HMA Level 3: Quality Control Managers Course

Conducted by the Clemson University Civil Engineering Department and SCDOT

Any Questions/Comments?

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Course Contents

Chapter 1

Introduction and Background

Chapter 1: Contents

- Introduction
- Purpose of Inspection
- QC Manager's Responsibilities
- QC Manager's Qualifications

Introduction

- QC Manager is a person who is knowledgeable about all aspects of roadway construction (mix design, plant problems, road problems, etc.). In addition, this person is capable of following all of the requirements of the plans and specifications.

Definitions

- Contract: A document that contains the agreement between the owner (SCDOT) and the contractor.
- Plans: The contract documents that show the location, physical aspects, and dimensions of the work.
- Specifications: The written technical requirements for the work.

QC Manager's Responsibilities

- Supervising role:
  - Sampling and testing
  - Record keeping
  - Plant operations
  - Safety

QC Manager's Qualifications

- Must hold the following certifications:
  - Level 1: QC Technician
  - Level 2: Mix Design Fundamentals
  - Level 2S: Superpave Mix Design
  - ARI: Asphalt Roadway Inspector

QC Manager's Qualifications

- A valid certificate of qualification must be in the QC Manager's possession.
- Contact: Mr. Chad Hawkins (SCDOT Bituminous Materials Engineer) at 803-737-6700.

End of Chapter 1

Any Questions?

Chapter 2

Aggregates

Chapter 2: Objectives

- Properties of aggregates.
- Sampling procedures for aggregates.
- Aggregate gradation and blending.
- Aggregate testing procedures.
- Effects of aggregates on various HMA mix properties.
- Superpave aggregate tests

Definition

- The word "Aggregate" refers to any combination of sand, gravel, and crushed stone in their natural or processed state.

Aggregate Types

- Fine Aggregate (FA)
  - Virtually all passes the #4 (4.75 mm) sieve and predominantly retained on the #200 (0.75 mm) sieve.
- Coarse Aggregate (CA)
  - Virtually all is retained on the #4 (4.75 mm) sieve.

Fine Aggregate Types

- Stone Screenings
- Creek Sand
- Natural Sand
- Processed Sand

Creek Sand

- Creek sand, or river sand, is dredged from creeks or rivers, screened, and used as is.
- More commonly used by concrete industry.
- Typically have a low dust content.

Stone Screenings

- By-product of the crushing operation at the quarry.
- Regular Screenings
  - High dust content (generally >10%)
- Washed Screenings (also known as Manufactured Sand)
  - Low dust content (generally <5%)

Natural Sand

- Sand that is common to a particular location.
- Typically found below the Fall Line. The Fall Line runs through Augusta, Columbia, and Florence.
- Generally have low dust contents.

Processed Sand

- Sands that go through some formal process (sieving or blending for example).
- Done to achieve a certain gradation.

Coarse Aggregate Types

- Crushed stone
- Gravel
- Marine limestone
- Slag
- RAM

Crushed Stone

- Most common type of CA.
- Three types in SC
  - Granite
  - Granite Gneiss
  - Marble Schist

Crushed Stone Background

- Good stone at the location.
- Site suitability
  - Transportation access
  - Overburden ratio
  - Drainage
  - Buffer zones
  - Water availability
  - Reclamation
- Crushing process (# and types of crushers, etc.)

Gravel

- Mined from the natural surroundings.
- No blasting involved.
- Can be crushed if so desired.
- Screened, washed, and separated into various sizes.

Marine Limestone

- Also called fossiliferous limestone.
- Made from fossils of marine creatures.
- One source in SC.
- Production is similar to that of crushed stone.
- Absorptive aggregate.

Slag

- By-product of the steel industry.
- When iron ore is heated to extreme temperatures, it becomes molten.
- The heavy iron sinks to the bottom, while impurities rise to the top.
- Impurities are poured off and quenched with water. This is slag.
- Can then be crushed into various sizes.
- Has a high specific gravity and high absorption.

RAM

- RAM: Reprocessed Aggregate Material
- Aggregate portion of our RAP.

RAM Troubleshooting

- Dirty stone
- Gradation changes
- Specific Gravity changes
- Material breakdown
- Mica
- Clay balls
- Roots

Aggregate Properties

Aggregate Properties

- Size and Grading
  - Nominal Maximum Aggregate Size
  - Maximum Aggregate Size

Size and Grading

- Nominal Maximum Aggregate Size: The sieve size that is one size larger than the first sieve to retain more than 10% of the material.
- Maximum Aggregate Size: One size larger than the nominal maximum aggregate size.

Size and Grading

- Aggregate gradations are graphed on a 0.45 Power chart.
- Maximum Density Line (MDL) is also drawn on the 0.45 Power chart.
- The MDL is drawn using our Maximum Aggregate Size.
- Examples to follow.

Size and Grading

- Aggregates can be described based on their gradation.
  - Dense (well) graded
  - Open graded
  - Fine graded
  - Coarse graded
  - One size (uniformly) graded
  - Gap graded

Aggregate Properties

- Cleanliness
  - Want our aggregates to be washed.
  - Dust on aggregate surface can lead to stripping problems.

Aggregate Properties

- Cleanliness
- Toughness
  - Los Angeles Abrasion Test
  - Soundness Test (Sodium Sulfate or Magnesium Sulfate)

Aggregate Properties

- Cleanliness
- Toughness
- Particle Shape
  - Affects the strength of our HMA mix.

Particle Shape

- Irregular or angular shaped particles tend to interlock.
- Rounded particles tend not to have the interlocking qualities.

Aggregate Properties

- Cleanliness
- Toughness
- Particle Shape
- Surface Texture
  - Surface texture influences both workability and strength.

Surface Texture

- A rough (sand paper like) texture as opposed to a smooth surface tends to increase the HMA mix strength.
- A smooth, rounded surface (like gravel) tends to increase the workability of the HMA mix.

