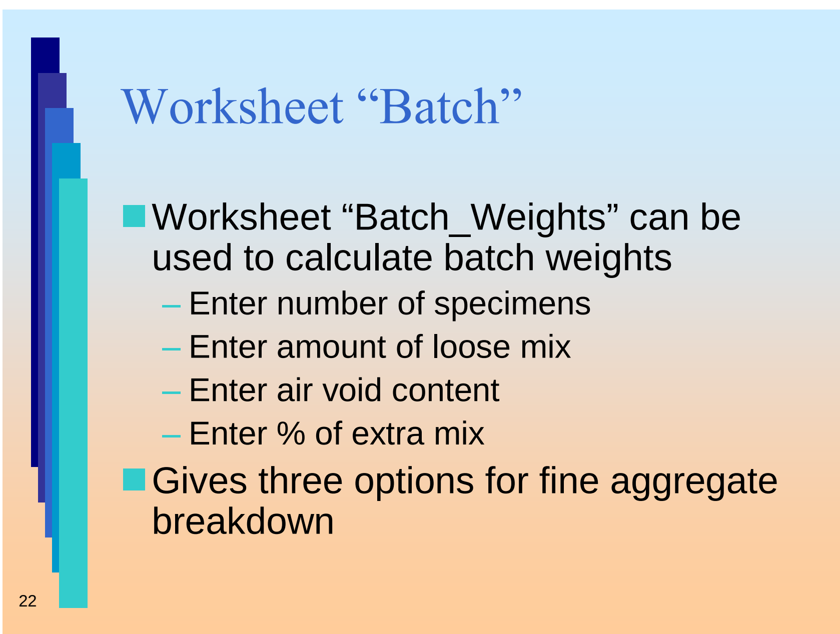
Slide 5-19

HMA Tools will estimate aggregate specification properties for the blends.

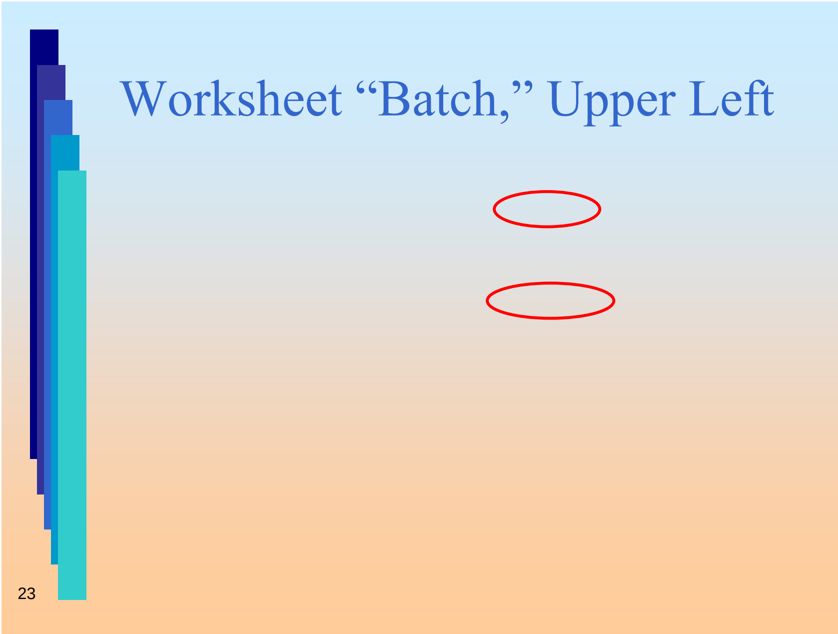
Slide 5-20

Slide 5-21

Volumetric data will appear after you prepare a trial batch and enter mix specific gravity data.

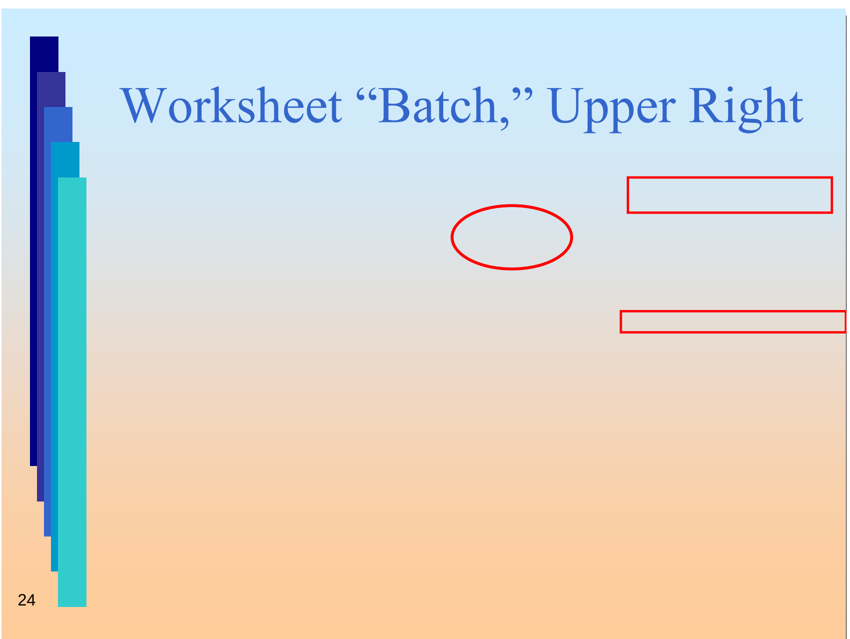


Slide 5-22



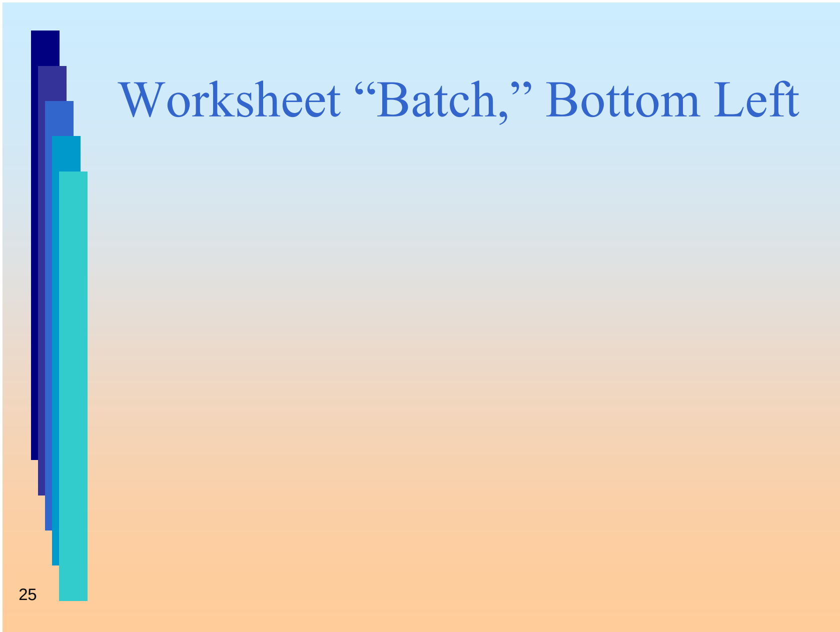
Slide 5-23

In the “Batch” worksheet, you can specify up to three different cylinder sizes and up to two different beam or slab sizes. In this example, we’ve specified two 150 mm-diameter by 100 mm-high gyratory cylinders.



Slide 5-24

You can also specify a certain amount of loose mix for doing tests such as theoretical maximum specific gravity. There is also a space for specifying the amount of extra mix in the batch—this is just to make sure you don’t run short. Make sure you enter the correct trial mix number in the upper right-hand corner.

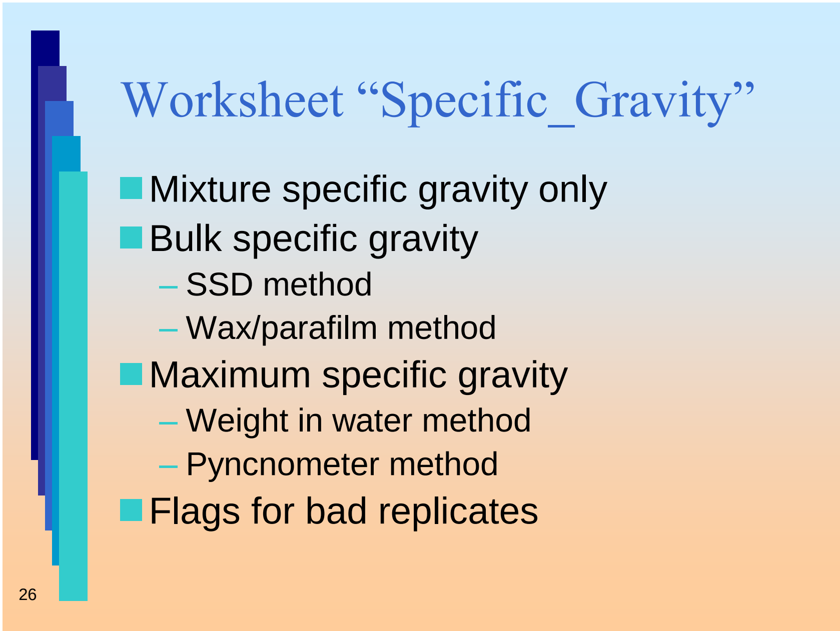


Slide 5-25

Three different breakdowns are given for fine aggregate: complete breakdown—weights for each sieve size; partial breakdown—weights for sets of two sieves; and no breakdown—a single weight for the fine aggregate fraction of each aggregate.

Slide 5-26

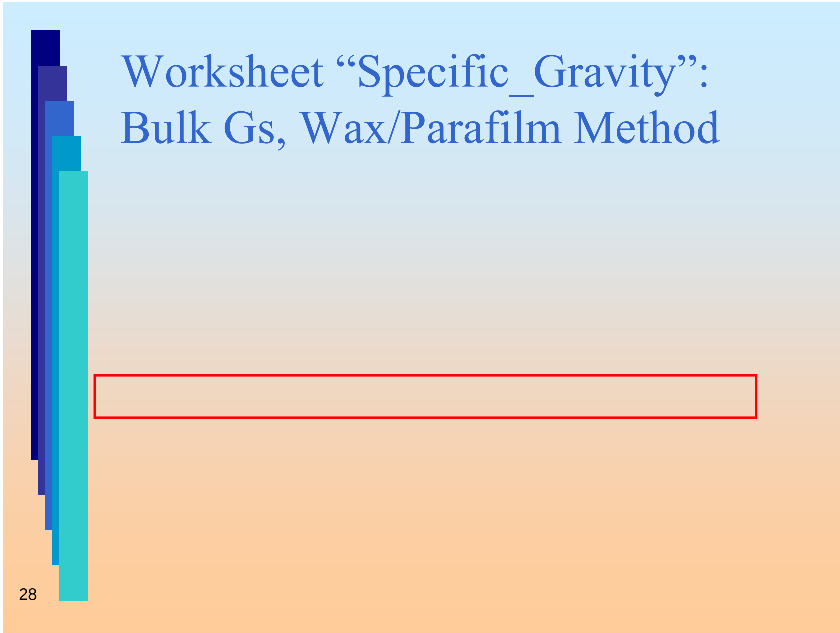
After calculating batch weights, the aggregate and asphalt binder are heated, weighed out, mixed and compacted in a gyratory compactor. Bulk and theoretical maximum specific gravity measurements are then made on the mix.



Slide 5-27

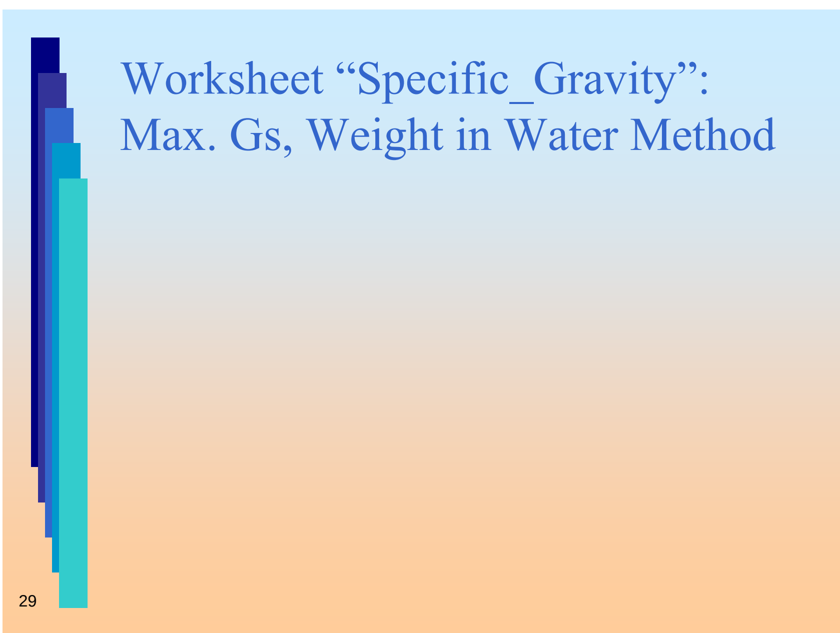
There isn't a worksheet for aggregate specific gravity in HMA Tools—just for mix specific gravity.

Slide 5-28

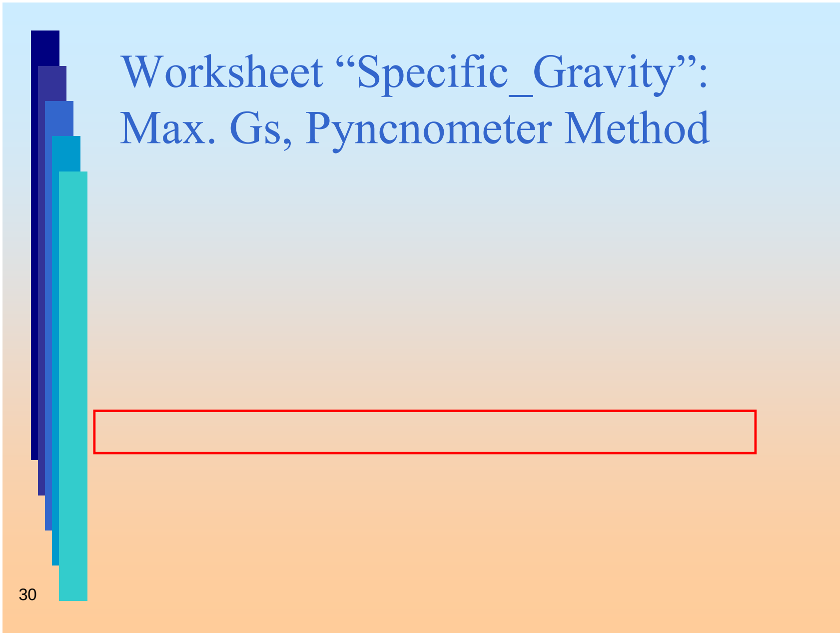


Slide 5-29

You can enter user-calculated values in this spreadsheet if you want—you don't have to use this worksheet to calculate specific gravity values. You do have to enter specific gravity values if you want HMA Tools to calculate volumetrics.



Slide 5-30



Slide 5-31

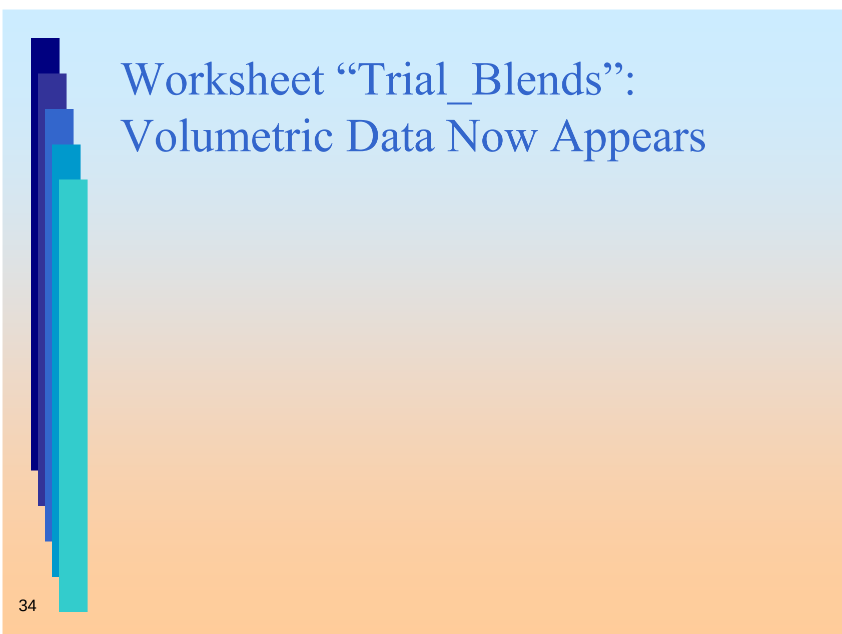
You can enter user-calculated values for maximum specific gravity also.

Slide 5-32

Various volumetric parameters, such as VMA, Vbe, air void content and dust:binder ratio appear at the bottom of worksheet “Specific_Gravity.” Many of these also will now appear on worksheet “Trial_Blends.”

Slide 5-33

The legend for the gradation plot in "Trial_Blends" will now include air void content and VMA for the trial mixes.



Slide 5-34

Volumetric data for the trial mixes now appears in worksheet "Trial_Blends" towards the bottom of the worksheet. Note that HMA Tools gives maximum and minimum values for air voids, VMA and dust:binder ratio.

NCHRP Project 9-33: A Mix Design Manual for Hot Mix Asphalt

UNIT 6: QUIZ ON PART 1 OF THE MIX DESIGN EXAMPLE PROBLEM

Number of Slides: 21

Approximate Time Required: 15 minutes

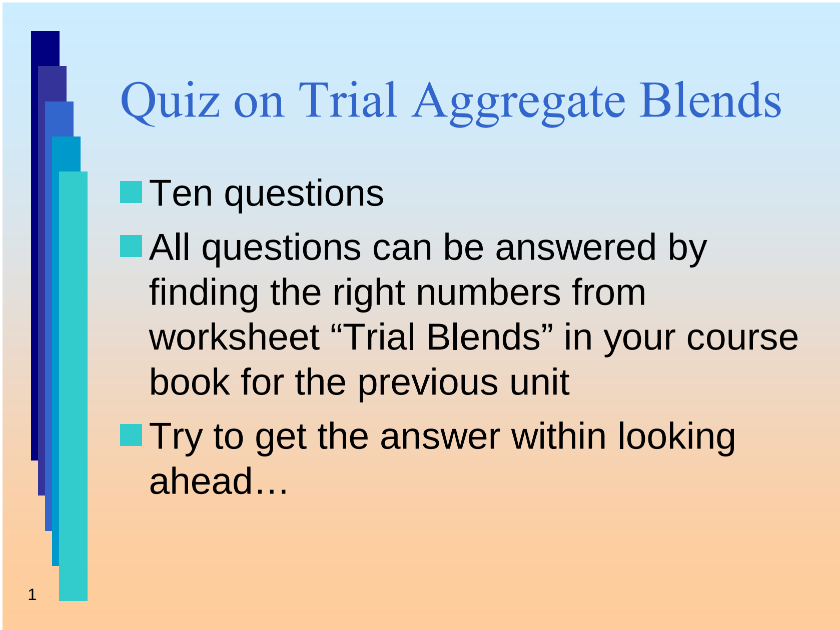
Purpose of Unit: To review important concepts from part 1 of the example mix design problem through a short quiz.

Important Concepts

- The worksheet "Trial_Blends" in HMA Tools contains most of the important information on trial mix designs, including binder content, aggregate gradation, aggregate specification properties and volumetric composition.
- Volumetric composition data—VMA, air voids, Vbe and VFA—cannot be calculated until the required data is filled out in worksheet "Specific_Gravity."

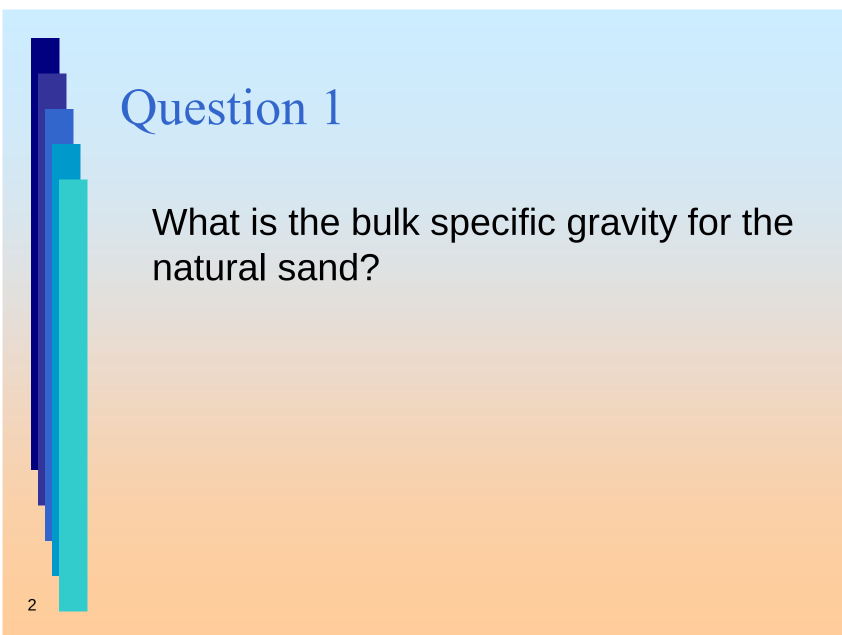
Description of Slides: The slides present a series of 10 questions dealing with the example problem covered in the previous unit (Unit 5). These slides are designed so that the answer is not initially on the slide, but appears once the down arrow key, return key, or page down key is pressed. All questions deal with information that can be found on different parts of the worksheet "Trial_Blends" shown in different slides in the previous unit. In the participant's manual, a slide presents a question, which is then followed by the answer—so the participants have the answer, but should be encouraged to look for the answer in the slides from the previous unit. This will help familiarize them with where different types of information can be found in the HMA Tools spreadsheet.

Instructor's Notes

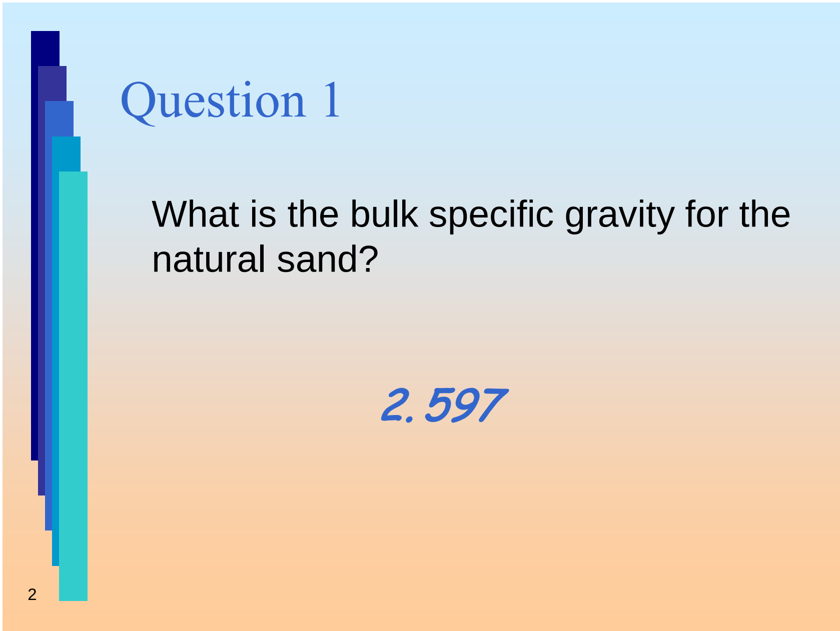


Slide 6-1

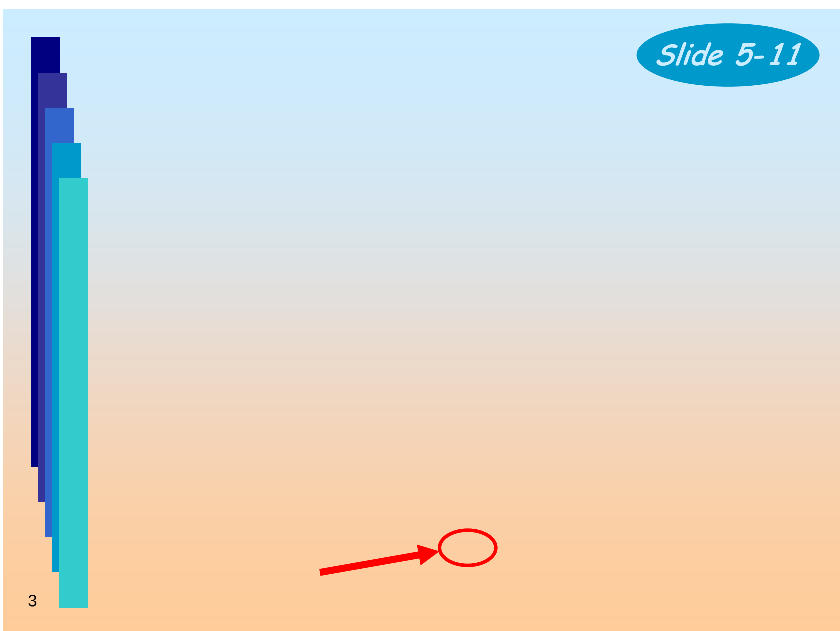
This quiz is a review on what has been covered so far. The answers to the questions can be found on different slides from the previous unit. All of the questions deal with different parts of the worksheet “Trial_Blends.” Answers are included in the workbook following each question, but participants should try to answer the questions without looking ahead.



Slide 6-2

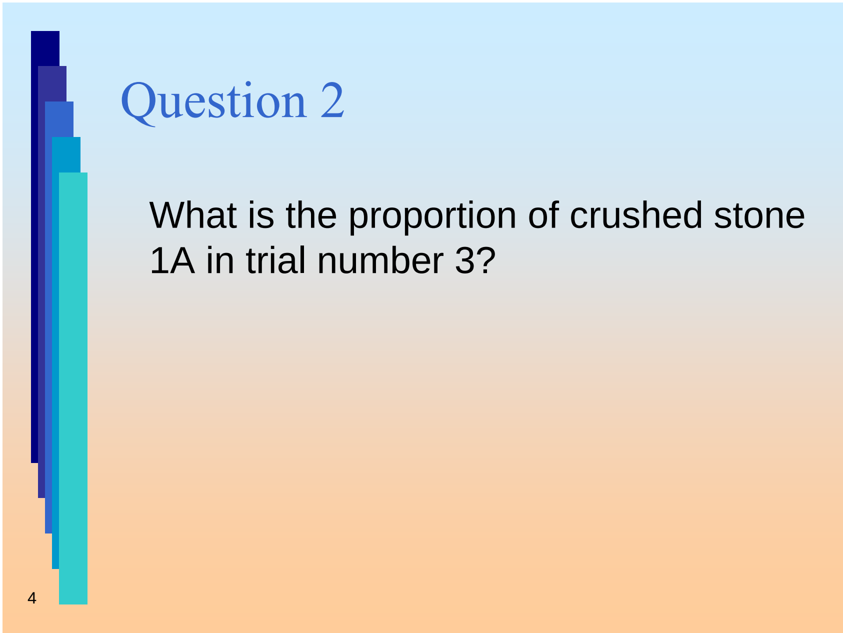


Slide 6-1

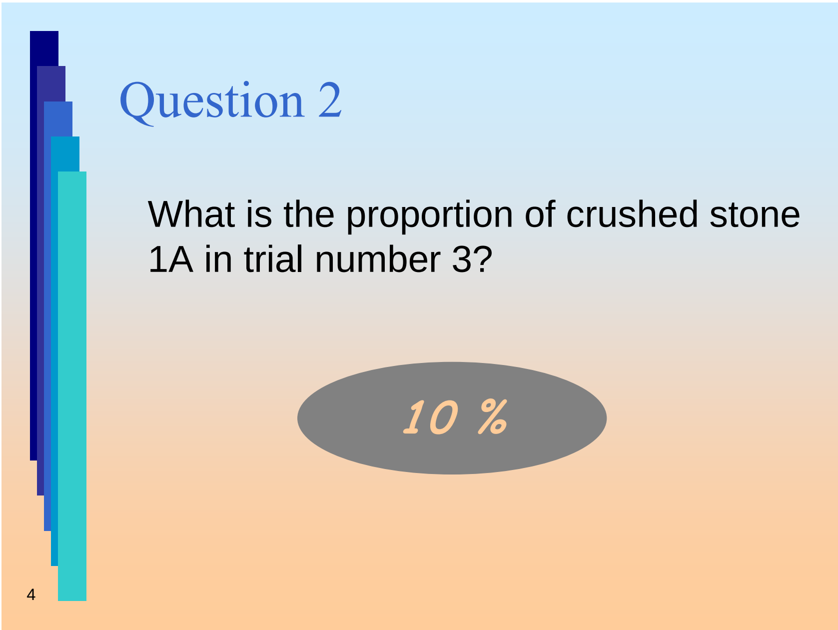


Slide 6-3

Gsa is the apparent specific gravity. This information can also be found on the “Aggregates” worksheet. As noted, this is slide 5-11 from the previous unit.


Question 2
What is the proportion of crushed stone 1A in trial number 3?
4

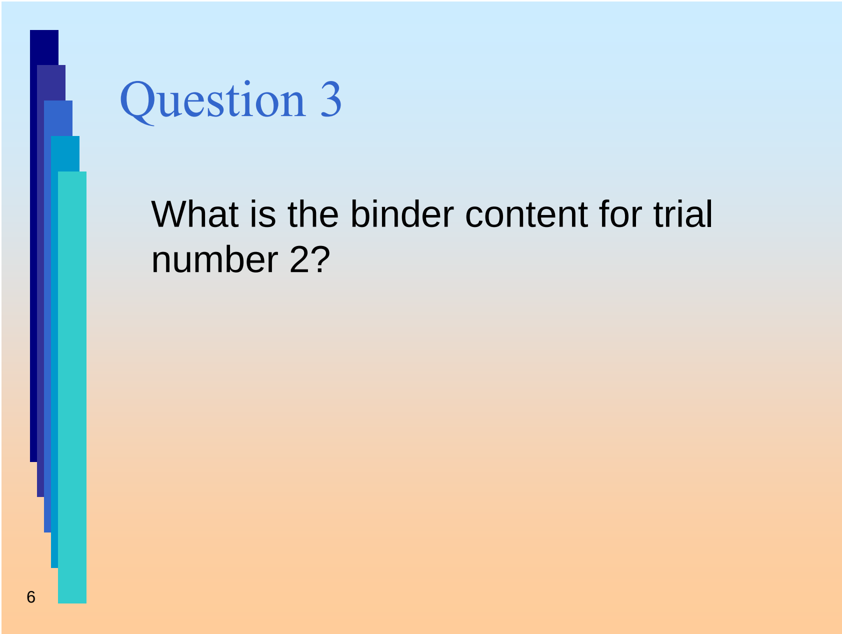
Slide 6-4



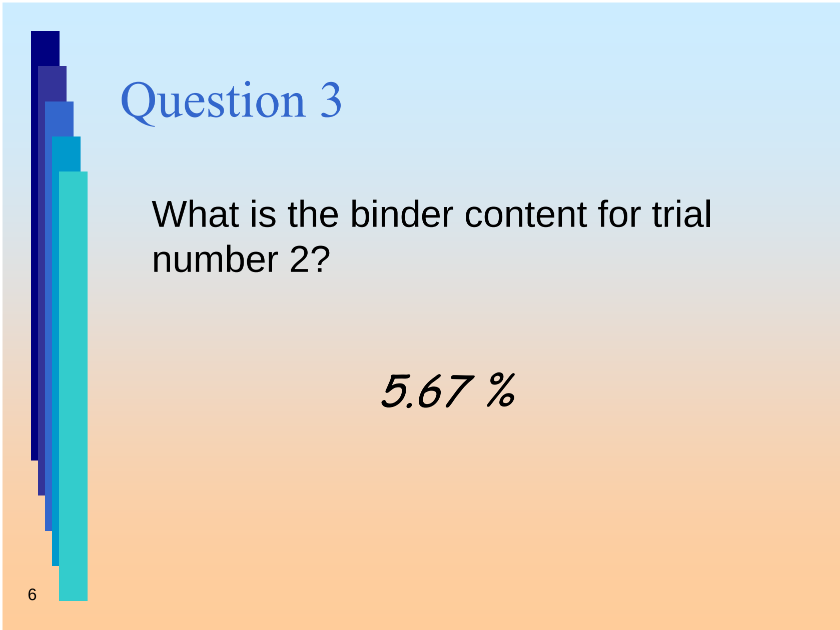
Slide 6-4

Slide 6-5

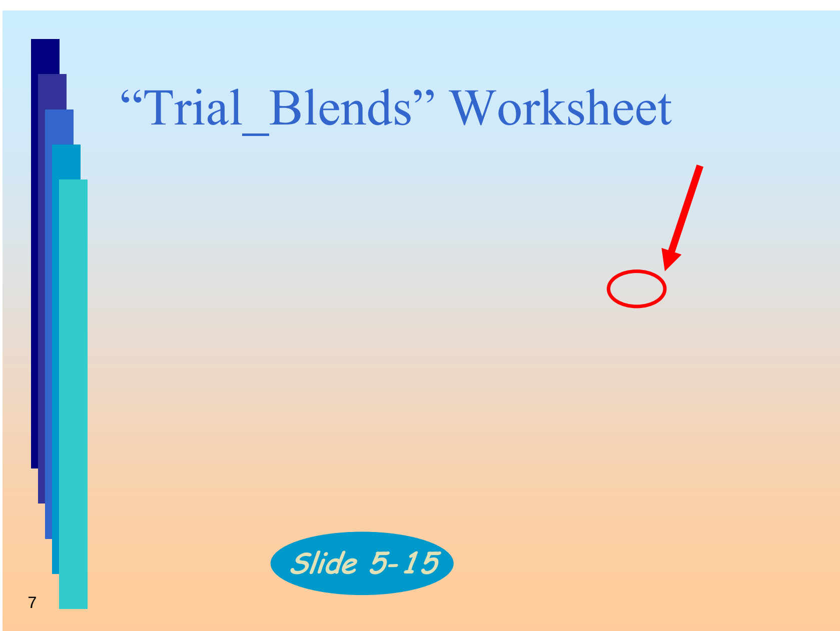
Slide 5-13 from the previous unit.



Slide 6-6



Slide 6-6



Slide 6-7

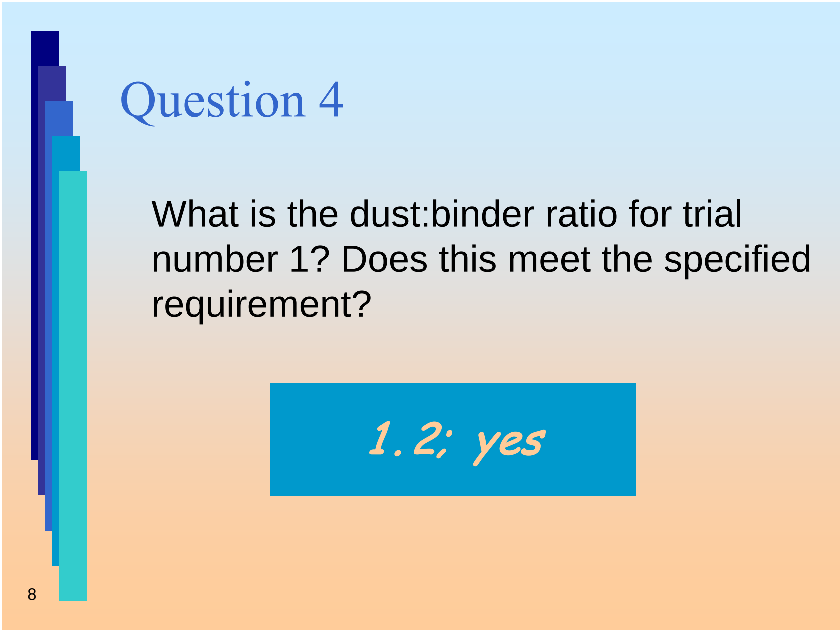
This information is found on slide 5-15 from the previous unit.

Question 4

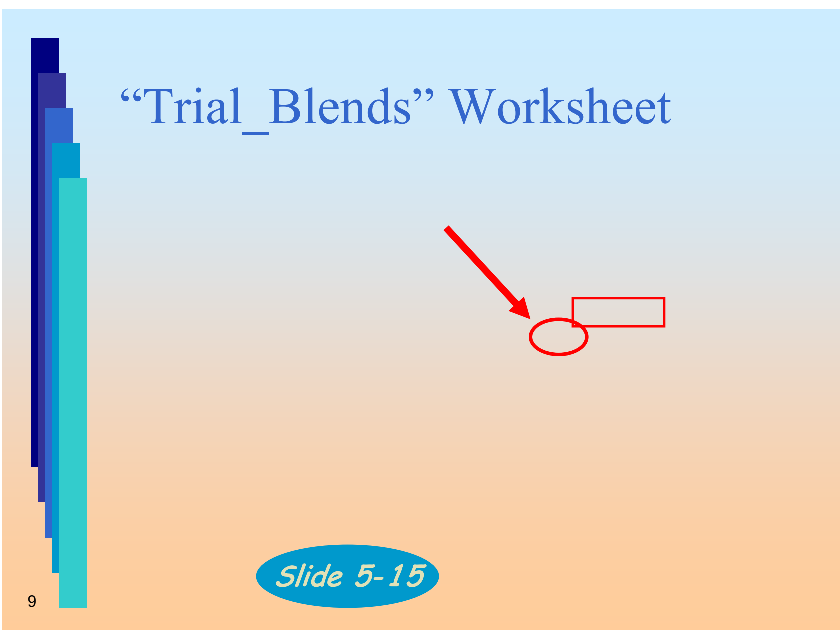
What is the dust:binder ratio for trial number 1? Does this meet the specified requirement?

8

Slide 6-8



Slide 6-8



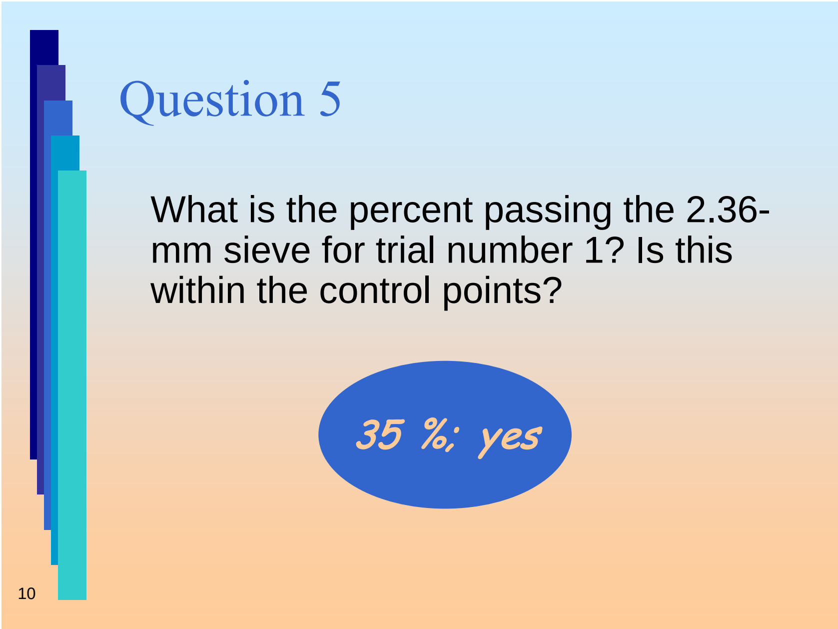
Slide 6-9

Question 5

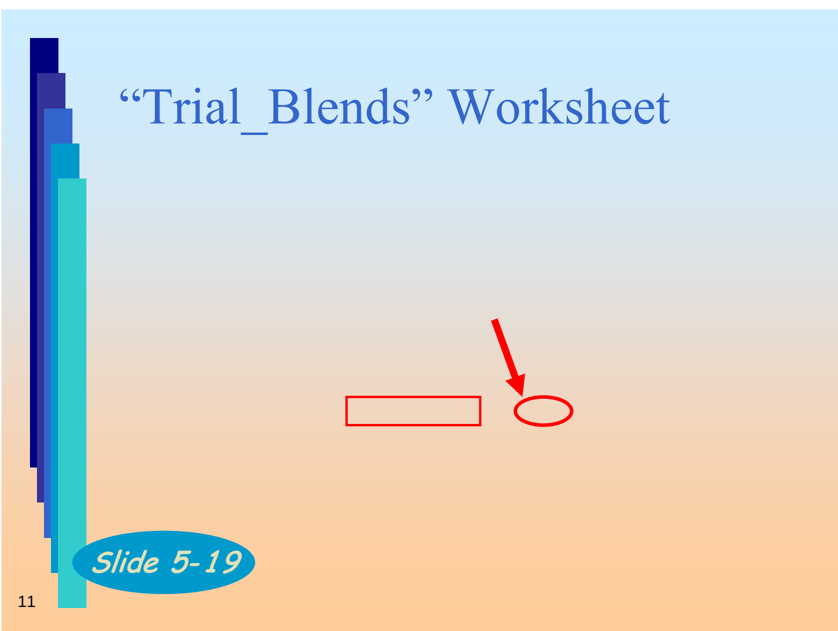
What is the percent passing the 2.36-mm sieve for trial number 1? Is this within the control points?

10

Slide 6-10

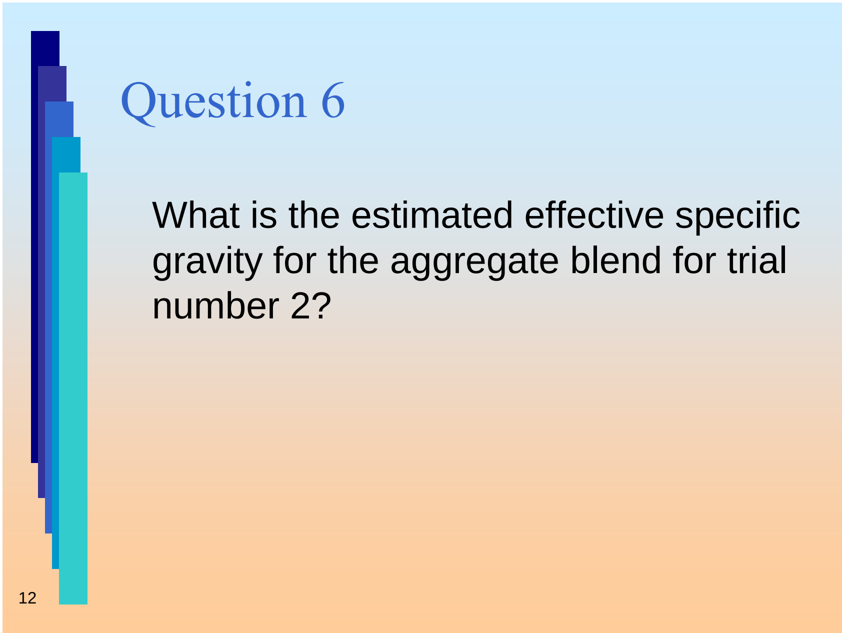


Slide 6-10

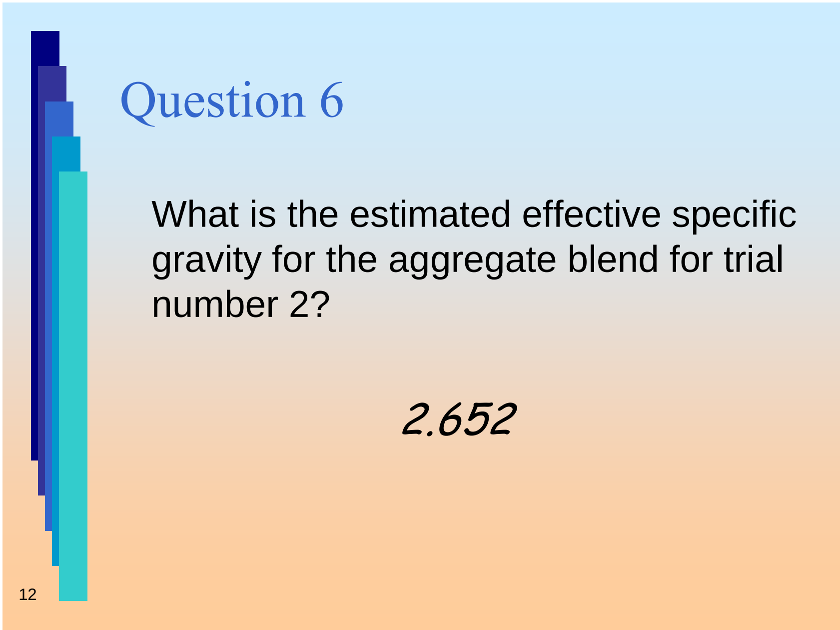


Slide 6-11

Slide 5-19 from the previous unit.