Aggregate Properties

- Cleanliness
- Toughness
- Particle Shape
- Surface Texture
- Absorption: Water and/or Asphalt Binder

Absorption

- An aggregate with 1% or less absorption is good for asphalt mixtures.
- All aggregates in SC except slag and marine limestone have absorption rates less than 1%.

Aggregate Properties

- Cleanliness
- Toughness
- Particle Shape
- Surface Texture
- Absorption
- Affinity for Asphalt: Lime and/or antistripping agents

Aggregate Properties

- Cleanliness
- Toughness
- Particle Shape
- Surface Texture
- Absorption
- Affinity for Asphalt
- Specific Gravity

Specific Gravity

- Specific Gravity is defined as: the ratio of the mass (or weight) of a given volume of aggregate to the mass (or weight) of an equal volume of water.
- Example: 1 ft^3 of water weighs 62.4 lbs. 1 ft^3 of solid stone weighs 156 lbs. The specific gravity is 156/62.4, or 2.500.

Bulk Specific Gravity

- The ratio of the weight of dry aggregate to the weight of water having a volume equal to the volume of the aggregate including both its permeable and impermeable pores.

Apparent Specific Gravity

- The ratio of the weight of dry aggregate to the weight of water having a volume equal to the solid volume of the aggregate excluding its permeable pores.

Bulk Specific Gravity (SSD)

- The ratio of the weight of the aggregate (including the weight of water it contains when its permeable voids are saturated) to the weight of an equal volume of water.

Aggregate Sampling

- We want to obtain a REPRESENTATIVE sample.
- Accuracy in sampling is just as important if not more so than testing.

Aggregate Sampling

- Stockpile sampling
- Belt sampling
- Must reduce these field samples to an appropriate testing size. There are two methods to do this:
  - Quartering
  - Sample splitter

Aggregate Gradations

- Main reason why we are sampling our aggregates.
- Sieve analysis gives us our gradation.
- Typically we are interested in the percent passing any given sieve.

Aggregate Gradations

- There are two types of gradations.
  - Dry Sieve Analysis
  - Wet Sieve Analysis

Wet Sieve Analysis (AASHTO T-11)

- The preparation is the same as for a dry sieve analysis except that before sieving the sample is immersed in water containing a wetting agent.
- The sample is agitated, and the water is poured off over a #200 sieve.
- This process is repeated until the wash water becomes clear.
- Material retained on the #200 sieve must be washed back into the sample.

Gradation Calculations

- To determine the % Passing any given sieve, divide the weight passing by the total weight.
- For a wet sieve analysis, remember to add back weight lost from washing.
  - Weight passing: Add loss to all sieves.
  - Weight retained: Add loss only to the Pan.
- Examples to follow.

Aggregate Blending

- Why is it necessary to blend aggregates?

Aggregate Blending

- For most HMA mixes, SCDOT requires at least 3 aggregate sources.
- RAP does count as an aggregate source.
- Ways to blend aggregates:
  - Graphical
  - Computer programs
  - Trial and error

Recycled Asphalt Pavement

- Allowable RAP percentages are shown below.

Type of Mix	% RAP
Asphalt Base Mixes	10 – 30
Binders, Surf. T-3, T-4	10 – 25
Surface T-1	10 – 20
19.0 mm and 25.0 mm	10 – 15

Recycled Asphalt Pavement

- Requirements for RAP use:
  - Milled from an SCDOT project
  - Date milled and approximate tons
  - Extraction and gradation data
  - Stockpile for each RAP source
  - Stockpile identification

Superpave Aggregate Testing

- As mentioned earlier, aggregate testing was almost forgotten during SHRP.
- Two types of aggregate testing were adopted.
  - Consensus Properties
  - Source Properties

Consensus Properties

- As the name implies, Consensus Properties were adopted by all DOT agencies.
- The Consensus Properties are:
  - Coarse Aggregate Angularity
  - Fine Aggregate Angularity
  - Flat and Elongated Particles
  - Sand Equivalent/Clay Content

Source Properties

- Source Properties are chosen by each state DOT.
- Source Properties for South Carolina:
  - Toughness (Los Angeles Abrasion)
  - Soundness
  - Deleterious Materials

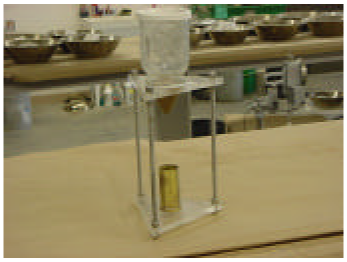
Coarse Aggregate Angularity

- Commonly known as “fractured faces” test.
- Simply measuring the number of fractured faces on an aggregate particle (+#4 material).
- Two groups:
  - 1 fractured face
  - 2 or more fractured faces
- Requirements depend upon
  - Position within the pavement
  - Traffic level

Fine Aggregate Angularity

- Measurement of air voids in an uncompacted sample of fine aggregate.
- Measured on -#8 material.
- Need to know the BSG of the fine aggregate.
- Requirements depend upon:
  - Position within the pavement
  - Traffic level

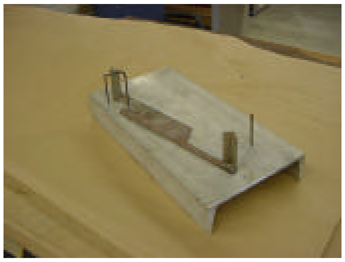
Fine Aggregate Angularity



Flat and Elongated Particles

- Measured on +#4 material.
- Measuring the largest to smallest dimension.
- SCDOT uses a 5:1 ratio.
- Test can be performed at a 3:1 or 2:1 ratio.
- Requirements depend upon:
  - Traffic level

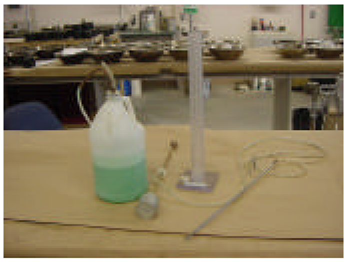
Flat and Elongated Particles



Sand Equivalent/Clay Content

- Measured on -#4 material.
- Test gives a measure of the amount of “clay-like” material in the fine aggregate.
- Requirements depend upon:
  - Traffic level

Sand Equivalent/Clay Content



Toughness

- Measured by the Los Angeles Abrasion Test.
- Proper size aggregate is placed in the drum along with appropriate number of steel "charges."
- Drum rotates 500 times at a speed of 30 rpm.
- After test is completed, the percent passing the #12 sieve is considered to be the percent loss. This is the LA value.