Question 6
What is the estimated effective specific gravity for the aggregate blend for trial number 2?
12

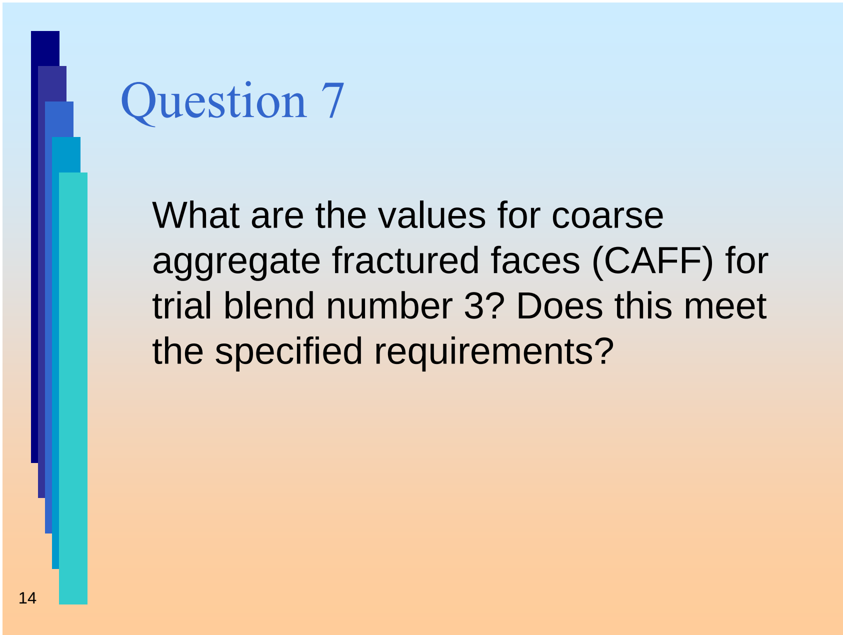
Slide 6-12



Slide 6-12

Slide 6-13

The effective specific gravity is the specific gravity based on the aggregate volume excluding voids permeable to asphalt. The value should be in between the bulk specific gravity (which is based on a volume including all permeable voids) and the apparent specific gravity (based on the volume excluding voids permeable to water). This information is found on Slide 5-20 from the previous unit.


Question 7
What are the values for coarse aggregate fractured faces (CAFF) for trial blend number 3? Does this meet the specified requirements?
14

Slide 6-14

Question 7

What are the values for coarse aggregate fractured faces (CAFF) for trial blend number 3? Does this meet the specified requirements?

96 % and 92 %; yes

14

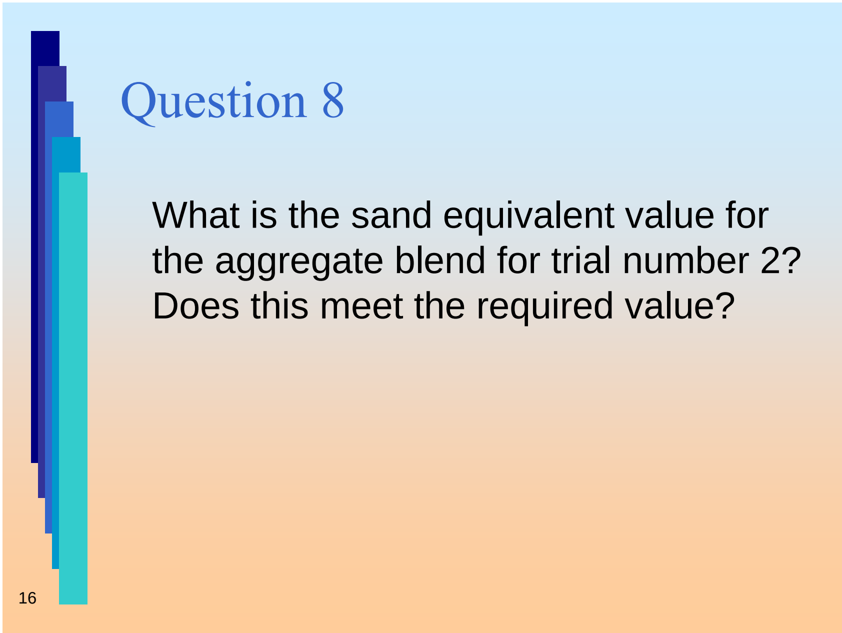
Slide 6-14

"Trial_Blends" Worksheet

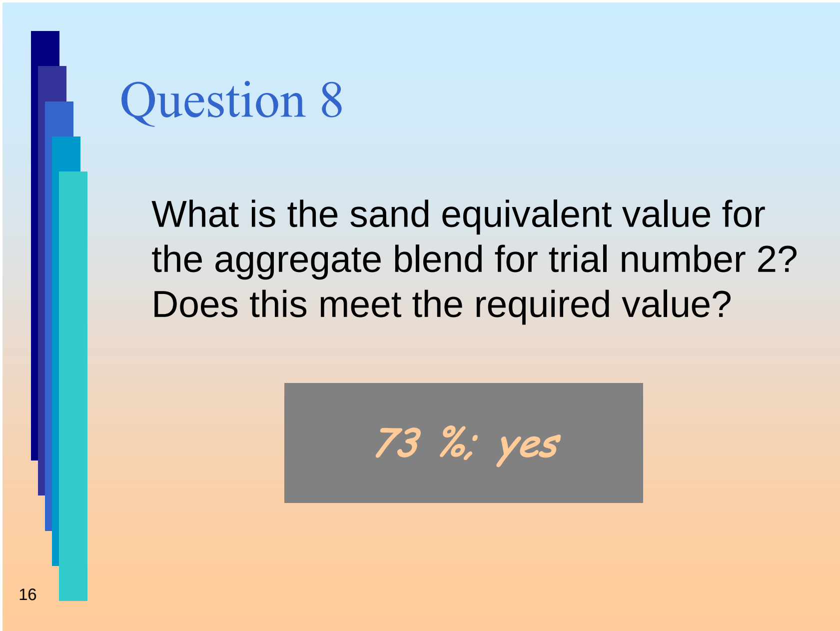
Slide 5-20

15

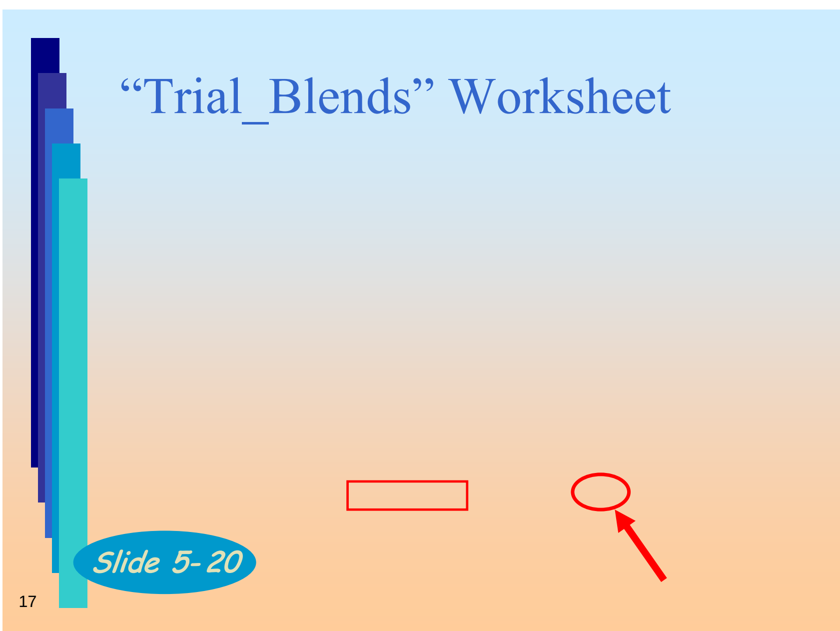
Slide 6-15


Question 8
What is the sand equivalent value for the aggregate blend for trial number 2? Does this meet the required value?
16

Slide 6-16



Slide 6-16



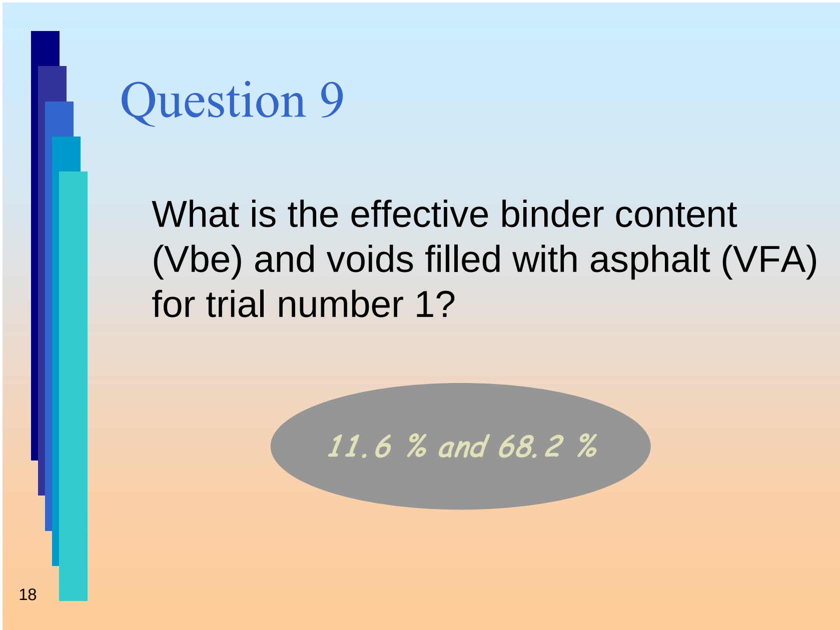
Slide 6-17

Question 9

What is the effective binder content (Vbe) and voids filled with asphalt (VFA) for trial number 1?

18

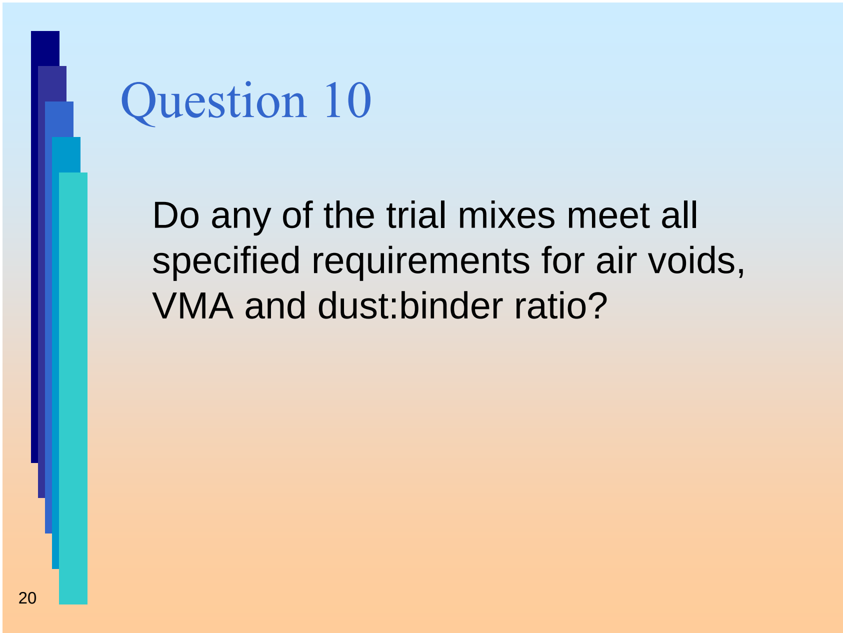
Slide 6-18



Slide 6-18

Slide 6-19

This information is found on Slide 5-34 of the previous unit. Note that this volumetric information will not appear until the required data has been filled out on worksheet "Specific_Gravity."


Question 10
Do any of the trial mixes meet all specified requirements for air voids, VMA and dust:binder ratio?
20

Slide 6-20

Question 10

Do any of the trial mixes meet all specified requirements for air voids, VMA and dust:binder ratio?

Yes; trial number 3

20

Slide 6-20

"Trial_Blends" Worksheet

Slide 5-34

21

Slide 6-21

The air voids and VMA are a bit low—close to the lower limit. In practice, a fourth trial mix might be advisable to try to get a mix with volumetric properties closer to the mid points of the specified ranges.

NCHRP Project 9-33: A Mix Design Manual for Hot Mix Asphalt

UNIT 7: MIX DESIGN EXAMPLE PROBLEM, PART 2

Number of Slides: 36

Approximate Time Required: 60 minutes

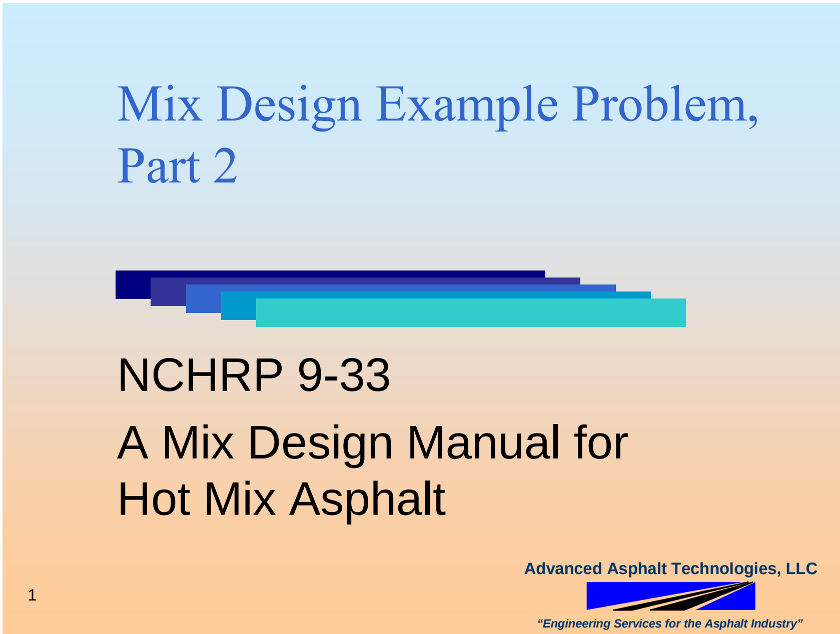
Purpose of Unit: To continue detailed mix design example. This part of the example (part 2) covers evaluating and refining trial mixes. This includes adjusting mixture composition to meet volumetric requirements, moisture resistance testing, rut resistance testing and generating a report for the final mix design.

Important Concepts

- In many cases, none of the initial trial mixes prepared as part of the mix design process will meet all volumetric requirements—they will need to be refined to meet VMA, air voids and other requirements.
- Once a trial mix meets all volumetric requirements, it is subjected to moisture resistance testing following AASHTO T-283.
- After T-283 testing, the mix design is complete if the design traffic level is below 3 million ESALs. If the mix is designed for 3 million ESALs or more, it must pass rut resistance testing.
- Rut resistance may be evaluated using one of six tests: asphalt mixture performance tester (AMPT) flow number test; AMPT flow time test; asphalt pavement analyzer (APA); Hamburg wheel tracking test; Superpave shear tester (SST); and the high-temperature indirect tension (IDT) strength test.
- Most properly prepared mix designs will pass the suggested requirements given in the manual for the various rut resistance tests.

Description of Slides: These slides cover the second part of the mix design process—evaluating and refining trial mixes. They are a combination of word slides, slides taken from the HMA Tools spreadsheet, and photographs of rut testing equipment.

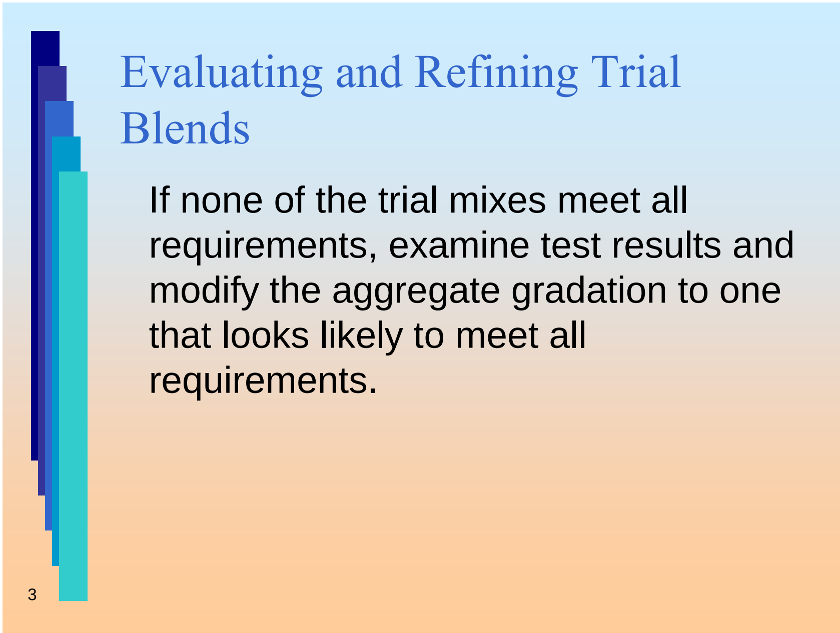
Instructor's Notes



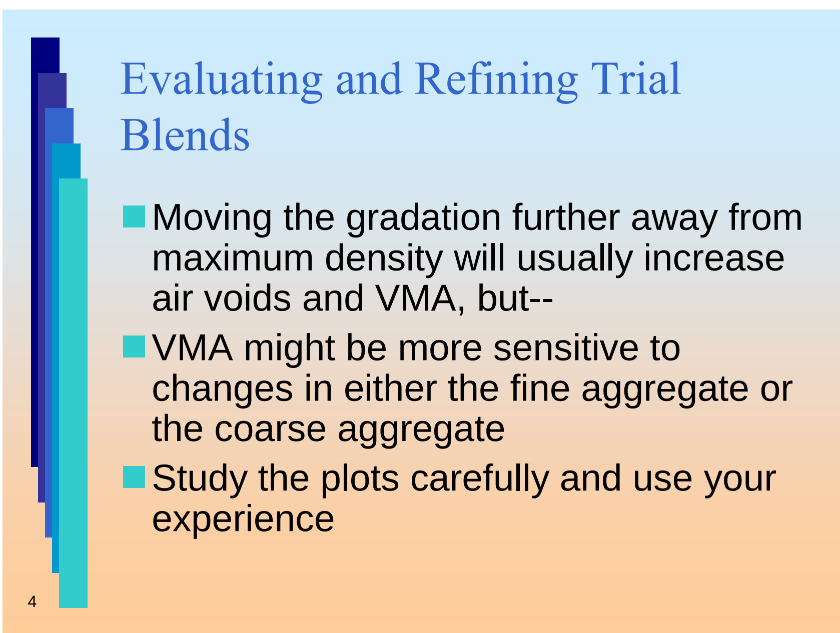
Slide 7-1

Slide 7-2

Even if one of the trial mixes meets all requirements, it might be desirable to get closer to the midpoints of specified ranges for VMA, air voids and dust/binder ratio—this will make it easier to adjust the mix during production.



Slide 7-3



Slide 7-4

In general, moving the gradation closer to the maximum density gradation will lower VMA, while moving away from the maximum density gradation will increase VMA. Also some specified aggregates will tend to increase VMA, while others will decrease VMA. Experience is the best guide on how specific aggregates will affect VMA.

Evaluating and Refining Trial Blends

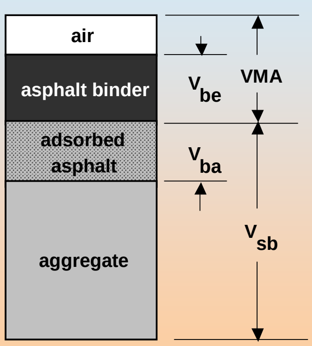
5

- Use other guidelines, rules, etc. as needed for adjusting aggregate blends
- Some technicians find the Bailey method useful
- HMA tools estimates dust:binder ratio and aggregate specification properties

Slide 7-5

Many technicians and engineers have found the Bailey method useful in developing aggregate blends for HMA mix designs. It is however somewhat complicated. The Asphalt Institute offers courses on the Bailey method that will help you to become proficient in this method. It isn't included in the manual because it is fairly complicated and some technicians and engineers don't like it for that reason.

Evaluating and Refining Trial Blends



If you are close to meeting all requirements, it is possible to modify the target VMA and/or air voids.

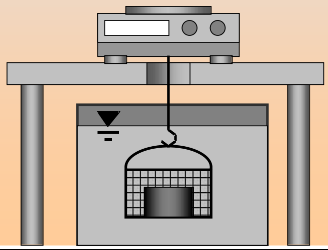
6

Slide 7-6

Adjusting the target VMA and air voids can help refine a mix if you are only off by a few tenths of a percent. For instance, if your air voids a slightly low, but your VMA is high, lowering the target VMA slightly might bring the design closer to the targets. Note that HMA Tools estimates asphalt absorption and this estimate will improve as more trial mixes are made. This will tend to bring mix designs closer to target values as more trial mixes are done.

Evaluating and Refining Trial Blends

When you have a new trial mix, batch, do specific gravity measurements, and check VMA and air voids—repeat as needed.



7

Slide 7-7

Evaluating and Refining Trial Blends

Once you have a mix design meeting all requirements, proceed to performance testing.

8

Slide 7-8

Performance testing means moisture resistance testing and rut testing for mixes designed for higher traffic levels.

Performance Testing

- Moisture resistance testing as per AASHTO T 283
- Rut resistance testing for mixes designed for traffic levels of 3,000,000 ESALs or more

9

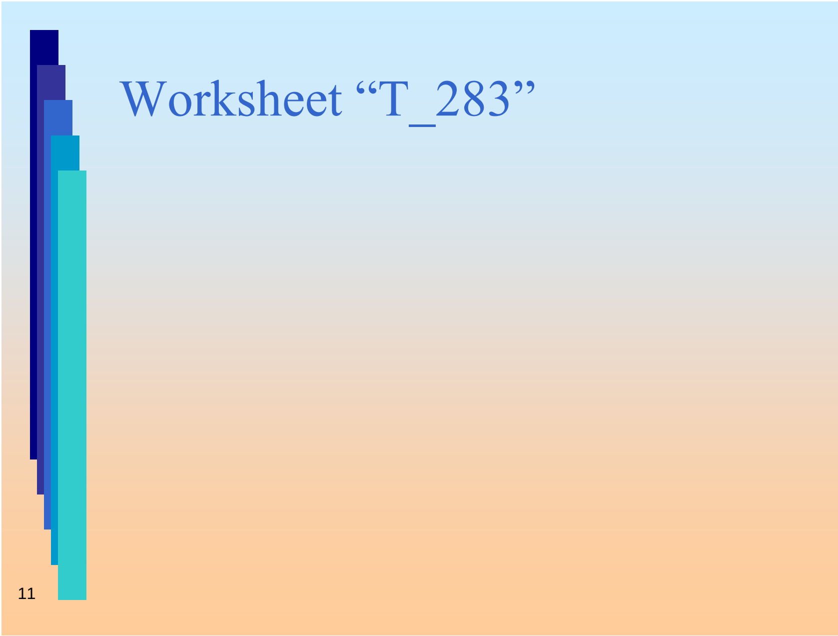
Slide 7-9

Worksheet "T_283"

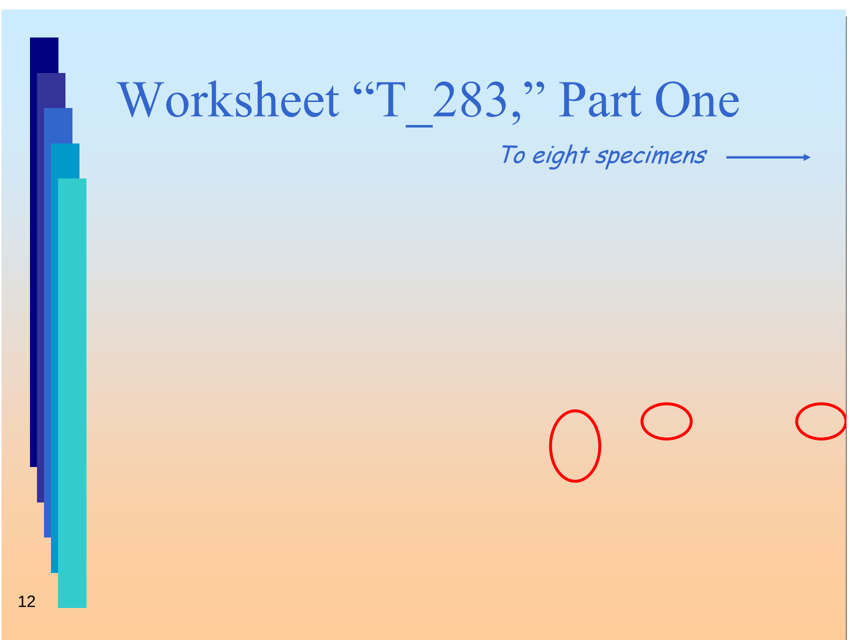
- Uses format nearly identical to worksheet contained in AASHTO T 283
- Includes maximum specific gravity calculation tool for use with this procedure only

10

Slide 7-10

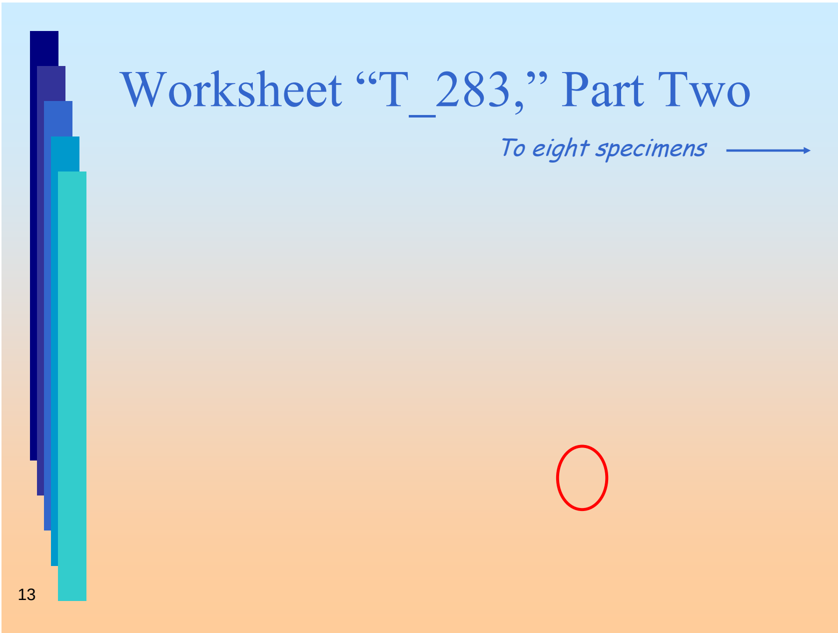


Slide 7-11



Slide 7-12

This worksheet very closely follows that included in the T-283 standard. You select specimens for conditioning with an "x" and HMA Tools will then calculate the average air voids for dry (unconditioned) and wet (conditioned) specimens. This helps to balance out the sets of specimens in terms of air void content.



Slide 7-13

Make sure you fill out the space for visual moisture damage and cracked or broken aggregate. The "T_283" worksheet has space for up to seven tests—one for each possible trial mix. You often might only do one test, but the space is there if you need to do more.

Slide 7-14

There is a place for calculating theoretical maximum specific gravity on the T_283 worksheet—this is for calculating maximum specific gravities for use only for this test. The results aren't linked to any other part of HMA Tools. You don't have to complete this unless you need to do a separate maximum specific gravity test. This normally wouldn't happen unless you were using HMA Tools to record results for T-283 testing that was not part of a mix design.

Acceptable Rut Resistance Tests

- AMPT flow number
- (AMPT flow time)
- APA
- SST/repeated shear
- Hamburg wheel tracking test
- High temperature IDT strength

15

Slide 7-15

Some states already are using rut resistance tests as part of their mix design process. If your state is one of those, use the test required by your highway department.

Asphalt Mixture Performance Tester

16

Slide 7-16

The Asphalt Mixture Performance Tester (AMPT) has recently been developed and is now commercially available. It costs about $50,000 and can perform a wide variety of mixture tests, including flow number, flow time and modulus (E*) tests. The AMPT is much easier to operate than a typical servo-hydraulic test system. The software has been designed to make testing as easy as possible and also to provide various checks on the quality of the test data to help make sure the tests are repeatable.

Slide 7-17

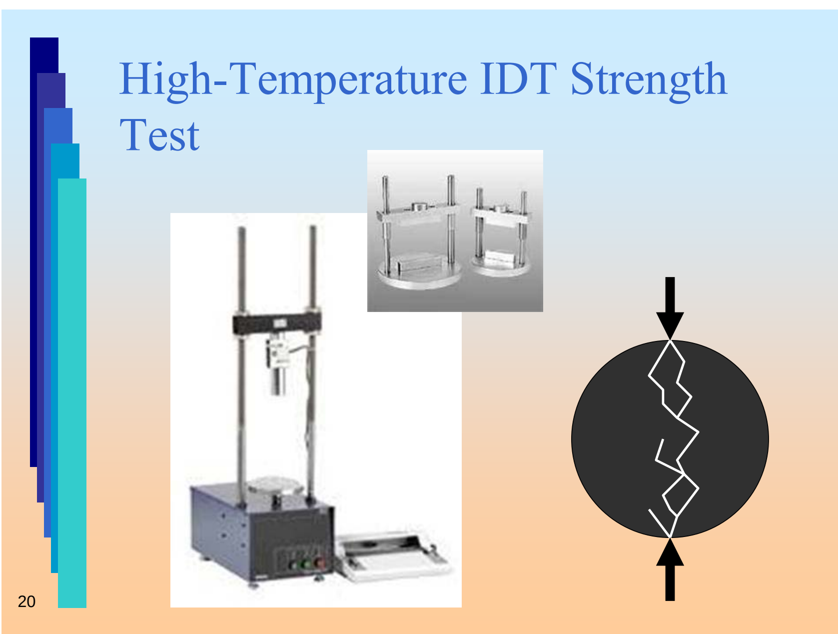
A number of states in the South are already using the APA as a performance test. In this test, a weighted wheel runs over a hose that lies over an HMA specimen. The hose is typically inflated to 100 psi, similar to the pressure of a truck tire. The test is most often run at 64 C, but can be run at other temperatures. The rut depth is measured at the completion of the test—typically 8,000 loading cycles.

Slide 7-18

The Superpave Shear Tester, or SST, is not recommended for routine use, and it is not suggested that laboratories that want to do performance testing purchase an SST. It is included here because there are a half dozen or so labs that already have an SST, and the repeated shear at constant height (RSCH) test performed with the SST is a good way to evaluate rut resistance and can be used as a performance test.

Slide 7-19

There are several states, including Texas and Colorado, using the Hamburg test as part of their mix design process. In this test, a steel wheel is passed over an asphalt concrete slab immersed in a water batch heated to 50 C. In the Texas version of the test, the number of cycles to reach a rut depth of ½-inch must be at least 10,000 for a mix made with a PG 64-22 binder.



Slide 7-20

The high-temperature IDT test is a relatively new procedure for evaluating rut resistance. It is easy to perform, and can be done using a simple marshall press and standard IDT test jigs. The results of this test correlate very well to other rut resistance tests and also have been correlated to field rutting data for a number of projects.

Guidelines for Performance Tests

- Test values in manual are guidelines
- Agency should evaluate and revise required test values in consideration of location conditions and materials

21

Slide 7-21

The Manual gives suggested values for the various tests as an aid in interpreting the results. Individual agencies should evaluate these suggested requirements in view of their local conditions and materials and modify them as appropriate.

Suggested Minimum Flow Number Values

Traffic Level *Million ESALs*	**Minimum Flow Number** *Cycles*
< 3	---
3 to < 10	340
10 to < 30	560
≥ 30	890

22

Slide 7-22

The flow number test is performed with the AMPT. In this test, a cylindrical specimen is subjected to pulse loading at a stress of about 90 psi. The flow number is the number of cycles it takes before the specimen starts to undergo tertiary flow—that is, rapidly increasing strains that indicate failure.

Suggested Minimum Flow Time Values

Traffic Level *Million ESALs*	**Minimum Flow Time** *Seconds*
< 3	---
3 to < 10	20
10 to < 30	72
≥ 30	280

23

Slide 7-23

The flow time test is also performed on the AMPT. The flow time test is similar to the flow number test, but instead of pulse loading a constant load or creep load is used. The flow time is the time in seconds required to reach tertiary flow.

Suggested Maximum Rut Depth Values for APA

Traffic Level *Million ESALs*	**Maximum Rut Depth** *mm*
< 3	---
3 to < 10	5
10 to < 30	4
≥ 30	3

24

Slide 7-24

These values are based on those used by the Oklahoma Department of Transportation, and are fairly typical for agencies using the APA test.

Texas Requirements for Hamburg Wheel Tracking Test

High Temperature Binder Grade	Minimum Passes to 0.5-inch Rut Depth
PG 64 or lower	10,000
PG 70	15,000
PG 76 or higher	20,000

25

Slide 7-25

These are the Texas requirements. There are few states using this test, so “typical” test requirements for the Hamburg test do not really exist.

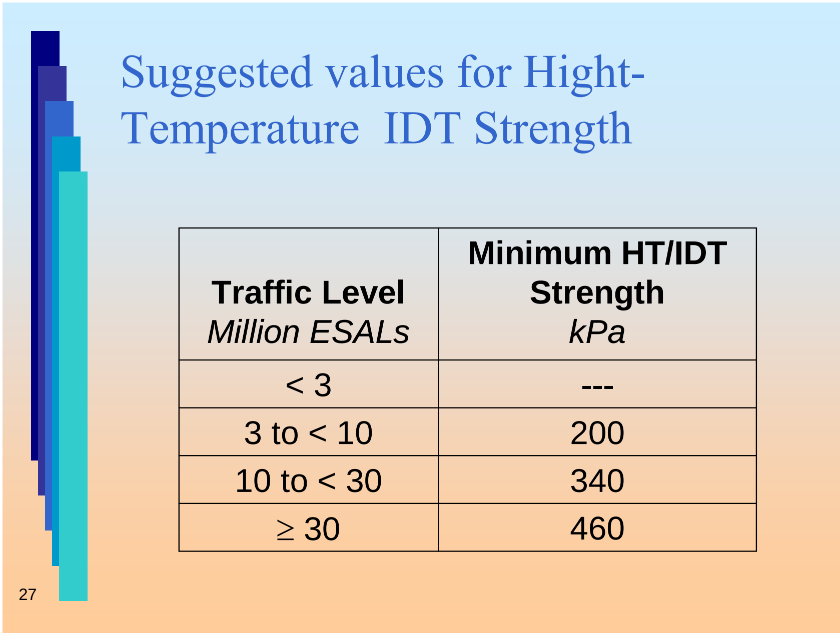
Suggested Maximum Values for SST/MPSS

Traffic Level *Million ESALs*	**Maximum Value for MPSS** *%*
< 3	---
3 to < 10	3.2
10 to < 30	2.2
≥ 30	1.4

26

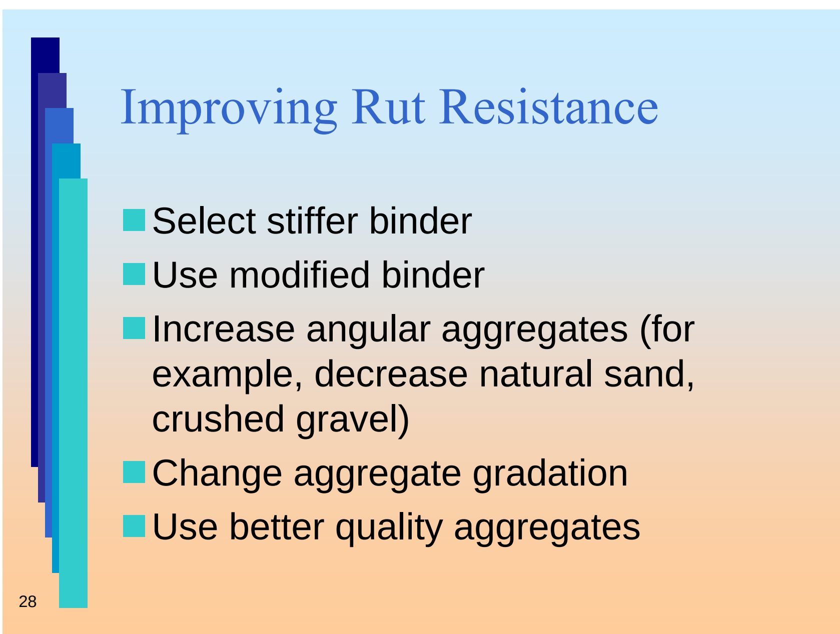
Slide 7-26

These values were developed during NCHRP Project 9-33. They are based on relating SST test data to rut depths predicted by a rutting model developed during that project.



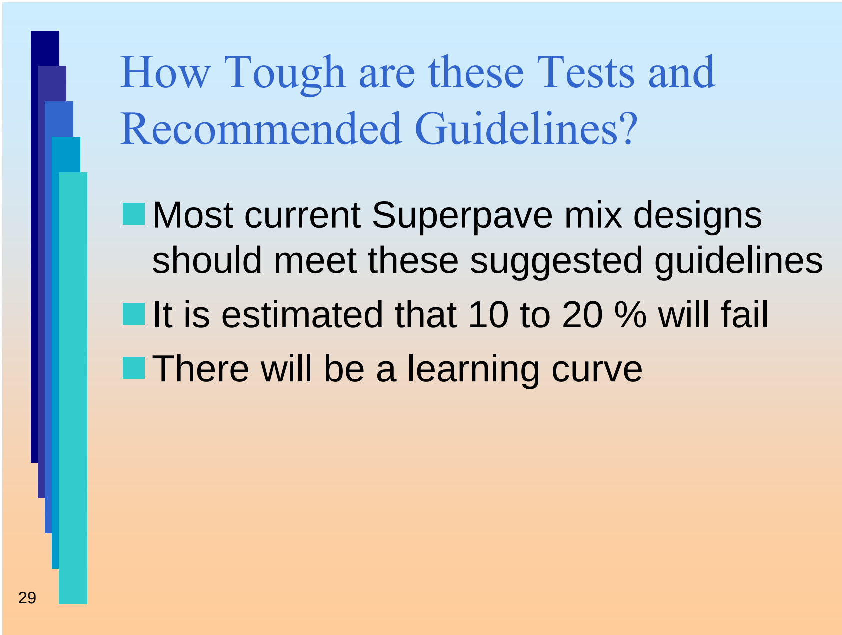
Slide 7-27

These values were also developed during NCHRP 9-33, using the same method. There has also been research relating the high temperature IDT test to rut depths measured at the FHWA ALF facility.



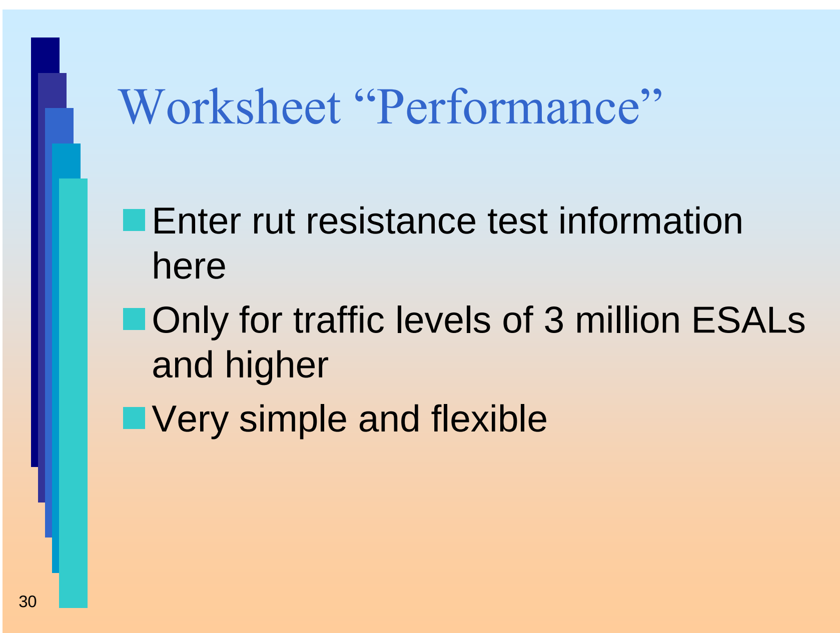
Slide 7-28

Most mixes designed using this procedure—or the Superpave method—should pass the rut resistance test. For those that fail, the first thing to do is to make sure the specimens were prepared properly, that the test was run following the right procedures and that the results were accurately calculated. If the test results seem suspect, repeat the test. If the mix still fails, there are a number of things that can be done to the design to improve rut resistance.



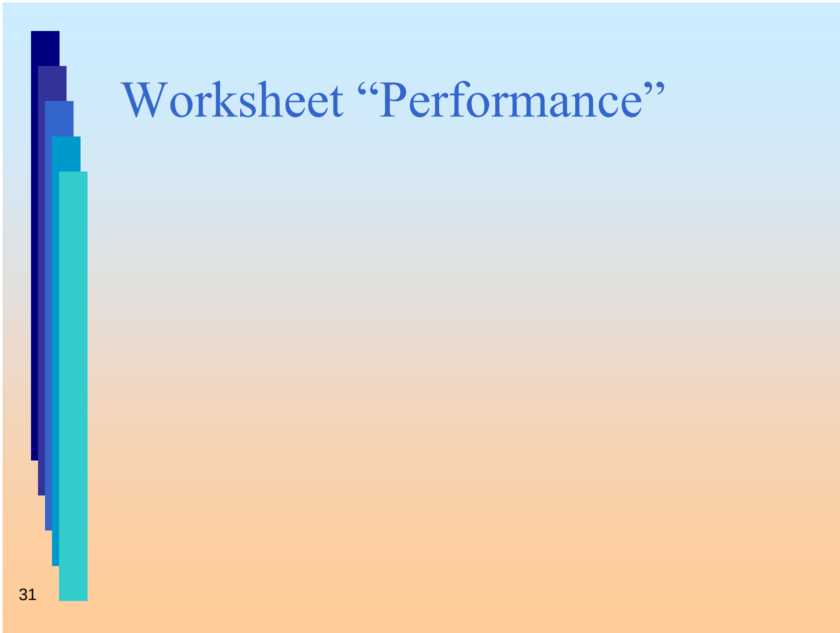
Slide 7-29

As noted earlier, the test guidelines have been devised so that roughly 80 to 90 % of properly designed mixes will pass.

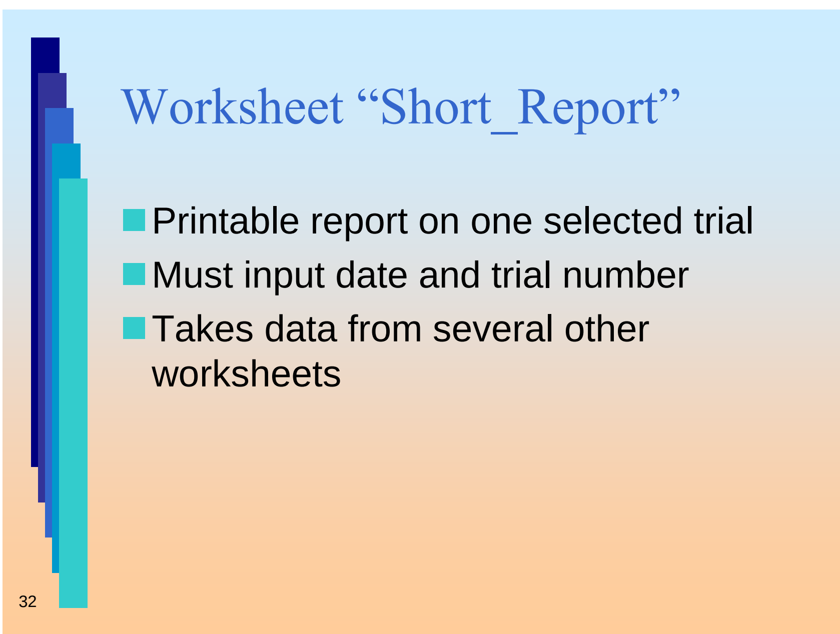


Slide 7-30

Results of the rut resistance test are recorded on worksheet "Performance." Like the T-283 worksheet, there is space for up to seven tests—one for each of up to seven trial batches, but many mixes will not require any performance tests, and for those that are tested, in most cases only the final trial mix will be tested.



Slide 7-31

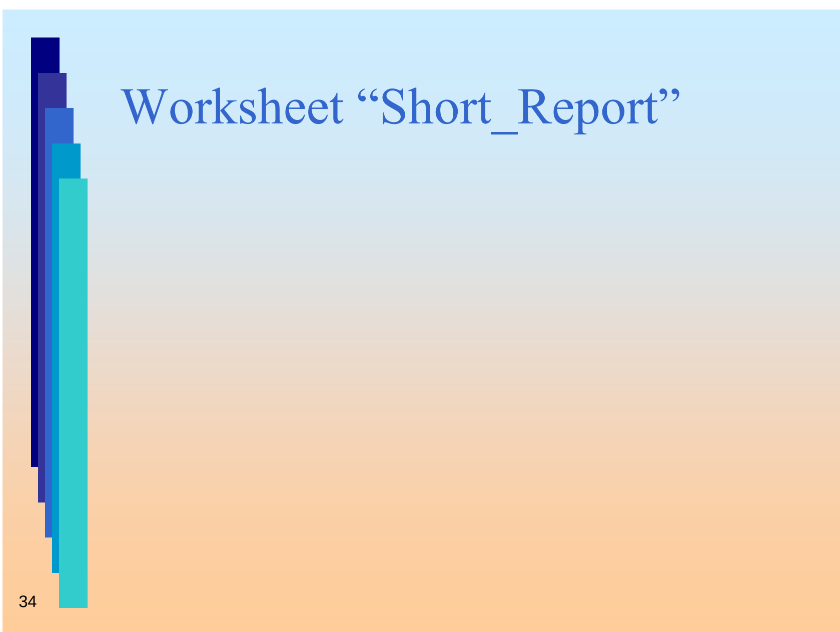


Slide 7-32

“Short_Report” is used to print out a detailed, one-page report on any selected trial mix. A longer report—giving information on all trial mixes if desired—can be printed from worksheet “Complete_Report.”

Slide 7-33

Short report gives the specific gravity values and proportions for each component of the mixtures.

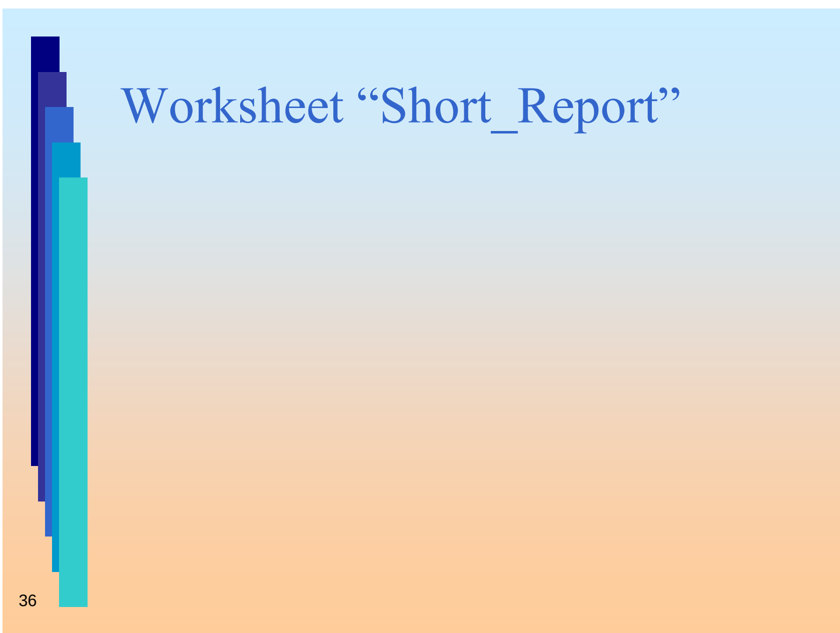


Slide 7-34

It also provides the volumetric properties, along with the requirements. The binder grading information is most important when RAP is being used—this lets you know what new binder grade must be used in the mix to make sure the blended binder grade meets requirements.

Slide 7-35

This part of the report gives the aggregate blend gradation along with the specifications.



Slide 7-36

The report also includes estimated aggregate specification properties.

NCHRP Project 9-33: A Mix Design Manual for Hot Mix Asphalt (HMA)

DATA FOR MIX DESIGN EXAMPLE PROBLEM, PART 3 / RAP

Data for new aggregates and binders are the same as for Part 1 of the Workshop. New data is for RAP aggregate, binder content and binder grade on pages 3 and 4.

General Information

Design traffic level...6 million ESALs
Binder PG Grade...PG 64-22
Aggregate NMAS ....9.5 mm
Dust/binder ratio ....standard
Location within pavement...................................surface course (within 100 mm of surface)

Aggregate Gradation Data

	Wt. Percent Passing for Aggregate			
Sieve Size, mm	**Crushed Stone No. 1**	**Crushed Stone No. 1A**	**Mfg. Sand**	**Natural Sand**
50	100.0	100.0	100.0	100.0
37.5	100.0	100.0	100.0	100.0
25	100.0	100.0	100.0	100.0
19	100.0	100.0	100.0	100.0
12.5	93.0	100.0	100.0	100.0
9.5	58.0	100.0	100.0	100.0
4.75	3.0	32.0	89.0	100.0
2.36	0.0	3.0	76.0	83.0
1.18	0.0	0.0	49.0	63.0
0.600	0.0	0.0	33.0	42.0
0.300	0.0	0.0	27.0	19.0
0.150	0.0	0.0	18.0	6.0
0.075	0.0	0.0	14.0	2.9

Aggregate Specific Gravity Values and Specification Property Data

Specific Gravity Values				
Bulk specific gravity	2.607	2.607	2.575	2.597
Apparent specific gravity	2.715	2.715	2.718	2.711
Aggregate Specification Property Data				
C.A. fractured faces, Wt. % particles with one fractured face	96.0	96.0		
C.A. fractured faces, Wt. % particles with at least two fractured faces	91.0	93.0		
C.A. flat & elongated particles, Wt. %	0.8	0.0		
F.A. angularity, Vol. % uncompacted voids			48.0	43.0
F.A., clay content, sand equivalent value, %			58.0	89.0

RAP Aggregate Gradation Data

Sieve Size, mm	Wt. % Passing
50	100.0
37.5	100.0
25	100.0
19	99.7
12.5	97.5
9.5	93.6
4.75	71.9
2.36	54.4
1.18	48.7
0.600	34.4
0.300	18.6
0.150	14.0
0.075	10.2

RAP Aggregate Specific Gravity Values and Specification Property Data

Aggregate Specific Gravity Values	
Fine Aggregate Portion Bulk Specific Gravity	2.525
Coarse Aggregate Portion Bulk Specific Gravity	2.640
Fine Aggregate Portion Apparent Specific Gravity	2.587
Coarse Aggregate Fraction Apparent Specific Gravity	2.694
Aggregate Specification Property Data	
C.A. fractured faces, Wt. % particles with one fractured face	100.0
C.A. fractured faces, Wt. % particles with at least two fractured faces	95.0
C.A. flat & elongated particles, Wt. %	1.5
F.A. angularity, Vol. % uncompacted voids	44.2

RAP Variability Analysis Data

Sieve Size, mm	*Wt. % Passing for Sample:*				
	No. 1	**No. 2**	**No. 3**	**No. 4**	**No. 5**
50	100.0	100.0	100.0	100.0	100.0
37.5	100.0	100.0	100.0	100.0	100.0
25	100.0	100.0	100.0	100.0	100.0
19	99.2	100.0	100.0	99.5	99.8
12.5	96.5	97.8	97.2	99.3	96.9
9.5	91.5	94.3	96.1	90.6	95.3
4.75	73.3	71.5	72.5	66.4	68.9
2.36	55.2	54.9	50.6	54.2	51.1
1.18	48.8	47.9	44.2	50.9	51.5
0.600	32.2	33.0	35.8	33.6	37.2
0.300	20.4	17.1	16.8	19.7	19.2
0.150	15.0	15.2	12.8	13.5	13.6
0.075	11.5	11.0	8.8	10.2	9.5
Asphalt Binder Content					
AC Wt. %	5.4	5.2	5.2	5.3	5.0

Asphalt Binder Test Data

Property	PG 58-28	PG 64-22	Recovered RAP Binder
Supplier	Jupiter Materials	Jupiter Materials	N/A
Specific Gravity	1.024	1.026	1.030
Grading Test Data			
Temperature, °C	*Unaged Binder, G*/sin δ, kPa*		
58	1.16		
64	0.55	1.54	
70		0.76	
76			1.81
82			0.94
	RTFOT Residue, G/sin δ, kPa*		
58	2.50		
64	1.16	3.46	
70		1.62	
76			4.21
82			2.12
	PAV Residue, G Sin δ, kPa*		*RTFOT Residue, G* sinδ, kPa*
13	4,990		
16	3,647		
19	2,635	7,183	
22		4,819	
25		3,145	6,359
28			4,713
	PAV Residue, S, MPa (m-value)		*RTFOT Residue, S, MPa (m-value)*
−6			175 (0.335)
−12		214 (0.359)	423 (0.299)
−18	216 (0.373)	507 (0.275)	
−24	548 (0.278)		

UNIT 8: MIX DESIGN EXAMPLE PROBLEM, PART 3—WORKING WITH RAP

Number of Slides: 43

Approximate Time Required: 90 minutes

Purpose of Unit: To explain how RAP is incorporated into dense graded mix designs.

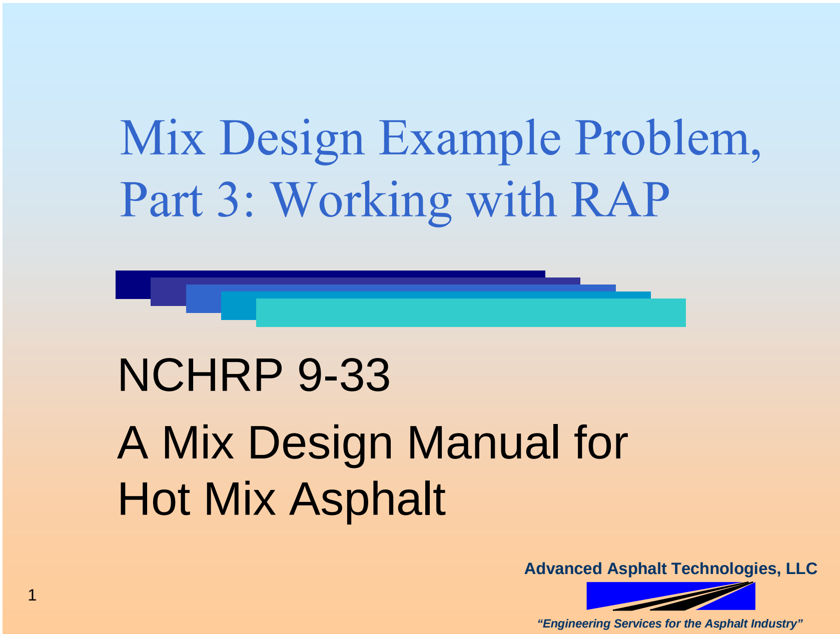
Important Concepts

- If 15 % or less RAP is added to the mix design, the procedure is much simpler than if larger amounts of RAP are added. Binder grade analysis and RAP variability analysis don't need to be performed.
- If more than 15 % RAP is to be used in a mix design, then both binder grade analysis and RAP variability analysis must be performed.
- The difference in the mix design process when RAP is added is in the initial stages. RAP must be sampled and tested, and then if large amounts of RAP are to be included in the mix design, a binder grade analysis and a RAP variability analysis must be performed.
- RAP stockpiles should be sampled from 5 to 10 different locations. Enough material must be gathered for both characterizing the RAP and doing the mix design.
- The RAP binder grade analysis is done to answer several questions about binder grade in the mix design: (1) with a given RAP content and a given new binder grade, what is the resulting grade of the blended binder; (2) given a specified new binder grade, what are the minimum and maximum amounts of RAP that can be used; and (3) with given amount of RAP, what is the required new binder grade that should be used?
- The RAP variability analysis is needed to determine how much RAP can be used in a mix design without significantly increasing the variability during production of the mix. The purpose of the variability analysis is not to meet agency requirements, but to ensure that the producer is not penalized for producing mix that is so variable that it does not meet typical state highway agency specifications.

Description of Slides: These slides continue the example problem that has been the basis for most of the course. In this case, the same aggregates are used but now a RAP stockpile is added to the materials. The slides explain the procedure used to incorporate RAP into the mix design. As in previous units, many of the slides show HMA Tools worksheets and how they are filled in during the mix design process. The slides emphasis RAP analysis, that is, binder grade analysis and RAP variability analysis. The RAP binder grade analysis is done to determine what new binder grade is needed to meet the specified final PG grade with a given amount of RAP. Alternately, the grade analysis can be used to determine what the maximum RAP content is given a new binder PG grade. The RAP variability analysis estimates how much of a RAP stockpile can be added to a mix design without significant increase in the production variability of the mix. Once the RAP binder and variability analyses are complete, the mix design proceeds as it would without RAP—the later parts of the mix design procedure are not shown in this slide set since this would simply repeat what was covered in the previous unit.

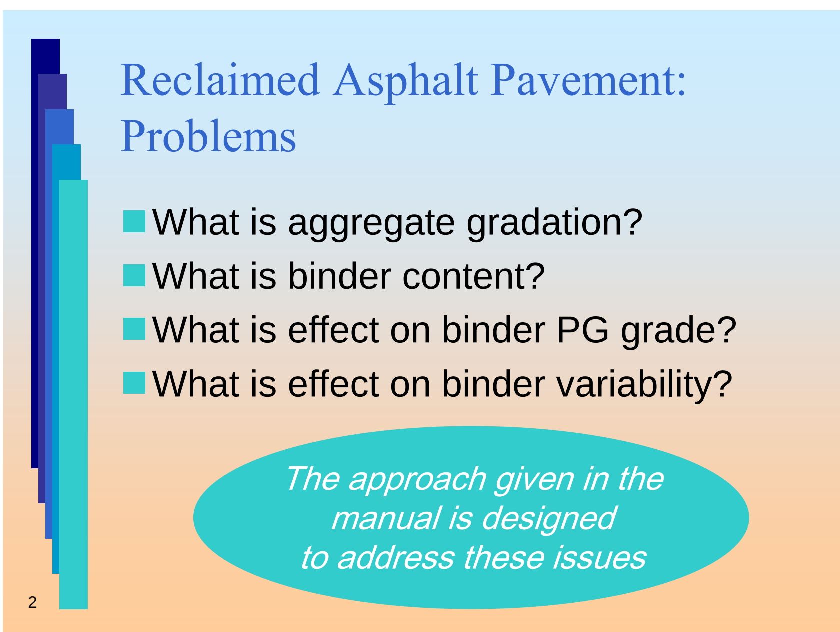
Note: This is a very long and somewhat complicated set of slides. It is suggested that a short break be given partway through the unit. A good place to pause for a short break is at the start of slide 26 titled *"Blended_Binders" Worksheet*.

<u>Instructor's Notes</u>



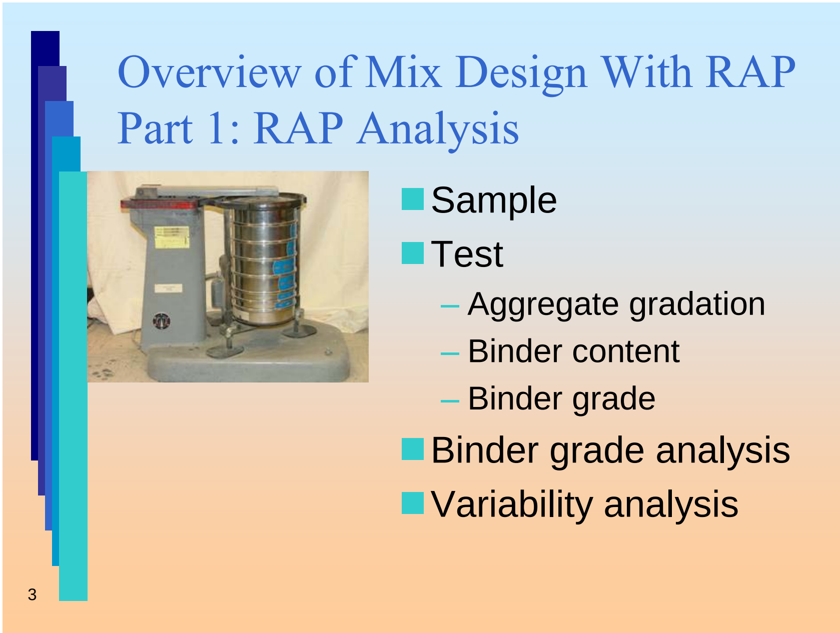
Slide 8-1

This is a continuation of the mix design problem—we are going to use the same aggregates, but this time we will include a RAP stockpile.



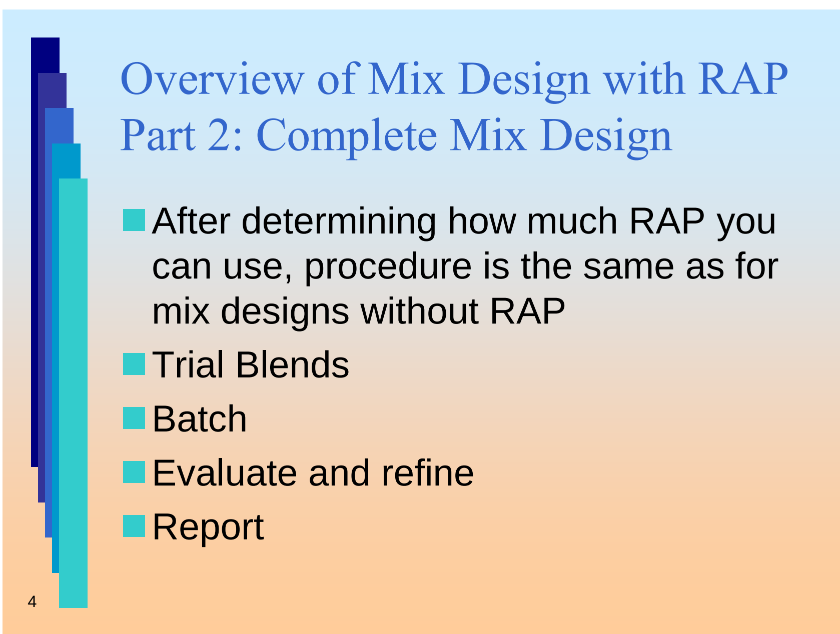
Slide 8-2

Before doing a mix design with RAP, you need information on the RAP stockpile. You don't need information on the RAP binder or RAP variability unless you are using more than 15 % RAP in your mix design. In this example, we are going to assume we want to use as much RAP as possible—up to the maximum recommended amount of 50 %.



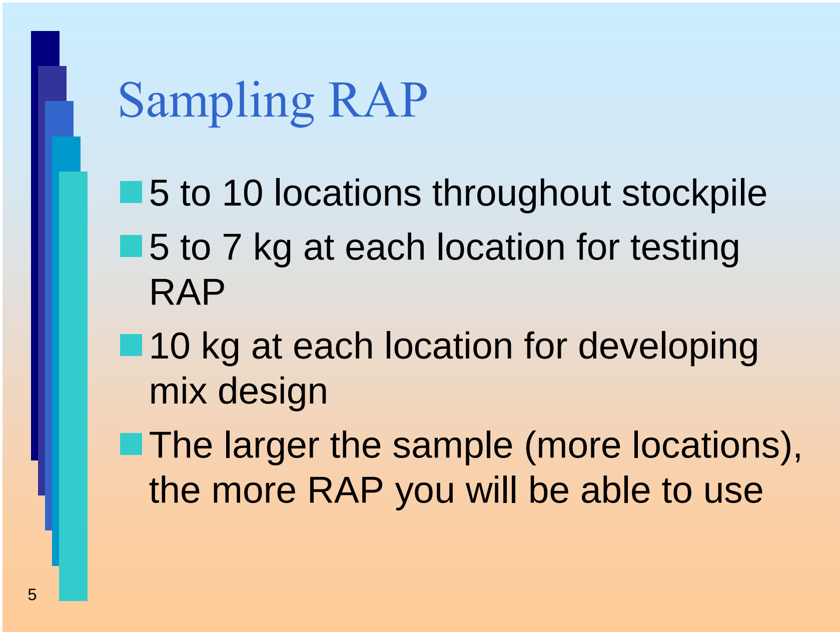
Slide 8-3

For mix designs with large amounts of RAP, there are four parts to the RAP analysis: Sample, test, binder grade analysis and variability analysis. The purpose of the RAP analysis is to determine how much RAP you can use in the mix design, and what the required PG grade is of the new binder that will be added to the mix.



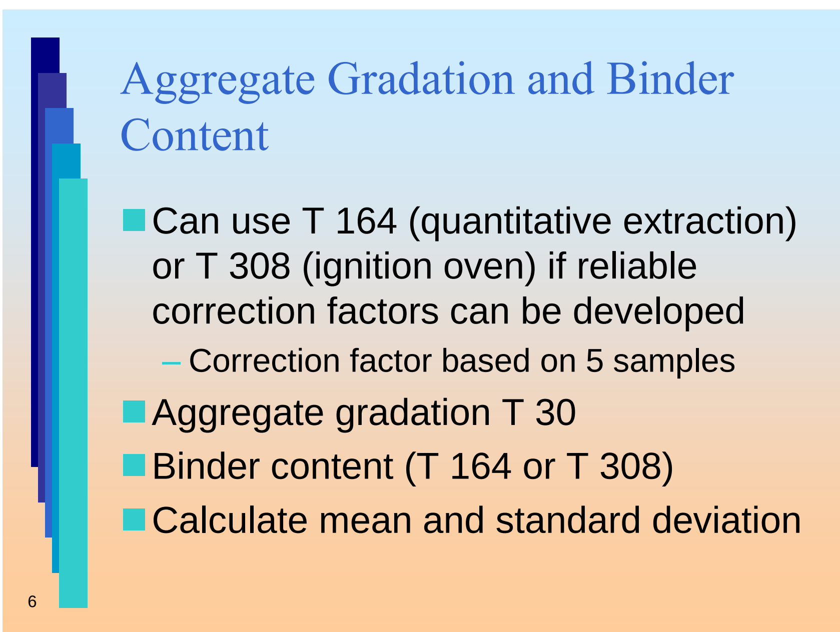
Slide 8-4

After completing the analysis, the mix design process is the same as for mix designs that don't use RAP. For this reason, this example will focus on RAP analysis.

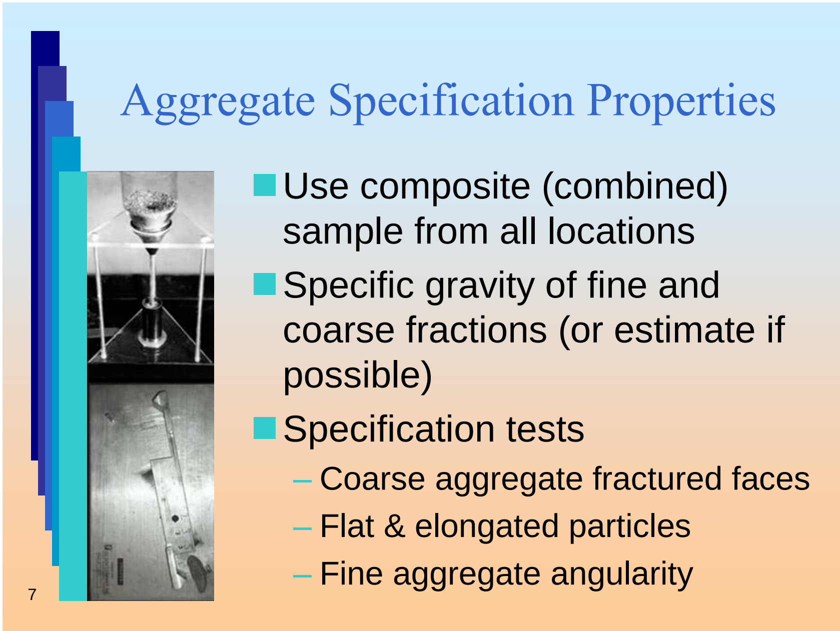


Slide 8-5

It's important to take RAP samples from numerous locations in the stockpile. RAP stockpiles can vary from place to place, so by taking lots of samples you will end up with a representative sample—that is, a sample that is truly similar to the overall composition of the stockpile. Also, you need a large number of samples to do a variability analysis. At least five is recommended, and the more samples you take, the more RAP you will be able to use in your mix design.

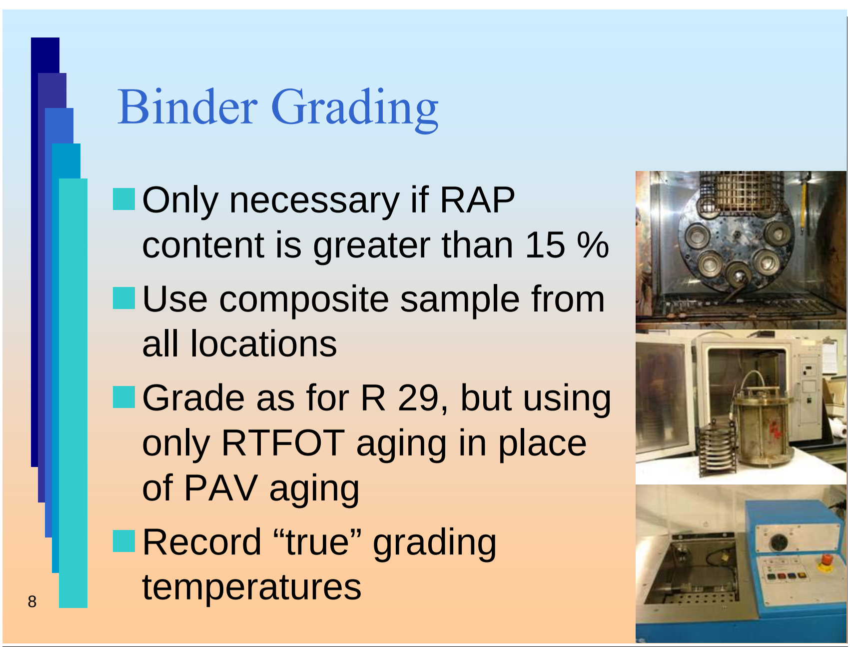


Slide 8-6



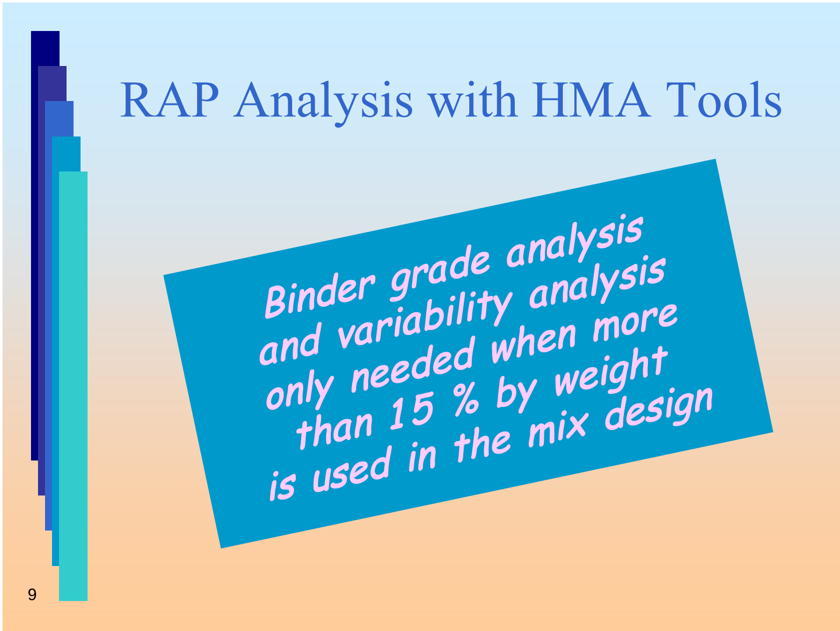
Slide 8-7

You don't do sand equivalent tests on RAP—it would be meaningless.

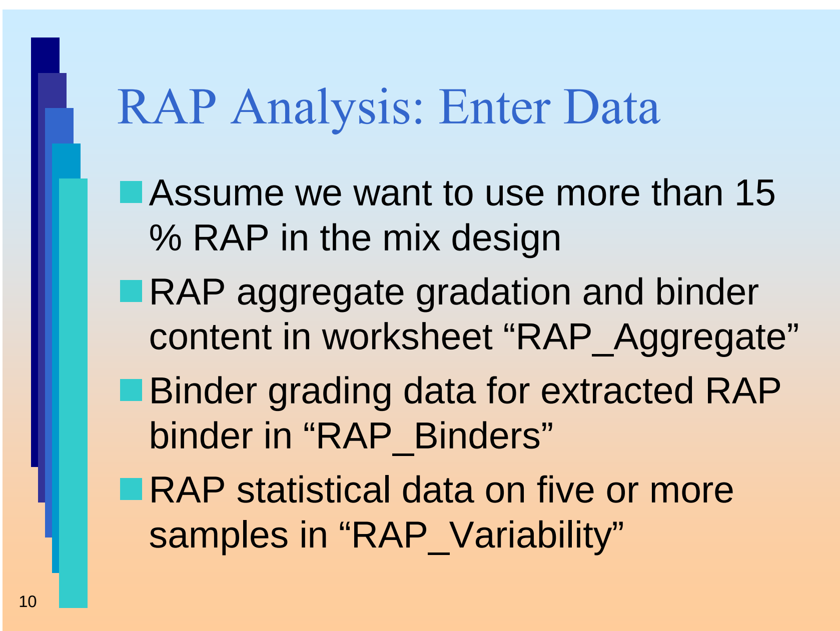


Slide 8-8

PG grading on binder recovered from RAP is only needed if you are using more than 15 % RAP in your mix design. The procedure is the same as R 29, but you don't use PAV aging—the binder is already "aged."



Slide 8-9



Slide 8-10

In this part of the example a mix design with RAP is demonstrated. After sampling the RAP, extracting the binder, testing the aggregate and grading the recovered binder, the resulting data is entered in various worksheets in HMA Tools.

Slide 8-11

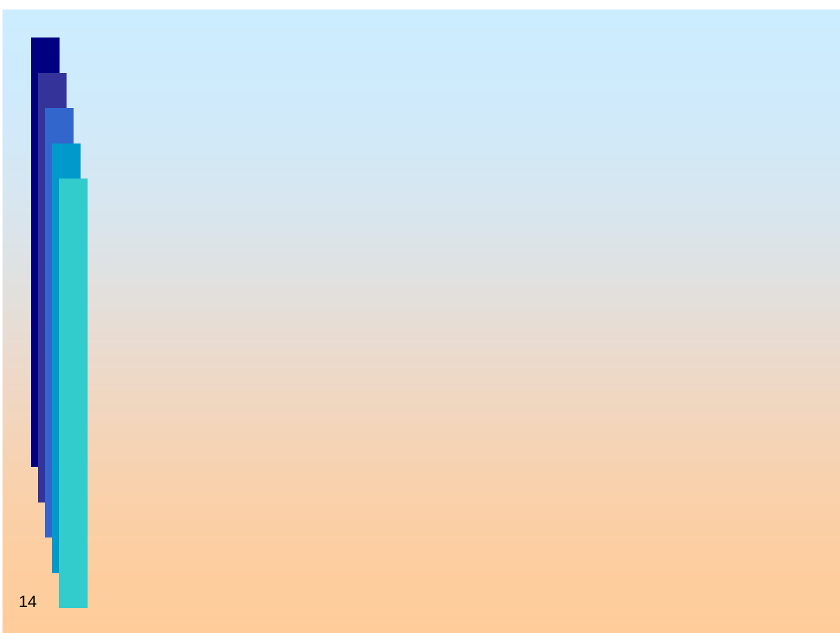
Specific gravity data is entered in worksheet "RAP_Aggregates."

Slide 8-12

You can enter data for up to four RAP stockpiles. In this case, we have measured specific gravity values for coarse and fine aggregate. HMA tools can also estimate RAP aggregate specific gravity values from the RAP theoretical maximum specific gravity, the RAP binder content, the RAP binder specific gravity and the estimated asphalt binder absorption for the RAP.

Slide 8-13

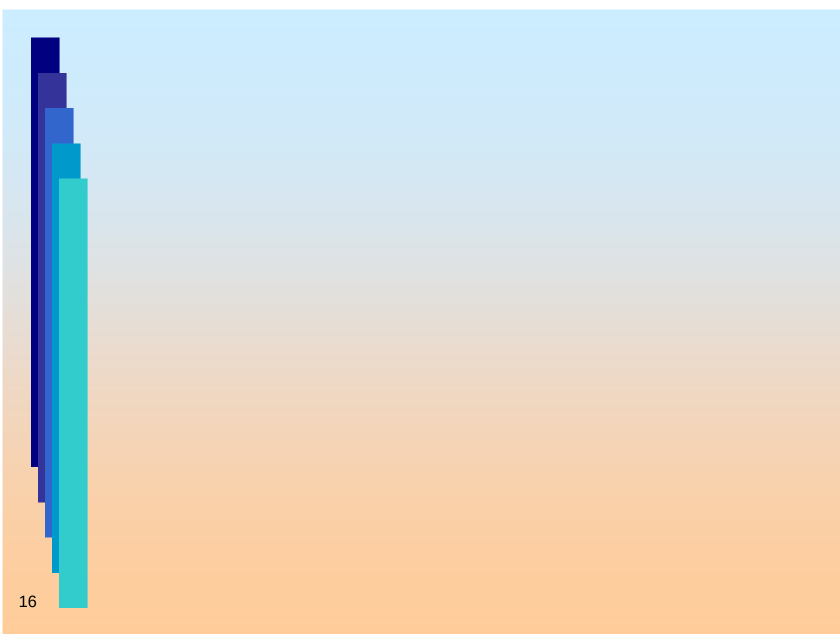
The RAP aggregate gradation data is also entered in "RAP_Aggregates." This information is automatically carried over the worksheet "Aggregates" and "Trial_Blends" for calculating aggregate blend gradations.



Slide 8-14

Slide 8-15

Binder test data must be entered for both the RAP binder and for any new binders that will be used in worksheet “Binders.” It can be useful to enter test data for several binders, since it might not be clear ahead of time what new binder grade will be needed in the final mix design.



Slide 8-16

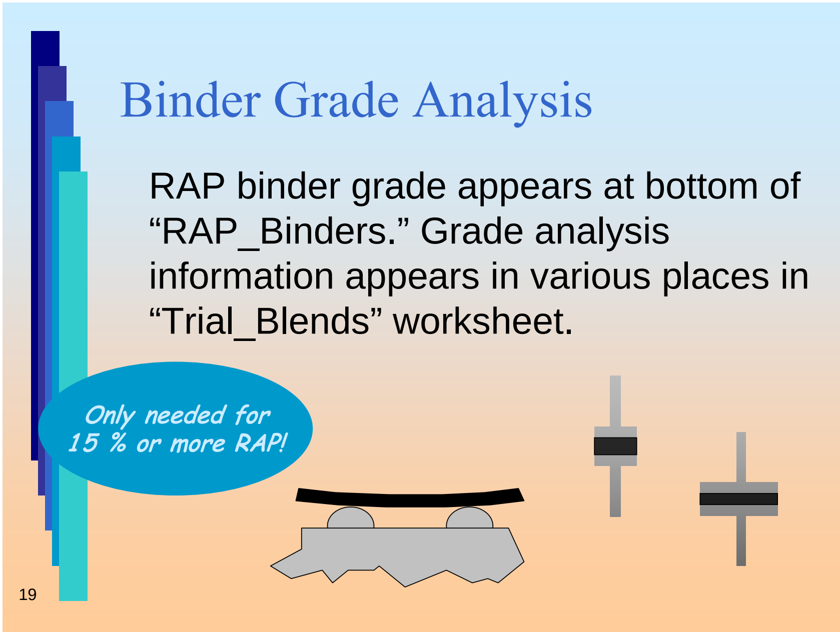
Binder data for up to four new binders can be entered in HMA Tools.

In HMA Tools, test data for RAP binders is entered in the same way as for new binders, in worksheet “RAP_Binders.”

Slide 8-17

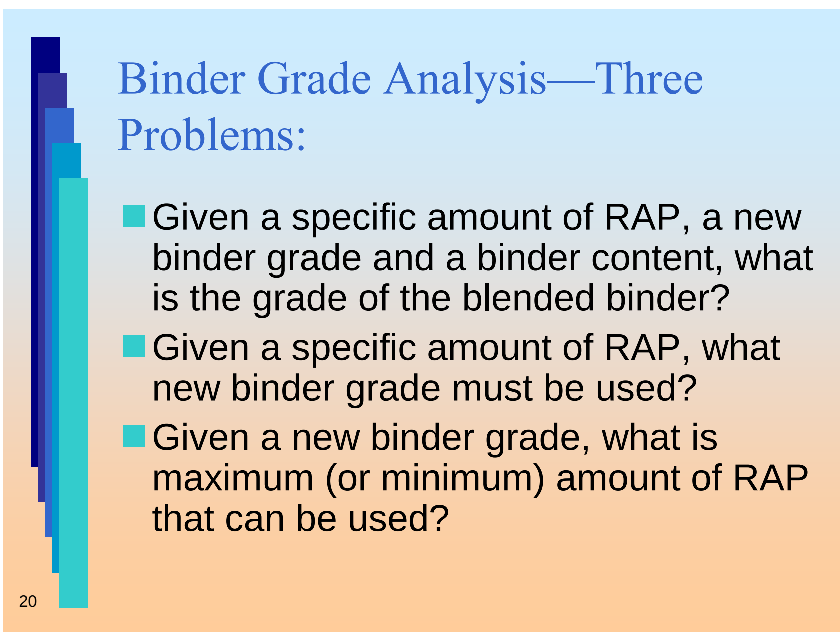
As for new binders, data for up to four RAP binders can be entered in worksheet “RAP_Binders.”

Slide 8-18



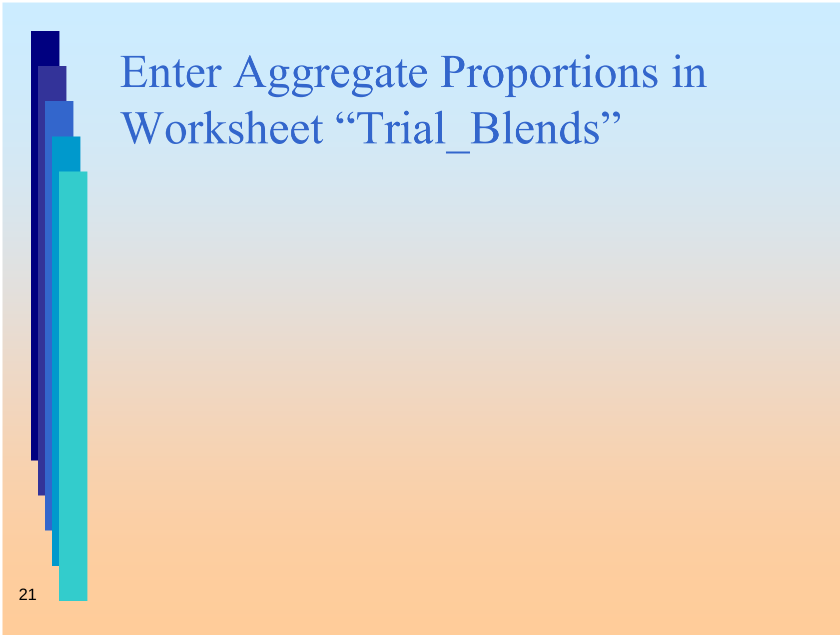
Slide 8-19

Once test data is entered for both new and RAP binders, grading results for each binder appears at the bottom of worksheets "Binders" or "RAP_Binders." RAP binder grade analysis is then performed by HMA tools and appears in various places in worksheet "Trial_Blends."



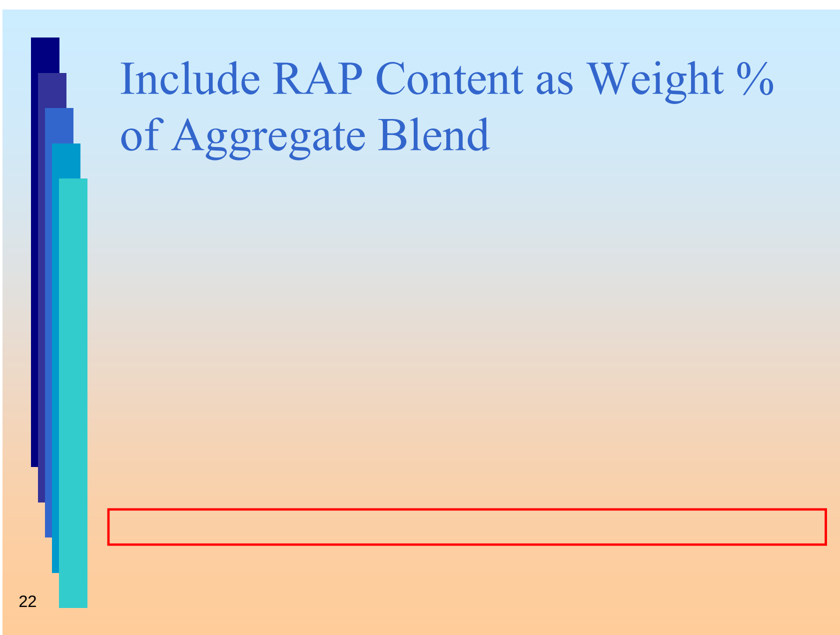
Slide 8-20

Binder grade analysis can be complicated—as noted in this slide, there are three different types of problem. HMA tools does all three.



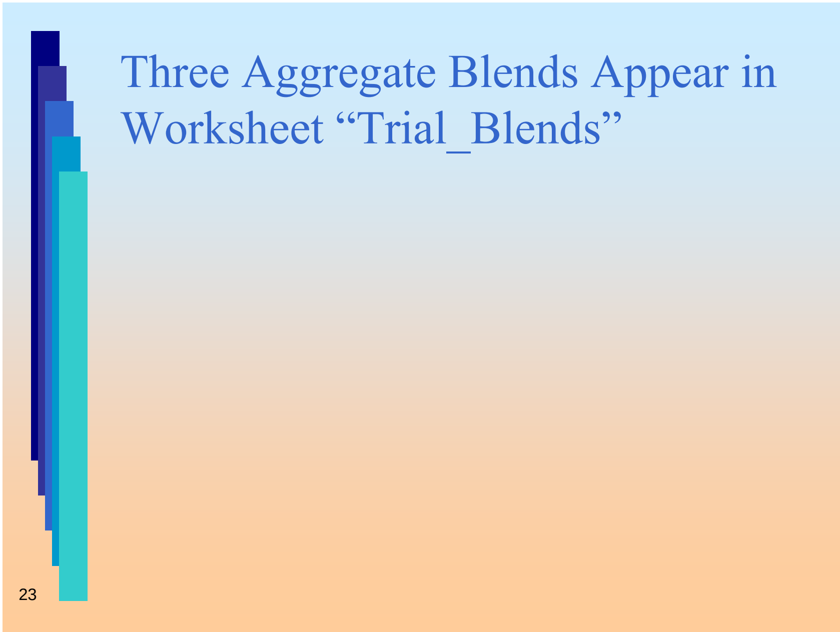
Slide 8-21

Before HMA Tools can perform the RAP binder grade analysis, the aggregate proportions—including the amount of RAP in the mix—must be entered in worksheet “Trial_Blends.”



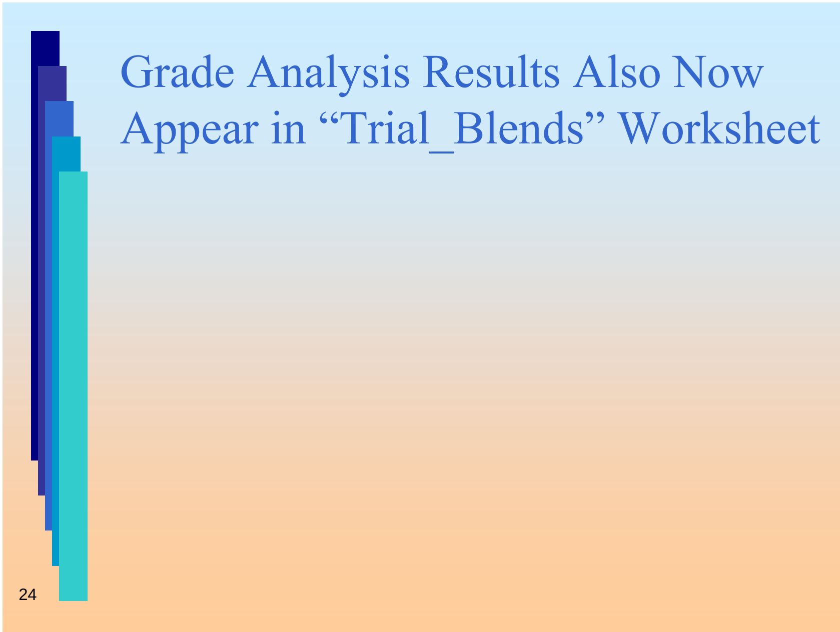
Slide 8-22

Note that the RAP proportion entered here represents the amount of RAP aggregate in the total aggregate blend. In this example we are using 40 % RAP in all three trials.



Slide 8-23

Now that the aggregate proportions have been entered in worksheet “Trial_Blends,” three aggregate blends appear in the plot at the top of the worksheet. Since specific gravity data hasn’t been entered yet, air voids and VMA don’t appear in the plot legend.