Los Angeles Abrasion Test

Soundness

- Aggregate is placed in chemical bath for 5 cycles.
- Chemicals used are Sodium Sulfate or Magnesium Sulfate.
- Measuring the chemical resistance of the aggregate.

Deleterious Materials

- Determining the amount of clay lumps and friable particles.
- Follow AASHTO T 112.

Aggregate Problems

- 1. The loader bucket on the loader charging the cold feed bins is 2' wider than the bins. What problem(s) may this cause and why?
- 2. A hole has been cut into the wall separating bins 1 and 2 on a batch plant. The #2 bin has a 5/16" screen over it. What problem(s) would this hole cause and why?

Aggregate Problems

- 3. A plant was producing an asphalt porous base mixture with gradation specifications identical to a #57 stone. Only #57 stone was used in the mix; however, the finished mix was too fine on the ½", #4, and #8 sieves. What was the probable cause and how could it be corrected?
- 4. Designing an asphalt surface mix, a combination of #789, RS, MS, and RAP were used. The mix did not meet the void requirements (too high). How could this problem be resolved?

Aggregate Problems

- 5. While making a surface mix, the plant received #789 stone (SG = 2.72). The mix was designed from material with a SG = 2.65. What problem(s) could this cause and why?
- 6. After running 6 extraction tests on a surface mix, the following results were obtained:
  - 1. too fine
  - 2. too coarse
  - 3. good
  - 4. too coarse
  - 5. good
  - 6. too fine

  Material is being produced at a batch plant. What could be the problem(s) and why?

Aggregate Problems

- 7. Technicians at the asphalt plant were testing #789 stone as it was being hauled from the quarry. The material was being tested using a Ro-Tap shaker. Is this according to the testing procedures? Why?
- 8. The plant computer indicates that an asphalt content of 6.2% is being metered. Extraction tests are 5.7%. Possible cause(s) and correction procedures?
- 9. An aggregate source has a high (40-50%) mica content. If 100% of this material is used in an asphalt mix, what problems could this cause and why?

Aggregate Problems

- 10. A crusher-run (1.5") material is delivered to the asphalt plant for use in AABC. Loads are fine and coarse, but the quarry technician's test results are well within the specifications. What is the probable cause and why?
- 11. Man. sand is delivered to the asphalt plant which contains large size pieces of clay. What is the probable cause and why?
- 12. #6M stone was delivered to the asphalt plant containing surge stone size particles. What is the probable cause and why?

Aggregate Problems

- 13. An asphalt mix design does not meet the minimum VMA requirement. The mix contained #789, RS, and MS. What should be changed to correct the VMA and why?
- 14. #57 stone was stockpiled. Some 70,000 tons was in a pile that was approximately 50' high. What problems could be expected and why?

Aggregate Problems

- 15. Materials for a Superpave project are to be stockpiled. Some 40,000 tons each of #67 and #78 stone are needed. How should this material be stockpiled? When and how should samples be taken for the mix design?
- 16. Large particles in an asphalt mixture being produced in a drum plant are uncoated. What are the possible causes and corrections?

Aggregate Problems

- 17. An asphalt surface mixture is being produced in early March with 10-15 mph winds. The material leaves the plant at 310°F and is checked on the road at 290°F. Breakdown rollers are some distance behind the paver. What is a probable result of placing this mixture?

End of Chapter 2

Any Questions?

Chapter 3

Asphalt Binder

Objectives

- Properties of Binder (AC)
- Previous Grading Systems
- Previous and Current Binder Testing Procedures
- Temperature-Viscosity Relationships

Historical Background

- Shipbuilding in Sumeria (6000 BC)
- Waterproofing, building and paving construction, mummification (2600 BC)
- Road construction (Roman Empire)
- First use of asphalt paving blocks (1824)
- First modern asphalt road (Paris 1858)
- First US road construction (New Jersey 1870)

Nature of Asphalt Binders

- Occur naturally in geological strata
  - Soft asphalt material (e.g., Trinidad Lake, western Canada)
  - Hard, friable, black material in rock formations
- Produced through crude petroleum refining

Definitions

- Bitumen:
  Mixtures of hydrocarbons soluble in carbon disulfide (CS_2)
- Asphalt:
  Dark brown to black cementitious material of solid or semisolid consistency at ambient temperatures in which the predominant constituents are bitumens which occur in nature as such or are obtained as residue by refining petroleum (ASTM D8)

Definitions

- Tar:
  Brown to black bituminous material of liquid or semisolid consistency obtained as condensates by destructive distillation of coal, petroleum, wood, and other organic materials (ASTM D8)

  Note: Bitumen content in coal tars is relatively low compared to petroleum asphalts. Although both tars and asphalts are referred to as bituminous materials, their physical and chemical properties differ greatly.

Crude Oil Classification

- Asphalt based crude
- Paraffin based crude
- Mixed base crude
- Low API Gravity (<25) or Heavy Crudes
- High API Gravity (>25) or Light Crudes
  - API: American Petroleum Institute
  - API Gravity: Density or weight of a unit volume of material expressed at 60°F

Crude Oil Refining

- Heat Exchanger
  - Temperature of crude oil is raised for initial distillation
- Atmospheric Distillation
  - Fractions are separated based on their boiling ranges
  - Lightest compounds vaporize and are drawn off for further processing
- Vacuum Distillation
  - Residuum from the atmospheric distillation is processed into asphalt binder by removing heavier gas oils

Asphalt Production and Classification

- Straight-Run Asphalt:
  Asphalt binder of desirable consistency is produced directly through vacuum distillation
- "Solvent Deasphalting" Process:
  Precipitate (hard) asphalt binder is produced via solvent extraction processing of vacuum residuum
- Air-Blown or Oxidized Asphalts:
  Special application (e.g., roofing, pipe coating) asphalts are produced by blowing air at high temperatures through asphalts of proper consistency

Molecular Structure of Asphalt

- Complex mixture of hydrocarbon groups
  - Aliphatic or Paraffinic
  - Napthenic or Cycloparaffins
  - Aromatic
- Heteroatoms: Sulfur, Oxygen, and Nitrogen
- Percent by weight:

Carbon:	70 - 85%
Hydrogen:	7 - 12%
Sulfur:	1 - 7%
Oxygen:	0 - 5%
Nitrogen:	0 - 1%

Asphalt Binder Composition

- Asphaltenes:
  High molecular weight fraction of asphalt binder. Exhibits strong tendencies to interact and associate into conglomerates.
- Resins:
  Medium molecular weight fraction of asphalt binder. Resins act as agents that peptize asphaltenes, thus providing a balanced and homogeneous system.
- Oils:
  Low molecular weight fraction of asphalt binder. Constitute the dispersion medium of peptized asphaltenes.

Asphalt Binder Types

- Asphalt Binders
  - Solid or semisolid at ambient temperatures
  - Liquefied by heat application
- Emulsified Asphalts
  - Emulsion of asphalt, water, and emulsifying agent
  - Liquid at ambient temperatures
- Cutback Asphalts
  - Blend of asphalt and petroleum solvents
  - Liquid at ambient temperatures

Properties of Asphalt Binders

- Thermoplastic material
- Strong cement with excellent adhesive properties
- Resistant to most acids, alkalies, and salts
- Waterproof
- Durable

Consistency of Asphalt Binders

- Measure of the fluidity of asphalts at any particular temperature
- Asphalt binders were graded based on consistency ranges at a standard temperature
- Old Consistency Tests
  - Penetration (empirical method)
  - Viscosity Tests (scientific method)
  - Softening Point

Penetration Testing (AASHTO T 49 or ASTM D 5)

- Empirical method of determining consistency.
- Penetration testing is usually conducted at 25°C (77°F) which approximates the average in-service temperature of asphalt pavements.
- Penetration is the distance in tenths of a millimeter that a standard needle can penetrate the asphalt binder sample vertically under known loading, timing, and temperature conditions.

Absolute Viscosity Testing (AASHTO T 202 or ASTM D 2171)

- Viscosity is the ratio between applied shear stress and rate of shear and is a measure of the resistance to flow of a liquid.
- Testing is conducted at a constant temperature of 60°C (140°F), which approximates the maximum in-service temperature of asphalt pavements.
- Viscosity at 60°C was used for asphalt binder grading.
- Unit: Poise (P)

Kinematic Viscosity Testing (AASHTO T 201 or ASTM D 2170)

- Ratio of the viscosity to the density of a liquid.
- Measure of the resistance to flow under gravity.
- Testing is conducted at a constant temperature of 135°C (275°F), which approximates the mixing and laydown temperatures used in the construction of HMA pavements.
- Unit: Centistoke (cSt)

Thin Film Oven Test (TFOT) (AASHTO T 179 or ASTM D 1754)

- Accelerated weathering test developed by the Bureau of Public Works (1940).
- Simulates the change in consistency (age hardening) of asphalt binders that takes place in hot mix plants.
- Measure of age hardening resistance of asphalts.
  - Loss of weight following TFOT
  - Penetration and viscosity changes following TFOT

Additional Asphalt Tests

- Rolling Thin Film Oven Test
  - Accelerated weathering test.
  - Variation of the TFOT used by highway agencies in the western US.
- Ductility Test
  - Measure of the adhesiveness and elasticity of asphalt binders.
  - Defined as the distance an asphalt briquette specimen stretches before breaking when the two ends are pulled apart at a specified rate of speed under standard temperature conditions.

Asphalt Binder Grading (Old Methods)

- Penetration grading (ASTM D 946)
  - Old, empirical method
  - Five standard grades: 40-50, 60-70, 85-100, 120-150, 200-300
- Absolute viscosity grading (ASTM D 3381)
  - Grading based on original asphalt binder
  - Viscosity grades: AC-2.5, AC-5, AC-10, AC-20, AC-30, AC-40
- AR absolute viscosity grading (ASTM D 3381)
  - Grading based on residue from the rolling thin film oven test
  - Viscosity grades: AR-1000, AR-2000, AR-4000, AR-8000, AR-16000

Asphalt Binder Grading

- Now we use “Performance Graded” asphalt binders.
- The grade of asphalt binder to be used is based on the environment where it is going to be used.
- This topic will be covered in greater detail soon!!

New Binder Test Methods

- Rotational Viscosity
- Dynamic Shear Rheometer
- Bending Beam Rheometer
- Direct Tension Test
- Binder Aging Procedures
  - Rolling Thin Film Oven Test (short term)
  - Pressure Aging Vessel (long term)

Viscosity Testing

- Viscosity is a measure of the resistance to flow.
- In the past, we used absolute and kinematic viscosities.
- Absolute viscosity
  - Measured at 140°F
  - Simulated "maximum" temperature that the asphalt mixture would see in the field
  - Measured in units called Poises (P)

Viscosity Testing

- Kinematic viscosity
  - Measured at 275°F
  - Simulated average compaction temperature of an asphalt mixture
  - Measured in units of centistokes (cSt)

New Method for Determining Viscosity

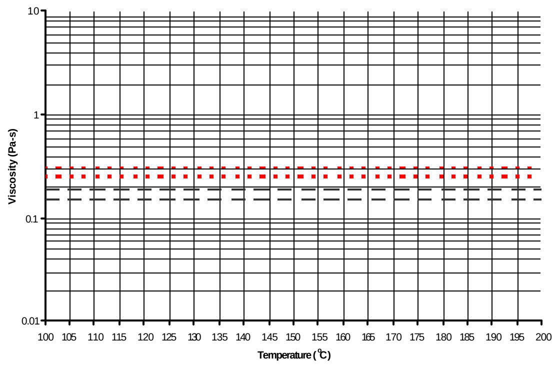
- Viscosities are now measured using a rotational viscometer.
- Samples are tested at 135℃ and 165℃.
- Measuring the torque required to rotate a spindle in the sample at a given speed (rpm).
- Measured in units of centiPoises (cP).