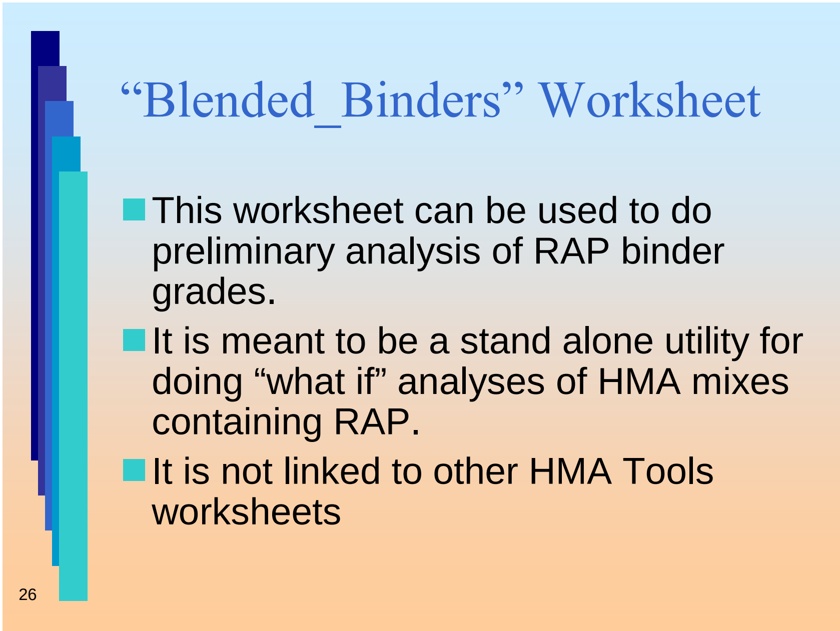


Slide 8-24

This part of the "Trial_Blend" worksheet shows two parts of the grade analysis: it shows the required new PG grade for the given trial mix, and also shows the final blended binder grade for each trial mix. The blended binder grade should be compared to the specified binder grade (PG 64-(25)-22). When giving PG binder grades, HMA Tools gives the required intermediate temperature grade in parentheses—the required intermediate temperature grade in this case is 25 C, that is, the intermediate temperature properties must be met at a maximum temperature of 25 C.

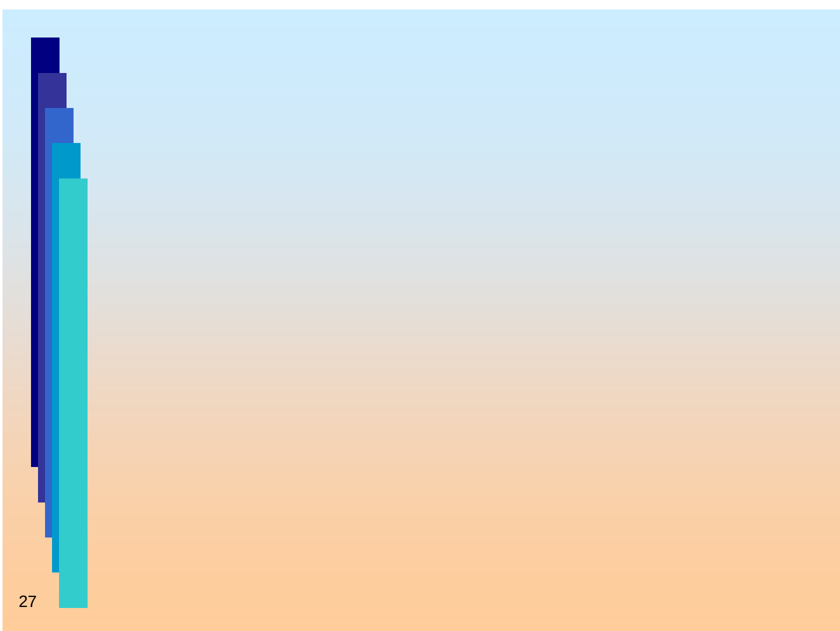
Slide 8-25

A little lower down in the "Trial_Blends" worksheet information on maximum and minimum RAP contents appears. Minimum RAP contents sometimes occur when you use a relatively soft new binder—then a minimum amount of RAP will be needed to ensure that the resulting blended binder has adequate high temperature properties. The minimum RAP content given will not go below 10 %, because it is assumed that this is the smallest proportion of RAP that can be accurately added to a mix. In this example, the PG 64-22 binder is obviously too stiff to use with 40 % RAP.



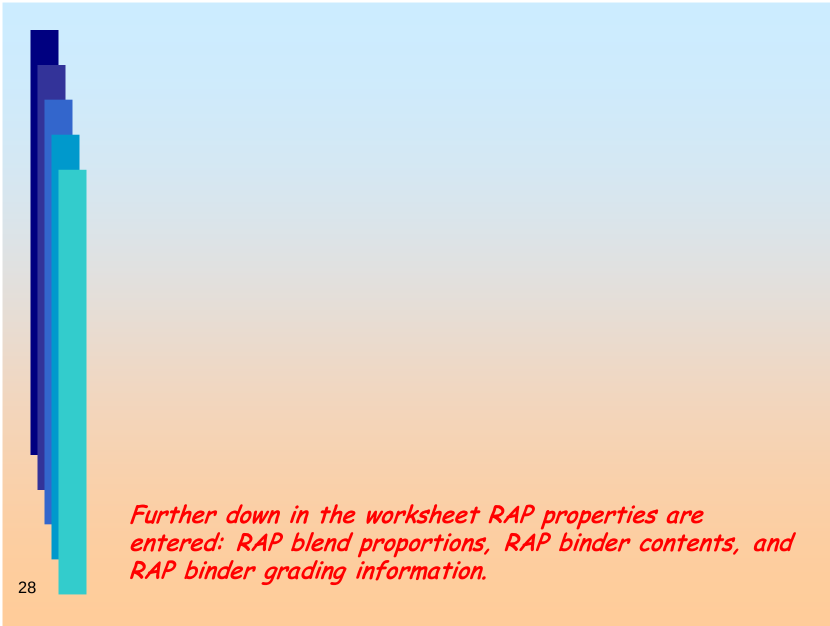
Slide 8-26

Sometimes technicians or engineers might want to do a preliminary RAP binder grade analysis, without going through an entire mix design. Worksheet “Blended_Binders” was developed for that purpose. This worksheet is not directly linked to other parts of HMA Tools—it is a stand-alone tool for RAP binder grade analysis. However, for convenience, data from other parts of HMA Tools is displayed in worksheet “Blended_Binders,” so the user will know, for instance, what the required binder grade is if the analysis is being done as part of a mix design.



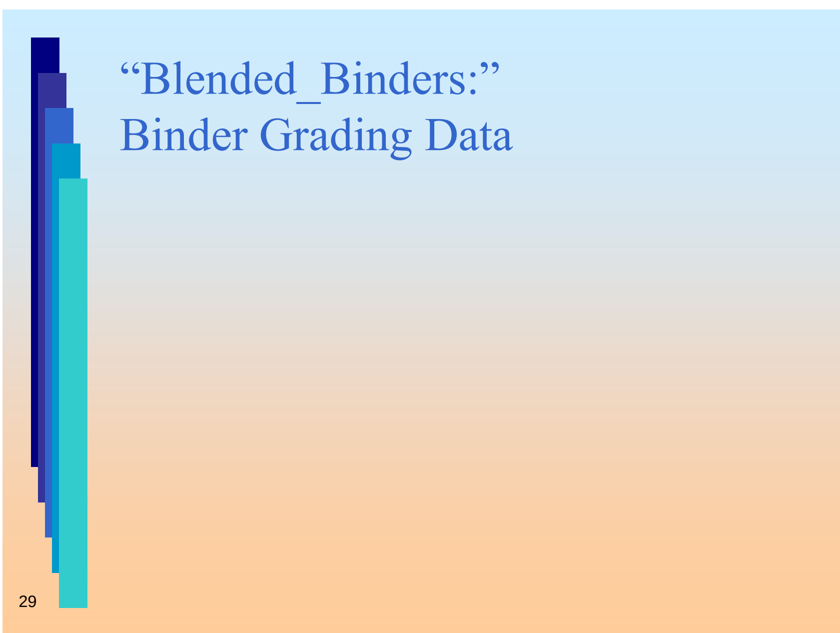
Slide 8-27

At the top of worksheet “Blended_Binders” data on the specified binder grade is entered, along with total binder content and estimated binder absorption.



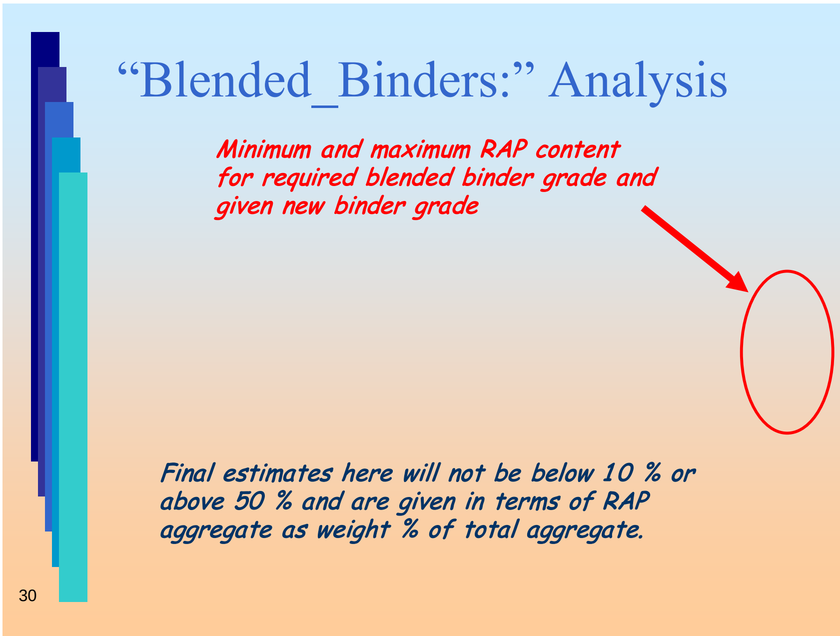
Slide 8-28

In this example, there is just one stockpile, so the RAP blend is 100 % of stockpile 1. The RAP binder grading information is taken from worksheet "RAP_Binders."



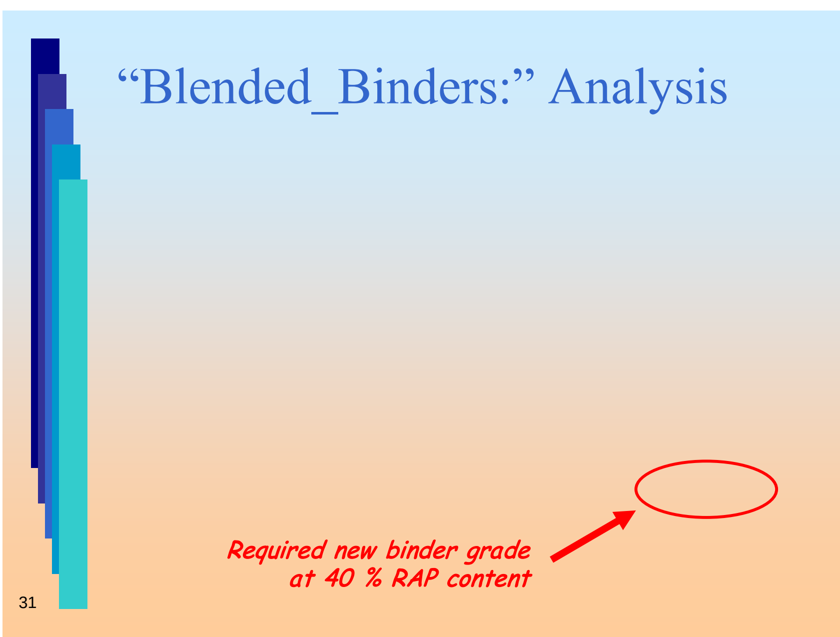
Slide 8-29

Then, the new binder grade is entered. Note that as with the RAP binder grading information, these are continuous grading temperatures.



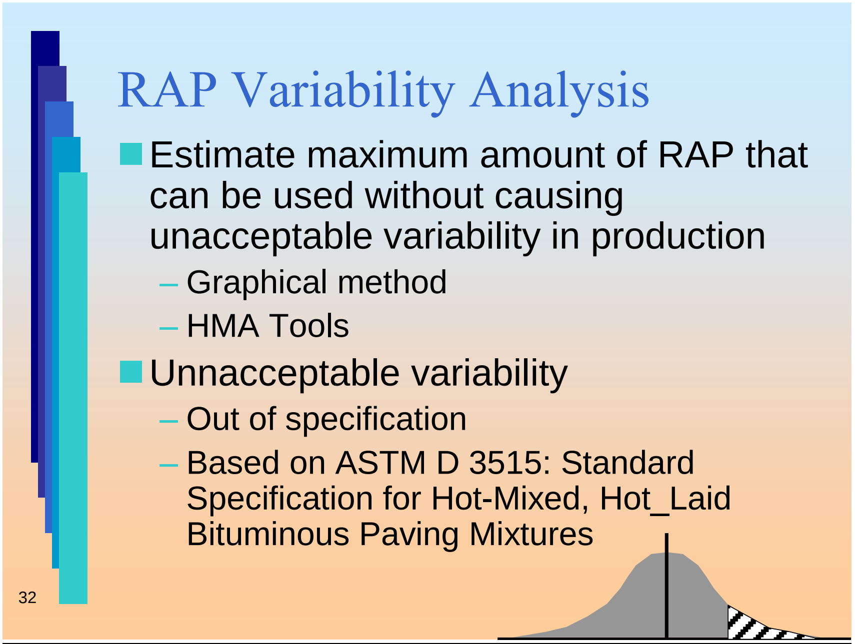
Slide 8-30

It is assumed that 10 % RAP is the minimum amount that can be accurately added to a mix, so the minimum RAP value given here will not go below 10 %. Similarly, it is assumed that most HMA plants would have trouble adding more than about 50 % RAP to a mix, so the maximum value will not go above 50 %.



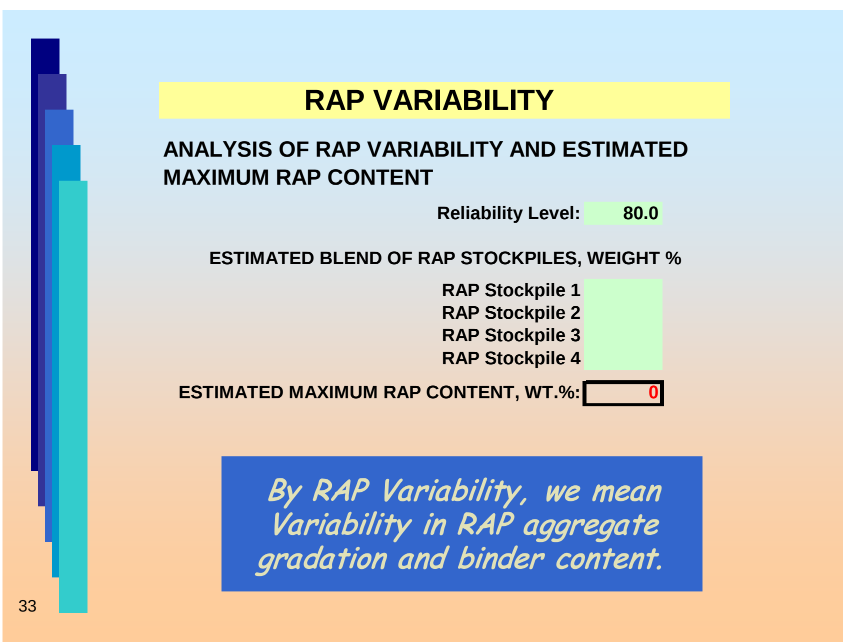
Slide 8-31

Moving down through the "Blended_Binders" worksheet, we enter the RAP content as % of the aggregate blend—40 % in this example. HMA Tools then calculates what the required new binder grade is to achieve the required binder grade with this RAP content.



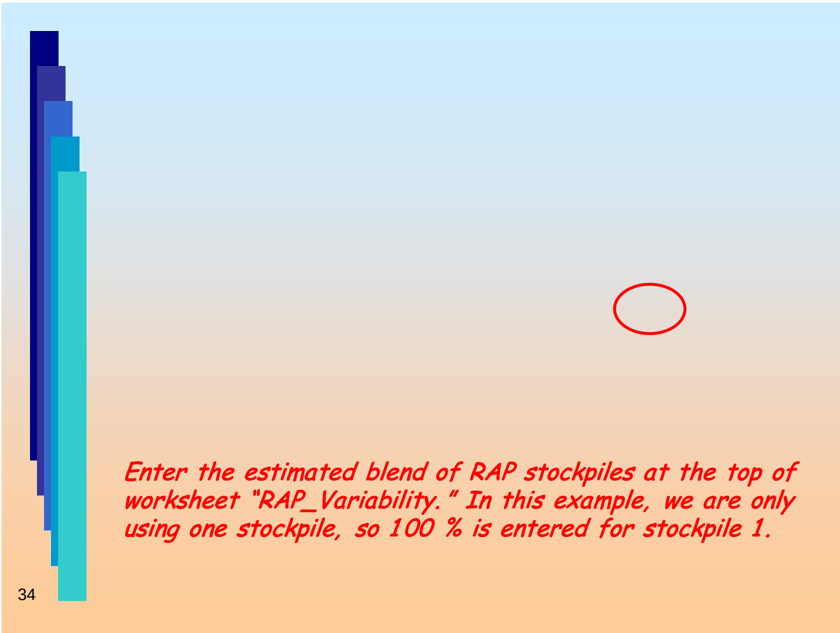
Slide 8-32

The second part of the RAP analysis is the variability analysis. The data for the variability analysis was entered earlier. Remember, the purpose of this analysis is to keep the producer from paying penalties for having his production go out of spec because there was too much of a highly variable RAP in the mix design.



Slide 8-33

In doing the RAP variability analysis, the blend proportions of up to four RAP stockpiles is first entered. We are only using one RAP stockpile, so 100 % is entered for RAP stockpile 1.

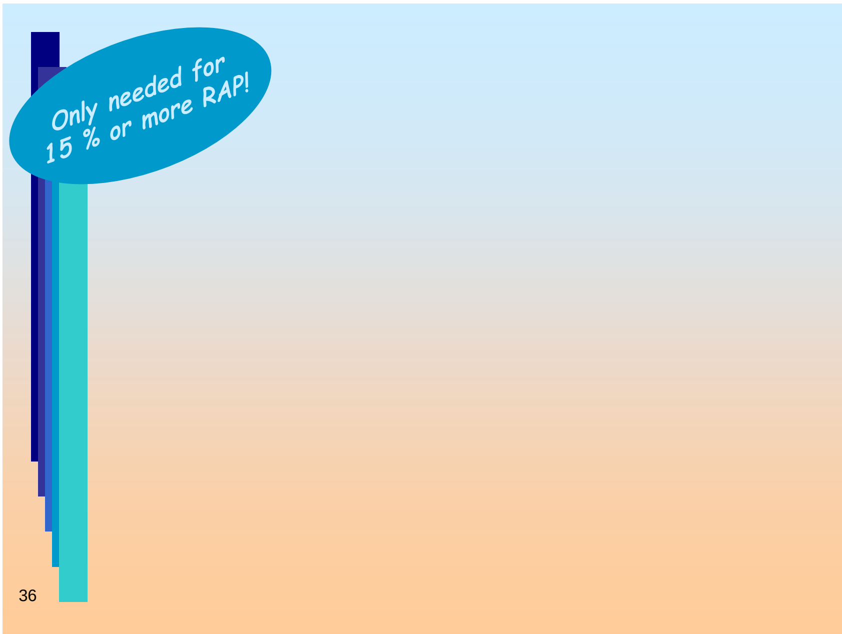


Slide 8-34

The reliability level should be kept at 80 %. The total of the blends must add up to 100 %. For instance, if you are using two RAP stockpiles, you might enter 50 % for each if you expect to blend them in roughly equal proportions. The estimated maximum RAP content shows zero % because we haven't entered any data on the RAP samples yet.

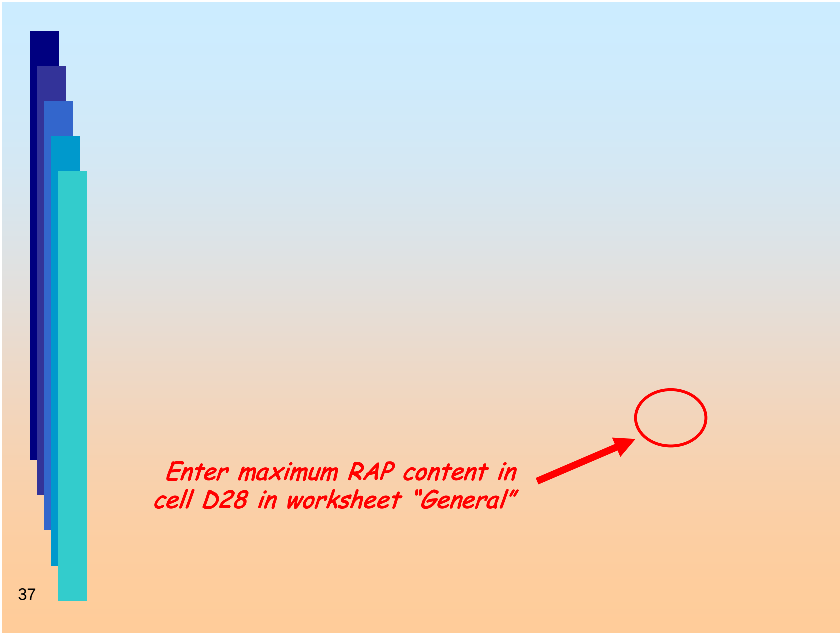
Slide 8-35

Next, aggregate gradation data and binder content information on multiple RAP samples are entered. The variability analysis might seem like a lot of work, but it is meant to benefit the producer. The variability analysis ensures that the variability of the resulting mix during production will not go out of specification and result in penalties or delays.



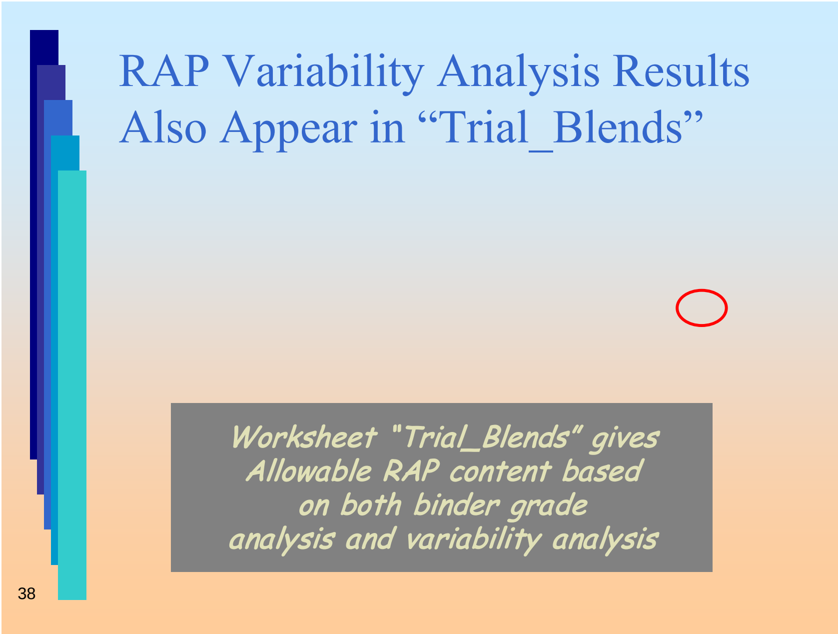
Slide 8-36

In this example, data for five samples are entered. As noted previously, entering data for a larger number of RAP samples will likely increase the amount of RAP that can be used in the mix design. This is because it results in more accurate estimates of RAP variability.

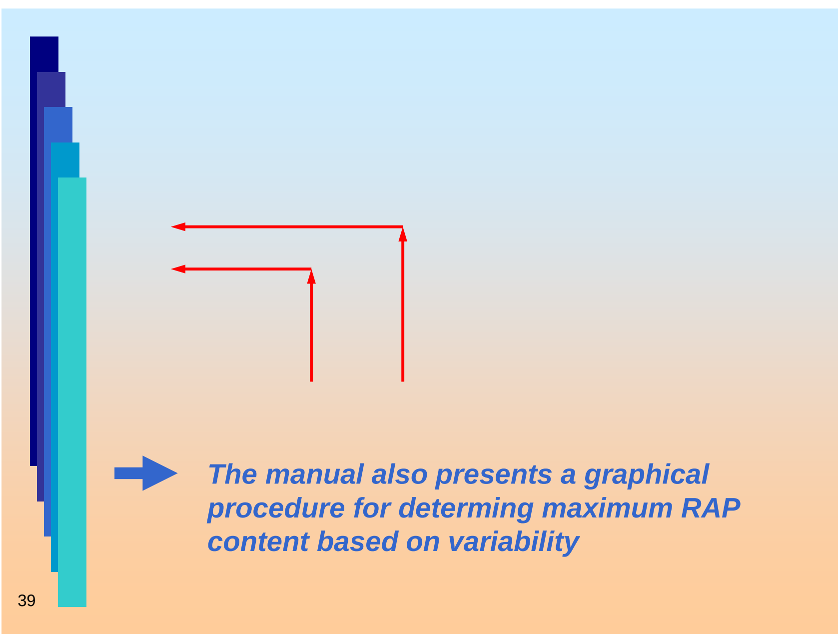


Slide 8-37

After entering aggregate gradation and binder content data in worksheet “RAP_Variability,” the estimated maximum RAP content appears—in this example, up to 43 % RAP can be used based on variability. However, the binder grade analysis might mean that we have to use less RAP than this. The maximum RAP content based on variability should be entered into cell D28 in worksheet “General.” The number then will carry through to other worksheets in HMA Tools. The reason this is not done automatically is because some agencies will have there own policies about maximum allowable RAP content.

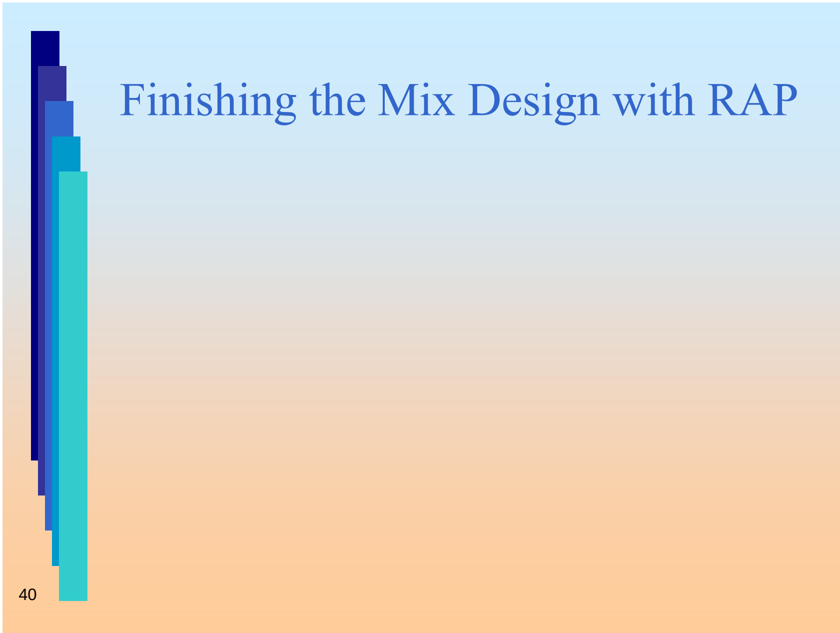


Slide 8-38



Slide 8-39

The Mix Design Manual includes a graphical procedure for determining maximum allowable RAP content based on variability. This is based on using 5 RAP samples. The maximum RAP contents determined using this procedure usually will be lower than if you used HMA Tools, especially if you use more than 5 RAP samples in the variability analysis.



Slide 8-40

Once the RAP analysis is done, and we know how much RAP we can use and what new binder grade to use in the mix—we continue with the mix design just as we would if there were no RAP in the mix.

Slide 8-41

The mix design now proceeds as in the previous example that didn't include RAP. Batches are weighed out, mixed and compacted. Then, bulk and maximum specific gravity values are determined and the volumetric properties compared with the specified requirements.

Completing the Mix Design

- Evaluate and refine the mix design
- Moisture resistance testing (T-283)
- Rut resistance testing if design traffic level is 3 million ESALs or more

42

Slide 8-42

Short report now includes RAP content and both total and new binder contents. Note that RAP content given here is RAP aggregate as weight % of total mix.

43

Slide 8-43

The reports now include RAP content and total and new binder content. The RAP content is slightly different here than when proportioning aggregate blends because the RAP content given here is the RAP aggregate as % by weight of the total mix (not weight % of the aggregate blend).

NCHRP Project 9-33: A Mix Design Manual for Hot Mix Asphalt

UNIT 9: QUIZ ON PART 3 OF THE MIX DESIGN EXAMPLE PROBLEM—MIX DESIGN WITH RAP

Number of Slides: 17

Approximate Time Required: 15 minutes

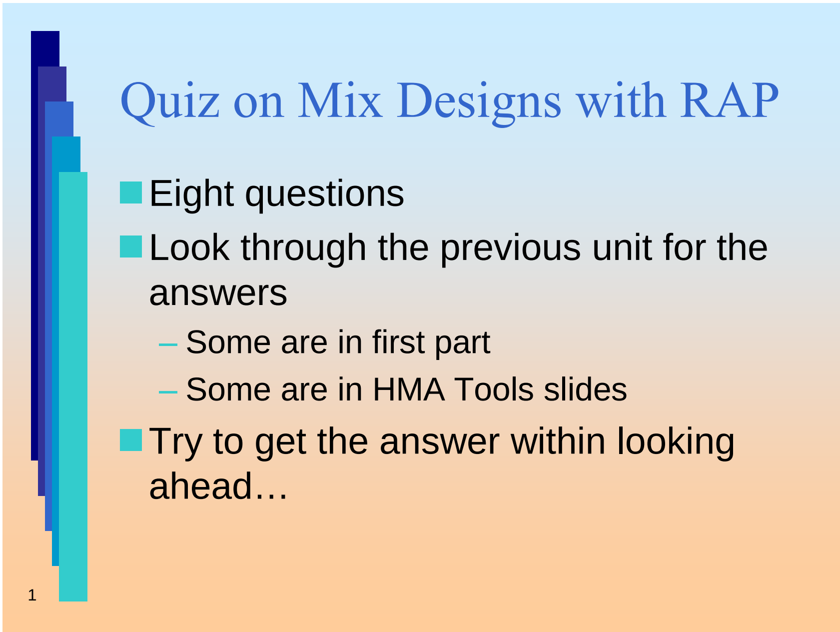
Purpose of Unit: To review important concepts from part 3 of the example mix design problem (incorporating RAP into a dense-graded HMA mix design) through a short quiz.

Important Concepts

- You need 5 to 10 large RAP samples to do a RAP mix design.
- You don't need to do a RAP binder grade analysis or a RAP variability analysis if you are using 15 % or less RAP in your mix design.
- As in a mix design without RAP, most of the important information pertaining to trial mixes can be found on worksheet "Trial_Blends."
- The maximum allowable RAP in a mix design can be controlled either by binder grade or by variability.

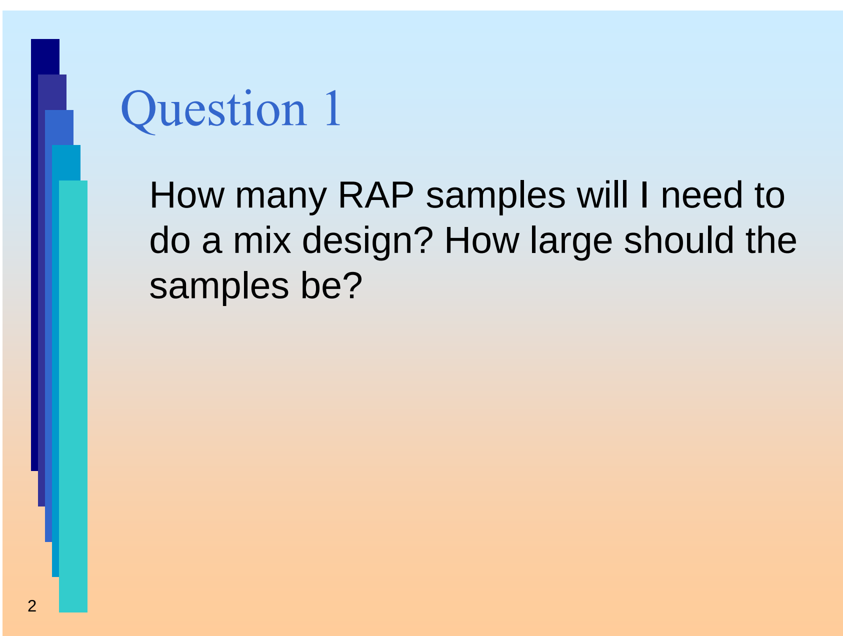
Description of Slides: The slides present a series of 8 questions dealing with the example problem covered in the previous unit (Unit 8). These slides are designed so that the answer is not initially on the slide, but appears once the down arrow key, return key, or page down key is pressed. All questions deal with information that can be found on different slides from the previous unit. In the participant's manual, a slide presents a question, which is then followed by the answer—so the participants have the answer, but should be encouraged to look for the answer in the slides from the previous unit.

Instructor's Notes

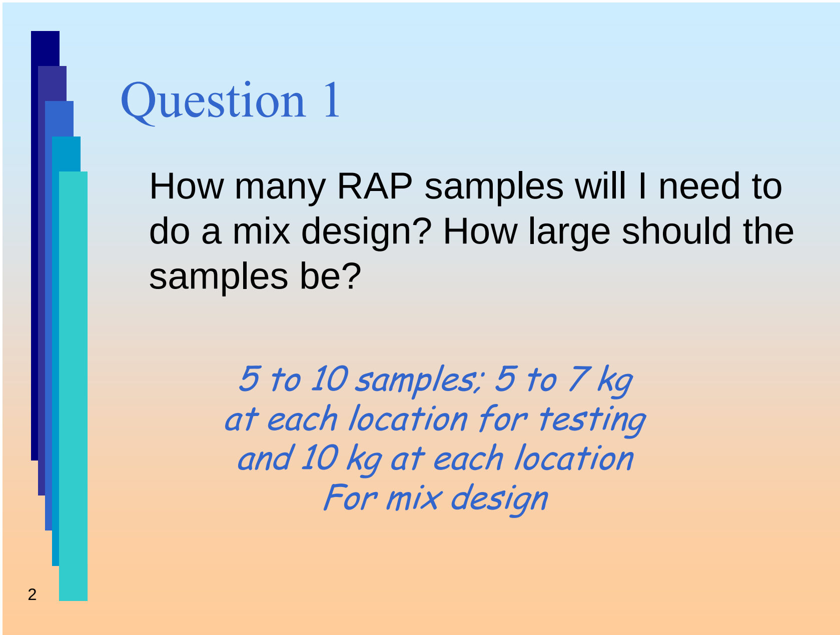


Slide 9-1

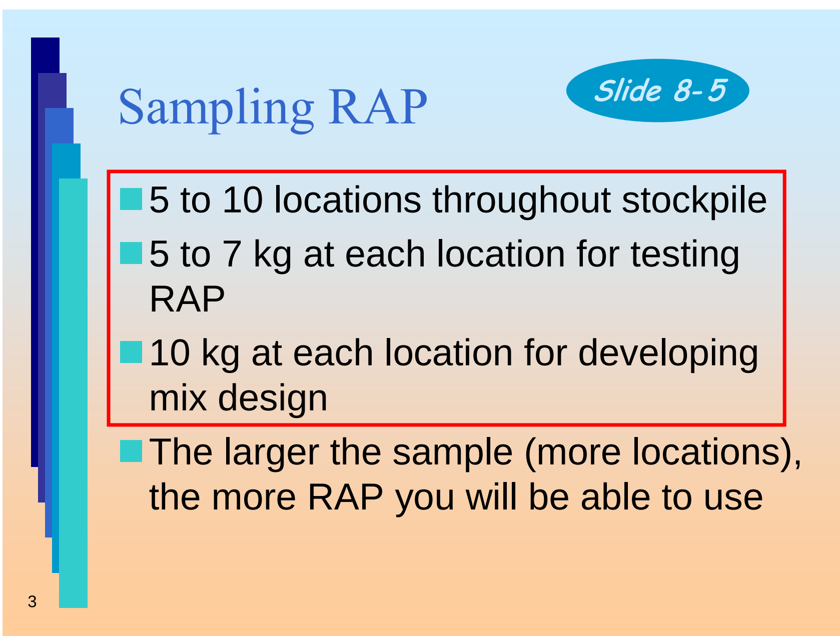
This is another quiz, similar to the first. In this quiz basic concepts about incorporating RAP into a mix design are reviewed. The questions can be answered by looking through the notebook pages on the previous unit.



Slide 9-2

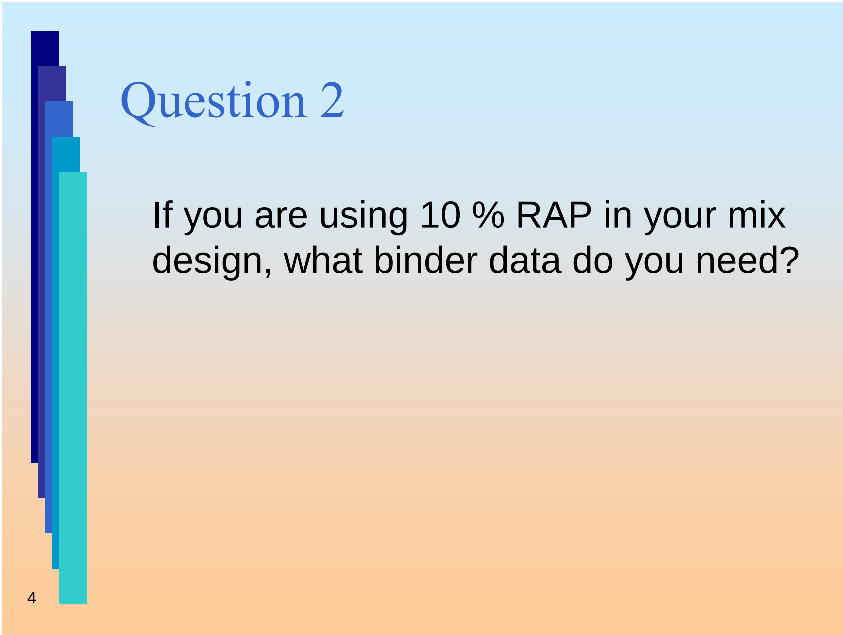


Slide 9-2

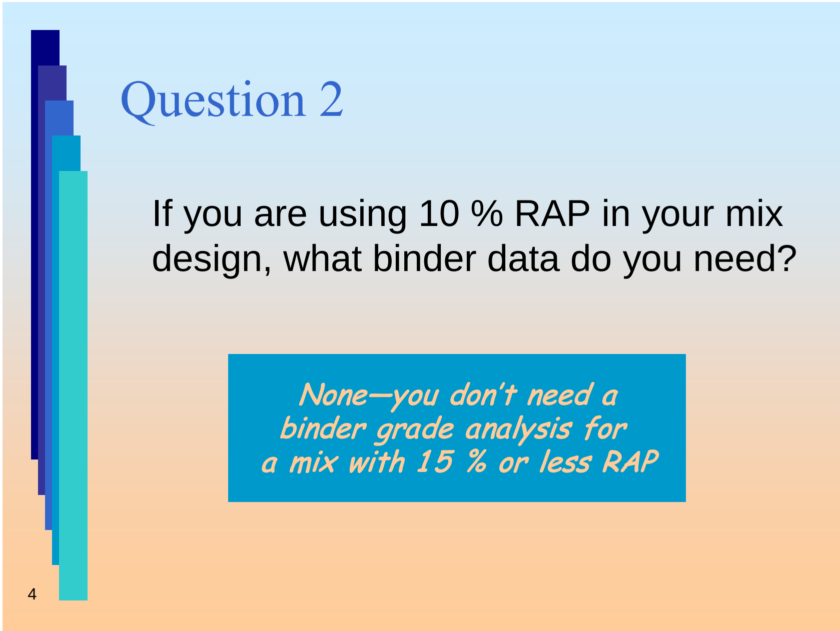


Slide 9-3

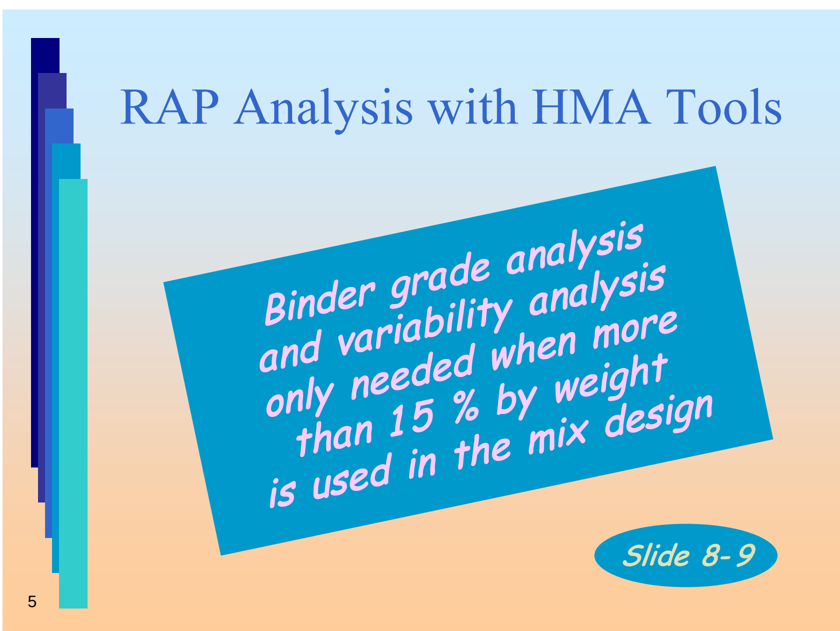
You need to make sure you have samples from enough different locations in the stockpile so that you have a truly representative sample. Also, you need to make sure you have enough material to characterize the RAP and to do the mix design.


Question 2
If you are using 10 % RAP in your mix design, what binder data do you need?
4

Slide 9-4

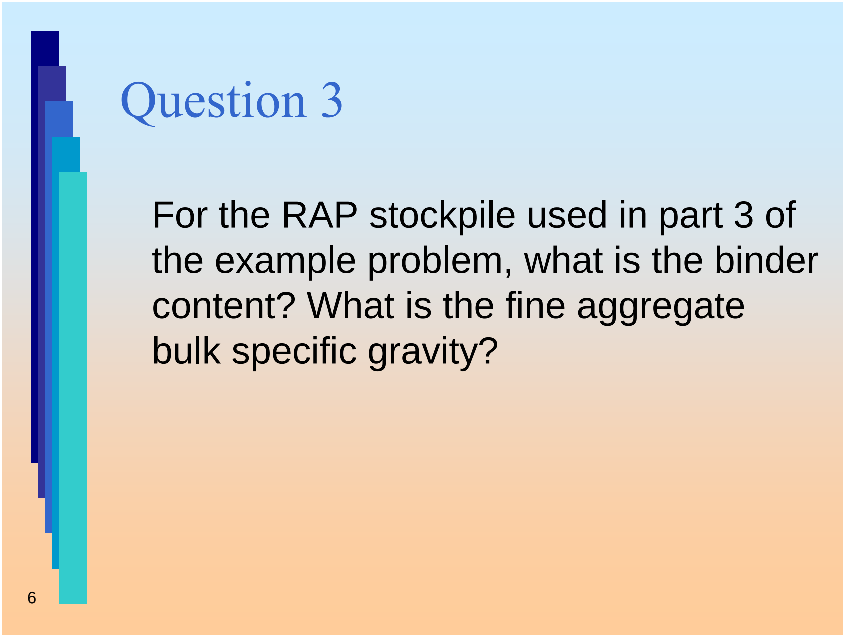


Slide 9-4

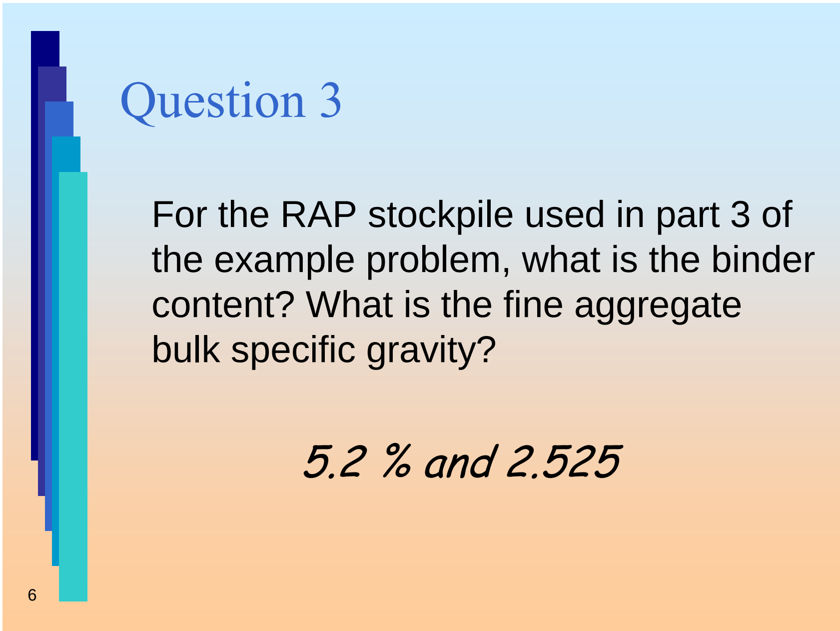


Slide 9-5

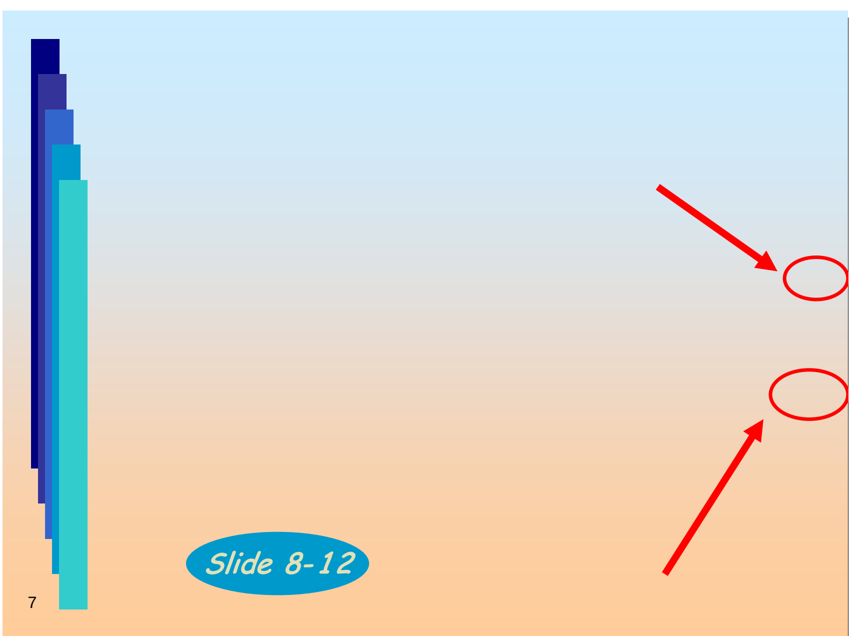
This is slide 8-9, but this point is made in a number of other places in Unit 8.