Brookfield Rotational Viscometer

Spindles and Test Tubes

Temp-Viscosity Chart

- Chart is in units of Pa-s.
- Must convert our results from rotational viscometer from cP to Pa-s.
- To do this, we divide the cP by 1000.
- So, 350 cP would be 0.35 Pa-s.



Temp-Viscosity Chart

- Our objective is to determine the "ideal" mixing and compaction temperatures for our asphalt binder. Procedure is the same as it was before.
- Mixing temperatures correspond to 0.15 to 0.19 Pa-s.
- Compaction temperatures correspond to 0.25 to 0.31 Pa-s.

SHRP Binder Grading

- Now we use performance graded (PG) binders.
- New binder specifications are performance based.
- Physical property requirements for the binder are the same, but the requirements for the geographic areas in which the binder is expected to serve have changed.

SHRP Binder Grading

- Binder is selected based on climate and pavement temperature.
- For the geographic area that a binder is to serve, the binder grade must meet the performance requirements in order to prevent the following:
  - Rutting
  - Fatigue Cracking
  - Low Temperature Cracking

PG Graded Binders

- PG graded binders include both a high and low temperature grade.
- In SC, PG 64-22 is primarily used.
  - 64°C: The binder will have adequate physical properties at temperatures up to 64°C.
  - -22°C: The binder will have adequate physical properties at temperatures as low as -22°C.

PG Graded Binders

- High Temperature Grade:
  - Measured at 20 mm below the surface of the mix. Why? Rutting.
  - Seven-day consecutive temperature.
- Low Temperature Grade:
  - Measured at the surface of the mix. Why? Low temperature cracking.
  - Minimum one-day temperature.

Binder Selection

- How do we select a binder grade for a given location?
- Need weather information for that area.
- Over 6500 weather stations across the US and Canada.
- Historical data was reviewed.
  - Highest 7-day temperature
  - Lowest temperature

Binder Selection

- Air temperature vs. pavement temperature.
  - Superpave software calculates the pavement temperature based on air temperature (for high temperature grade). No adjustments needed for low temperature grade.
- Reliability techniques are then used to decide on the proper binder grade.
- Based on the probability of not exceeding the high or low temperature grades.

SHRP Binder Grades

High Temp. Grade	Low Temp. Grade
PG 46	-(34, 40, 46)
PG 52	-(10, 16, 22, 28, 34, 40, 46)
PG 58	-(16, 22, 28, 34, 40)
PG 64	-(10, 16, 22, 28, 34, 40)
PG 70	-(10, 16, 22, 28, 34, 40)
PG 76	-(10, 16, 22, 28, 34)
PG 82	-(10, 16, 22, 28, 34)

Effect of Loading Rate

- Use binder with more stiffness at higher temperatures (higher high temperature grade).
  - Slow moving loads increase by one high temperature grade.
  - Stationary loads increase by two high temperature grades.
  - No effect on the low temperature grade.

Effect of Loading Rate (Examples)

Toll Road	PG 64-22
Toll Booth	PG 70-22
Rest Area	PG 76-22

Polymerized Asphalt Binders

- Binders are considered to be polymer modified binders when the high temperature grade is 76°C or higher.
- Polymer: Material added to the binder to enhance its physical properties.
- Examples of polymers used in asphalt binders: plastics, rubber

End of Chapter 3

Any Questions?

Chapter 4

Marshall Method of Mix Design

Hot Mix Asphalt (HMA) Mix Design Methods

- Marshall
  - The US Army Corps of Engineers developed mix design criteria based on the original concepts formulated by Bruce Marshall, Bituminous Engineer with the Mississippi State Highway Department.
- Hveem
  - The original concepts of this method were formulated and advanced by Francis N. Hveem, Research Engineer with the California Department of Transportation.

Mix Design Objective

- The purpose of mix design is to determine the optimum combination of asphalt binder and aggregate that will provide a durable asphalt pavement which can perform well under a variety of loading and environmental conditions.

Mix Design Process

- Select aggregate source
  - Must meet aggregate requirements such as:
    - Los Angeles Abrasion
    - Sand Equivalent
    - Specific Gravity
    - Absorption
    - etc.
- Develop aggregate blend that will meet the specifications

Mix Design Process

- Dry aggregates to a constant weight (105°C to 110°C).
- Sieve and separate aggregates into the desired size fractions (1/2”, 3/8”, etc.).
- Prepare “pans” according to your aggregate blend.

Aggregate Pan Preparation

- Total aggregate weight: 1140-1160 grams
- Want an aggregate weight that will yield a 2.5" thick asphalt sample.
- Hydrated Lime: Add 1% by total weight of aggregate (this must be included in your aggregate blend)
- Water: 5% by total weight of aggregate

Asphalt Binder Selection

- Must determine which grade of binder to use.
- For Marshall mixtures in SC, use PG 64-22.
- Measure rotational viscosity at 135°C and 165°C.
- Additional binder tests:
  - Dynamic Shear Rheometer
  - Bending Beam Rheometer

Mixing and Compaction Temperature of the Asphalt Mix

- Mixing temperature
  - Asphalt binder should be heated to a viscosity range of 0.17 ± 0.20 Pa-s.
- Compaction temperature
  - Asphalt binder should be heated to a viscosity range of 0.28 ± 0.30 Pa-s.