Question 3
For the RAP stockpile used in part 3 of the example problem, what is the binder content? What is the fine aggregate bulk specific gravity?
6

Slide 9-6

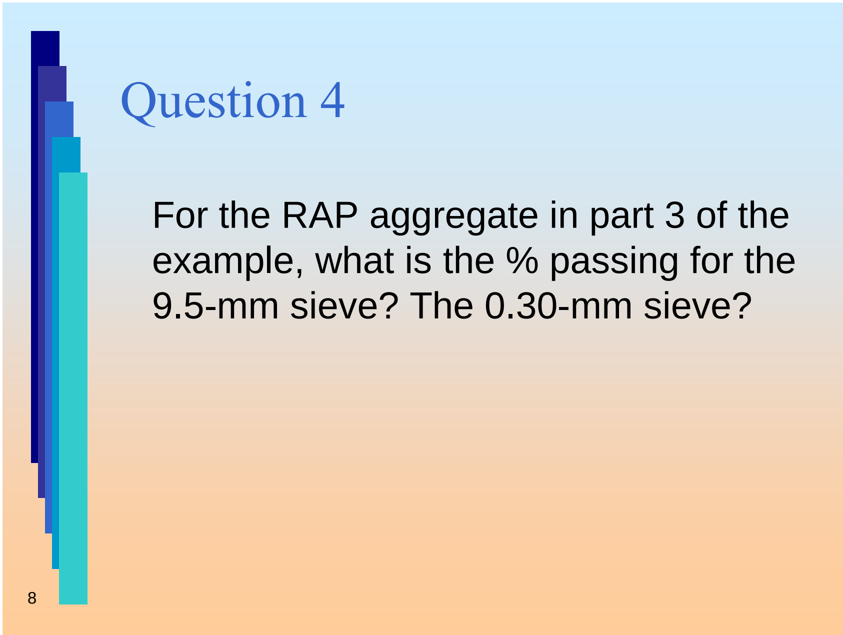


Slide 9-6

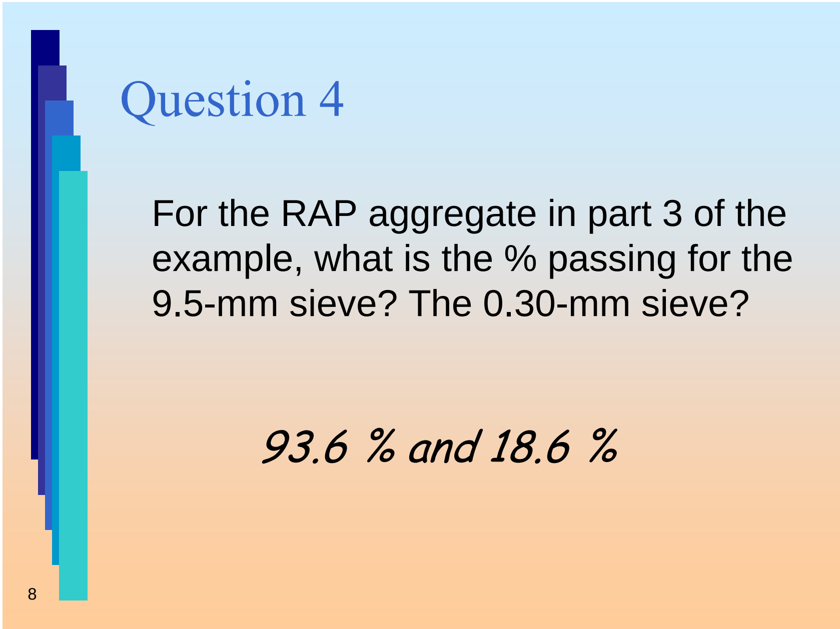


Slide 9-7

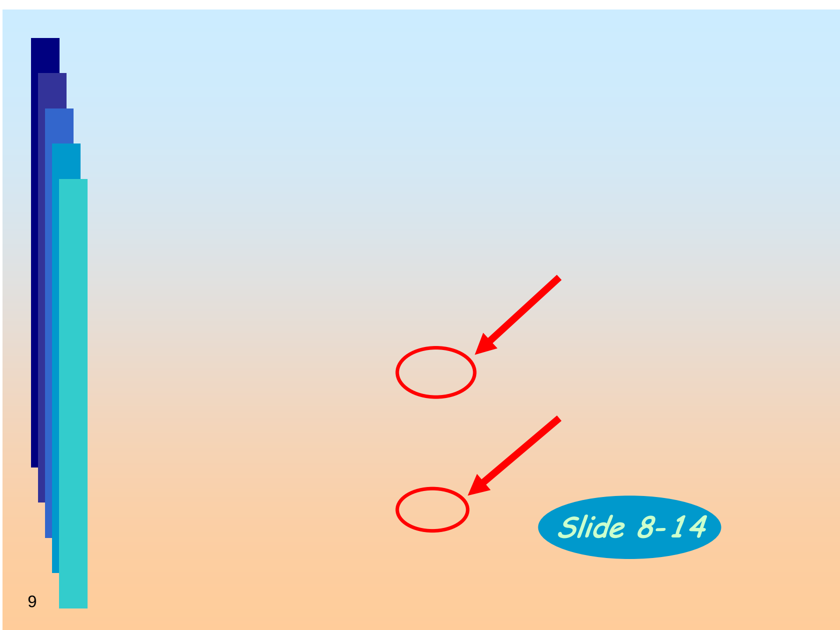
This is slide 8-12, which shows part of worksheet "RAP_Aggregates."


Question 4
For the RAP aggregate in part 3 of the example, what is the % passing for the 9.5-mm sieve? The 0.30-mm sieve?
8

Slide 9-8



Slide 9-8



Slide 9-9

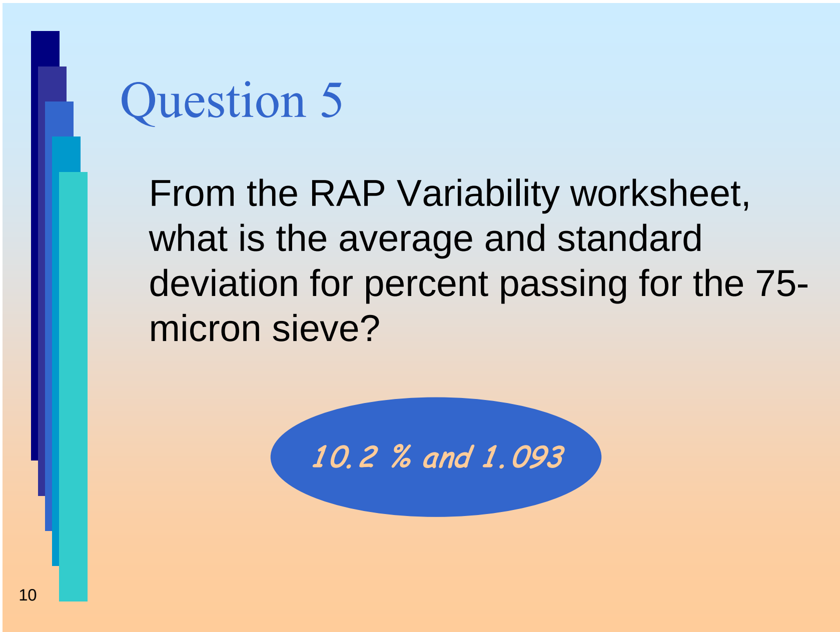
The answer to this question is found on slide 8-14. This is also part of worksheet “RAP_Aggregates.”

Question 5

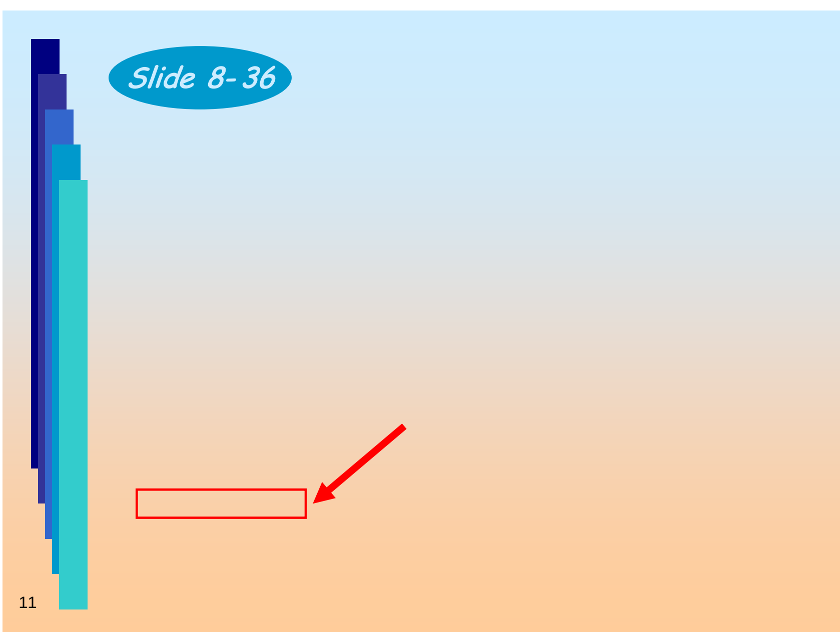
From the RAP Variability worksheet, what is the average and standard deviation for percent passing for the 75-micron sieve?

10

Slide 9-10

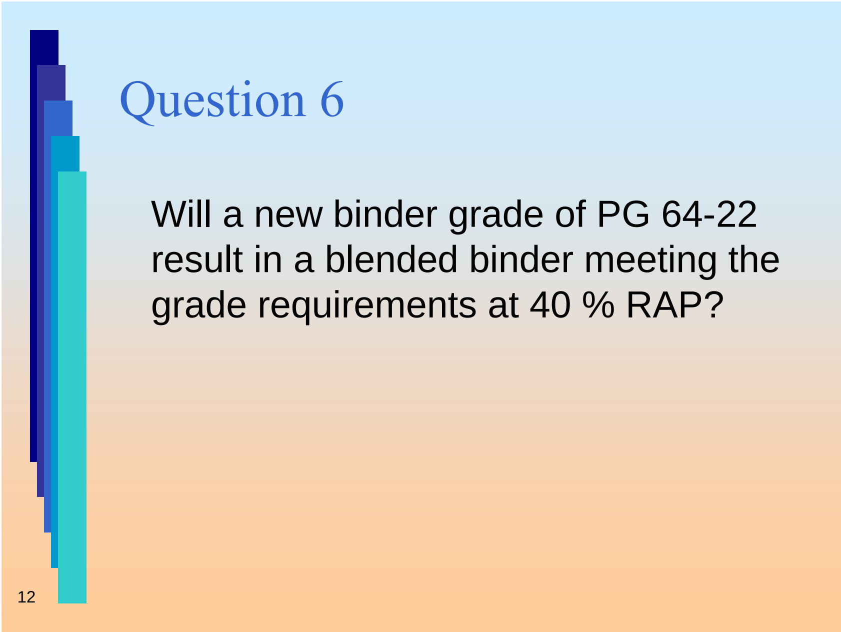


Slide 9-10

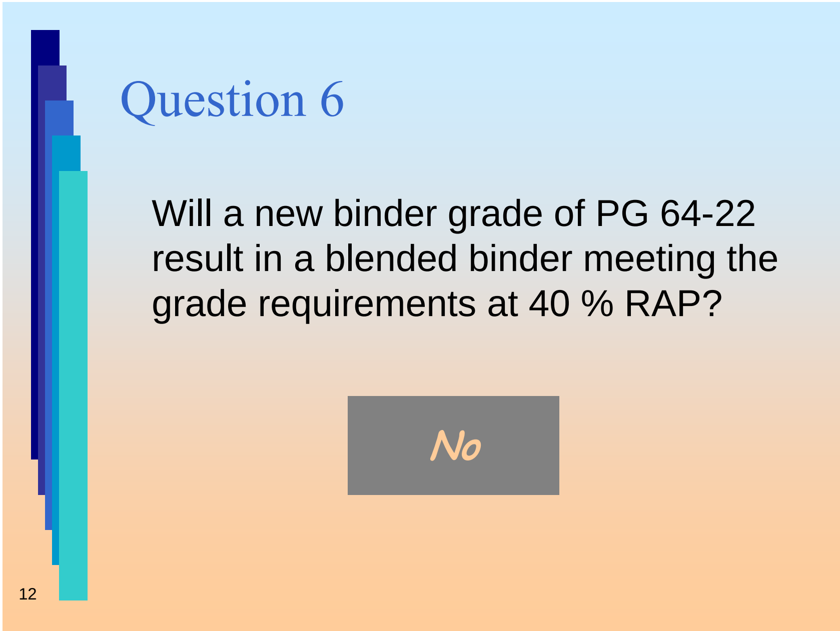


Slide 9-11

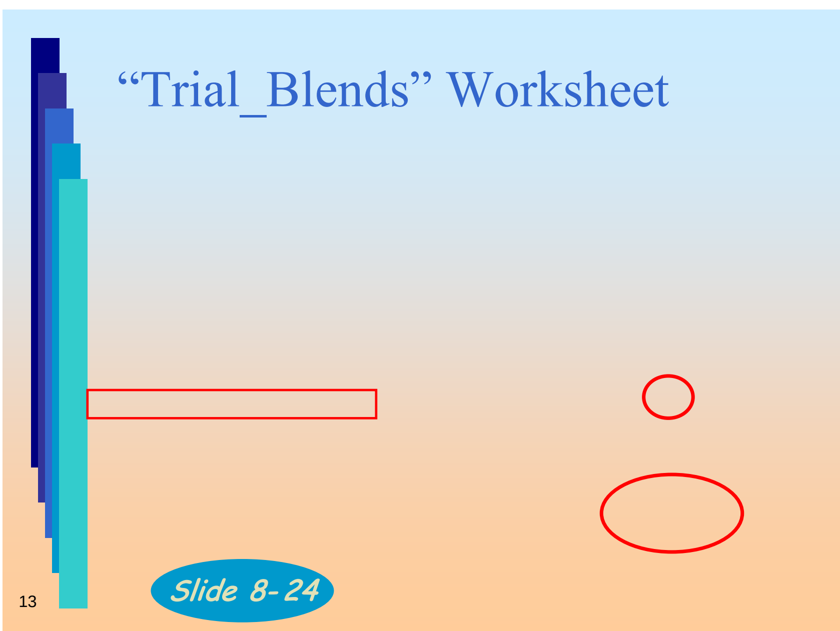
This is slide 8-36. Note that the averages and standard deviations here won't show up until at least two sets of data are entered in the space to the right.


Question 6
Will a new binder grade of PG 64-22 result in a blended binder meeting the grade requirements at 40 % RAP?
12

Slide 9-12

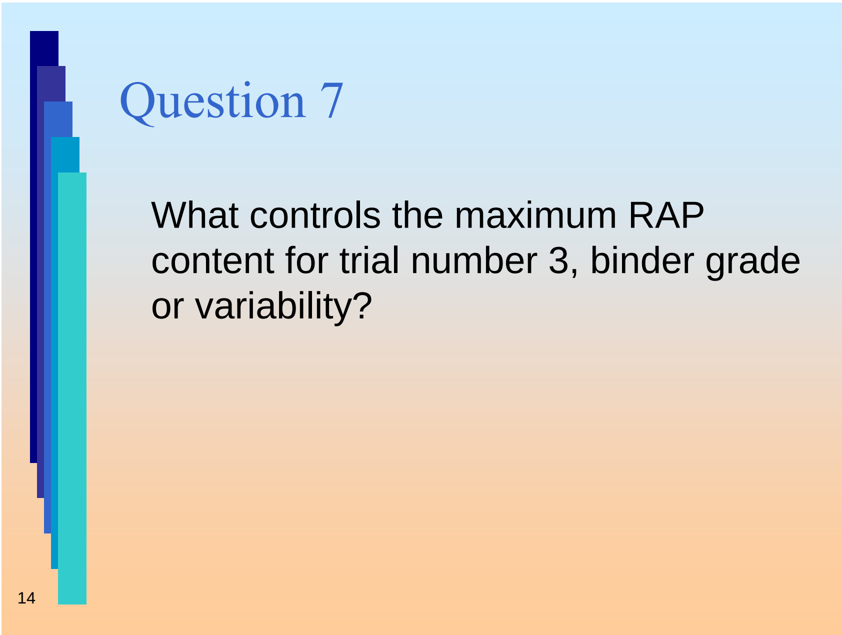


Slide 9-12

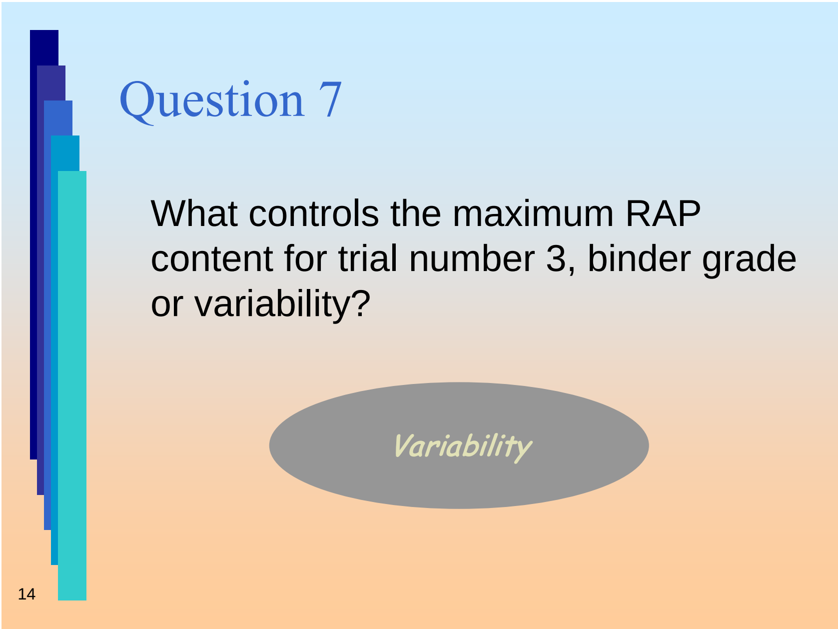


Slide 9-13

The answer to this question is found on slide 8-24. The required PG grade is 64-(25)-22, while the blended binder grade if the PG 64-22 new binder is used is PG 70-(25)-16. The high and intermediate temperature grades are OK, but the low temperature grade temperature is too high at -16 C.


Question 7
What controls the maximum RAP content for trial number 3, binder grade or variability?
14

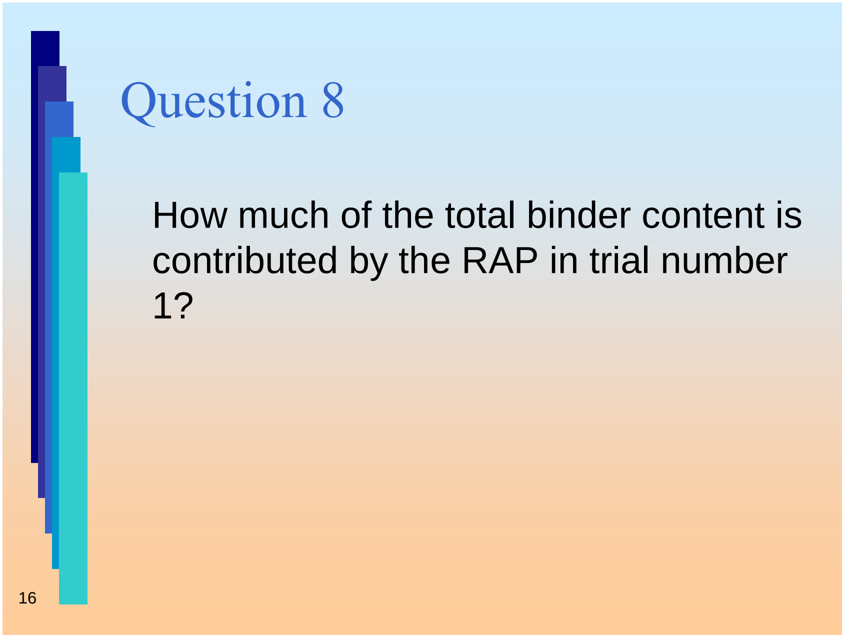
Slide 9-14



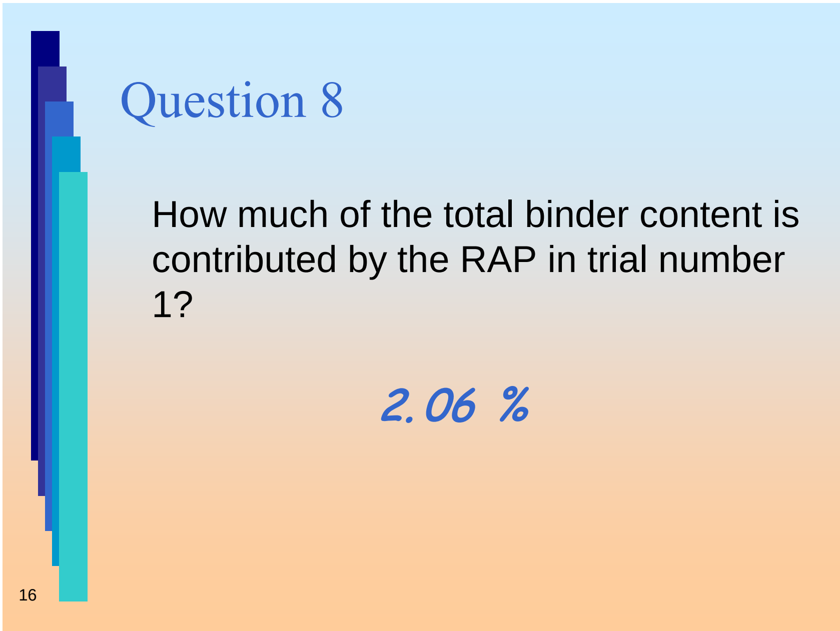
Slide 9-14

Slide 9-15

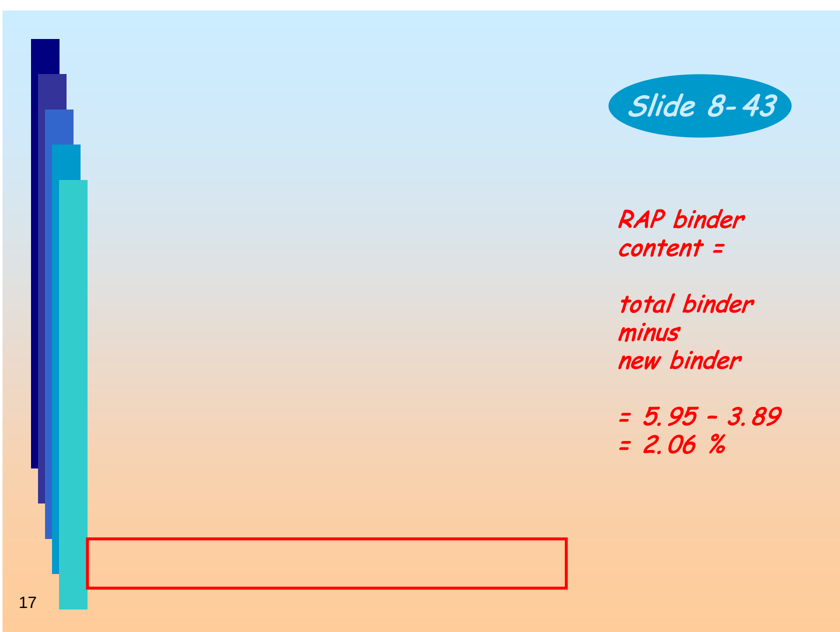
This is slide 8-38, which shows part of the "Trial_Blends" worksheet. The maximum RAP content based on variability is 43 %, and based on binder grade it's 50 %, so variability controls.


Question 8
How much of the total binder content is contributed by the RAP in trial number 1?
16

Slide 9-16



Slide 9-16



Slide 9-17

You have to do a little thinking to answer this. This shows slide 8-43, the last slide in Unit 8. The RAP binder content is not shown directly—you have to calculate it by subtracting the new binder content from the total binder content.

NOTES

NOTES

Recommended Standard Specification for

Volumetric Mix Design of Dense-Graded HMA

NCHRP 9-33 Designation M 1

1. SCOPE

1.1. This specification for volumetric mix design uses aggregate and mixture properties to produce a hot mix asphalt (HMA) job mix formula.

1.2. This standard specifies minimum quality requirements for binder, aggregate, and dense-graded HMA mix designs.

1.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards:*

- M 320, Performance-Graded Asphalt binder
- R 29, Grading or Verifying the Performance Grade of an Asphalt Binder
- T 11, Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 164, Quantitative Extraction of Bitumen from Bituminous Paving Mixtures
- T 170, Recovery of Asphalt from Solution by Abson Method
- T 176, Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test
- T 240, Effect of Heat and Air on a Moving Film of Asphalt (Rolling Thin-Film Oven Test)
- T 283, Resistance of compacted Asphalt Mixtures to Moisture-Induced Damage
- T 304, Uncompacted Void Content of Fine Aggregate
- T 308, Determining the Asphalt Binder Content of Hot-Mix Asphalt (HMA) by the Ignition Method
- T 312, Preparing and Determining the Density of Hot-Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory compactor
- T 319, Quantitative Extraction and Recovery of Asphalt Binder from Asphalt Mixtures

2.2. *ASTM Standards:*

- D 4791, Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate
- D 5821, Determining the Percentage of Fractured Particles in Coarse Aggregate

2.3. Asphalt Institute Publication:

- MS-2, *Mix Design Methods for Asphalt Concrete and Other Mix Types*

2.4. *National Asphalt Pavement Association Publication*

- IS 128, *HMA Pavement Mix Type Selection Guide*

2.5. Other References:

- Recommended Standard Practice M 2, Design of Dense-Graded HMA
- *LTPP Seasonal Asphalt Concrete Pavement Temperature Models*. FHWA-RD-97-103, FHWA, U.S. Department of Transportation, Washington, DC, September 1988.
- LTPPBind can be downloaded at http://ltpp-products.com/OtherProducts.asp

3. TERMINOLOGY

3.1. *HMA*—hot mix asphalt

3.2. *design ESALs*—Design equivalent (80 kN) single axle loads, normally specified over a 20-year design life.

3.2.1. *Discussion*—design ESALs are the anticipated project traffic level expected on the design lane over the design life of the pavement.

3.3. *air voids* (V_a)—The total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as a percent of the bulk volume of the compacted paving mixture (Note 1)

Note 1—Term defined in Asphalt Institute Manual MS-2, Mix Design Methods for Asphalt Concrete and Other Mix types.

3.4. *voids in the mineral aggregate* (VMA)—The volume of the intergranular void space between the aggregate particles of a compacted paving mixture that includes the air voids and the effective binder content, expressed as a percent of the total volume of the specimen (Note 1).

3.5. *absorbed binder volume* (V_{ba})—The volume of asphalt binder in a mixture absorbed into the permeable voids in the aggregate.

3.6. *effective binder volume* (V_{be})—The volume of asphalt binder in a mixture, excluding the volume of binder absorbed by the aggregate.

3.7. *voids filled with asphalt* (VFA)—the percentage of the VMA filled with binder (the effective binder volume divided by the VMA).

3.8. *dust-to-binder ratio* ($P_{0.075}/P_{be}$)—By mass, the ratio between the percent of aggregate passing the 75-µm (No. 200) sieve ($P_{0.075}$) and the effective binder content (P_{be}).

3.9. *nominal maximum aggregate size*—One size larger than the first sieve that retains more than 10 percent aggregate (Note 2).

3.10. *maximum aggregate size*—One size larger than the nominal maximum aggregate size (Note 2).

Note 2—The definitions given in Sections 3.7 and 3.8 also apply to Superpave mixes, but differ from the definitions published in other AASHTO standards.

3.11. *reclaimed asphalt pavement* (RAP)—Pavement materials, removed, processed, or both, containing asphalt binder and aggregate.

3.12. *primary control sieve* (PCS)—The sieve defining the break point between fine- and coarse-graded mixtures for each nominal maximum aggregate size, as defined in Table 5 below.

4. SIGNIFICANCE AND USE

4.1. This standard may be used to select and evaluate materials for dense-graded HMA volumetric mix designs.

5. BINDER REQUIREMENTS

5.1. The binder shall be a performance-graded (PG) binder, meeting the requirements of AASHTO M 320, which is appropriate for the climate and traffic-loading conditions at the site of the paving project or as specified by the contract documents.

5.1.1. In most cases, binder grade selections should follow specifications established by the agency.

5.1.2. In cases where specifications for binder grade selection have not been established by the agency, or where unusual traffic loading or environmental conditions make such specifications suspect, the following procedure may be used to determine binder grade.

5.1.2.1. Determine the mean and the standard deviation of the yearly, 7-day-average, maximum pavement temperature, measured 20 mm below the pavement surface, and the mean and the standard deviation of the yearly, 1-day-minimum pavement temperature, measured at the pavement surface, at the site of the paving project. These temperatures can be determined by use of the LTPPBind software or be supplied by the specifying agency. Often, actual site data is not available, and representative data from the nearest weather station will have to be used.

5.1.2.2. Using the latest available version of LTPPBind software, the maximum and minimum pavement temperatures determined in 5.1.2.1, and a reliability level of 98%, determine the required binder grade for a traffic level less than 0.3 million ESALs and standard traffic speed.

5.1.2.3. For traffic levels of 0.3 million ESALs or more, for traffic speeds of 70 km/h or less, or both, adjust the binder grade determined in 5.1.2.2. according to the grade adjustments given in Table 1.

Table 1—High Temperature Binder Grade Adjustments for Traffic Level and Speed

Traffic Speed Category:	**Very Slow**	**Slow**	**Fast**
Traffic speed, mph (kph):	< 15 (< 25)	15 to < 45 (25 to < 70)	≥ 45 (≥ 70)
20-year Design Traffic (MESALs)	*Grade Adjustment for Traffic Speed Level Given Above and Design Traffic Level at Left:*		
< 0.3	---	---	---
0.3 to < 3	2	1	---
3 to < 10	3[a]	2	1
10 to < 30	4[a]	3[a]	2
≥ 30	4[a]	4[a]	3[a]

[a] *Consider use of polymer-modified binder. If a polymer-modified binder is used, high temperature grade may be reduced one grade (6 °C) provided rut resistance is verified using suitable performance testing.*

Note 4—The grade adjustments in Table 1 should not necessarily be applied to "base" binder grades specified by the agency, since such "base" binder grades are normally already adjusted for traffic level and speed.

5.2. If RAP is to be used in the mixture, and the RAP content is not greater than 15% by total mix weight, the binder grade can be selected as described in 5.1. If the RAP content is greater than 15% by total mix weight, the blended binder grade, as determined following the procedure given in the Appendix to this standard or some equivalent method, must meet the requirements as described in 5.1.

6. COMBINED AGGREGATE REQUIREMENTS

6.1. *Size Requirements*

6.1.1. *Nominal Maximum Size*—The combined aggregate shall have a nominal maximum aggregate size of 4.75 to 19.0 mm for HMA surface courses and no larger than 37.5 mm for HMA subsurface courses. Recommended nominal maximum aggregate sizes for different applications and lift thicknesses are given in Table 2.

Table 2—Recommended Aggregate Nominal Maximum Aggregate Sizes for Dense-Graded HMA Mixtures

Application	Recommended NMAS, mm	Minimum Lift Thickness, mm	
		Fine-Graded Mixtures	Coarse-Graded Mixtures
Leveling course mixtures	4.75	15 to 25	20 to 25
	9.5	30 to 50	40 to 50
Wearing course mixtures	4.75	15 to 25	20 to 25
	9.5	30 to 50	40 to 50
	12.5	40 to 65	50 to 65
Intermediate course mixtures	19.0	60 to 100	75 to 100
	25.0	75 to 125	100 to 125
Base course mixtures	19.0	60 to 100	75 to 100
	25.0	75 to 125	100 to 125
	37.5	115 to 150	150
Rich base course mixtures	9.5	30 to 50	40 to 50
	12.5	40 to 65	50 to 65

Note 5—Additional guidance on selection of the appropriate nominal maximum size mixture can be found in the National Asphalt Pavement Association's publication IS 128.

6.1.2. *Gradation Control Points*—The combined aggregate should conform to the gradation recommendations listed in Table 3 (19.0-mm through 37.5-mm sizes) and Table 4 (4.75-mm through 12.5-mm sizes) when tested according to T 11 and T 27.

Table 3—Control Points for 19.0-mm through 37.5-mm Aggregate Gradations for Dense-graded HMA Mixtures

Sieve Size (mm)	*Percent Passing for Nominal Maximum Aggregate Size:*					
	37.5 mm		**25.0 mm**		**19.0 mm**	
	Min.	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**
50.0	100	---	---	---	---	---
37.5	90	100	100	---	---	---
25.0	---	90	90	100	100	---
19.0	---	---	---	90	90	100
12.5	---	---	---	---	---	90
9.5	---	---	---	---	---	---
4.75	---	---	---	---	---	---
2.36	15	41	19	45	23	49
1.18	---	---	---	---	---	---
0.600	---	---	---	---	---	---
0.075	0	6	1	7	2	8

Table 4—Control Points for 4.75-mm through 12.5-mm Aggregate Gradations for Dense-graded HMA Mixtures

Sieve Size (mm)	*Percent Passing for Nominal Maximum Aggregate Size:*					
	12.5 mm		**9.5 mm**		**4.75 mm**	
	Min.	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**
50.0	---	---	---	---	---	---
37.5	---	---	---	---	---	---
25.0	---	---	---	---	---	---
19.0	100	---	---	---	---	---
12.5	90	100	100	---	100	---
9.5	---	90	90	100	95	100
4.75	---	---	---	90	90	100
2.36	28	58	32	67	---	---
1.18	---	---	---	---	30	60
0.600	---	---	---	---	---	---
0.075	2	10	2	10	6	12

6.1.3. *Gradation Classification*—The combined aggregate gradation shall be classified as coarse-graded when it passes below the primary control sieve (PCS) control point as defined in Table 5. All other gradations shall be classified as fine-graded.

Table 5—Gradation Classification and Primary Control Sieve Sizes

Aggregate NMAS (mm)	Primary Control Sieve (mm)	PCS Control Point (% Passing)
4.75	1.18	42
9.5	2.36	47
12.5	2.36	39
19.0	4.75	47
25.0	4.75	40
37.5	9.5	47

6.2. *Coarse Aggregate Fractured Faces Requirements*—The aggregate shall meet the percentage of fractured faces requirements specified in Table 6 and measured according to ASTM D 5821.

Table 6—Coarse Aggregate Fracture Faces Requirements.

Design ESALs (million)	Percentage of Particles with at Least One/Two Fractured Faces, for Depth of Pavement Layer[a], mm	
	0 to 100[b]	Below 100[b]
< 0.30	55 / ---	--- / ---
0.3 to < 3	75 / ---	50 / ---
3 to < 10	85 / 80	60 / ---
10 to < 30	95 / 90	80 / 75
30 or more	98 / 98[c]	98/ 98[c]

[a]Depth of pavement layer is measured from pavement surface to surface of pavement layer.
[b]If less than 25 percent of a construction lift is within 100 mm of the surface, the lift may be considered to be below 100 mm for mixture design purposes.
[c]The CAFF requirement for design traffic levels of 30 million ESALs or more may be reduced to 95/95 if experience with local conditions and materials indicate that this would provide HMA mixtures with adequate rut resistance under very heavy traffic.

6.3. *Fine Aggregate Angularity Requirements*—The aggregate shall meet the uncompacted void content of fine aggregate requirements specified in Table 7 and measured according to AASHTO T 304, Method A.

Table 7—Fine Aggregate Angularity Requirements

Design ESALs (million)	Depth of Pavement Layer from Surface, mm	
	0 to 100[a]	Below 100[a]
< 0.30	---[b]	---
0.3 to < 3	40	---
3 to < 10	45[c]	40
10 to < 30	45[c]	45[c]
30 or more	45[c]	45[c]

Criteria are presented as percent air voids in loosely compacted fine aggregate.

[a]If less than 25 percent of a construction lift is within 100 mm of the surface, the lift may be considered to be below 100 mm for mixture design purposes.
[b]Although there is no FAA requirement for design traffic levels below 0.30 million ESALS, consideration should be given to requiring a minimum uncompacted void content of 40 percent for 4.75 mm nominal maximum aggregate size mixes.
[c]The FAA requirement of 45 may be reduced to 43 if experience with local conditions and materials indicate that this would produce HMA mixtures with adequate rut resistance under the given design traffic level.

6.4. *Sand Equivalent Requirements*—Aggregates not derived from RAP shall meet the sand equivalent (clay content) requirements specified in Table 8 and measured according to AASHTO T 176. RAP aggregates need not meet the requirements of Table 8.

Table 8—Maximum Clay Content Requirements

Design ESALs (million)	Minimum Sand Equivalency Value
< 0.30	40
0.3 to < 3	40
3 to < 10	45
10 to < 30	45
30 or more	50

Criteria are presented as Sand Equivalent Value.

6.5. *Flat-and-Elongated Requirements*—The aggregate shall meet the flat-and-elongated requirements specified in Table 9 and measured according to ASTM D 4791, with the exception that material passing the 9.5-mm sieve and retained on the 4.75-mm sieve shall be included. The aggregate shall be measured using the ratio of 5:1, comparing the length (longest dimension) to the thickness (smallest dimension) of the aggregate particles.

Table 9—Criteria for Flat and Elongated Particles

Design ESALs (million)	Maximum Percentage of Flat and Elongated Particles at 5:1
< 0.30	---
0.3 to < 3	10
3 to < 10	10
10 to < 30	10
30 or more	10

Criteria are presented as percent flat and elongated particles by mass.

6.6. When RAP is used in the mixture, the RAP aggregate shall be extracted from the RAP using a solvent extraction (AASHTO T 164) or ignition oven (AASHTO T 308) as specified by the agency. The RAP aggregate shall be included in determination of gradation, coarse aggregate fractured faces, fine aggregate angularity, and flat-and-elongated requirements. The sand equivalent requirements shall be waived for the RAP aggregate but shall apply to the remainder of the aggregate blend.

7. HMA DESIGN REQUIREMENTS

7.1. The binder and aggregate in the HMA shall conform to the requirements of Sections 5 and 6.

7.2. The HMA design, when compacted in accordance with AASHTO T 312 at the design number of gyrations, shall have an air void content of 4.0 ±0.5%. The VMA shall meet the requirements given in Table 10. The dust-to-binder ratio shall meet the requirements given in Table 11.

Table 10—VMA Requirements for Standard Dense-Graded Mixtures

Aggregate NMAS (mm)	Minimum VMA[a] (%)	Maximum VMA[a] (%)
4.75	16.0 to 17.0	18.0 to 19.0
9.5	15.0 to 16.0	17.0 to 18.0
12.5	14.0 to 15.0	16.0 to 17.0
19.0	13.0 to 14.0	15.0 to 16.0
25.0	12.0 to 13.0	14.0 to 15.0
37.5	11.0 to 12.0	13.0 to 14.0

[a]The specifying agency may establish minimum and maximum values for VMA within the stated ranges. Lower values for VMA will tend to produce HMA with improved rut resistance, while higher values for VMA will tend to produce HMA with better fatigue resistance and durability.

Table 11—Requirements for Dust/Binder Ratio

Mix Aggregate NMAS, mm	**Allowable Range for Dust/Binder Ratio, by Weight**
> 4.75	0.8 to 1.6[a]
4.75	0.9 to 2.0

[a]The specifying agency may lower the allowable range for dust/binder ratio to 0.6 to 1.2 if warranted by local conditions and materials. However, the dust/binder ratio should not be lowered if VMA requirements are increased above the standard values as listed in Table 8-6.

7.3. The HMA design, when compacted according to T 312 at 7.0 ±0.5 percent air voids and tested in accordance with T 283 shall have a minimum tensile strength ratio of 0.80.

APPENDIX A: PROCEDURES FOR BLENDED BINDER GRADE TESTING AND CALCULATIONS FOR HMA MIXTURES CONTAINING MORE THAN 15% RECLAIMED ASPHALT BY WEIGHT

A1. Blending of RAP binders can be accomplished by knowing the desired final performance grade (critical temperature) of the blended binder, the physical properties (and critical temperatures) of the recovered RAP binder, and either the physical properties (and critical temperature) of the virgin asphalt binder or the desired percentage of RAP in the mixture.

A2. *Determine the physical properties and critical temperature of the RAP binder.*

A2.1. Recover the RAP binder using AASHTO T 319 (Note A1) with an appropriate solvent. At least 50 g of recovered RAP binder are needed for testing. Perform binder classification testing using the tests in M 320. Rotational viscosity, flash point, and mass loss tests are not required.

Note A1—While AASHTO T 319 is the preferred method, at the discretion of the agency, AASHTO T 170 may be used. Research conducted under NCHRP Project 9-12 (NCHRP Report 452 and NCHRP Research Results Digest 253) indicated that AASHTO T 170 might affect recovered binder properties.

A2.2. Determine the percentage of binder that is contributed by the RAP using Equation A1:

$$\%RAPB = \frac{(ps_{RAP} \times Pb_{RAP})(100 - Pb)}{Pb\left(100 - \frac{ps_{RAP} \times Pb_{RAP}}{100}\right)} \tag{A1}$$

where:

%RAPB = percentage of total binder content that is obtained from the RAP, wt%

Pb_{RAP} = binder content of RAP, wt%

ps_{RAP} = stockpile percentage of RAP in the total blend, wt%

Pb = binder content of the mixture, wt%

A2.3. Determine G*/sinδ for the recovered binder in accordance with AASHTO T 315 at two temperatures: one resulting in G*/sinδ greater than 1.00 kPa, and one resulting in G*/sinδ less than 1.00 kPa.

A2.3.1 Compute the As Recovered true high temperature grade to the nearest 0.1 degree using Equation A2.

$$T_{as\ recovered} = T_1 + \left[\frac{\log(G_1) \times (T_2 - T_1)}{\log(G_1) - \log(G_2)}\right] \tag{A2}$$

where:

$T_{as\ recovered}$ = critical temperature where G*/sinδ equals 1.00 kPa for the as recovered RAP binder

T_1 = test temperature where G*/sinδ is closest to but above 1.00 kPa

G_1 = G*/sinδ for temperature T_1, kPa

T_2 = test temperature where G*/sinδ is closest to but below 1.00 kPa

G_2 = G*/sinδ for temperature T_2, kPa

A2.4. Condition the remaining binder in accordance with AASHTO T 240.

A2.5. Determine G*/sinδ for the RRTFOT conditioned binder in accordance with AASHTO T 315 at two temperatures: one resulting in G*/sinδ greater than 2.20 kPa, and one resulting in G*/sinδ less than 2.20 kPa.

A2.5.1. Compute the RRTFOT true high temperature grade to the nearest 0.1 degree using Equation A3.

$$T_{RTFOT} = T_1 + \left[\frac{\left(\log(G_1) - 0.3424\right) \times (T_2 - T_1)}{\log(G_1) - \log(G_2)} \right] \tag{A3}$$

where:

T_{RRTFOT} = critical temperature where G*/sinδ equals 2.20 kPa for the RRTFOT conditioned RAP binder
T_1 = test temperature where G*/sinδ is closest to but greater than 2.20 kPa
G_1 = G*/sinδ for temperature T_1, kPa
T_2 = test temperature where G*/sinδ is closest to but less than 2.20 kPa
G_2 = G*/sinδ for temperature T_2, kPa

A2.6. Determine G*×sinδ for the PAV conditioned binder in accordance with AASHTO T 315 at two temperatures; one resulting in G*×sinδ greater than 5,000 kPa and one resulting in G*×sinδ less than 5,000 kPa.

A2.6.1. Compute the true intermediate temperature grade to the nearest 0.1 degree using Equation A4.

$$T_{\text{int}ermediate} = T_1 + \left[\frac{(\log(G_1) - 3.6990) \times (T_2 - T_1)}{\log(G_1) - \log(G_2)} \right] \tag{A4}$$

where:

$T_{intermediate}$ = critical temperature where G*×sinδ equals 5,000 kPa for the PAV conditioned RAP binder
T_1 = test temperature where G*×sinδ is closest to but above 5,000 kPa
G_1 = G*×sinδ for temperature T_1, kPa
T_2 = test temperature where G*×sinδ is closest to but below 5,000 kPa
G_2 = G*×sinδ for temperature T_2, kPa

A2.7. Determine the low temperature creep stiffness, S, and m-value for the PAV conditioned binder in accordance with AASHTO T 313 at two temperatures; one resulting in S greater than 300 MPa, and one resulting in S less than 300 MPa.

A2.7.1. Compute the true low temperature grade for S to the nearest 0.1 degree using Equation A5.

$$T_S = T_1 + \left[\frac{\left(\log(S_1) - 2.4771\right) \times (T_2 - T_1)}{\log(S_1) - \log(S_2)} \right] \tag{A5}$$

where:

T_S	=	critical temperature where S equals 300 MPa for the PAV conditioned RAP binder
T_1	=	test temperature where S is closest to but greater than 300 MPa
S_1	=	S for temperature T_1, MPa
T_2	=	test temperature where S is closest to but less than 300 kPa
S_2	=	S for temperature T_2, MPa

A2.7.2. Compute the true low temperature grade for the m-value to the nearest 0.1 degree using Equation A6.

$$T_m = T_1 + \left[\frac{\left(0.300 - m_1\right) \times (T_2 - T_1)}{(m_2 - m_1)} \right] \tag{A6}$$

where:

T_m	=	critical temperature where the m-value equals 0.300 kPa for the PAV conditioned RAP binder
T_1	=	test temperature for the lower m-value.
m_1	=	m-value for temperature T_1
T_2	=	test temperature for the higher m-value.
m_2	=	m-value for temperature T_2

A2.8. Determine the performance grade for the recovered binder.

A2.8.1. The critical high temperature grade for the recovered binder is the lower of the two for the as recovered (Section A2.3.1) and the RRTFOT conditions (Section A2.5.1).

A2.8.2. The critical low temperature grade for the recovered binder is the higher of the two for the creep stiffness (Section A2.7.1) and the m-value (A2.7.2).

A2.8.3. The critical intermediate grade for the recovered binder is the true intermediate temperature grade determined in Section A2.6.1.

A3. *Estimate the properties and grade of the blended binder from the properties of the recovered and virgin binders and the percentage of RAP.*

A3.1. Determine the critical temperature of the blended binder from the high, intermediate, and low temperature test data using Equation A7:

$$T_c(blend) = T_c(virgin) + \frac{\%RAPB}{100}\left(T_c(RAP) - T_C(virgin)\right) \quad \text{(A7)}$$

Where:

$T_c(blend)$	=	critical temperature for the blend of RAP and new binder
$T_c(virgin)$	=	critical temperature for the new binder
$T_c(RAP)$	=	critical temperature for the RAP binder
$\%RAPB$	=	percentage of total binder content that is obtained from the RAP, wt%

A3.2. The critical high temperature grade for the blended binder is the lower of the two calculated using Equation A7 for the as recovered and the RRTFOT conditions minus a factor of safety [Note A2].

A3.3. The critical low temperature grade for the blended binder is the higher of the two calculated using Equation A7 for the creep stiffness and the m-value plus a factor of safety [Note A2].

A3.4. The critical intermediate grade for the blended binder is the true intermediate temperature grade calculated using Equation A7 plus a factor of safety [Note A2].

Note A2—A factor of safety of 2°C is suggested for determining high and low critical temperatures and a factor of safety of 1°C is suggested for determining the intermediate critical temperature when grading a blended binder for an HMA mix design containing more than 15% RAP. The factor of safety provides for errors in the grading procedure.

A4. *Estimation of the Required Virgin Binder Properties from the specified Blended Binder Grade and RAP Content*

A4.1. Determine the critical temperature of the virgin asphalt binder from high, intermediate, and low temperature test data using Equation A8:

$$T_c(virgin) = \frac{T_c(spec) - \frac{\%RAPB}{100}\left(T_c(RAP)\right)}{\left(1 - \frac{\%RAPB}{100}\right)} \quad \text{(A8)}$$

where:

$T_c(spec)$ = design critical temperature

	=	critical temperature to meet performance grade requirements ± factor of safety [Note A3]
$T_c(virgin)$	=	critical temperature for the new binder
$T_c(RAP)$	=	critical temperature for the RAP binder
%RAPB	=	percentage of total binder content that is RAP, wt%

Note A3—The suggested factor of safety is +2°C for the critical high temperature, −2°C for the critical low temperature, and −1°C for critical intermediate temperature. The factor of safety provides for errors in the grading procedure.

A4.2. The critical high temperature grade for the virgin binder is the lower of the two calculated using Equation A8 for the as recovered and the RRTFOT conditions.

A4.4. The critical low temperature grade for the virgin binder is the higher of the two calculated using Equation A8 for the creep stiffness and the m-value.

A4.5. The critical intermediate grade for the virgin binder is the true intermediate temperature grade calculated using Equation A8.

A5. *Determine the percentage of RAP from required blended binder grade and virgin binder properties.*

A5.1. Determine the percentage of RAP based upon the high, intermediate and low temperature test data using equation A9:

$$\%RAPB = \left[\frac{T_c(spec) - T_c(virgin)}{T_c(RAP) - T_c(virgin)}\right] \times 100\% \tag{A9}$$

where:

$T_c(spec)$	=	design critical temperature = critical temperature to meet performance grade requirements ± factor of safety [Note A4]
$T_c(virgin)$	=	critical temperature for the new binder
$T_c(RAP)$	=	critical temperature for the RAP binder
%RAPB	=	percentage of total binder content that is RAP, wt%

Note A4—Care must be used in applying Equation A9. If the virgin binder meets the required critical temperature ($T_c(spec)$), but the RAP binder does not, the value given by Equation A9 represents a maximum allowable RAP content. If the RAP binder meets the required critical temperature, but the virgin binder does not, the values given by Equation A9 represents a minimum required RAP content. If both the virgin and RAP binders exceed the required critical temperature, then the maximum allowable RAP based on that critical temperature is 100%. If both the virgin and RAP binders fail to meet the required critical temperature, then no combination of these binders will satisfy the given grading requirement.

Note A5—Regardless of the results of the binder grading analysis, the RAP content of HMA mixtures shall not exceed 50%.

Recommended Standard Practice for

Volumetric Mix Design of Dense-Graded HMA

NCHRP Project 9-33 Designation M 2

1. SCOPE

1.1. This standard for mix design evaluation uses aggregate and mixture properties to produce a hot mix asphalt (HMA) job mix formula. The mix design is based on the volumetric properties of the HMA in terms of the air voids (V_a), voids in the mineral aggregate (VMA), and voids filled with asphalt (VFA).

1.2. This standard may also be used to provide a preliminary selection of mix parameters as a starting point for mix evaluation and performance prediction analyses that primarily use T 320 and T 322.

1.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards:*

- M 320, Performance-Graded Asphalt binder
- R 29, Grading or Verifying the Performance Grade of an Asphalt Binder
- R 30, Mixture Conditioning of Hot-Mix Asphalt (HMA)
- T 2, Sampling of Aggregates
- T 11, Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 84, Specific Gravity and Absorption of Fine Aggregate
- T 85, Specific Gravity and Absorption of Coarse Aggregate
- T 100, Specific Gravity of Soils
- T 164, Quantitative Extraction of Bitumen from Bituminous Paving Mixtures
- T 166, Bulk Specific Gravity of Compacted Asphalt Mixtures Using Saturated Surface-Dry Specimens
- T 209, Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures
- T 228, Specific Gravity of Semi-Solid Bituminous Materials
- T 240, Effect of Heat and Air on a Moving Film of Asphalt (Rolling Thin-Film Oven Test)
- T 248, Reducing Samples of Aggregate to Testing Size

- T 275, Bulk Specific Gravity of Compacted Bituminous Mixtures Using Paraffin-Coated Specimens
- T 283, Resistance of compacted Asphalt Mixtures to Moisture-Induced Damage
- T 308, Determining the Asphalt Binder Content of Hot-Mix Asphalt (HMA) by the Ignition Method
- T 312, Preparing and Determining the Density of Hot-Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory compactor
- T 320, Determining the Permanent Shear Strain and Stiffness of Asphalt Mixtures Using the Superpave Shear Tester (SST)
- T 324, Hamburg Wheel-Track Testing of Compacted Hot-Mix Asphalt (HMA)

2.2. Asphalt Institute Publication:

- MS-2, *Mix Design Methods for Asphalt Concrete and Other Mix Types*

2.3. *National Asphalt Pavement Association Publication*

- IS 128, *HMA Pavement Mix Type Selection Guide*

2.4. Other References:

- NCHRP M 1, Recommended Standard Specification for Design of Dense-Graded HMA
- *NCHRP Report 508—Accelerated Laboratory Rutting Tests: Evaluation of the Asphalt Pavement Analyzer*, A. Cooley, Transportation Research Board, Washington, DC, 2003.
- *NCHRP Report 629, Ruggedness Testing of the Dynamic Modulus and Flow Number Tests with the Simple Performance Tester*, R. Bonaquist, Transportation Research Board, Washington, DC, 2008.
- *LTPP Seasonal Asphalt Concrete Pavement Temperature Models*. FHWA-RD-97-103, FHWA, U.S. Department of Transportation, Washington, DC, September 1988.

3. TERMINOLOGY

3.1. *HMA*—hot mix asphalt

3.2. *design ESALs*—Design equivalent (80 kN) single axle loads.

3.2.1. *Discussion*—design ESALs are the anticipated project traffic level expected on the design lane over the design life of the pavement.

3.3. *air voids* (V_a)—The total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as a percent of the bulk volume of the compacted paving mixture (Note 1)

Note 1—As defined in Asphalt Institute Manual MS-2, Mix Design Methods for Asphalt Concrete and Other Mix types.

3.4. *voids in the mineral aggregate* (VMA)—The volume of the intergranular void space between the aggregate particles of a compacted paving mixture that includes the air voids and the effective binder content, expressed as a percent of the total volume of the specimen (Note 1).

3.5. *absorbed binder volume* (V_{ba})—The volume of binder absorbed into the aggregate (equal to the difference in aggregate volume when calculated with the bulk specific gravity and effective specific gravity).

3.6. *binder content* (P_b)—The percent by mass of binder in the total mixture including binder and aggregate.

3.7. *effective binder volume* (V_{be})—The volume of binder which is not absorbed into the aggregate.

3.8. *voids filled with asphalt* (VFA)—the percentage of the VMA filled with binder (the effective binder volume divided by the VMA).

3.9. *dust-to-binder ratio* ($P_{0.075}/P_{be}$)—By mass, the ratio between the percent of aggregate passing the 75-µm (No. 200) sieve ($P_{0.75}$) and the effective binder content (P_{be}).

3.10. *nominal maximum aggregate size*—One size larger than the first sieve that retains more than 10 percent aggregate (Note 2).

3.11. *maximum aggregate size*—One size larger than the nominal maximum aggregate size (Note 2).

Note 2—The definitions given in Sections 3.10 and 3.11 also apply to Superpave mixes, but differ from the definitions published in other AASHTO standards.

3.12. *reclaimed asphalt pavement* (RAP)—Pavement materials, removed, processed, or both, containing asphalt binder and aggregate.

3.13. *primary control sieve* (PCS)—the sieve defining the break point between fine- and coarse-graded mixtures for each nominal maximum aggregate size.

3.14. *compositional requirement*—specified requirements on aggregate quality and mixture composition, including coarse aggregate crush count, flat and elongated particles, fine aggregate angularity, clay content/sand equivalent, VMA, air voids, and dust:binder ratio.

4. SUMMARY OF THE PRACTICE

4.1. *Gather Information*—All pertinent information concerning the paving project and mix design are gathered and organized. This should include information on potential binders, aggregates, and RAP stockpiles

4.2. *Select Asphalt Binder*—An asphalt binder meeting the performance grading requirements as specified in NCHRP 9-33 M 1 is selected.

4.3. *Determine Compaction Level*—Based upon anticipated traffic level, the number of design gyrations is selected.

4.4. *Select Nominal Maximum Aggregate Size*—The nominal maximum aggregate size (NMAS) is usually specified by the agency, and depends on the lift thickness to be used in the paving project.

4.5. *Determine Target VMA and Air Voids Value*—Target VMA increases one percent for every size increase in NMAS, but may be increased up to 1.0% at the agency's discretion. The target air voids value is usually specified at 4.0%, but may vary from 3.5 to 4.5%.

4.6. *Calculate Target Binder Content*—The target effect binder volume (V_{be}) is the target VMA minus the target air voids value.

4.7. *Calculate Aggregate Volume*—The aggregate volume is calculated as 100% minus VMA.

4.8. *Proportion Aggregate Blends for Trial Mixtures*—Aggregate and RAP stockpiles are selected, based on NMAS, available materials and the values of specified properties. Aggregate properties specified by the agency but not addressed in this standard must also be considered. Prepare aggregate blends for three trial mixtures by proportioning selected aggregates and RAP to create coarse, dense and fine aggregate gradations, that is, near the upper specification limits, through the center of the specification limits and near the lower specification limits for the aggregate gradation.

4.9. *Calculate Trial Mixture Proportions by Weight and Check Dust/Binder Ratio*—The volumetric mix proportions are used to calculate mix proportions by weight and batch weights for trial mixes.

4.10. *Evaluate and Refine Trial Mixtures*—For each trial mixture, specimens are prepared using the Superpave gyratory compactor, and their bulk specific gravity determined, along with the theoretical maximum specific gravity of the loose mixture. From these data, VMA, air voids and dust to binder ratio are calculated and evaluated to determine if they meet the specified compositional requirements. If one of the trial mixtures meets all compositional requirements it is selected for performance evaluation. If none of the trial mixtures meets all compositional requirements, then additional trial mixtures are prepared and evaluated until a mixture meeting all established compositional requirements has been developed.

4.11. Evaluate Performance—The moisture resistance of the selected trial mixture is evaluated in accordance with AASHTO T 283. If necessary, the mix design is modified to meet the requirements of AASHTO T 283. The rut resistance of the trial mixture is then evaluated using one of six test methods. The mix design is modified as needed until rut resistance requirements are met.

4.12. *Compile Mix Design Report*—A clear and concise report documenting project information, the composition of the final mix design, and the values of all specified properties is prepared.

4. SIGNIFICANCE AND USE

4.1. This standard may be used to select and evaluate materials for dense-graded HMA volumetric mix designs.

5. GATHER INFORMATION

5.1. All pertinent information concerning the paving project and mix design shall be gathered and compiled. This includes the name or code identifying the paving project, the location, the lift thickness or NMAS specified by the agency, the design traffic level, the design life of the pavement, the VMA and air voids if specified by the agency, the binder performance grade if specified by the agency, and other agency-specified properties not addressed in this specification.

5.2. A list of available materials should be compiled, including available aggregates and their specification properties, RAP stockpiles and their specification properties, and asphalt binders and their specification properties.

6. SELECT ASPHALT BINDER

6.1. In many cases, the agency will specify the binder performance grade to be used in the mix design for the paving project. If not, select an asphalt binder meeting the requirements of NCHRP 9-33 M 1. If RAP materials are being used, and the total RAP content of the mix exceeds 15% by weight, the performance grade of the blended binder—new binder plus RAP binder—must meet the specified requirements. Procedures for determining blended binder grades for HMA mix designs containing RAP are given in NCHRP 9-33 M 1.

7. DETERMINE COMPACTION LEVEL

7.1. The number of design gyrations for the mix design shall be as specified in Table 1.

Table 1 – Gyratory Compaction Effort for Dense-Graded HMA Mixtures

Design ESALs (millions)	N_{design}	Typical Roadway[a]
< 0.3	50	Applications include roadways with very light traffic volumes such as local roads, country roads, and city streets where truck traffic is prohibited or at a very minimal level. Traffic on these roadways would be considered local in nature, not regional, intrastate, or interstate. Special purpose roadways serving recreational sites or areas may also be applicable to this level.
0.3 to < 3	75	Applications include many collector roads or access streets. Medium-trafficked city streets and the majority of country roadways may be applicable to this level.
3 to < 30	100	Applications include many two-lane, multilane, divided, and partially or completely controlled access roadways. Among these are medium to highly trafficked city streets, many state routes, U.S. highways, and some rural Interstates.
≥ 30	125	Applications include the vast majority of the U.S. Interstate System, both rural and urban in nature. Special applications such as truck-weighing stations or truck-climbing lanes on two-lane roadways may also be applicable to this level.

[a]As defined in *A Policy on Geometric Design of Highways and Streets*, 2004, AASHTO.

Note 2 – When specified by the agency and the top of the design layer is ≥ 100 mm from the pavement surface and the estimated design traffic level is ≥ 0.3 million ESALs, decrease the estimated design traffic level by one, unless the mixture will be exposed to significant mainline construction traffic prior to being overlaid. If less than 25 percent of a construction lift is within 100 mm of the surface, the lift may be considered to be below 100 mm for the mixture design purposes.

Note 3 – When it is estimated that the design traffic level is between 3 and <10 million ESALs, the Agency may, at its discretion, specify N_{design} at 75.

8. SELECT NOMINAL MAXIMUM AGGREGATE SIZE

8.1. The NMAS for the mix design is usually specified by the agency.

8.2. In cased where the NMAS has not been specified by the agency, select the NMAS following the guidelines given in Table 2.

Table 2—Recommended Aggregate NMAS for Different Applications and Lift Thicknesses

Application	Recommended NMAS, mm	Minimum Lift Thickness, mm: Fine-Graded Mixtures	Minimum Lift Thickness, mm: Coarse-Graded Mixtures
Leveling course mixtures	4.75	15 to 25	20 to 25
	9.5	30 to 50	40 to 50
Wearing course mixtures	4.75	15 to 25	20 to 25
	9.5	30 to 50	40 to 50
	12.5	40 to 65	50 to 65
Intermediate course mixtures	19.0	60 to 100	75 to 100
	25.0	75 to 125	100 to 125
Base course mixtures	19.0	60 to 100	75 to 100
	25.0	75 to 125	100 to 125
	37.5	115 to 150	150
Rich base course mixtures	9.5	30 to 50	40 to 50
	12.5	40 to 65	50 to 65

9. DETERMINE TARGET VMA AND AIR VOIDS VALUES

9.1. Select the target VMA for the mix design. The target VMA shall be between the minimum and maximum values specified in Table 3, and should preferably be in the center of the specified range.

9.2. Select the target air void content for the mix design. The target air void content shall be between 3.5 and 4.5%, and should preferably be set at 4.0%.

Table 3—VMA Values for Dense-Graded HMA Mixtures

Aggregate NMAS (mm)	Minimum VMA[A] (%)	Maximum VMA[A] (%)
4.75	16.0 to 17.0	18.0 to 19.0
9.5	15.0 to 16.0	17.0 to 18.0
12.5	14.0 to 15.0	16.0 to 17.0
19.0	13.0 to 14.0	15.0 to 16.0
25.0	12.0 to 13.0	14.0 to 15.0
37.5	11.0 to 12.0	13.0 to 14.0

[A]The specifying agency may establish minimum and maximum values for VMA within the stated ranges. Lower values for VMA will tend to produce HMA with improved rut resistance, while higher values for VMA will tend to produce HMA with better fatigue resistance and durability.

10. CALCULATE TARGET BINDER CONTENT

10.1. The target binder content, expressed as a volume (V_b) is calculated as the target VMA minus the target air voids, plus 1.0% to account for absorption of binder by the aggregate.

10.2. If desired, a more accurate estimate of the effect of absorption can be used in calculating total binder content based upon the water absorption of the aggregate. Using this approach, the target binder content is calculated using Equation 1:

$$V_b = VBE + \left(1 - \frac{VMA}{100}\right)\left(\frac{G_{sb} P_{wa}}{2}\right) \qquad (1)$$

Where:

V_b	=	total asphalt content by volume%
VBE	=	effective asphalt content by volume%
VMA	=	voids in the mineral aggregate
	=	V_{be} + air void content
G_{sb}	=	aggregate bulk specific gravity
P_{wa}	=	water absorption of the aggregate, weight%

11. CALCULATE AGGREGATE VOLUME

11.1 The total aggregate volume percentage is calculated as 100% minus the target VMA.

12. PROPORTION AGGREGATE BLENDS FOR TRIAL MIXTURES

12.1. Select aggregates and RAP materials (if applicable) that will be used for the mix design.

12.1.1. The aggregates and RAP materials shall conform to the NMAS selected for the mix design.

12.1.2. The aggregates and RAP materials shall be selected so that the final aggregate blend will likely pass aggregate requirements specified in NCHRP 9-33 M 1, and any other applicable requirements specified by the agency.

Note 5—Initial conformance to aggregate specifications is normally estimated based upon the properties of individual aggregates and RAP materials and the composition of the aggregate blend. Final conformance must be based on actual measurement of the final aggregate blend.

Note 6—RAP aggregates need not meet clay content (sand equivalent) requirements.

12.2. Characterize the properties of the aggregates.

12.2.1. Obtain samples of aggregates to be used for the mix design from the aggregate stockpiles in accordance with AASHTO T 2.

12.2.2. Reduce the samples of aggregate according to AASHTO T 248 to sizes meeting the requirements specified in AASHTO T 27.

12.2.3. Wash and grade each aggregate according to the procedures given in AASHTO T 11 and AASHTO T 27.

12.2.4. Determine the bulk and apparent specific gravity for each coarse and fine aggregate in accordance with AASHTO T 85 and AASHTO T 84, respectively, and determine the specific gravity of the mineral filler in accordance with AASHTO T 100.

12.3. Characterize the RAP materials, if applicable, following the procedures given in Appendix A. This will include determination of the binder content, the aggregate gradation, the RAP aggregate bulk and apparent specific gravity, the RAP aggregate specification properties (not including clay content/sand equivalent, which does not apply), and the RAP binder grade. The RAP characterization should also include an estimate of the maximum amount of RAP that can be used in the mix design without increasing the production variability of the final mix to an unacceptable level.

Note 7—It is recommended that the field compaction temperature be greater than the as-recovered high temperature grade of the RAP binder. If the total time that the HMA will remain at a temperature above the as-recovered high temperature grade of the RAP binder is expected to be less than 2 hours, it is recommended that a plant mixing study be conducted to ensure that the RAP binder and new binder adequately mix.

Note 8—In most cases, the ignition oven, AASHTO T 308, can be used to obtain the representative sample of RAP aggregate for consensus property testing.

12.4. Determine the proportions of the aggregate blends for up to three initial trial mixtures.

Note 9—For mix designs using new materials, or that differ substantially in volumetric composition from existing mix designs, three trial mixtures should initially be prepared. If an existing mix design is being refined with only minor changes in materials, composition, or both, only one or two initial trial mixtures may be necessary.

12.4.1. Determining aggregate proportions for an aggregate blend for a trial mix is largely a trial-and-error procedure. Initial proportions are assumed for each aggregate in a blend and the resulting gradation is calculated and compared to the desired gradation. If it is close to the target gradation, the proportions are used for the trial mixture. If not, the proportions are altered until an acceptable gradation is produced.

Note 10—For new mix designs involving three initial trial mixtures, one trial mixture should be towards the upper limits of the gradation band given in NCHRP 9-33 M 1 (“fine” gradation),one should be near the lower limit (“coarse” gradation), and one should be near the center of the gradation band (“dense” gradation). When modifying existing mix designs, experience is the best guide in developing aggregate blends for one or two initial trial mixtures.

12.4.2. Calculate the percent passing for each aggregate blend using Equation 2:

$$P = (P_{mA} \times a) + (P_{mB} \times b) + (P_{mC} \times c) + \ldots \qquad (2)$$

Where:

P_m	=	Percentage of aggregate passing sieve size m for the combined blend of aggregates A, B, C, etc.
P_{mA}	=	Percentage of material passing sieve size m for aggregate A
a	=	Fraction of aggregate A in combined aggregate blend
P_{mB}	=	Percentage of material passing sieve size m for aggregate B
b	=	Fraction of aggregate B in combined aggregate blend
P_{mC}	=	Percentage of material passing sieve size m for aggregate C

c = Fraction of aggregate C in combined aggregate blend

12.4.3. Compare the gradations of the aggregate trial blends with the gradation control points given in NCHRP 9-33 M 1, and verify that the gradations meet or nearly meet these limits.

Note 11—Other than the requirements for NMAS, the aggregate gradations described in NCHRP 9-33 M 1 should be considered guidelines and not requirements. If necessary, aggregate blends may deviate from the control points given in NCHRP 9-33 M 1, except for the control points defining the NMAS. Also, the requirements for dust to binder ratio given in NCHRP 9-33 M 1 must be met.

Note 12—If desired, the specification properties of the aggregate blends can be estimated from the blend proportions and the properties of the individual aggregates and RAP materials, to verify that they will likely meet the requirements of NCHRP 9-33 M 1.

13. CALCULATE TRIAL MIXTURE PROPORTIONS BY WEIGHT AND CHECK DUST/BINDER RATIO

13.1. Calculate the overall aggregate bulk specific gravity using Equation 3:

$$G_{sb} = \frac{P_{s1/A} + P_{s2/A} + P_{s3/A} + \cdots}{\left(\frac{P_{s1/A}}{G_{sb1}}\right) + \left(\frac{P_{s2/A}}{G_{sb2}}\right) + \left(\frac{P_{s3/A}}{G_{sb3}}\right) + \cdots} \tag{3}$$

Where:

G_{sb} = overall bulk specific gravity for aggregate blend
$P_{s1/A}$ = volume% of aggregate 1 in aggregate blend
G_{sb1} = bulk specific gravity for aggregate 1
$P_{s2/A}$ = volume% of aggregate 2 in aggregate blend
G_{sb2} = bulk specific gravity for aggregate 2
$P_{s3/A}$ = volume% of aggregate 3 in aggregate blend
G_{sb3} = bulk specific gravity for aggregate 3

13.2. Calculate the asphalt binder content by weight using Equation 4:

$$P_b = \frac{V_b G_b}{V_{sb} G_{sb} + V_b G_b} \times 100\% \tag{4}$$

Where:

P_b	=	total binder content,% by total mix weight
V_b	=	total binder content,% by total mix volume
G_b	=	binder specific gravity
V_{sb}	=	aggregate content,% by total mix volume
G_{sb}	=	overall bulk specific gravity of aggregate (Equation 3)

13.3. Estimate the effective asphalt binder content by weight using Equation 5:

$$P_{be} = \frac{V_{be}G_b}{V_{sb}G_{sb} + V_bG_b} \times 100\% \tag{5}$$

Where:

P_{be}	=	effective binder content,% by total mix weight
V_{be}	=	effective binder content,% by total mix volume
G_b	=	binder specific gravity
V_{sb}	=	aggregate content,% by total mix volume
G_{sb}	=	overall bulk specific gravity of aggregate (Equation 3)

13.4. Calculate the aggregate content using Equation 6:

$$P_s = \frac{V_{sb}G_{sb}}{V_{sb}G_{sb} + V_bG_b} \times 100\% \tag{6}$$

Where:

P_b	=	total aggregate content,% by total mix weight
V_b	=	total binder content,% by total mix volume
G_b	=	binder specific gravity
V_{sb}	=	aggregate content,% by total mix volume
G_{sb}	=	overall bulk specific gravity of aggregate (Equation 3)

13.5. Calculate the weight percentage of each aggregate using Equation 7:

$$P_{s1} = P_s\left(\frac{P_{s1/A}}{100}\right) \tag{7}$$

Where:

P_{s1}	=	weight percent (by total mix) of aggregate 1 (or aggregate 2, 3, etc.)

P_s = weight percent (by total mix) of combined aggregate, from Equation 7
$P_{s1/A}$ = weight percent (in aggregate blend) of aggregate 1 (or aggregate 2, 3, etc.)

13.6. Estimate the percent of mineral dust (material finer than 0.075 mm) in the total mixture using Equation 8:

$$P_{0.075} = \frac{P_{0.075/s1}P_{s1} + P_{0.075/s2}P_{s2} + P_{0.075/s3}P_{s3} + \cdots}{100} \tag{8}$$

Where:

$P_{0.075}$ = mineral dust content (material finer than 0.075 mm), percent by total mix weight
$P_{0.075/s1}$ =% passing the 0.075 mm sieve for aggregate 1
P_{s1} = weight percent (by total mix) of aggregate 1
$P_{0.075/s2}$ =% passing the 0.075 mm sieve for aggregate 2
P_{s2} = weight percent (by total mix) of aggregate 2
$P_{0.075/s3}$ =% passing the 0.075 mm sieve for aggregate 3
P_{s3} = weight percent (by total mix) of aggregate 3

13.7. Estimate the dust to binder ratio using Equation 9:

$$D/B = \frac{P_{0.075}}{P_{be}} \tag{9}$$

Where:

D/B = dust to binder ratio, calculated using effective binder content
$P_{0.075}$ = mineral dust content,% by total mix weight (Equation 8)
P_{be} = effective binder content,% by total mix weight (Equation 5)

13.7.1. Verify that the dust to binder ratio meets the requirements of NCHRP 9-33 M 1.

14. EVALUATE AND REFINE TRIAL MIXTURES

14.1. Prepare replicate specimens for specific gravity measurements for each trial mixture.

Note 13—At least two replicate specimens are required, but three or more may be prepared if desired. Generally, 4500 to 4700 g of aggregate are sufficient for each compacted gyratory specimen having a height of 110 to 120 mm, for aggregate having bulk specific gravity values from 2.55 to 2.70.

14.1.1 Determine batch weights for each trial mixture by multiplying the total mix weight by the weight fraction of each component (weight percentage divided by 100%).

14.1.2. Weight out aggregates for each batch, taking care to avoid segregation while handling the aggregates. This may require sieving coarse aggregates into different size fractions and weighing out these fractions separately.

14.1.3. Condition the mixture in accordance with R 30, and compact specimens using the Superpave gyratory compactor in accordance with T 312, with the number of gyrations determined as described in Section 7.

14.2. Determine the bulk specific gravity (G_{mb}) of each of the compacted specimens in accordance with AASHTO T 166 or AASHTO T 275 as appropriate.

14.3. Determine the air void content and VMA of the specimens.

14.3.1. Calculation the air void content of each compacted specimen using Equation 10:

$$V_a = 100\left[1 - \left(\frac{G_{mb}}{G_{mm}}\right)\right] \tag{10}$$

Where:

V_a = Air void content, volume%
G_{mb} = Bulk specific gravity of compacted mixture
G_{mm} = Maximum theoretical specific gravity of loose mixture

14.3.2. Calculate the effective asphalt content of each compacted specimen using Equation 11:

$$V_{be} = V_b - G_{mb}\left[\left(\frac{P_b}{G_b}\right) + \left(\frac{P_s}{G_{sb}}\right) - \left(\frac{100}{G_{mm}}\right)\right] \tag{11}$$

Where:

V_{be} = Effective binder content, percent by total mixture volume
V_b = Total binder content, percent by total mixture volume
G_{mb} = Bulk specific gravity of the mixture
P_b = Total asphalt binder content,% by mix mass
G_b = Specific gravity of the asphalt binder
P_s = Total aggregate content,% by mix mass
= 100 – Pb
G_{sb} = Average bulk specific gravity for the aggregate blend
G_{mm} = Maximum specific gravity of the mixture

14.3.3. Calculate the VMA using Equation 12:

$$VMA = V_a + V_{be} \tag{12}$$

Where:

VMA	=	Voids in mineral aggregate, percent by total mixture volume
V_a	=	Air void content
V_{be}	=	Effective binder content, percent by total mixture volume

14.4. Tabulate all specified properties for trial mixtures and compare to required values. Select as the final mix design the trial mixture that meets all requirements with the property values most nearly in the center of the specified ranges. Proceed to performance evaluation as described in 14.6.

14.5. If none of the trial mixtures meet all requirements, additional trial mixtures must be prepared and evaluated. Proportion aggregate blends for additional trial mixtures based upon the properties of initial trial mixtures.

Note 14—Evaluating and refining trial mixtures when developing an HMA mix design is largely a trial-and-error process. Judgment and experience are an important part of this process. Additional useful information concerning developing and adjusting aggregate blends for HMA trial mixtures can be found in the Asphalt Institute's MS-2, Transportation Research Circular E-C044: *Bailey Method for Gradation Selection in Hot-Mix Asphalt Mixture Design*. and *Mix Design Manual for Hot-Mix Asphalt*, developed during NCHRP Project 9-33.

14.5.1. Prepare specimens from additional trial mixtures and determine the bulk and theoretical maximum specific gravity values. Calculate air voids, VMA, dust to binder ratio and other specified properties to determine if any of the additional trial mixtures meet all requirements. If not, continue to modify the aggregate blends for trial mixtures, prepare specimens, and evaluate specified properties, until a suitable mix design has been developed. Proceed to performance evaluation of the final mix design as described in 15.

15. EVALUATE PERFORMANCE OF THE MIX DESIGN.

15.1. Evaluate the moisture resistance of the final mix design.

15.1.2. Using the final mix design, prepare six mixture specimens (nine are needed if freeze-thaw testing is required). Condition the mixture in accordance with AASHTO R 30, and compact the specimens to 7.0 ± 0.5 percent air voids in accordance with AASHTO T 312.

15.1.3. Test the specimens and calculate the tensile strength ratio in accordance with AASHTO T 283.

15.1.4. If the tensile strength ratio is less than 0.80, adjust the mix design to increase the moisture resistance of the mix to an acceptable level as measured using AASHTO T 283. Such adjustments might include adding hydrated lime to the mixture, adding various anti-strip additives, or changing the source of the aggregate binder, or both. Once the required tensile strength ratio of 0.80 is achieved (along with all other specified requirements), proceed to rut resistance evaluation.

15.2. Evaluate the rut resistance of the final mix design.

15.2.1. Select the test to be used in evaluating rut resistance. Allowable procedures are the asphalt mixture performance tester (AMPT), using either the flow number test (14.6.2.3) or the flow time test (14.6.2.4); the asphalt pavement analyzer (APA, 14.6.2.5); the Hamburg wheel tracking test (HWTT, 14.6.2.6); the Superpave shear tester, repeated shear at constant height (SST/RSCH) test (14.6.2.7); or the high temperature indirect tensile (HT/IDT) strength test (14.6.2.8).

15.2.2. Using the final mix design, prepare the required number and type of specimens for the selected rut resistance test. Condition the mixtures in accordance with R 30.

15.2.3. For AMPT testing using the flow number procedure, follow procedures given in *NCHRP Report 629, Ruggedness Testing of the Dynamic Modulus and Flow Number Tests with the Simple Performance Tester*. Prepare two specimens in accordance with AASHTO T 312, with a final air void content within 0.5 percent of the expected as-constructed air void content. If the as-constructed air void content is not specified, compact the specimens to an air void content of 7.0 ± 0.5%. Final nominal specimen dimensions are 150 mm high by 100 mm in diameter. For mixtures designed for fast traffic (≥ 70 kph), the test temperature shall be the average, 7-day maximum pavement temperature 20 mm from the surface, at 50% reliability as determined using LTPPBind version 3.1. For slow traffic (25 to < 70 kph), the test temperature shall be 6°C higher than the test temperature for fast traffic; for very slow traffic (< 25 kph), the test temperature shall be 12°C higher. In all cases, the test temperature shall be controlled to within 0.5°C of that specified. Perform the flow number test and report the average of the results for the two specimens tested. The recommended minimum flow number values as a function of design traffic level are shown in Table 4 (Note 15). If the required minimum flow number value is not met, the mix must be modified to improve rut resistance, while meeting all other applicable requirements as given in this standard (Note 16).

Table 4—Recommended Minimum Flow Number Requirements

Traffic Level *Million ESALs*	**Minimum Flow Number** *Cycles*
< 3	---
3 to < 10	340
10 to < 30	560
≥ 30	890

Note 15—The minimum flow number values, and other recommended test values for rut resistance tests given in this standard, should be considered guidelines that should be evaluated and modified as necessary by the agency to account for local materials, climate and traffic conditions.

Note 16—Rut resistance of HMA mixtures can be improved by a variety of methods: increasing the high temperature binder grade; using a polymer modified binder if not already in use; by using aggregate with increased angularity, hardness, or both; or by a combination of these methods.

15.2.4. For AMPT testing using the flow time procedure, follow procedures given in *NCHRP Report 629, Ruggedness Testing of the Dynamic Modulus and Flow Number Tests with the Simple Performance Tester*. Prepare two specimens in accordance with T 312, with a final air void content within 0.5 percent of the expected as-constructed air void content. If the as-constructed air void content is not specified, compact the specimens to an air void content of 7.0 ± 0.5%. Final nominal specimen dimensions are 150 mm high by 100 mm in diameter. For mixtures designed for fast traffic (≥ 70 kph), the test temperature shall be the average, 7-day maximum pavement temperature 20 mm from the surface, at 50% reliability as determined using LTPPBind version 3.1. For slow traffic (25 to < 70 kph), the test temperature shall be 6°C higher than the test temperature for fast traffic; for very slow traffic (< 25 kph), the test temperature shall be 12°C higher. In all cases the test temperature shall be controlled to within 0.5°C of that specified. Perform the flow time test and report the average of the results for the two specimens tested. The recommended minimum flow time values as a function of design traffic level are shown in Table 5 (Note 15). If the required minimum flow time value is not met, the mix must be modified to improve rut resistance, while meeting all other applicable requirements as given in this standard (Note 16).

Table 5—Recommended Minimum Flow Time Requirements

Traffic Level *Million ESALs*	**Minimum Flow Time** *s*
< 3	---
3 to < 10	110
10 to < 30	180
≥ 30	290

15.2.5. For rut resistance testing using the APA device, follow procedures given in Appendix B of *NCHRP Report 508—Accelerated Laboratory Rutting Tests: Evaluation of the Asphalt Pavement Analyzer*. Prepare six specimens in accordance with AASHTO T 312, with a final air void content of 4.0 ± 0.5%. Final nominal specimen dimensions are 150 mm high by 75 mm in diameter. The test temperature shall be the temperature corresponding to the high-temperature binder performance grade specified for the project by the agency. Perform the APA test and report the average of the results for the six specimens tested, as described in Appendix B of *NCHRP Report 508*. The recommended maximum rut depth values as a function of design traffic level are shown in Table 6 (Note 15). If the maximum rut depth value is exceeded, the mix must be modified to improve rut resistance, while meeting all other applicable requirements as given in this standard (Note 16).

Table 6—Recommended Maximum Rut Depths for the APA Test.

Traffic Level *Million ESALs*	**Maximum Rut Depth** *mm*
< 3	---
3 to < 10	5
10 to < 30	4
≥ 30	3

-

15.2.6. For rut resistance testing using the Hamburg wheel tracking test, follow procedures given in AASHTO T 324. Prepare two specimens in accordance with T 312, with a final air void content of 7.0 ± 2.0%. Final nominal specimen dimensions are 150 mm high by 75 mm in diameter. The test temperature shall be 40 ± 1°C for mixtures made with non-modified binders having a high temperature grade of PG 64 or less, and 50 ± 1°C for mixtures made with binders having a high temperature grade above PG 64. The wheel load shall be 705 ± 2 N. Perform the Hamburg wheel tracking test under wet conditions and report the average of the results for the two specimens tested, as wheel passes to a 12-mm rut depth. The recommended minimum values as a function of design traffic level are shown in Table 7 (Note 15). If the number of passes does not meet the required value, the mix must be modified to improve rut resistance, while meeting all other applicable requirements as given in this standard (Note 16).

Table 7—Recommended Minimum Passes to a 12-mm Rut Depth for Hamburg Wheel Tracking Test

High Temperature Binder Grade	Minimum Passes to 12-mm Rut Depth
PG 64 or lower	10,000
PG 70	15,000
PG 76 or higher	20,000

15.2.7. For rut resistance testing using the SST/RSCH test, follow procedures given in AASHTO T 320 for the repeated shear at constant height test (Note 17). Prepare two specimens in accordance with AASHTO T 312, with a final air void content of 3.0 ± 0.5%. Prepare specimens as described in T 320. For mixtures designed for fast traffic (≥ 70 kph), the test temperature shall be the average, 7-day maximum pavement temperature 20 mm from the surface, at 50% reliability as determined using LTPPBind version 3.1. For slow traffic (25 to < 70 kph), the test temperature shall be 6°C higher than the test temperature for fast traffic; for very slow traffic (< 25 kph), the test temperature shall be 12°C higher. Perform the SST/RSCH test and report the average of the results for the two specimens tested. The recommended maximum values for permanent shear strain (MPSS) as a function of design traffic level are shown in Table 8 (Note 15). If the required MPSS value is exceeded, the mix must be modified to improve rut resistance, while meeting all other applicable requirements as given in this standard (Note 16).

Table 8—Recommended Maximum Values for MPSS Determined Using the SST/RSCH Test

Traffic Level *Million ESALs*	**Maximum Value for MPSS** *%*
< 3	---
3 to < 10	3.2
10 to < 30	2.2
≥ 30	1.4

Note 17—Due to the cost and complexity of the SST, the SST/RSCH test procedure is not recommended for routine use by most pavements and materials testing laboratories. The procedure has been included in this standard so that research laboratories that have the SST and have significant experience with it can use it as an acceptable method for evaluating rut resistance in the design of HMA mixtures.

15.2.8. For rut resistance testing using the HT/IDT test, perform an indirect tension test according to AASHTO T 283 for unconditioned (dry) laboratory-prepared, laboratory compacted specimens, but with the following exceptions. The specimen size shall be 100 ± 10 mm high, and 150-mm in diameter. For mixtures designed for fast traffic (≥ 70 kph), the test temperature (the conditioning temperature immediately prior to testing) shall be 10°C lower than the average, 7-day maximum pavement temperature 20 mm from the surface, at 50% reliability as determined using LTPPBind version 3.1. In all cases, the test conditioning temperature shall be controlled to within 0.5°C of that specified. For slow traffic (25 to < 70 kph), the test temperature shall be 6°C higher than the test temperature for fast traffic; for very slow traffic (< 25 kph), the test temperature shall be 12°C higher. Perform the HT/IDT test and report the average of the results for the two specimens tested. The recommended minimum indirect tensile strengths as a function of design traffic level are shown in Table 9 (Note 15). If the required strength is not met, the mix must be modified to improve rut resistance, while meeting all other applicable requirements as given in this standard (Note 16).

Table 9—Recommended Minimum High-Temperature Indirect Tensile Strength Requirements.

Traffic Level *Million ESALs*	**Minimum HT/IDT Strength** *kPa*
< 3	---
3 to < 10	200
10 to < 30	340
≥ 30	460

16. COMPILE MIX DESIGN REPORT

16.1. Compile a report on the final mix design, summarizing all pertinent project information, information on the composition of the mix design, and all pertinent data on specification tests on the mixture.

Appendix A: Recommended Procedure for Characterizing Reclaimed Asphalt Pavement Stockpiles

A1. Sampling

A1.1. Obtain representative samples from between 5 to 10 locations within the RAP stockpile in accordance with AASHTO T 2.

Note A1—The size of each sample should be large enough to determine the properties of the RAP stockpile as described in this Appendix and to have sufficient material for subsequent mixture design and analysis work. A 5 to 7 kg sample at each location is recommended for determining RAP stockpile properties. An additional 10 kg sample per mixture design is recommended at each location to provide sufficient RAP materials for mixture design and analysis.

A1.2. From each sample location split a 5 to 7 kg sample in accordance with AASHTO T 248 for determining the properties of the RAP stockpile. Combine the remainder of the sample from each location for use in mixture design and analysis.

Note A2—If AASHTO T 308 will be used for determining asphalt content and a reasonable estimate of the correction factor for the aggregate is not known, split approximately 7 kg samples for 5 of the 10 samples to develop corrections factors by determining asphalt contents using both AASHTO T 164 and AASHTO T 308.

A1.3. From each 5 to 7 kg sample split an appropriate size sample in accordance with AASHTO T 248 for determining asphalt content and gradation in accordance with AASHTO T 308 or AASHTO T 164. The sample size will depend on the nominal maximum aggregate size of the RAP.

Note A3—If correction factors will be determined using AASHTO T 164, split two samples (one for AASHTO T 308 and one for AASHTO T 164) from 5 of the 10 samples.

A1.4. Combine the remainder of the stockpile property sample from each location. Then split the following representative samples in accordance with AASHTO T 248, as listed in Table A1:

Table A1—Sample Sizes for RAP Testing

Purpose	Approximate Size
RAP Binder Properties	2.5 kg
RAP Aggregate Properties	5.0 kg
RAP Aggregate Specific Gravity Using Effective Specific Gravity	0.5 to 4 kg depending on the maximum particle size

A2. Binder Content and Gradation

A2.1. Determine the binder content of the RAP at each sampling location in accordance with AASHTO T 308 or AASHTO T 164.