Preparation of Marshall Samples

- Determination of Optimum Binder Content
  - Four binder percentages at 0.5% increments
  - Two percentages above and two below the expected optimum binder content
  - Minimum of two Marshall samples for each binder content
  - Minimum of eight samples for each mix design series

Preparation of Marshall Samples

- Prepare a minimum of eight aggregate pans (~1140 grams).
- Heat aggregate pans to a temperature not to exceed 50°F above the mixing temperature range.
- Heat binder to mixing temperature range.

Preparation of Marshall Samples

- Asphalt binder should be used within one hour after reaching mixing temperature.
- Determine the weight of binder, by total weight of the mix, required to obtain each desired binder content.
- Molds, spoons, mixing bowls, spatulas, and compaction hammer to a temperature of 200°F to 300°F.

Preparation of Marshall Samples

- Charge mixing bowl with heated aggregate and pre-determined amount of binder.
- Mixing temperature should be within the established range.
- Mix the aggregate and binder quickly and thoroughly until all aggregate particles are evenly coated with binder.
  - Mechanical mixer
  - Hand mixing

Preparation of Marshall Samples

- Place a paper disc in the bottom of the mold.
- Pour entire batch into the mold.
- Tamp the mixture vigorously with a heated spatula.
  - 15 times around the perimeter
  - 10 times in the middle
- Smooth mix to a rounded shape.
- Place a paper disc on top of the mix.

Preparation of Marshall Samples

- Temperature of the mix should be within the compaction temperature range.
  - Allow sample to cool if temperature is too high.
  - Discard sample if temperature is too cool.
  - Do not reheat the mix.
- Place charged mold on the compaction pedestal.
- Position compaction hammer vertically into the mold.

Preparation of Marshall Samples

- Apply 50 or 75 blows to the top surface of the sample as specified by the design traffic category.
- Reverse mold and apply the same number of blows to the reverse face of the sample.
- After compaction, remove collar, base plate, and paper discs. Label sample with a wax crayon.
- Allow sample to cool in air (fans can be used in this process).

Preparation of Marshall Samples

- When samples can be handled without gloves, extrude samples from molds using a hydraulic jack.
- Allow samples to continue to cool until they reach room temperature (77°F).
- All samples will be tested as follows:
  - Bulk Specific Gravity determination
  - Stability and Flow testing
  - Determination of volumetric properties

Bulk Specific Gravity Testing

- Conduct BSG testing on samples after they have reached room temperature (77°F).
- Follow AASHTO T 166 procedures.
- Average BSG values of all samples at the same binder content.
- Samples at the same binder content must be within ± 0.020 of one another.

Marshall Stability and Flow

- Immerse samples in a hot water bath (140°F ± 1.8°F) for 30 to 40 minutes.
- Remove sample from water bath and dry surface.
- Place sample in the center of the breaking head.
- Position breaking head in the center of the testing apparatus.
- Apply load at a rate of 51 mm (2 inches) per minute until sample fails.
- Testing must be completed within 30 seconds of removing sample from hot water bath.

Marshall Stability and Flow

- Stability
  - Maximum load resistance in pounds (Newtons).
  - Must correct stability for samples that are not 2.5 inches in height by using a correction factor.
- Flow
  - Total movement, or strain, measured in units of .01 inches (0.25 mm), occurring during stability testing between points of no load and maximum load.

Rice (Maximum) Specific Gravity

- Prepare two aggregate pans identical to those batched for determination of optimum binder content.
- Samples are mixed at the highest binder content.
- Follow AASHTO T 209 procedures.
- MSG samples must be within ± 0.018 of one another.
- Use MSG values to calculate Effective Specific Gravity (ESG) of the aggregate.
- The calculated ESG value is used to determine MSG values at binder contents other than the binder content chosen for mixing MSG samples.

Volumetric Properties

- Mixture volumetric properties must be calculated.
- Called volumetric properties because we are dealing with volumes (air, aggregate, binder).
- Definitions and equations follow.

Definitions

- Voids in Mineral Aggregate (VMA): The volume of void space between the aggregate particles of a compacted asphalt mixture. In other words, VMA is the air voids and the effective asphalt binder.
- %VMA = %Binder by Volume + %Air Voids

Definitions

- Air Voids (or Voids in Total Mix):
  - The total volume of small pockets of air between the aggregate particles (coated with binder) expressed as a percent of the total volume of the mix.
  - Usually, the % Air Voids is in the range of 3% to 7%.

Definitions

- Voids Filled with Asphalt (VFA):
  - The percent of the VMA that consists of asphalt binder.
- In order to calculate the %VMA, %VFA, and %Air Voids, the following must be known:
  - BSG of the mix
  - MSG of the mix
  - SG of the binder

Effective Specific Gravity of Aggregate

$$ESG = \frac{100 - \%Binder}{\frac{100}{MSG} - \frac{\%Binder}{SGofBinder}}$$

Maximum Specific Gravity of the Mixture

$$MSG = \frac{100}{\frac{\%Binder}{SGofBinder} + \frac{\%Agg}{ESG}}$$

Density and Air Voids

- Density or Unit Weight:
  - Density = BSG * 1.0 kg/m³ (or 62.4 lbs/ft³)
- % Air Voids:

$$\%AV = \frac{MSG - BSG}{MSG} * 100$$

VMA Calculations

- %VMA = % Binder by Volume + % Air Voids
  - % Binder by Volume = $\frac{\%Binder * BSGofMix}{SGofBinder}$
- % VFA = $\left(\frac{\%BinderbyVolume}{\%VMA}\right)*100$

Volumetric Calculations

- Must calculate the following at each binder content:
  - % Air Voids
  - % VMA
  - % VFA
- Use formulas given in the previous slides.

Interpretation of Results

- Plot “best fit” curves for all mix properties.
  - Binder Content vs. % Air Voids
  - Binder Content vs. % VMA
  - Binder Content vs. % VFA
  - Binder Content vs. Stability
  - Binder Content vs. Flow
  - Binder Content vs. Density

Optimum Binder Content

- The optimum binder content is the average of three binder values determined as listed below:
  - Binder Content vs. % Air Voids (4.0% Air)
  - Binder Content vs. % Air Voids (4.5% Air)
  - Binder Content vs. % VFA (75% VFA)

Now What??