Note A4—If reasonable estimates of the ignition oven correction factor can be made, use AASHTO T 308. If the correction factors for local aggregate are highly variable use AASHTO T 164 or determine correction factors by testing 5 of the 10 samples using both AASHTO T 164 and AASHTO T 308.

A2.2. Determine the gradation of the RAP aggregate in accordance with AASHTO T 30.

A2.3. Determine the average and standard deviation of the binder content and percent passing each sieve size.

A2.4. Estimate the maximum RAP content that can be used based on variability from Figures A1 through A4 (Note A5).

Note A5—Other statistically based methods of variability analysis may be used to estimate the amount of RAP that can be used in an HMA mix design without causing an unacceptable increase in production variability. The general approach in any method used should be to maintain final variability in aggregate gradation and binder content significantly below maximum variability in HMA production as recommended by AASHTO, ASTM, or the agency.

A2.4.1. For mix designs using a single RAP stockpile or blends of stockpiles in which one of the RAP stockpiles makes up more than 70% of the RAP blend, determine the maximum amount of RAP that can be used based on aggregate gradation variability from Figure A1, by entering the chart on the horizontal axis with the standard deviation for percent passing for a given sieve size and reading the maximum RAP content on the vertical axis; repeat for each sieve size in the gradation. Also determine the maximum amount of RAP that can be used based on binder content variability from Figure A2, by entering the chart with standard deviation for binder content and reading the maximum RAP content on the vertical axis. The final maximum RAP content that can be used in the mix design based on RAP variability is the lowest maximum RAP content among the values determined for all sieve sizes and the binder content, but in no case shall exceed 50% (Note A6).

Note A6—Figures A1 through A4 are based on standard deviations calculated for N=5 RAP samples taken from widely separated locations within the RAP stockpile. These figures are not valid for sample sizes below N = 5. Using standard deviations calculated from a sample size greater than N = 5 is not recommended for these charts. However, other methods of estimating maximum RAP contents for HMA mix designs based on variability will often provide more accurate results and, in general, higher RAP contents when larger samples sizes are used.

A2.4.2. For mix designs using a blend of RAP stockpiles in which none of the RAP stockpiles makes up more than 70% of the RAP blend, determine the maximum amount of RAP that can be used based on aggregate gradation variability from Figure A3, by entering the chart on the horizontal axis with the standard deviation for percent passing for a given sieve size and reading the maximum RAP content on the vertical axis; repeat for each sieve size in each of the RAP aggregate gradations. Also determine the maximum amount of RAP that can be used based on binder content variability from Figure A2, by entering the chart with standard deviation for binder content and reading the maximum RAP content on the vertical axis for each of the RAP stockpiles in the blend. The final maximum RAP content that can be used in the mix design based on RAP variability is the lowest maximum RAP content among the values determined for all sieve sizes for all RAP stockpiles and for binder contents for all RAP stockpiles in the blend, but in no case shall exceed 50% (Note A6).

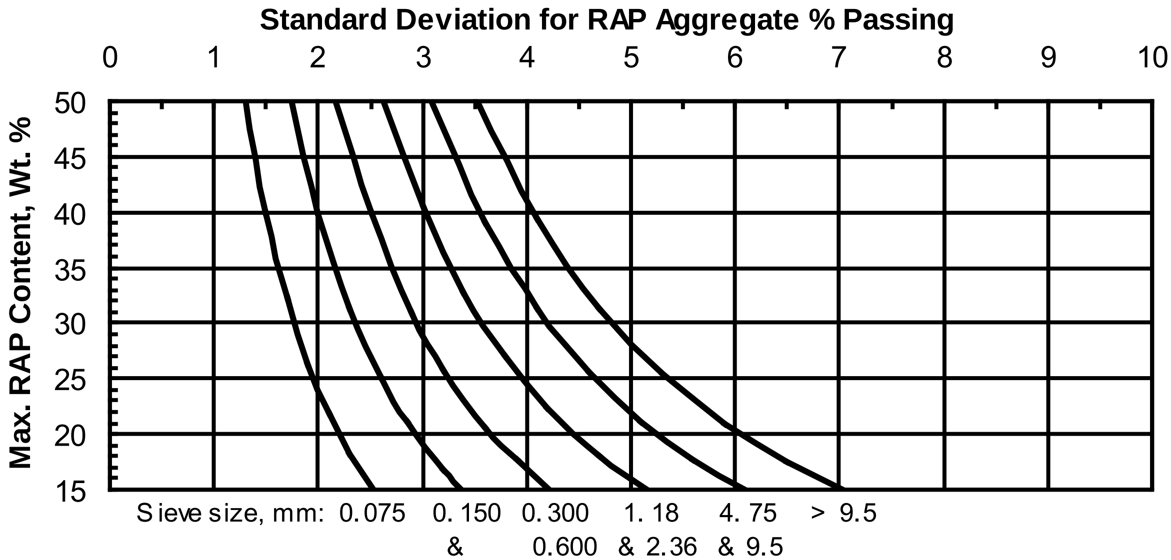


Figure A1—Maximum RAP Content as a Function of Standard Deviation for Aggregate % Passing, for n = 5 Samples from a Single RAP Stockpile

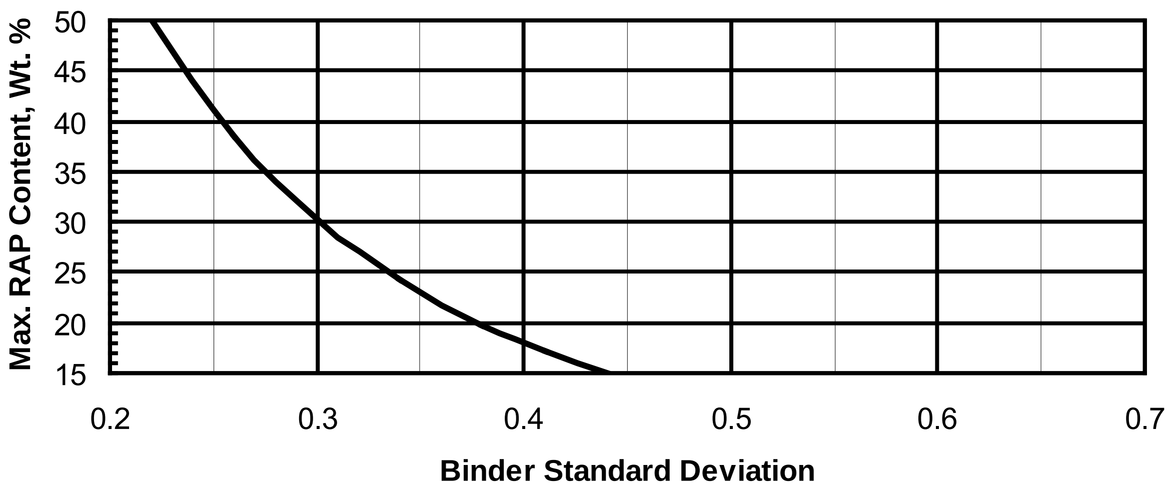


Figure A2—Maximum RAP Content as a Function of Standard Deviation for Asphalt Binder Content, for n = 5 Samples from a Single RAP Stockpile

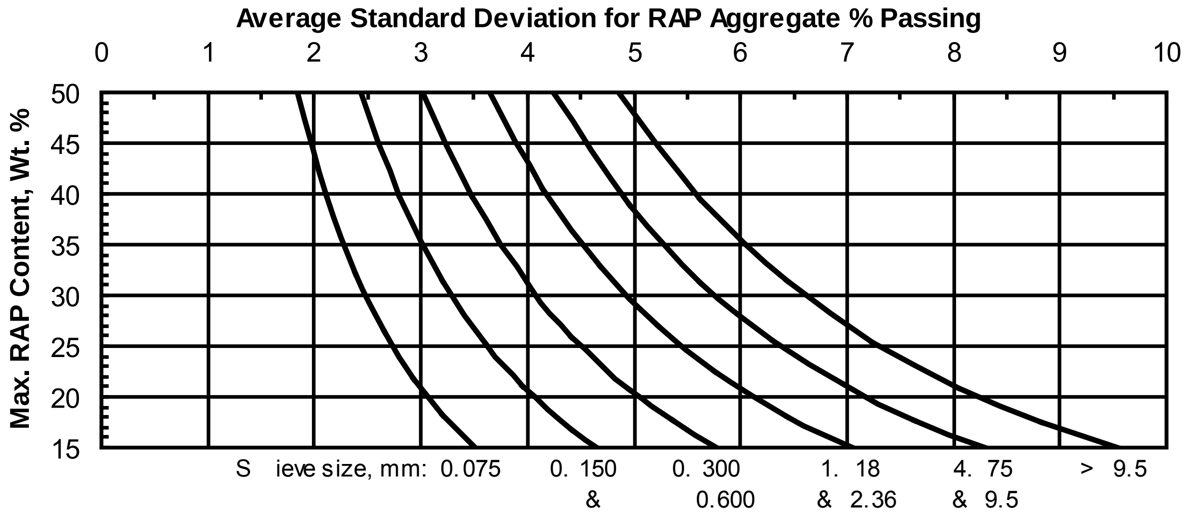


Figure A3—Maximum RAP Content as a Function of Average Standard Deviation for Aggregate % Passing, for n = 5 Samples from a Blend of RAP Stockpiles, and No Stockpile Making up More than 70% of the RAP Blend

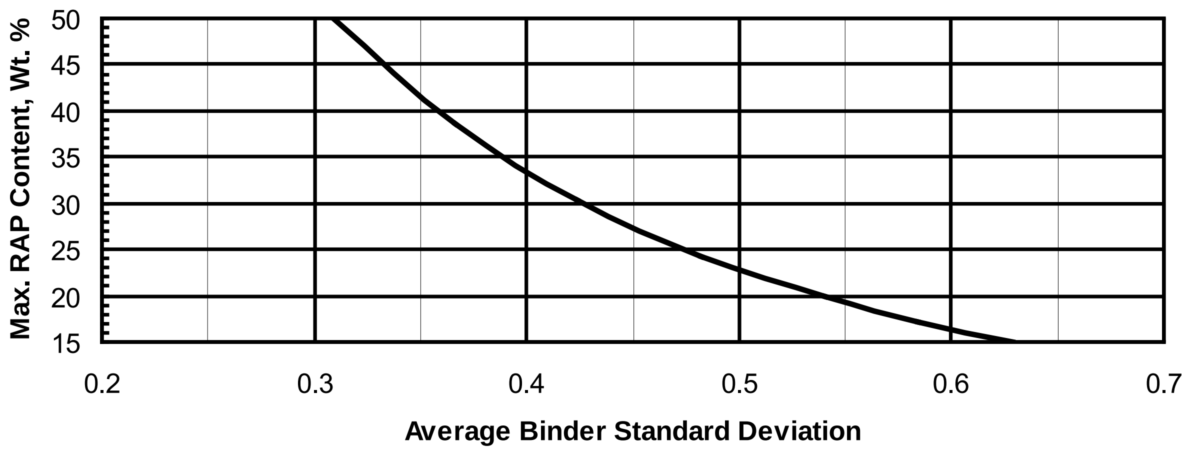


Figure A4—Maximum RAP Content as a Function of Average Standard Deviation for Asphalt Binder Content, for n = 5 Samples from a blend of RAP Stockpiles, and No Stockpile Making up More than 70% of the RAP Blend

A3. RAP Aggregate Properties

A3.1. Remove the binder from the 5 kg combined sample of RAP in accordance with AASHTO T 308 to obtain a sample of the RAP aggregate for testing.

A3.2. Split the RAP aggregate sample on the 4.75 mm sieve.

A3.3. Determine the bulk specific gravity of the coarse fraction of the RAP aggregate in accordance with AASHTO T 85.

A3.4. Determine the bulk specific gravity of the fine fraction of the RAP aggregate in accordance with AASHTO T 84.

Note A7—The bulk specific gravity of the RAP aggregate may be determined without removing the RAP binder if a reasonable estimate of the binder absorption is known. See Section A3.8 for details of this optional procedure.

A3.5. Determine the angularity of the coarse fraction of the RAP aggregate in accordance with ASTM D 5821.

A3.6. Determine the amount of flat and elongated particles in the coarse fraction of the RAP aggregate in accordance with ASTM D 4791.

A3.7. Determine the angularity of the fine fraction of the RAP aggregate in accordance with AASHTO T 304.

A3.8. Alternative Method for Determining Bulk Specific Gravity of RAP Aggregate

Note A8—A reasonable estimate of the binder absorption for the RAP aggregate must be known to apply this procedure. The accuracy of this approach depends on the accuracy of the estimated binder absorption.

A3.8.1. Determine the maximum specific gravity of the RAP in accordance with AASHTO T 209.

A3.8.2. Compute the effective specific gravity of the RAP aggregate using Equation A1.

$$G_{se} = \frac{100 - P_b}{\frac{100}{G_{mm}} - \frac{P_b}{G_b}} \tag{A1}$$

where:

G_{se} = effective specific gravity of the RAP aggregate

P_b	=	binder content of the RAP (See Section A2)
G_{mm}	=	maximum specific gravity of the RAP
G_b	=	specific gravity of the RAP binder (assumed)

A3.8.3. Compute the bulk specific gravity of the combined RAP aggregate using Equation A2.

$$G_{sb} = \frac{G_{se}}{\left[\left(\frac{P_{ba} G_{se}}{100 \times G_b}\right) + 1\right]} \qquad \text{(A2)}$$

where:

G_{sb}	=	bulk specific gravity of the combined RAP aggregate
G_{se}	=	effective specific gravity of the RAP aggregate (Equation A1)
P_{ba}	=	percent absorbed binder (assumed)
G_b	=	specific gravity of the RAP binder (assumed)

A4. RAP Binder Properties

A4.1. Extract and recover approximately 100 g of RAP binder in accordance with AASHTO T 164 and ASTM D 5404.

A4.2. Determine G*/sinδ for the recovered binder in accordance with AASHTO T 315 at two temperatures; one resulting in G*/sinδ greater than 1.00 kPa, and one resulting in G*/sinδ less than 1.00 kPa.

A4.3. Compute the As Recovered true high temperature grade to the nearest 0.1 degree using Equation A3.

$$T_{as\ recovered} = T_1 + \left[\frac{\log(G_1) \times (T_2 - T_1)}{\log(G_1) - \log(G_2)}\right] \qquad \text{(A3)}$$

where:

$T_{as\ recovered}$	=	temperature where G*/sinδ equals 1.00 kPa for the as recovered RAP binder
T_1	=	test temperature where G*/sinδ is closest to but above 1.00 kPa
G_1	=	G*/sinδ for temperature T_1, kPa
T_2	=	test temperature where G*/sinδ is closest to but below 1.00 kPa
G_2	=	G*/sinδ for temperature T_2, kPa

A4.4. Condition the remaining binder in accordance with AASHTO T 240.

A4.5. Determine G*/sinδ for the RRTFOT conditioned binder in accordance with AASHTO T 315 at two temperatures; one resulting in G*/sinδ greater than 2.20 kPa, and one resulting in G*/sinδ less than 2.20 kPa.

A4.6. Compute the RRTFOT true high temperature grade to the nearest 0.1 degree using Equation A4.

$$T_{RTFOT} = T_1 + \left[\frac{\left(\log(G_1) - 0.3424\right) \times (T_2 - T_1)}{\log(G_1) - \log(G_2)} \right] \quad \text{(A4)}$$

where:

T_{RRTFOT} = temperature where G*/sinδ equals 2.20 kPa for the RRTFOT conditioned RAP binder
T_1 = test temperature where G*/sinδ is closest to but above 2.20 kPa
G_1 = G*/sinδ for temperature T_1, kPa
T_2 = test temperature where G*/sinδ is closest to but below 2.20 kPa
G_2 = G*/sinδ for temperature T_2, kPa

A4.7. Determine G*×sinδ for the PAV conditioned binder in accordance with AASHTO T 315 at two temperatures; one resulting in G*×sinδ greater than 5,000 kPa, and one resulting in G*×sinδ less than 5,000 kPa.

A4.8. Compute the true intermediate temperature grade to the nearest 0.1 degree using Equation A5.

$$T_{intermediate} = T_1 + \left[\frac{(\log(G_1) - 3.6990) \times (T_2 - T_1)}{\log(G_1) - \log(G_2)} \right] \quad \text{(A5)}$$

where:

$T_{intermediate}$ = temperature where G*×sinδ equals 5,000 kPa for the PAV conditioned RAP binder
T_1 = test temperature where G*×sinδ is closest to but above 5,000 kPa
G_1 = G*×sinδ for temperature T_1, kPa
T_2 = test temperature where G*×sinδ is closest to but below 5,000 kPa
G_2 = G*×sinδ for temperature T_2, kPa

A4.9. Determine the low temperature creep stiffness, S, and m-value for the PAV conditioned binder in accordance with AASHTO T 313 at two temperatures; one resulting in S greater than 300 MPa, and one resulting in S less than 300 MPa.

A4.10. Compute the true low temperature grade for S to the nearest 0.1 degree using Equation A6.

$$T_S = T_1 + \left[\frac{\left(\log(S_1) - 2.4771\right) \times (T_2 - T_1)}{\log(S_1) - \log(S_2)} \right] \tag{A6}$$

where:

T_S	=	temperature where S equals 300 MPa for the PAV conditioned RAP binder
T_1	=	test temperature where S is closest to but above 300 MPa
S_1	=	S for temperature T_1, MPa
T_2	=	test temperature where S is closest to but below 300 kPa
S_2	=	S for temperature T_2, MPa

A4.11. Compute the true low temperature grade for the m-value to the nearest 0.1 degree using Equation A7.

$$T_m = T_1 + \left[\frac{\left(0.300 - m_1\right) \times (T_2 - T_1)}{(m_2 - m_1)} \right] \tag{A7}$$

where:

T_m	=	temperature where the m-value equals 0.300 kPa for the PAV conditioned RAP binder
T_1	=	test temperature for the lower m-value.
m_1	=	m-value for temperature T_1
T_2	=	test temperature for the higher m-value.
m_2	=	m-value for temperature T_2

A4.12. The critical high temperature grade for blending chart analyses is the lower of the two for the as recovered (Section A4.3) and the RRTFOT condition (Section A4.6).

A4.13. The critical low temperature grade for blending chart analyses is the higher of the two for the creep stiffness (Section A4.11) and the m-value (A4.12).

A4.14. The critical intermediate grade for blending chart analyses is the true intermediate temperature grade determined in Section A4.9.

APPENDIX F: TUTORIAL

TUTORIAL

This self-study document is meant to familiarize technicians and engineers with the most important parts of the Manual and with the HMA Tools spreadsheet. The first part of this tutorial covers Chapters 3, 4, and 5 of the manual, which cover asphalt binders, aggregates, and volumetric composition, respectively. For each chapter, you should read the chapter and then answer the questions presented in the tutorial. You should then correct your work using the answers given on the following page in the tutorial. For any incorrect answers, you should go back to the manual and review the section that covers the topic the question dealt with, and make sure you understand the correct answer to the question.

The largest part of the tutorial is an example mix design, which involves information covered in Chapter 8 of the manual on the design of dense-graded HMA mixtures. Because the example mix design includes reclaimed asphalt pavement (RAP), it also involves much of the information covered in Chapter 9. The example is done in a step-by-step fashion, giving the reader instructions for each part of the mix design and then presenting the solution on the following page. The mix design has been done using the HMA Tools spreadsheet, so readers will find it easier to follow if they use HMA Tools when working through the mix design.

As discussed on the last page of the tutorial, there are four technical chapters not covered in the tutorial:

Chapter 7. Selection of Asphalt Concrete Mix Type
Chapter 10. Design of Gap-Graded HMA Mixtures
Chapter 11. Design of Open-Graded Mixtures
Chapter 12. Field Adjustments and Quality Assurance of HMA Mixtures

Many technicians and engineers will not have need of the information in these chapters on a regular basis. Others, however will find that they do need the information in one or more of these chapters, in which case they should be carefully read.

The amount of time required to work through this tutorial will vary from person to person, depending on their level of experience and how carefully they work. Experienced technicians and engineers working quickly might be able to complete this tutorial in a few hours. Technicians and engineers new to the HMA industry working more slowly might require an entire day to complete the work.

Chapter 3. Asphalt Binders

After studying Chapter 3 of the manual, answer the questions below.

1. The stiffness of most asphalt binders changes very little with temperature (true / false).

2. What are the upper and lower pavement temperatures for a PG 64-22 binder?

3. What are the two common methods for laboratory aging of asphalt binders?

4. What three specification tests are performed on asphalt binders using the dynamic shear rheometer?

5. What are the two tests used to control low temperature properties of asphalt binders?

6. The following properties were measured for an asphalt binder. Does this material meet all the requirements for a PG 76-16 binder?

Test	Temperature, °C	Result
Tests on original binder		
Flash Point	---	327°C
Viscosity	135	4.7 Pa-s
Dynamic shear rheometer, G*/sin δ at 10 rad/s	76	1.07 kPa
Tests on residue from thin-film oven test		
Mass loss	---	0.6%
Dynamic shear rheometer, G*/sin δ at 10 rad/s	76	2.05 kPa
Tests on residue from pressure aging vessel		
Dynamic shear rheometer, G* sin δ at 10 rad/s	34	5,617 kPa
Bending beam rheometer, stiffness at 60 s	-6	238 MPa
Bending beam rheometer, m-value at 60 s	-6	0.287

Chapter 3. Asphalt Binders

Solutions

1. The stiffness of most asphalt binders changes very little with temperature (true / false).

   False (see pages 3-1 and 3-2).

2. What are the upper and lower pavement temperatures for a PG 64-22 binder?

   Upper pavement temperature 64 °C, lower pavement temperature -22 °C (see pages 3-4 and 3-5).

3. What are the two methods normally used for laboratory aging of asphalt binders?

   The rolling thin-film oven test, or RTFOT, and the pressure aging vessel, or PAV (see pages 3-7 and 3-8).

4. What three specification tests are performed on asphalt binders using the dynamic shear rheometer?

   The high-temperature test on original binder, high-temperature test on RTFOT residue, and intermediate-temperature test on PAV residue (see pages 3-8 through 3-10).

5. What are the two tests used to control low temperature properties of asphalt binders?

   The bending beam rheometer or the direct tension test (see pages 3-10 through 3-12).

6. The following properties were measured for an asphalt binder. Does this material meet all the requirements for a PG 76-16 binder?

   The viscosity at 135 °C is too high. The value for $G^*/\sin\delta$ at 76 °C on the rolling thin-film oven test residue is too low. The value of $G^* \sin\delta$ at 34 °C on the pressure aging vessel residue is too high. The m-value measured with the bending beam rheometer at -6 °C is too low.

   See Table 3-1 on pages 3-13 through 3-15.

Chapter 4. Aggregates

After studying Chapter 4 of the manual, answer the questions below.

1. What are the definitions of coarse aggregate, fine aggregate, and mineral filler?

2. For a 12.5 mm nominal maximum aggregate size, what is the minimum sample size for a sieve analysis?

3. For the data below on a sieve analysis of a fine aggregate, calculate % retained, cumulative % retained and % passing for each sieve size and complete the table. Also, calculate the error for the sieve analysis.

(1) Sieve Size, mm	**(2)** Weight Retained, g	**(3)** % Retained, Wt.%	**(4)** Cumulative % Retained, Wt.%	**(5)** % Passing, Wt.%
19.0	0.0			
12.5	0.0			
9.5	85.4			
4.75	195.6			
2.36	207.5			
1.18	238.0			
0.60	202.7			
0.30	153.4			
0.15	85.9			
0.075	55.6			
pan	47.2			
Total:				
Original Sample Size:	1276.3			
Error, Wt.%:				

4. What are typical specific gravity values for the following aggregates: diabase, limestone, sandstone, basalt? What is the typical specific gravity of asphalt cement binder?

5. The following test data was gathered during a specific gravity determination on a coarse aggregate sample:

    Dry weight of aggregate in air: 2,307.7 g
    Weight of saturated, surface-dry aggregate in air: 2,315.2 g
    Weight of aggregate in water: 1,432.6 g

    What is the bulk specific gravity of this aggregate?

6. What are the standard specification properties (previously called "Superpave consensus properties") for coarse and fine aggregate?

7. For an HMA mixture designed for a traffic level of 23 million ESALs, what are the required values for the various aggregate specification properties?

Chapter 4. Aggregates

Solutions

1. What are the definitions of coarse aggregate, fine aggregate, and mineral filler?

   Coarse aggregate is that which is retained on the 2.36 mm sieve, while fine aggregate is that which passes the 2.36 mm sieve. Mineral filler passes the 0.075-mm sieve (see page 4-1).

2. For a 12.5 mm nominal maximum aggregate size, what is the minimum sample size for a sieve analysis?

   2 kg (see Table 4-1 on page 4-4).

3. For the data below on a sieve analysis of a fine aggregate, calculate % retained, cumulative % retained and % passing for each sieve size and complete the table. Also, calculate the error for the sieve analysis.

   The completed table is given below (see pages 4-5 through 4-7).

(1) Sieve Size, mm	(2) Weight Retained, g	(3) % Retained, Wt.%	(4) Cumulative % Retained, Wt.%	(5) % Passing, Wt.%
19.0	0.0	0.0	0.0	100.0
12.5	0.0	0.0	0.0	100.0
9.5	85.4	6.7	6.7	93.3
4.75	195.6	15.3	22.0	78.0
2.36	207.5	16.3	38.3	61.7
1.18	238.0	18.6	56.9	43.1
0.60	202.7	15.9	72.8	27.2
0.30	153.4	12.0	84.8	15.2
0.15	85.9	6.7	91.6	8.4
0.075	55.6	4.4	95.9	4.1
pan	47.2	3.7	99.6	0.4
Total:	1271.3	99.6		
Original Sample Size:	1276.3			
Error, Wt.%:	0.39			

4. What are typical specific gravity values for the following aggregates: diabase, limestone, sandstone, basalt? What is the typical specific gravity of asphalt cement binder?

   Diabase: 2.96; limestone, 2.66; sandstone, 2.54; basalt, 2.86. The typical specific gravity of asphalt cement binder is 1.03 (see Table 4-5 on page 4-13).

5. The following test data was gathered during a specific gravity determination on a coarse aggregate sample:

   Dry weight of aggregate in air: 2,307.7 g
   Weight of saturated, surface-dry aggregate in air: 2,315.2 g
   Weight of aggregate in water: 1,432.6 g

   What is the bulk specific gravity of this aggregate?

   Bulk specific gravity = A / (B – C) = 2,307.7/(2,315.2 – 1,432.6) = 2.615

   See pages 4-13 and 4-14.

6. What are the standard specification properties (previously called "Superpave consensus properties") for coarse and fine aggregate?

   For coarse aggregate: fractured faces and flat and elongated particles. For fine aggregate: fine aggregate angularity (uncompacted voids) and clay content/sand equivalent (see pages 4-18 through 4-27).

7. For an HMA surface course mixture (to be placed entirely within 100 mm of the pavement surface), designed for a traffic level of 23 million ESALs, what are the required values for the various aggregate specification properties?

Coarse aggregate fractured faces:	*95% minimum with at least one fractured face, 90% minimum with at least two fractured faces*
Flat and elongated particles:	*10% maximum*
Fine aggregate angularity:	*45% minimum uncompacted voids*
Clay content:	*45% minimum sand equivalent value*

   See pages 4-18 through 4-27.

Chapter 5. Mixture Volumetric Composition

After studying Chapter 5 of the manual, answer the questions below.

1. If a core from a pavement has a density of 94.2%, what the air void content of the core?

2. An HMA mixture has a total asphalt content of 6.0% by total mix weight, and the aggregate absorbs 0.5% of the asphalt binder. What is the effective asphalt content of this mixture?

3. An HMA mixture contains 3.5% air voids, and has an effective asphalt content of 11.3% by volume. What is the VMA for this mixture?

4. The theoretical maximum specific gravity of an HMA mixture is being determined in a laboratory. The data for the test are given below.

   Mass of oven-dry mixture in air: 1,205.2 g
   Mass of container filled with water at 25°C: 2,307.4 g
   Mass of container with mixture filled with water at 25°C: 3,025.7 g

   What is the theoretical maximum specific gravity for this mixture?

5. A compacted HMA specimen has a bulk specific gravity of 2.372. The theoretical maximum specific gravity for this mixture is 2.448. What is the air void content of this specimen?

Chapter 5. Mixture Volumetric Composition

Solutions

1. If a core from a pavement has a density of 94.2%, what the air void content of the core?

   The air void content would be 100 – 94.2 = 5.8% (see page 5-5).

2. An HMA mixture has a total asphalt content of 6.0% by total mix weight, and the aggregate absorbs 0.5% of the asphalt. What is the effective asphalt content of this mixture?

   The effective asphalt content is 6.0 - 0.5 = 5.5% by total mix weight (see page 5-7 or Equation 5-8 on page 5-22).

3. An HMA mixture contains 3.5% air voids, and has an effective asphalt content of 11.3% by volume. What is the VMA for this mixture?

   The VMA would be 11.3 + 3.5 = 14.8% by volume (see page 5-8 /or Equation 5-11 on page 5-22).

4. The theoretical maximum specific gravity of an HMA mixture is being determined in a laboratory. The data for the test are given below.

   Mass of oven-dry mixture in air: 1,205.2 g
   Mass of container filled with water at 25°C: 2,307.4 g
   Maxx of container with mixture filled with water at 25°C: 3,025.7 g

   What is the theoretical maximum specific gravity for this mixture?

   $G_{mm} = A / (A + D – E) = 1{,}205.2 / (1{,}205.2 + 2{,}307.4 – 3{,}025.7) = 2.475$

   See pages 5-15 through 5-17 and Equation 5-2.

5. A compacted HMA specimen has a bulk specific gravity of 2.372. The theoretical maximum specific gravity for this mixture is 2.448. What is the air void content of this specimen?

   $VA = 100 [1 – (G_{mb}/G_{mm})] = 100 [1 – (2.372/2.448)] = 3.10\%$

   See Equation 5-4 on page 5-20.

Chapters 8 and 9: Dense-Graded HMA Mix Design Example

Please read through Chapters 8 and 9 of the Mix Design Manual and then work through this example mix design, which will take you through most of the steps of a typical HMA mix design. You should work through the problem using the HMA Tools *spreadsheet, if possible. If you want to use another spreadsheet or computer program, it should obtain the same results, but it will be much easier to follow through the example and the solution if you use* HMA Tools.

Enter General Information for the Mix Design

Listed below is general information for the mix design example. Enter this information in HMA Tools on worksheet “General.”

Project:	“Tutorial”
To be placed within 100 mm of surface:	yes
Dust/binder ratio:	standard
Specified binder grade:	PG 64-22 (25°C intermediate grade)
Design traffic level:	800,000 ESALs
Nominal maximum aggregate size, mm:	12.5

Turn to the next page to see what the worksheet “General” should now look like.

GENERAL INFORMATION

Date (mm/dd/yyyy):	1/19/2009	
Project:	Tutorial	
Tech./Engr.:	J. Doe	
NMAS (size in mm):	12.5	
To be placed within 100 mm of surface (yes/no):	Yes	
Traffic Level (million ESALs):	0.8	
Dust/Binder ratio (standard/low):	standard	
Specified Binder PG Grade, PG-	64-22	
Specified High Temperature PG Grade:	64	
Specified Low Temperature PG Grade:	-22	
Specified Intermediate Temperature PG Grade:	25	
Compactor Manufacturer and Model:	Pine	
Compactor Angle Calibration Method:		
PG 76-22 Binder or Higher (yes/no)	no	
Ndesign	75	
Minimum VMA:	14.0	
Maximum VMA:	16.0	
Midpoint VMA/Suggested Target VMA:	15.0	
Select Target VMA:		
Select Target Air Voids (4.0 % suggested, +/- 0.5 %):		
Minimum Dust/Binder Ratio:	0.8	
Maximum Dust/Binder Ratio:	1.6	
Maximum Allowable RAP Content		
CA Fractured Faces, One Fractured Face, Min. %	75	
CA Frctured Faces, Two Fractured Faces, Min. %	0	**Retained on**
CA Flat & Elongated, 5:1 Ratio, Max. %	10	**Sieve, mm**
	#N/A	
	#N/A	
FA Angularity, Uncompacted Voids, Min. %	40	**Passing**
Sand Equivalent, Min. %	40	**Sieve, mm**
	#N/A	
	#N/A	

Notice that the values for N_{design}, VMA, dust/binder ratio, and aggregate specification properties are automatically calculated and displayed on the worksheet.

Select Target VMA and Air Voids

For most HMA mix designs, the target VMA should be approximately halfway between the minimum and maximum values—in this example, 15.0%. The target air void content should normally be 4.0%. Fill out cells C23 and C24 with these values. The green cells appearing with the aggregate specification properties are for adding user-defined aggregate specification properties. In this example, we won't use any additional aggregate specification properties. We will fill out the maximum allowable RAP value later in the mix design.

Enter Aggregate Gradation, Specific Gravity and Specification Propery Values

The table below lists aggregate gradation data, specific gravity values and specification property data for four aggregates that will be used in this example mix design. Use this information to complete the “Aggregates” worksheet in HMA Tools.

	Percent passing for aggregate:			
Sieve Size, mm	**Coarse 1**	**Coarse 2**	**Coarse 3**	**Mfg. Fines**
37.5	100.0	100.0	100.0	100.0
25.0	100.0	100.0	100.0	100.0
19.0	100.0	100.0	100.0	100.0
12.5	99.7	100.0	100.0	100.0
9.5	49.6	65.8	100.0	100.0
4.75	1.3	2.6	56.0	99.1
2.36	0.7	1.3	2.6	75.6
1.18	0.7	1.3	1.6	50.2
0.60	0.7	1.3	1.6	34.1
0.30	0.7	1.3	1.6	24.0
0.15	0.7	1.3	1.6	16.1
0.075	0.7	1.3	1.6	10.0
Specific Gravity Values				
Bulk Gs	2.704	2.680	2.628	2.666
Apparent Gs	2.742	2.735	2.713	2.737
Aggregate Specification Property Data				
CAFF (1 face/ 2 faces)	100/99	100/98	100/99	
Flat & elongated, Wt.%	2.0	4.0	2.0	
FAA, Uncomp. voids,%				47.4
Clay content, sand equivalent,%				66.4

Turn to the next page to see what the completed worksheet “Aggregates” should now look like.

AGGREGATE PROPERTIES

Help Appears Below

Aggregate Name/Code	Coarse 1	Coarse 2	Coarse 3	Mfg. Fines
Bulk Spec. Grav.	2.704	2.680	2.628	2.666
Apparent Spec. Grav.	2.742	2.735	2.713	2.737
Water Absorption	0.51	0.75	1.19	0.97
CAFF, One Fractured Face, %	100.0	100.0	100.0	
CAFF, Two Fractured Faces, %	99.0	98.0	99.0	
Flat & Elong., %	2.0	4.0	2.0	
FAA, Uncompacted Voids				47.4
Sand Eq.				66.4
Size, mm	***Sieve Analysis, Weight % Passing***			
50.000	100.0	100.0	100.0	100.0
37.500	100.0	100.0	100.0	100.0
25.000	100.0	100.0	100.0	100.0
19.000	100.0	100.0	100.0	100.0
12.500	99.7	100.0	100.0	100.0
9.500	49.6	65.8	100.0	100.0
4.750	1.3	2.6	56.0	99.1
2.360	0.7	1.3	2.6	75.6
1.180	0.7	1.3	1.6	50.2
0.600	0.7	1.3	1.6	34.1
0.300	0.7	1.3	1.6	24.0
0.150	0.7	1.3	1.6	16.1
0.075	0.7	1.3	1.6	10.0

Make sure that the data on the percentage of one and two fractured faces are entered separately in the correct cells.

Calculate Average RAP properties and Maximum Allowable RAP Content Based on Variability.

Standards and specification for designing HMA mixtures containing RAP vary widely among different agencies. Technicians and engineers responsible for preparing HMA mix designs should follow the standards applicable in their state, or standards specified by the owner on privately funded projects. In the approach used in the *Manual* and HMA Tools, it is assumed no grade adjustments or variability analysis are needed if the RAP content is 15% or less. At RAP contents greater than 15%, a variability analysis must be performed, in which the maximum amount of RAP that can be added to the mix without exceeding normal production variability limits is calculated. This ensures that adding RAP to your mix will not cause your production variability to exceed specified limits. This analysis is separate from the asphalt binder performance grade analysis, which might result in a separate limit on RAP content for the mix design. The RAP binder analysis is covered later in this tutorial.

Listed below are gradation and asphalt content data for five RAP samples taken from different spots in the RAP stockpile. Use this data to fill out the worksheet "RAP_Variability," under stockpile 1 (HMA Tools can handle up to four different RAP stockpiles).

Sieve Size, mm	**% Passing for Sample:**				
	Sample 1	**Sample 2**	**Sample 3**	**Sample 4**	**Sample 5**
37.5	100.0	100.0	100.0	100.0	100.0
25.0	100.0	100.0	100.0	100.0	100.0
19.0	100.0	100.0	100.0	100.0	100.0
12.5	99.1	98.6	97.5	99.6	99.5
9.5	96.1	93.5	92.2	94.4	97.2
4.75	73.3	69.5	67.2	73.3	74.2
2.36	57.4	53.0	51.9	56.8	56.7
1.18	46.2	40.7	39.4	43.7	44.6
0.60	34.8	31.3	28.6	31.6	35.8
0.30	23.1	21.8	19.8	22.0	22.5
0.15	15.7	13.5	13.4	14.2	14.9
0.075	11.1	9.2	8.5	9.8	11.2
Asphalt Binder Content, Wt.%	3.8	3.3	3.2	3.4	3.7

Turn to the next page to see what the completed worksheet looks like.

RAP STATISTICS

ANALYSIS OF RAP VARIABILITY AND ESTIMATED MAXIMUM RAP CONTENT

Reliability Level: 80.0

ESTIMATED BLEND OF RAP STOCKPILES, WEIGHT %

RAP Stockpile 1	100
RAP Stockpile 2	
RAP Stockpile 3	
RAP Stockpile 4	

ESTIMATED MAXIMUM RAP CONTENT, WT.%: 31 *Enter in cell D28 on Worksheet General*

RAP STOCKPILE 1

			SAMPLE NUMBER:										
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Average	**Std. Dev.**	**Sieve Size, mm**											
100.0	**0.000**	**50.000**	100.0	100.0	100.0	100.0	100.0						
100.0	**0.000**	**37.500**	100.0	100.0	100.0	100.0	100.0						
100.0	**0.000**	**25.000**	100.0	100.0	100.0	100.0	100.0						
100.0	**0.000**	**19.000**	100.0	100.0	100.0	100.0	100.0						
98.9	**0.856**	**12.500**	99.1	98.6	97.5	99.6	99.5						
94.7	**1.999**	**9.500**	96.1	93.5	92.2	94.4	97.2						
71.5	**3.011**	**4.750**	73.3	69.5	67.2	73.3	74.2						
55.2	**2.519**	**2.360**	57.4	53.0	51.9	56.8	56.7						
42.9	**2.807**	**1.180**	46.2	40.7	39.4	43.7	44.6						
32.4	**2.899**	**0.600**	34.8	31.3	28.6	31.6	35.8						
21.8	**1.246**	**0.300**	23.1	21.8	19.8	22.0	22.5						
14.3	**0.971**	**0.150**	15.7	13.5	13.4	14.2	14.9						
10.0	**1.180**	**0.075**	11.1	9.2	8.5	9.8	11.2						
3.5	**0.259**	**Asphalt Binder Content**	3.8	3.3	3.2	3.4	3.7						

Again, data for up to four RAP stockpiles can be entered in this worksheet. Only the data for stockpile 1 is shown here. **The estimated maximum RAP content in this case is 31%; enter this value in worksheet "General" in cell D28.**

Enter RAP Aggregate Data

Enter the average RAP aggregate gradation calculated in the previous step (cells A19:A31 of worksheet "RAP_Variability") in worksheet "RAP_Aggregates" in cells C31:C43. Also, enter the average RAP asphalt binder content in cell C6 of "RAP_Aggregates." The data entered in worksheet "RAP_Aggregates" can be taken from the average calculated during the RAP variability analysis, or it can be data from other sources, such as an average value determined from plant QA records.

Enter a binder specific gravity value of 1.03 in cell C7 of worksheet "RAP_Aggregates." Also, immediately below this cell enter a theoretical maximum specific gravity value of 2.489 and an estimated binder absorption value of 0.50%. The binder absorption value for RAP stockpiles can be estimated from values for similar mix designs, or from records on the RAP mixture, if available. In this example, the aggregate specific gravity is estimated from the theoretical maximum specific gravity and estimated absorption. Another approach is to determine the bulk and apparent specific gravity of the fine and coarse RAP aggregate, as produced by solvent extraction or an ignition oven. This data would be entered in cells C11:C14. Either approach can be used in HMA Tools.

You will also need to enter data for consensus properties on this worksheet:

Coarse aggregate fractured faces (Wt.% with at least one fractured face): 99
Coarse aggregate fractured faces (Wt.% with at least two fractured faces): 94
Flat and elongated particles (Wt.%): 3.0
Fine aggregate angularity (uncompacted voids,%): 46.7

Turn to the next page to see what the completed "RAP_Aggregates" worksheet should look like.

RAP Aggregates

	RAP 1	RAP 2	RAP 3	RAP4
Description:	**RSP No. 18**			
Binder Content, Wt. %	3.48			
Binder Specific Gravity	1.030			
Maximum Theoretical Specifif Gravity	2.489			
Estimated Binder Absorption, Wt. %	0.50			
Measured Fine Aggregate Bulk Specific Gravity				
Measured Coarse Aggregate Bulk Specific Gravity				
Measured Fine Aggregate Apparent Specific Gravity				
Measured Coarse Aggregate Apparent Specific Gravity				
RAP Aggregate Average Bulk Specific Gravity	2.590	#N/A	#N/A	#N/A
RAP Aggregate Average Apparent Specific Gravity	2.624	#N/A	#N/A	#N/A
RAP Water Absorption	0.50	#N/A	#N/A	#N/A
CAFF, One Fractured Face, %	99.0			
CAFF, Two Fractured Faces, %	94.0			
Flat & Elong., %	3.0			
0				
0				
FAA, Uncompacted Voids	46.7			
Sand Eq.	#N/A	#N/A	#N/A	#N/A
0				
0				
Size, mm				
50.000	100.0			
37.500	100.0			
25.000	100.0			
19.000	100.0			
12.500	98.9			
9.500	94.7			
4.750	71.5			
2.360	55.2			
1.180	42.9			
0.600	32.4			
0.300	21.8			
0.150	14.3			
0.075	10.0			

Data for up to four different RAP aggregates can be entered in this worksheet. The data is carried over automatically to other parts of HMA Tools.

Enter Grading Data for New Binder

When more than 15% RAP is used in a mix design, you must enter grading data for one or more new asphalt binders (HMA Tools allows you to enter data for up to four different new binders and binders from up to four RAP stockpiles). With these data HMA Tools can calculate the performance grade of the blended binder—new binder plus binder from the RAP—to determine if it meets the given requirements. If you aren't using RAP in your design, or if you are using RAP but not more than 15% by total mix weight, you don't need to enter any binder grading data. In this example, we are using more than 15% RAP, so we must enter binder grading data. Enter the following data on binder grading in worksheet "Binders." The binder is a PG 64-22 supplied by Acme Materials, with a specific gravity of 1.024.

<table>
<tr><td colspan="3">High temperature grading on unaged binder, using dynamic shear rheometer</td></tr>
<tr><th>Temperature
°C</th><th colspan="2">G*/sin δ
kPa</th></tr>
<tr><td>64</td><td colspan="2">1.54</td></tr>
<tr><td>70</td><td colspan="2">0.76</td></tr>
<tr><td colspan="3">High temperature grading on residue from RTFOT oven, using dynamic shear rheometer</td></tr>
<tr><th>Temperature,
°C</th><th colspan="2">G*/sin δ
kPa</th></tr>
<tr><td>64</td><td colspan="2">3.46</td></tr>
<tr><td>70</td><td colspan="2">1.62</td></tr>
<tr><td colspan="3">Intermediate temperature grading on residue from pressure aging vessel, using dynamic shear rheometer</td></tr>
<tr><th>Temperature
°C</th><th colspan="2">G* sin δ
kPa</th></tr>
<tr><td>19</td><td colspan="2">6,183</td></tr>
<tr><td>22</td><td colspan="2">4,219</td></tr>
<tr><td>25</td><td colspan="2">2,845</td></tr>
<tr><td colspan="3">Low temperature grading on residue from pressure aging vessel, using bending beam rheometer</td></tr>
<tr><th>Temperature
°C</th><th>Stiffness
MPa</th><th>m-value</th></tr>
<tr><td>−12</td><td>144</td><td>0.395</td></tr>
<tr><td>−18</td><td>365</td><td>0.312</td></tr>
</table>

Turn to the next page to see what the completed worksheet looks like.