- Must check all mix properties at the optimum binder content to see if the mix design meets the specifications. If not, must re-design mix.
  - Air Voids
  - Binder Content
  - VMA
  - VFA
  - Stability
  - Flow
  - Dust to Binder Ratio

Indirect Tensile Strength Testing

- Test has different names.
  - Indirect Tensile Strength (ITS)
  - Moisture Susceptibility
  - Tunnicliff and Root
  - Stripping Test
- Need to ensure that the mix will not incur moisture damage.

ITS Testing

- Need to batch a minimum of four aggregate pans (same size as for Marshall testing).
- Samples are mixed at the optimum binder content.
- Air void requirements are 6% to 8%. This is done to simulate the in-place density of the asphalt mixture.
- To achieve this, we must apply fewer blows per side.

ITS Testing

- BSG, MSG, and Air Voids must be determined for all samples.
- BSG rules still apply (± 0.020)
- Need to group samples into our “Dry” subset and “Wet” subset.
- Average the highest and lowest air voids, then average the two middle values.

ITS Testing

- Grouping samples: an example

Sample 1	6.6% Air	6.7% Avg.
Sample 2	6.8% Air	
Sample 3	6.3% Air	6.6% Avg.
Sample 4	6.9% Air	

- High average is our "Dry" set.

ITS Testing

- Dry samples are set aside.
- Wet samples are saturated to 55% to 80% by using a vacuum.
  - If saturation is less than 55%, apply vacuum again.
  - If saturation is greater than 80%, sample must be thrown away.
- After saturation, Wet samples are placed in the hot bath (140°F) for 24 hours.

ITS Testing

- After 24 hours in the hot bath, Wet samples are placed in the cold bath (77°F) for 1 to 2 hours.
- Dry and Wet samples are then broken using the Stability loading machine, but using a different breaking head.
- ITS breaking head has bars along the top and bottom.
- The bars force the sample to break as if loaded in tension, thus the reason why it is called Indirect Tensile Strength.

ITS Testing

- Peak load for each sample is used to calculate the sample's strength.
- Dry and Wet Tensile Strengths are calculated.
- Tensile Strength Ratio (TSR) is calculated.
- TSR = $\frac{WetTS}{DryTS} * 100\%$

ITS Testing

- Requirements:
  - Wet Tensile Strength = 65 psi
  - Tensile Strength Ratio = 85%
- If requirements are not met:
  - May want to make more samples if values are close to the requirements.
  - If requirements still cannot be met, the mix must be re-designed.

End of Chapter 4

Any Questions?

Chapter 5

Introduction to Superpave Mix Design

Chapter 4: Contents

- Materials Selection
- Terminologies Used
- Mix Design Procedure
- Gyratory Compactor

Materials Selection

- Must select an aggregate source that will meet the consensus property and source property requirements.
- Certain other restrictions may apply:
  - No gravel or natural sands can be used (SCDOT specifications)
  - Use of RAP (depends on type of mix per SCDOT specifications)

Materials Selection

- Select an appropriate grade of binder. This will be listed in the contract documents.
- Binder must meet the requirements of AASHTO M xxx.

SHRP Terminologies

- Specific gravities are written out differently (no longer say BSG or MSG).
- G_{mm}: Rice (Maximum) SG
- G_{mb}: Bulk SG of mixture
- G_{se}: Effective SG of aggregate
- G_{sb}: Bulk SG of aggregate
- G_{b}: SG of binder

SHRP Terminologies

- There are three levels of compaction for Superpave mixtures. Values for the number of gyrations can be found in:
  - Contract documents (specifications)
  - FHWA manual

SHRP Terminologies

- Three levels of compaction:
  - $N_{initial}$: Represents compaction after the mix is placed by the paver.
  - N_{design}: Represents compaction after rolling is completed.
  - $N_{maximum}$: Represents compaction at the end of the pavement design life.

Superpave Mix Design

- After selection of materials, the mix design can commence.
- Select an aggregate blend that will meet the gradation specifications.
- Hydrated Lime must be used at a rate of 1% by dry aggregate weight.

Superpave Mix Design

- Minimum of 16 aggregate pans must be batched.
  - 10 pans of 4500-4700 grams
    - 8 for N_{design}
    - 2 for $N_{maximum}$
  - 2 pans at 1500-2000 grams for G_{mm}
  - 4 pans at 1140-1160 grams for ITS
- Remember to mix in 5% water by total aggregate weight.

Superpave Mix Design

- Aggregate pans need to be heated at no more than 50°F above mixing temperature.
- Molds, mixing bowl, spoons, etc. should be heated to 200°F to 300°F.
- Binder should be heated to mixing temperature (should not be heated for more than an hour before it is used).

Superpave Mix Design

- The 8 N_{design} and 2 G_{mm} batches should be mixed first.
- 8 N_{design} samples: 2 samples at 4 binder percentages.
- Two binder percentages should be above and two should be below the expected optimum binder content.
- 2 G_{mm} samples: mixed at highest binder percentage.

Superpave Mix Design

- Determine the correct amount of binder to add.
- N_{design} samples should be mixed with a mechanical mixer.
- After mixing each sample, it is cured in the oven for 2 hours at the compaction temperature (G_{mm} samples are not).
- Mix needs to be spread out on non-absorptive paper in a large sized pan (there are specifications on the size of the pans to use).

Superpave Mix Design

- Should wait 10 minutes before mixing the next sample.
- After 2 hours in the oven, samples can be compacted in the gyratory compactor.
- Mix is placed in the heated mold (paper disc on bottom). No tamping necessary. Check mix temperature.

Superpave Mix Design

- When sample is within compaction temperature range, place sample in gyratory compactor and begin compaction (paper disc on top).
  - If sample is too hot, allow it to cool.
  - If sample is too cold, throw it away.
  - Samples cannot be reheated.

Superpave Mix Design

- After sample is compacted, it can be removed from the mold instantly.
- Allow samples to cool to room temperature (77°F). This will take a while.
- Perform G_{mb} testing on samples according to AASHTO T 166.

Superpave Mix Design

- Perform G_{mm} testing according to AASHTO T 209.
- Average G_{mb} values at each binder content.
- Determine G_{mm} values at each binder content using G_{se}.
- Using height information (from gyratory compactor printout), determine corrected G_{mb} at $N_{initial}$.

Superpave Mix Design

- Determine volumetric properties:
  - $\%G_{mm}$ at $N_{initial}$ (air voids)
  - $\%G_{mm}$ at N_{design} (air voids)
  - % VMA
  - % VFA

Superpave Mix Design

- Draw "best fit" graphs:
  - Binder Content vs. % Air Voids
  - Binder Content vs. % VMA
  - Binder Content vs. % VFA
  - Binder Content vs. $\%G_{mm}$ at $N_{initial}$
- Optimum binder content is at 4% Air Voids.

Superpave Mix Design

- Check other mix properties at optimum binder content to see if mix meets specifications.
- If mix does not meet the specifications, try another aggregate blend.
- If mix meets the specifications, the mix design process can continue.

Superpave Mix Design

- Mix 2 $N_{maximum}$ samples at the optimum binder content.
- Samples are mixed, compacted, and tested in the same manner as the N_{design} samples.
- For these samples, only one criteria is of concern: $\%G_{mm}$ at $N_{maximum}$ = 98%.

Superpave Mix Design

- If the mix does not meet the compaction requirements at $N_{maximum}$, try another aggregate blend.
- If the specification is met, ITS samples can be mixed.
- ITS samples are mixed at the optimum binder content.

Superpave Mix Design

- Samples are mixed and compacted in the same manner as for a Marshall mix design. All ITS requirements for a Superpave mix design are the same as for a Marshall mix design (see ITS testing in Chapter 4).
- If mix does not meet ITS requirements, try another aggregate blend.

Gyratory Compactor

- Texas used it. French operational characteristics were added.
- Samples are 150 mm in diameter.
- Samples are up to a 37.5 mm (1.5 inch) nominal maximum aggregate size.
- Gyratory compactor is able to record the height of the sample at each gyration.

Gyratory Compactor Components

- Reaction frame (rotating base)
- Loading system (ram)
- Molds
- Calibration devices
- Printer
- Control panel

Pine Gyratory Compactor

Troxler Gyratory Compactor

Gyratory Compactor Calibrations

- Sample height
  - Calibration kit includes a "dummy sample" that is precision milled to a known height.
- Ram pressure
  - Calibration kit includes a load cell that can determine the ram pressure.
- Gyration angle
  - Calibration kit includes a digital micrometer. Using the length measured, the gyratory compactor can calculate the angle. Note: You will need a heated sample to run this calibration.
- Rotational speed
  - The gyratory compactor can calculate the speed at which it operates.

Gyratory Compactor

- Compaction pressure of 600 kPa (roughly 87 psi)
- Samples are compacted at an angle of 1.25°. This simulates the angle created as the roller wheel passes any given location on the mat.
- Gyratory compactor operates at a speed of 30 gyrations (revolutions) per minute. The Marshall hammer operates at 1 blow per second.

End of Chapter 5

Any Questions?

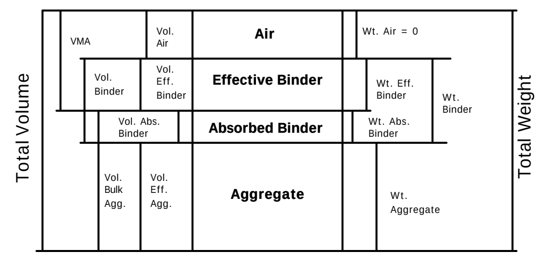
Chapter 6

Asphalt Mixture Volumetrics

SHRP Terminologies

- Specific gravities are written out differently (no longer say BSG or MSG).
- G_{mm}: Rice (Maximum) SG
- G_{mb}: Bulk SG of mixture
- G_{se}: Effective SG of aggregate
- G_{sb}: Bulk SG of aggregate
- G_b: SG of binder

Block Diagram



Calculations

- Need to get volumes of air, binder, and aggregate to find the volumetric properties.
- We use the definition of Specific Gravity to get an equation.
- SG = $\dfrac{Weight}{Volume * g_{water}}$

  where g is the density of water (62.4 lbs/ft³ or 1.0 kg/m³).

Calculations

- We can rearrange the equation to solve for a volume, or to solve for a weight.
- Volume = $\dfrac{Weight}{SG * 1 (or\ 62.4)}$
- Weight = Volume * SG * 1 (or 62.4)

Volumetric Calculations

- Once all volumes are calculated, volumetric properties can be determined.
- % Air Voids = $\dfrac{V_{Air}}{V_{Total}} * 100\%$
- % VMA = $\dfrac{V_{Air} + V_{Eff.Binder}}{V_{Total}} * 100\%$

Volumetric Calculations

- % VFA = $\dfrac{V_{Eff.Binder}}{V_{Air} + V_{Eff.Binder}} * 100\%$
- Time for an example problem.
  - G_{mb} = 2.377
  - G_b = 1.032
  - % binder = 5.5%
  - G_{sb} = 2.659
  - G_{se} = 2.671
  - Determine: % Air Voids, % VMA, % VFA, % Effective Binder
  - Bonus: What is the G_{mm} value??

Volumetric Calculations

- Another example problem:
  - G_{mb} = 2.388
  - G_b = 1.034
  - % binder is 5.3%
  - G_{sb} = 2.663
  - G_{se} = 2.677
  - Find: % Air Voids, % VMA, % VFA, % Effective Binder
  - Bonus: What is the G_{mm} value?

End of Chapter 6

Any Questions?