BINDERS

Grade: **PG 58-28**
Producer/Description: **Acme**

Specific Gravity 1.024

> *Note that HMA Tools calculates the binder grade based on the data entered. This is a PG 64-22 binder. Because some agencies have specific requirements on intermediate temperature grading, HMA Tools also gives the intermediate temperature grading, in parentheses between the high and low temperature grades—in this example, PG 64-(22)-22*

Unaged Binder

	Temp. *C*	|G*|/sin delta *kPa*
High Temperature Grading	64	1.54
	70	0.76

RTFOT Residue

	Temp. *C*	|G*|/sin delta *kPa*
High Temperature Grading	64	3.46
	70	1.62

Continuous High Temp. Grade, C: 67.6
High Temperature Grade: 64

PAV Residue

	Temp. *C*	|G*| x sin delta *kPa*
Intermediate Temperature Grading	19	6,183
	22	4,219
	25	2,845

Continuous Intermediate Temp. Grade, C: 20.7
Intermediate Temperature Grade: 22

	Temp. *C*	S *Mpa*	m-value
Low Temp. Grading, BBR	-12	144	0.395
	-18	365	0.312

Continuous Critical Temp./Stiffness, C:	-16.7	0.0
Continuous Critical Temp./m-value, C:	-19.0	0.0
BBR Continuous Low Temp. Grade, C:	-16.7	0.0

BBR Low Temperature Grade: -22

	Temp. *C*	Strain at Failure *%*
Low Temp. Grading, Direct Tension (optional):		

DT Continuous Critical Temp. C: #N/A

DT Low Temperature Grade: #N/A

Continuous Critical Temp., BBR and DT, C: -16.7
Low Temperature Grade, BBR and DT, C: -22
Low Temp. Grade from Intermediate Temp. Grade: -28

Final Low Temperature Grade: -22

Final Binder PG Grade: **PG 64-(22)-22**

Enter Grading Data for RAP Binder

Now, enter the data below on the grading of the recovered RAP binder in worksheet "RAP_Binders." Again, remember that you don't need this information if you are using less than 15% RAP in your mix design. The specific gravity of the binder is 1.03.

<table>
<tr><td colspan="3">High temperature grading on unaged binder, using dynamic shear rheometer</td></tr>
<tr><th>Temperature
°C</th><th colspan="2">G*/sin δ
kPa</th></tr>
<tr><td>76</td><td colspan="2">1.51</td></tr>
<tr><td>82</td><td colspan="2">0.78</td></tr>
<tr><td colspan="3">High temperature grading on residue from RTFOT oven, using dynamic shear rheometer</td></tr>
<tr><th>Temperature,
°C</th><th colspan="2">G*/sin δ
kPa</th></tr>
<tr><td>76</td><td colspan="2">3.24</td></tr>
<tr><td>82</td><td colspan="2">1.63</td></tr>
<tr><td colspan="3">Intermediate temperature grading on residue from pressure aging vessel, using dynamic shear rheometer</td></tr>
<tr><th>Temperature
°C</th><th colspan="2">G* sin δ
kPa</th></tr>
<tr><td>22</td><td colspan="2">5.087</td></tr>
<tr><td>25</td><td colspan="2">3,770</td></tr>
<tr><td>28</td><td colspan="2">2,813</td></tr>
<tr><td colspan="3">Low temperature grading on residue from pressure aging vessel, using bending beam rheometer</td></tr>
<tr><th>Temperature
°C</th><th>Stiffness
MPa</th><th>m-value</th></tr>
<tr><td>–6</td><td>78</td><td>0.321</td></tr>
<tr><td>–12</td><td>158</td><td>0.285</td></tr>
</table>

Turn to the next page to see what the completed worksheet "RAP_Binders" should look like.

RAP BINDERS

Rap Binder 1

Specific Gravity	1.030	

Unaged Binder

	Temp. *C*	|G*|/sin delta *kPa*
High Temperature Grading	76	1.51
	82	0.78

RTFOT Residue

	Temp. *C*	|G*|/sin delta *kPa*
High Temperature Grading	76	3.24
	82	1.63

Continuous High Temp. Grade, C:	79.4
High Temperature Grade:	76

	Temp. *C*	|G*| x sin delta *kPa*
Intermediate Temperature Grading	22	5,087
	25	3,770
	28	2,813

Continuous Intermediate Temp. Grade, C:	22.2
Intermediate Temperature Grade:	25

	Temp. *C*	S *Mpa*	m-value
Low Temp. Grading, BBR	-6	78	0.321
	-12	158	0.285

Continuous Critical Temp./Stiffness, C:	-17.5
Continuous Critical Temp./m-value, C:	-9.4
BBR Continuous Low Temp. Grade, C:	-9.4
BBR Low Temperature Grade:	-16

	Temp. *C*	Strain at Failure *%*
Low Temp. Grading, Direct Tension (optional):		

DT Continuous Critical Temp. C:	#N/A
DT Low Temperature Grade:	#N/A
Continuous Critical Temp., BBR and DT, C:	-9.4
Low Temperature Grade, BBR and DT, C:	-16
Low Temp. Grade from Intermediate Temp. Grade:	-34
Final Low Temperature Grade:	-16
Final Binder PG Grade:	**PG 76-(25)-16**

Develop Aggregate Blends for Three Trial Mixes

HMA Tools makes it easy to develop aggregate blends for trial mixes. Go to worksheet "Trial_Blends." Aggregate blends are developed by entering aggregate blend data—in percentage by weight—in cells F25:L36. Up to seven different blends can be entered. The plot in the upper left hand corner shows the control points for the given aggregate size and will plot any or all gradations. To show an aggregate blend on this plot, place an "X" in row 23 above the blend or blends that you want to plot. The plot in the upper right is a new type of plot, called a continuous maximum density gradation plot. In this plot, any part of a gradation that plots above the horizontal axis is fine graded, while parts of a gradation that plot below the horizontal axis are coarse graded. If part of gradation follows the horizontal axis very closely, it means that it is close to the maximum density gradation. The advantage of this plot is that it allows you to determine not just the gradation type of a complete aggregate blend, but also to evaluate how the gradation of a blend varies with particle size. It is useful when adjusting blends with the purpose of changing VMA. In general, the further away a gradation is from the horizontal axis, the greater the VMA will be.

Just as in the Superpave system, we will develop three aggregate blends, if possible a dense/fine gradation, and dense/dense gradation and a dense/coarse gradation. "Dense/fine" means that a gradation is for a dense-graded HMA mixture, but with a finely graded aggregate. Another way of thinking of this is that a dense/fine gradation is an aggregate that is on the fine side of a dense gradation. Using trial and error and looking at the two plots, try to develop dense/fine, dense/dense and dense/coarse aggregate blends using 30% RAP. Remember that the control points should only be considered as guidelines and not absolute specification requirements. Also, you should enter the target VMA and air voids in rows 40 and 42, respectively, for each trial mixture. Use the overall target values we selected earlier—15% for VMA and 4% for air voids. In a real mix design, you can change these values slightly to refine your trial blends, but we'll stay with these targets in this example.

You can check the estimated properties of your trial gradations below the aggregate blending area in worksheet "Trial_Blends." For examples, the dust:binder ratios for each trial are given in cells F45:L45. These values can be compared to the required range given immediately above in row 44.

In cells F49:L52 the required new binder performance grade is listed for each trial mix. If you have the choice of several binder grades, this information would allow you to pick the one that would provide you with the correct final blended binder performance grade for the mixture. In cells F56:L69 you must mark the binder you are using for each trial mix. In this example, we only have one binder choice, so you should put an "X" in cells F56, G56 and H56. HMA Tools allows you to enter data for up to four new binders. If we entered data for more than one binder, we could place an "X" for whichever binder we wanted to use for a given trial mix. HMA Tools would then calculate blended binder grade information using data for the selected binder. This allows you to determine which of up to four binders will provide the best overall performance in your HMA mix. Once you mark your binder choice, HMA Tools will display the blended binder grade in cells F62:L62; this can be compared to the required binder grade given in row 61. Aggregate gradation data is given in cells B74:L86.

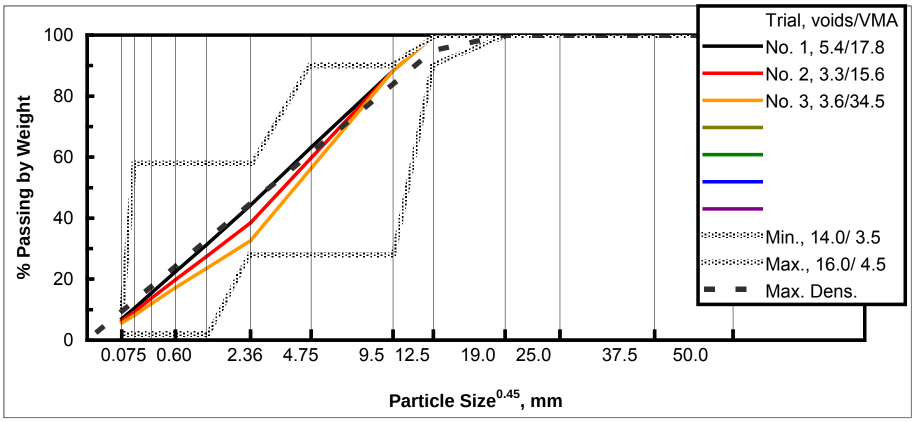
As you develop your trial blends, look through worksheet “Trial_Blends” and try to make sure all or most requirements are given. However, most volumetric information won’t be given, since it cannot be calculated until bulk and maximum specific gravity tests are performed on the trial mixes and the resulting data entered in HMA Tools. For example, in the gradation plot, the legend in the upper right-hand corner will show VMA and air void content once specific gravity measurements have been made and entered in worksheet “Specific_Gravity.” Since this hasn’t yet been done, the key just says “#NA” for all trial mixes.

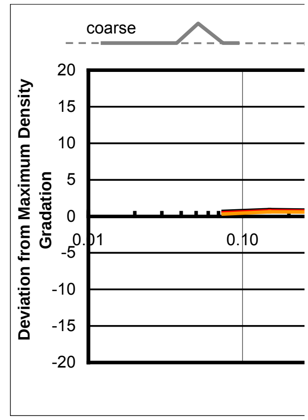
You might be wondering how HMA Tools calculates binder contents for the trial mixes. This is done volumetrically, by assuming that the trial mix will have the target VMA and target air voids. Of course, most of the time the trial mix won’t, but using this approach we are sure that the trial mix will have the correct amount of binder so that if the air void target is met, the VMA target will also be met. This approach is simple, and also means that we don’t have to worry about estimating optimum binder content—once the air void content is met, VMA will also be met and we will have our design binder content.

After you have experimented with aggregate blending and developed gradations for three trial blends, look at the next page to see one solution for these three gradation—but remember, your trial blends will probably be a little different. That doesn’t mean they are wrong.

TRIAL AGGREGATE BLENDS

help appears at lower right





INCLUDE MAX. DENSITY GRADATION:			X						
PLOT (X):			X	x	x				
Material	**Gsb**	**Gsa**	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**	**Trial 6**	**Trial 7**
Coarse 1	2.704	2.742	12	12	12				
Coarse 2	2.680	2.735	12	12	12				
Coarse 3	2.628	2.713	10	18	26				
Mfg. Fines	2.666	2.737	36	28	20				
#N/A	0.000	0.000							
#N/A	0.000	0.000							
#N/A	0.000	0.000							
#N/A	0.000	0.000							
RSP No. 18	2.590	2.624	30	30	30				
#N/A	0.000	0.000							
#N/A	0.000	0.000							
#N/A	0.000	0.000							
TOTAL			100	100	100	0	0	0	0

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7
Overall Target VMA, Vol. %				15.0			
Target VMA for Trial Batch, Vol. %	15.0	15.0	15.0				
Overal Target Air Voids, Vol. %				4.0			
Target Voids for Trial Batch, Vol. %	4.0	4.0	4.0				
Binder Content for Trial Batch, Wt. %	5.13	4.40	25.51	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Specified Dust/Binder Ratio:				0.8 to 1.6			
Estimated Dust/Effective Binder Ratio	1.4	1.3	1.1	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

Required New PG Grade for Selected Stockpile Blends (conservative)

	Trial 1	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**	**Trial 6**	**Trial 7**
High Temperature (Min.)	64.0	64.0	64.0	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Low Temperature/BBR (Max.)	-28.0	-28.0	-28.0	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Low Temperature/DT (Max.)	#N/A	#N/A	#N/A	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Intermediate Temperature (Max.)	25.0	25.9	25.1	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

Select Binder (X)

	Trial 1	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**	**Trial 6**	**Trial 7**
PG 58-28 / Acme Materials	X	X	X				
/							
/							
/							
BINDER NO	1	1	1	???	???	???	???
SPECIFIED BINDER GRADE				64-(25)-22			
BLENDED GRADE, PG-	64-(22)-22	64-(25)-22	64-(22)-22	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

Allowable RAP Content for Binder Grade and Variability

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7
Min. RAP for Binder Grade, Wt. %	10.0	10.0	10.0	#N/A	#N/A	#N/A	#N/A
Max. RAP for Binder Grade, Wt. %	50.0	47.7	50.0	#N/A	#N/A	#N/A	#N/A
Max. RAP for Variability, Wt. %				0			
Total RAP Content, Wt. %	29.5	29.7	23.2	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

Comments on Trial Blends

Because of the size of the "Trial_Blends" worksheet, only part of the worksheet is shown above. Again, remember that your three trial blends may not look the same as the ones given above. Note that a dense/fine trial blend could not be developed, because the dust/binder ratio becomes too high—1.6. Although 1.6 is barely acceptable, the amount of mineral filler in an HMA mixture will usually increase significantly during plant production compared to the original mix design. Therefore, you should avoid developing mix designs with dust/binder ratios close to the maximum allowable value. If none of these trial mixes were to prove acceptable after volumetric analysis, it would probably be necessary to reduce the amount of RAP in the mix design and try to develop a dense/fine graded mix.

The three mixes shown above all seem reasonable—they meet gradation requirements, and the blended binder meets the given requirements for the performance grade. At the bottom of the previous page, minimum and maximum allowable RAP contents are given for the trial mixes. How can you have a minimum RAP content? If you anticipate using a large amount of RAP and then select a relatively soft new binder, you might have a minimum RAP content so that the blended binder meets the given high-temperature PG requirements. Note that you have minimum and maximum RAP contents based on both binder grading requirements, and on RAP variability—remember, we earlier determined that the variability in this RAP material meant that we could not use more than 30% RAP in our mix design without having our production variability increase to unacceptably high levels. If you forgot to enter the calculated maximum RAP value in worksheet "General," it won't show up in this worksheet.

Before continuing, you should change your three trial blends to match those given on the previous page. That way, as you continue through the tutorial your numbers on the various HMA Tools worksheets will be the same as those shown here.

Calculate Batch Weights for Gyratory Specimens

To complete the evaluation of the trial mixes, trial batches must be prepared and gyratory specimens compacted. When preparing trial batches, aggregate stockpiles are usually broken down into different fractions and weighed out separately. This helps prevents segregation during weighing and batching. Different laboratories follow different procedures for breaking down aggregates when preparing trial batches. Most laboratories completely break down coarse aggregates—one fraction for each sieve size. Many laboratories don't break down fine aggregate at all, but some will partially or even completely break down fine aggregate also. HMA Tools gives batch weights for each separate size fraction of coarse aggregates, and three different break downs for fine aggregate: no breakdown, partial break down and complete break down. RAP materials are not normally broken down when preparing trial batches. HMA Tools also provides asphalt weights.

To have HMA Tools calculate batch weights, you must enter data in the worksheet "Batch." This includes project information, and the number and size of specimens. You can specify both cylindrical specimens—like gyratory specimens—or beams and slabs, or both. You can also specify a certain weight of loose mix, and an extra percentage of mix to make sure that there is enough mixture for all specimens. You must also specify which trial mix (by number) you are preparing a batch for (cell O1 of worksheet "Batch"), and the air void content (cell K6).

In this example, assume two 150 mm diameter, 100 mm high gyratory specimens will be prepared from trial batch 2, Specify 20% extra mix for the trial batch to make sure there will be enough mix for the gyratory specimens, and 4% air voids. The next page shows what the complete worksheet should look like.

BATCHING REPORT

Compacted Specimens & Loose Mix:

Trial Batch No.: 2

Cylinders:

Dia., mm	Ht., mm	No.	Loose Mix, g:
150	100	2	

Target Air Voids, %: 4.0

Beams/Slabs:

W, mm	L, mm	T, mm	No.

Date (mm/dd/yyyy):	
Project:	Tutorial
Tech./Engr.:	J. Doe
NMAS (mm):	12.5
Surface Course:	Yes
Traffic Level (MESALs):	0.8

Estimated Gmb:	2.349
Pb, Wt. %:	4.40
Pb/New, Wt. %:	3.36
Specimen Vol., m^3	0.00353
Extra mix, %:	20
Total Wt., g:	9,962
New Binder Wt., g:	335

Size Fractions, mm: **Aggregate Batch Weights, grams:**

	Min.	Max.	Coarse 1	Coarse 2	Coarse 3	Mfg. Fines	#N/A	#N/A	#N/A	#N/A	RSP No. 18	#N/A	#N/A	#N/A
Coarse Aggregate														
	37.5	50.0	0	0	0	0	0	0	0	0	0	0	0	0
	25.0	37.5	0	0	0	0	0	0	0	0	0	0	0	0
	19.0	25.0	0	0	0	0	0	0	0	0	0	0	0	0
	12.5	19.0	3	0	0	0	0	0	0	0	33	0	0	0
	9.5	12.5	573	391	0	0	0	0	0	0	124	0	0	0
	4.75	9.5	552	722	754	24	0	0	0	0	687	0	0	0
	2.36	4.75	7	15	915	627	0	0	0	0	483	0	0	0
Fine Aggregate														
	1.180	2.360	0	0	17	677	0	0	0	0	364	0	0	0
	0.600	1.180	0	0	0	429	0	0	0	0	311	0	0	0
Complete	0.300	0.600	0	0	0	269	0	0	0	0	314	0	0	0
Breakdown	0.150	0.300	0	0	0	211	0	0	0	0	222	0	0	0
	0.075	0.150	0	0	0	163	0	0	0	0	127	0	0	0
	0.000	0.075	8	15	27	267	0	0	0	0	296	0	0	0
Partial	0.600	2.360	0	0	17	1,106	0	0	0	0	675	0	0	0
Breakdown	0.150	0.600	0	0	0	480	0	0	0	0	536	0	0	0
	0.000	0.150	8	15	27	430	0	0	0	0	423	0	0	0
No Breakdown	0.000	2.360	8	15	44	2,016	0	0	0	0	1,634	0	0	0
Total Weight:	**9,962**		**1,143**	**1,143**	**1,713**	**2,667**	**0**	**0**	**0**	**0**	**2,961**	**0**	**0**	**0**

Specific Gravity Measurements

In order to complete the evaluation of the trial mixes, the specific gravity of the mixes—both the theoretical maximum specific gravity values of loose mix and the bulk specific gravity of the compacted specimens—are measured. Data from specific gravity measurements are entered in worksheet “Specific_Gravity.” In this worksheet, you can either enter raw data from the measurements and have HMA Tools calculate the specific gravity values, or you can just enter the correct specific gravity values without the raw data—this would happen, for instance, if your laboratory has its own forms for recording specific gravity measurements and does not want to use HMA Tools for this purpose.

Enter the following data for specific gravity measurements in worksheet “Specific_Gravity:”

Trial Mix No. 1

Bulk Specific Gravity—Weight in Water/SSD Method

Measurement	Specimen 1	Specimen 2
Dry mass in air, g	4,683.0	4,746.3
SSD mass in air, g	4,695.2	4,751.8
Mass in water, g	2,697.0	2,743.7

Theoretical Maximum Specific Gravity—Pyncnometer Method

Measurement	Specimen 1	Specimen 2
Dry mass in air, g	2,085.1	2,089.9
Mass of pyncnometer filled with water, g	7,573.1	7,648.5
Mass of pyncnometer with mix and water, g	8,812.6	8,891.9

Trial Mixes No. 2 and No. 3

Measurement	Trial Mix No. 1	Trial Mix No. 2
Bulk Specific Gravity	2.378	2.367
Theoretical Maximum Specific Gravity	2.462	2.463

Turn to the next page to see what the completed worksheet should look like. On the page after that one is a copy of the worksheet “Trial_Blends,” showing what it will now look like after completing the specific gravity information.

SPECIFIC GRAVITY CALCULATIONS

BULK SPECIFIC GRAVITY

	Trial 1			Trial 2			Trial 3		
Weight in Water/SSD Method	**1-1**	**1-2**	**1-3**	**2-1**	**2-2**	**2-3**	**3-1**	**3-2**	**3-3**
Dry mass in air, g, A	4683.0	4746.3							
SSD mass in air, g, B	4695.2	4751.8							
Mass in water, g, C	2697.0	2743.7							
Water absorption, Wt. %, (B-A)/(B-C) x 100%	0.61	0.27							
Low absorption or high absorption (> 2%)?	Low			#N/A			#N/A		
Bulk specific gravity, dry basis, A/(B-C)	2.344	2.364	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Average	2.354			#N/A			#N/A		
Range		0.020			#N/A			#N/A	
Acceptable? (Within d2s Precision)		YES			#N/A			#N/A	
Weight in Water/Wax/Parafilm Method									
Dry mass in air, g, A									
Dry mass in air, coated specimen, g, D									
Mass in water, coated specimen, g, E									
Specific gravity of coating, F									
Bulk specific gravity, dry basis, A/[D-E-(D-A)/F]	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Average	#N/A			#N/A			#N/A		
Range		#N/A			#N/A			#N/A	
Acceptable? (Within d2s Precision)		#N/A			#N/A			#N/A	
User-Calculated Value									
Bulk specific gravity, dry basis				2.378			2.367		
USE BULK SPECIFIC GRAVITY	2.354			2.378			2.367		
COMMENTS									

MAXIMUM SPECIFIC GRAVITY

	1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3
Weight in Water Method									
Dry mass in air, g, A									
Surface-dry mass in air, g, A'									
(dry-back method for porous aggregate only)									
Mass of specimen in water, g, C									
Theor. Max. Sp. Grav., A/(A-C) or A/(A'-C)									
Range		#N/A			#N/A			#N/A	
Accpetable? (Within d2s precision)		#N/A			#N/A			#N/A	
Pyncnometer Method									
Dry mass in air, g, A	2085.1	2089.9							
Surface-dry mass in air, g, A'									
(dry-back method for porous aggregate only)									
Mass of pyncnometer filled with water, g, F	7573.1	7648.5							
Mass of pync. With mix and water, g, G	8812.6	8891.9							
Correction for Thermal Exp. Of Binder, g, H	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Density of water at test temp., Mg/m^3, dw	0.997	0.997	0.997	0.997	0.997	0.997	0.997	0.997	0.997
Theor. Max. Sp. Grav., {A/[(A+F)-(G+H)]} x (dw/0.997) or {A/[(A'+F)-(G+H)]} x (dw/0.997)	2.466	2.469							
Range		0.003			#N/A			#N/A	
Accpetable? (Within d2s precision)		YES			#N/A			#N/A	
User-Calculated Value									
Theoretical maximum specific gravity				2.462			2.463		
USE THEORETICAL MAXIMUM SPECIFIC GRAVITY	2.467			2.462			2.463		

SPECIFIC GRAVITY CALCULATIONS (continued from previous page)

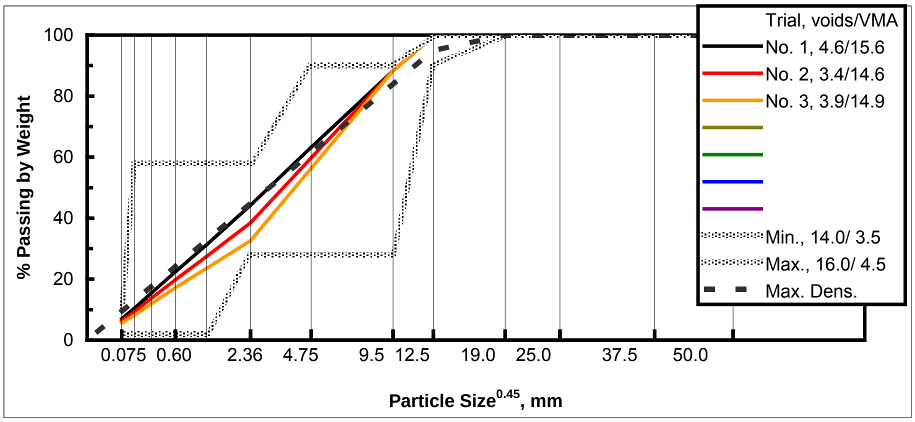
User-Calculated Value			
Theoretical maximum specific gravity		2.462	2.463
USE THEORETICAL MAXIMUM SPECIFIC GRAVITY	2.467	2.462	2.463
VOLUMETRIC ANALYSIS			
Aggregate bulk specific gravity, dry basis	2.645	2.642	2.639
Air void content, % by volume	4.6	3.4	3.9
Asphalt content, % by weight	5.13	5.10	5.10
Aggregate content, % by weight	94.87	94.90	94.90
VMA, % by volume	15.6	14.6	14.9
Vbe, % by volume	11.0	11.2	11.0
Calculated Agg. Eff. Specific Gravity	2.670	2.662	2.664
Calc. Absorbed asphalt, % by Agg. Wt.	0.37	0.30	0.36
Absorbed asphalt, % by total weight	0.35	0.28	0.34
Absorbed asphalt, % by total volume	0.80	0.66	0.79
Effective asphalt, % by total weight	4.78	4.82	4.75
Dust/binder ratio	1.39	1.25	1.13

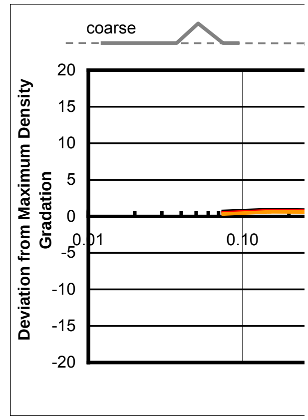
A useful feature of the “Specific_Gravity” worksheet is that if you use this to enter data from specific gravity measurements, it will flag results that exceed AASHTO d2s single-operator precision limits. In other words, it will warn you if your specific gravity replicate measurements are further apart than what should normally be expected. These warnings appear in rows 16, 28 and 61 for each of three different tests—two different methods for bulk specific gravity measurements and theoretical maximum specific gravity. Which of the two methods for determining bulk specific gravity of HMA specimens is used will normally depend on the absorption of the specimen; the bulk specific gravity of highly absorptive mixtures—those with water absorption values greater than 2.0 percent—should be determined using the wax/parafilm method. HMA Tools will warn you in row 12 if the absorption of the mixture is above 2.0%, meaning that you must use the wax/parafilm method for that mixture.

At the bottom of the worksheet is listed the results of a complete volumetric analysis of each of the three trial mixes. These are values calculated from the composition of the mixture and the specific gravity measurements, and are not estimates. These values are carried back to the worksheet “Trial_Mixtures” and will now appear in several places within this worksheet, including the gradation plots. This makes adjusting aggregate gradations to meet volumetric requirements much easier. On The next page the “Trial_Blends” worksheet is shown again, this time as it appears after completing the “Specific_Gravity” worksheet.

TRIAL AGGREGATE BLENDS

help appears at lower right





Material	Gsb	Gsa	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7
INCLUDE MAX. DENSITY GRADATION:			X						
PLOT (X):			X	x	x				
Coarse 1	2.704	2.742	12	12	12				
Coarse 2	2.680	2.735	12	12	12				
Coarse 3	2.628	2.713	10	18	26				
Mfg. Fines	2.666	2.737	36	28	20				
#N/A	0.000	0.000							
#N/A	0.000	0.000							
#N/A	0.000	0.000							
#N/A	0.000	0.000							
RSP No. 18	2.590	2.624	30	30	30				
#N/A	0.000	0.000							
#N/A	0.000	0.000							
#N/A	0.000	0.000							
TOTAL			100	100	100	0	0	0	0

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7
Overall Target VMA, Vol. %				15.0			
Target VMA for Trial Batch, Vol. %	15.0	15.0	15.0				
Overal Target Air Voids, Vol. %				4.0			
Target Voids for Trial Batch, Vol. %	4.0	4.0	4.0				
Binder Content for Trial Batch, Wt. %	5.13	5.10	5.10	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Specified Dust/Binder Ratio:				0.8 to 1.6			
Estimated Dust/Effective Binder Ratio	1.4	1.3	1.1	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

Required New PG Grade for Selected Stockpile Blends (conservative)

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7
High Temperature (Min.)	64.0	64.0	64.0	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Low Temperature/BBR (Max.)	-28.0	-28.0	-28.0	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Low Temperature/DT (Max.)	#N/A	#N/A	#N/A	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Intermediate Temperature (Max.)	25.0	25.7	25.7	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

Select Binder (X)

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7
PG 58-28 / Acme Materials	X	X	X				
/							
/							
/							
BINDER NO	1	1	1	???	???	???	???
SPECIFIED BINDER GRADE				64-(25)-22			
BLENDED GRADE, PG-	64-(22)-22	64-(22)-22	64-(22)-22	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

Allowable RAP Content for Binder Grade and Variability

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7
Min. RAP for Binder Grade, Wt. %	10.0	10.0	10.0	#N/A	#N/A	#N/A	#N/A
Max. RAP for Binder Grade, Wt. %	50.0	50.0	50.0	#N/A	#N/A	#N/A	#N/A
Max. RAP for Variability, Wt. %				0			
Total RAP Content, Wt. %	29.5	29.5	29.5	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

Evaluating and Refining Trial Mixtures

After mixing, compacting, and analyzing the volumetric composition of the three trial mixtures, the specification requirements of each should be analyzed. This is best done by reviewing information on the worksheet “Trial_Blends.” But remember, specific gravity testing must first be performed on the trial mixtures and entered into worksheet “Specific_Gravity.” Check the various specification requirements on all there trial mixtures. Which, if any, meets all requirements? If more than one meets all requirements, which seems to best meet the various specifications? Turn to the next page to see a comparison of specification requirements for all three trial mixtures.

The table below summarizes all the various requirements for this HMA mix design. All three trial mixes meet most of the requirements, but mixes 1 and 2 fail the air void requirement of 3.5 to 4.5% (the air void content of mix 1 is too high, while the air void content of mix 2 is slightly low). Therefore, trial mix 3 meets all requirements, and would be the mix to select for moisture resistance testing. In practice when developing a new HMA mix design, many times none of the trial mixes will meet all requirements. In that case, you need to determine which trial mix comes closest to meeting all requirements, and then modify it so that it does meet all requirements. This is a trial-and-error procedure that may require quite a few iterations before a final mix design is developed.

Note that the minimum and maximum RAP contents for binder grade—10 and 50%, respectively—are based not on the binder grade analysis, but on practical limits for adding RAP at typical hot mix plants. It is difficult to add less than 10% RAP to a mix accurately, and also difficult to add more than 50% RAP at many plants. For this reason, if the calculated minimum RAP content is less than 10%, HMA Tools will return 10%. Similarly if the calculated maximum RAP content based on binder grade analysis is over 50%, HMA Tools will list the maximum as 50%.

	Specified Value		**Trial Mix Number**		
Property	**Min.**	**Max.**	**1**	**2**	**3**
VMA, Vol.%	14.0	16.0	15.6	14.6	14.9
Air voids, Vol.%	3.5	4.5	**4.6**	**3.4**	3.9
Blended Binder performance Grade					
High temperature, °C	64	---	64	64	64
Low temperature, °C	---	–22	–22	–22	–22
Intermediate Temp., °C	---	25	22	22	22
Dust/binder ratio	0.8	1.6	1.4	1.3	1.1
Max. RAP content based on variability analysis,% by total mix weight	---	30	See Below		
Min. and Max. RAP content based on binder grade analysis	10	50			
Actual RAP content	See above		29.5	29.5	29.5
CAFF/one face, Wt.%	75	---	100	100	100
CAFF/two faces, Wt.%	---	---	98	98	98
Flat & elongated particles, Wt.%	---	10	3	3	3
FAA, uncompacted voids, Vol.%	40	---	47	47	47
Clay content, sand equivalent	40	---	66	66	66

Moisture Resistance Testing (AASHTO T 283)

Just as in Superpave, one of the last steps in the mix design is performing moisture resistance testing following AASHTO T283. In HMA Tools, moisture resistance test data are entered in worksheet “T_283.” This worksheet follows very closely the example data form included in the AASHTO standard method for this test. The worksheet will calculate bulk specific gravity, air voids, indirect tensile strength, and tensile strength ratio once the appropriate data are entered. You must enter theoretical maximum specific gravity data in cell F23 in order to calculate percent air voids. This value can be taken from worksheet “Specific_Gravity,” or it can be calculated separately using the theoretical maximum specific gravity tool that appears at the bottom of this worksheet. Once air void contents are calculated, the “T_283” worksheet will rank the specimens according to their air void content, so they can be split up for conditioned or unconditioned testing.

An example of a completed “T 283” worksheet appears on the next page. Note that up to seven sets of moisture resistance testing data can be added in this form—one for each of up to seven trial mixtures. However, usually you will only need to enter data for only one or two trial mixes for a mix design. The large numbers “1” in the left hand margin of the worksheet indicate that this form is for trial mix 1. You need to make certain when entering moisture resistance data in this worksheet that you are entering data in correct location for the trial mix tested. The performance test worksheet “Performance” is set up the same way.

AASHTO T 283

Project:	Tutorial
Trial Blend Number:	1
Additive:	None
Additive Dosage:	
Compaction Method:	Gyratory
Compaction Effort:	75
Date Tested:	10/30/2009
Tested by:	J. Doe

Help for Worksheet T-283

This worksheet is for recording data for AAHTO T 283: Resistance of Compacted H
procedure. Project data is entered in the cells to the right of this help box. Specime
worksheet closely follow the data form included in the AASHTO T-283 write-up.

A calculation tool for theoretical maximum specific gravity appears at right, as an ai
are not carried over into any other part of HMA Tools.

Seven separate tables are included in this worksheet--one for each trial batch. You
Find the table with the correct trial batch number by paging down through the works
worksheet in large black numbers. You don't need to fill out all the tables, only for tl

		Specimen Number: 1	2	3	4	5	6	7	8
Diameter, mm (in.)	D	150.0	150.0	150.0	150.0	150.0	150.0		
Thickness, mm (in.)	t	95.2	93.7	99.3	94.5	95.1	98.0		
Dry Mass in Air, g	A	3852.5	3797.2	4059.6	3825.9	4101.1	3968.2		
Saturated, Surface-Dry Mass in Air, g	B	3865.9	3812.0	4071.4	3866.1	4119.1	3980.1		
Mass in Water, g	C	2179.8	2163.8	2290.5	2187.4	2336.7	2245.1		
Volume (B - C), cm^3	E	1686.1	1648.2	1780.9	1678.7	1782.4	1735.0	0.0	0.0
Bulk Specific Gravity, (A/E)	Gmb	2.285	2.304	2.280	2.279	2.301	2.287	#DIV/0!	#DIV/0!
Maximum Specific Gravity (Gmm worksheet appears below)	Gmm	2.463							
% Air Voids [100 x (Gmm - Gmb)/Gmm]	Pa	7.2	6.5	7.4	7.5	6.6	7.1	0.0	0.0
Rank		3	6	2	1	5	4		
Select for Conditioning (X)			x		x		x		
Average % Air Voids, Dry Specimens		7.1							
Average % Air Voids, Wet Specimens		7.0							
Volume of Air Voids (Pa x E/100), cm^3	Va	121.95	106.50	132.67	125.35	117.32	123.88	0.00	0.00
Load, Dry Specimen, N (lbf)	Pa	18307		17550		17805			
Saturation Time, min			10		10		10		
Saturation Vacuum			51		51		50		
Vacuum Units (kPa, psi, mm Hg, or in. Hg			kPa		kPa		kPa		
Thickness after Saturation, mm (in.)	t'		94.1		95.3		98.2		
SSD Mass after Saturation, g	B'		3875.1		3919.5		4055.8		
Volume of Absorbed Water (B' - A), cm^3	J'		77.9		93.6		87.6		
% Saturation (100 x J' / Va)	S'		73.1		74.7		70.7		
Load, Wet Specimen, N (lbf)	P'		16404		15731		15790		
Dry Strength [2000 x P/ pi x t x D)], kPa (psi)	S1	816.1		750.1		794.6			
Wet Strength [2000 x P/ pi x t x D)], kPa (psi)	S2		739.9		700.6		682.4		
Visual Moisture Damage (0 = none, 5 = severe)		1							
Cracked and/or Broken Aggregate (yes/no)		no							
Tensile Strength Ratio (Average S2 / Average S1)		0.90							

Performance Testing

In the Superpave mix design method, there is no performance or “proof” test after completing a volumetric mix design. In the mix design procedure described in this manual, HMA mix designs intended for traffic levels of 3,000,000 ESALs or greater must be evaluated for rut resistance using one of six performance tests:

- Asphalt mixture performance test (AMPT), flow number test
- AMPT, flow time test
- Asphalt pavement analyzer (APA)
- Hamburg wheel tracking test
- Superpave shear tester, repeated load at constant height (SST/RSCH) test
- Indirect tensile strength at high temperature

Suggested minimum or maximum values for these tests (or other guidelines) are given in the manual, in Chapter 8. Flexibility is allowed in which test to run, since there are significant data supporting the usefulness of each of these tests, and a number of agencies have already begun to implement performance testing with several of these procedures. Because performance testing of HMA mixtures as part of the mix design process is just beginning, it is strongly recommended that after selecting a performance test to use in their state, highway agencies review the specification values given in the *Manual* with consideration of their local materials, climate, and traffic levels. It is likely that many highway agencies will modify the performance test requirements given in this manual, so technicians and engineers responsible for developing HMA mix designs should stay informed of the latest standards and specifications issued by their state.

Because the mix design in this example is intended for a traffic level of only 800,000 ESALs, no performance test is required. If performance testing were required, this information should be entered in worksheet “Performance” of HMA Tools. This worksheet is very simple, and does not perform any calculations, since the nature of possible performance tests varies widely. As mentioned previously, this worksheet allows you to enter data for up to seven mixtures, in other words, for each of up to seven trial mixes. When entering data in worksheet “Performance” you need to make certain you are entering data in the correct location; the trial mix number is shown in large numbers in the left hand number of the worksheet. The information in worksheet “Performance” is carried over into worksheets “Report” and “Complete_Report” so that the summary report on the selected mixture will include the results of performance testing when required.

For engineers and technicians interested in learning more about evaluating the performance of HMA mixtures, Chapter 6 of the *Manual* covers this topic in detail, and includes useful information on the testing needed to design HMA pavements with the Mechanistic-Empirical Pavement Design Guide.

Printing a Report on a Mix Design

Once you have completed a mix design, or if you want to summarize one or more trial mixes, you can use HMA Tools to print out a report. Go to worksheet “Short_Report,” and fill out the date in cell D4, and place “3” in cell D5, meaning you want to generate a report for trial mix No. 3. Then just print out the report, which will look just like the computer screen. Compare your report to the one that appears on the next page.

Worksheet “Short_Report” generates a short but fairly complete report on a single selected mix design. You may wish to generate a report on a complete series of tests used in developing a mix design. In that case, use worksheet “Complete_Report” to do you report. This worksheet prints out reports on all trial mixes.

SHORT REPORT ON HMA MIX DESIGN

Date (mm/dd/yyyy):		**Surface Course (yes/no):**	Yes
Select Trial Blend No. 1 through 7	**3**	**Traffic Level (million ESALs):**	0.8
Project:	Tutorial	**Ndesign:**	75
Tech./Engr.:	J. Doe	**Compactor Type:**	Not specified
NMAS (size in mm):	12.5	**Angle Calibration Method:**	Not specified

Material	Gsb	Gsa	Wt. %
Coarse 1	2.704	2.742	**11.4**
Coarse 2	2.680	2.735	**11.4**
Coarse 3	2.628	2.713	**24.7**
Mfg. Fines	2.666	2.737	**19.0**
#N/A	#N/A	#N/A	**0.0**
#N/A	#N/A	#N/A	**0.0**
#N/A	#N/A	#N/A	**0.0**
#N/A	#N/A	#N/A	**0.0**
RSP No. 18	2.590	2.624	**28.5**
#N/A	#N/A	#N/A	**0.0**
#N/A	#N/A	#N/A	**0.0**
#N/A	#N/A	#N/A	**0.0**

MIXTURE VOLUMETRIC PROPERTIES

	Specifications	Value
Voids	**3.5 to 4.5**	**3.9**
VMA	**14 to 16.0**	**14.9**
Dust/Binder	**0.8 to 1.6**	**1.1**
Vbe	**NA**	**11.0**
VFA	**NA**	**73.8**

Total Asphalt Binder	**5.10**	**Required Asphalt Binder Grade:**	**PG-64-(25)-22**
New Asphalt Binder	**4.07**	**Blended Asphalt Binder Grade:**	**PG-64-(22)-22**
Aggregate Blend Effective Specfic Gravity:	**2.664**	**New Asphalt Binder Grade:**	**64-(22)-22**

AGGREGATE GRADATION

	Percent Passing:		
Sieve Size, mm	Min.	Max.	Blend
50.000	100	100	**100**
37.500	100	100	**100**
25.000	100	100	**100**
19.000	100	100	**100**
12.500	90	100	**100**
9.500	28	90	**88**
4.750	28	90	**56**
2.360	28	58	**33**
1.180	2	58	**24**
0.600	2	58	**17**
0.300	2	58	**12**
0.150	2	58	**8**
0.075	2	10	**5.7**

OTHER AGGREGATE PROPERTIES

Coarse Aggregate	Specification	Value
CAFF, One Fracture Face, %	75 % Min.	**100.0**
CAFF, Two Fractured Faces, %	0 % Min.	**98.0**
Flat & Elong., %	10 % Max.	**3.0**
	#N/A	**#N/A**
	#N/A	**#N/A**
Fine Aggregate		
FAA, Uncompacted Voids, %	40 % Min.	**47.0**
Sand Eq., %	40 % Min.	**66.0**
	#N/A	**#DIV/0!**
	#N/A	**#DIV/0!**

MOISTURE RESISTANCE (AASHTO T 283)

TSR	**#DIV/0!**
Visual Moisture Damage (0 = none, 5 = severe)	**0**
Cracked and/or Broken Aggregate (yes/no)	**0.00**
Additive:	**0**
Dosage	

ESTIMATED MIXTURE DYNAMIC MODULUS, PSI

	Temperature, F:				
Freq., Hz	**14**	**40**	**70**	**100**	**130**
25	2,936,000	2,111,000	920,000	279,500	88,800
10	2,837,000	1,891,000	706,000	193,100	63,200
5	2,751,000	1,713,000	565,000	145,000	50,900
1	2,508,000	1,275,000	316,000	75,900	36,700
0.5	2,383,000	1,089,000	240,000	59,500	34,300
0.1	2,039,000	699,000	124,000	39,600	32,000

PERFORMANCE TESTING

Type of Performance Test:	**0**	
Design Traffic Level (million ESALs):	**0**	
Required Result / Units, Min. / Max.:	**0**	**0**
Test Result / Units	**0**	**0**

Comments: 0

Other Chapters in the Mix Design Manual

Congratulations! You have completed the tutorial. This exercise was meant to familiarize technicians and engineers with the most important parts of the *Manual*, and with the HMA Tools spreadsheet. There are four chapters in the manual that were not covered in this tutorial:

Chapter 7. Selection of Asphalt Concrete Mix Type
Chapter 10. Design of Gap-Graded HMA Mixtures
Chapter 11. Design of Open-Graded Mixtures
Chapter 12. Field Adjustments and Quality Assurance of HMA Mixtures

Chapter 7 is a discussion of what HMA mix type should be used for a given application. Selection of mix type is usually done by engineers responsible for pavement design, and so most technicians involved in mix design will never have to make this decision. However, there may be some cases where private clients are not sure what type of mix they need and the technician or laboratory engineer will need to help decide the appropriate type of HMA to use for a certain application. In these cases, Chapter 7 will provide all or most of the information to make an appropriate selection.

Open-graded and especially gap-graded mixtures are becoming increasingly common on our nation's highway pavements; if you find yourself designing these types of mixtures, you should carefully read Chapters 10 or 11. Keep in mind that requirements for these mix types tend to vary quite a bit from state to state, so make sure you have your agency's latest specifications for the type of mix you are designing.

Chapter 12 covers information that is needed when taking an HMA mix design from the laboratory to field production. Many technicians and engineers that do mix design work will not be involved directly in this part of the HMA business, but some may find that they become involved in field production. Most HMA mix designs as produced in the laboratory really represent starting points for the final job mix formula used during production. This is because the aggregates in a mix will be changed during processing at the plant—for example, the amount of fines in a plant produced mix will usually be higher than for the identical laboratory mix design. These differences in aggregate gradation will often require adjustments in the mix in order to meet specifications. The second topic covered in Chapter 12 is quality assurance. Again, many technicians and engineers may not have a need for this information, but for those involved in HMA quality assurance, Chapter 12 provides useful information on production variability, control charts, and acceptance plans.