58th Annual Asphalt Paving Conference

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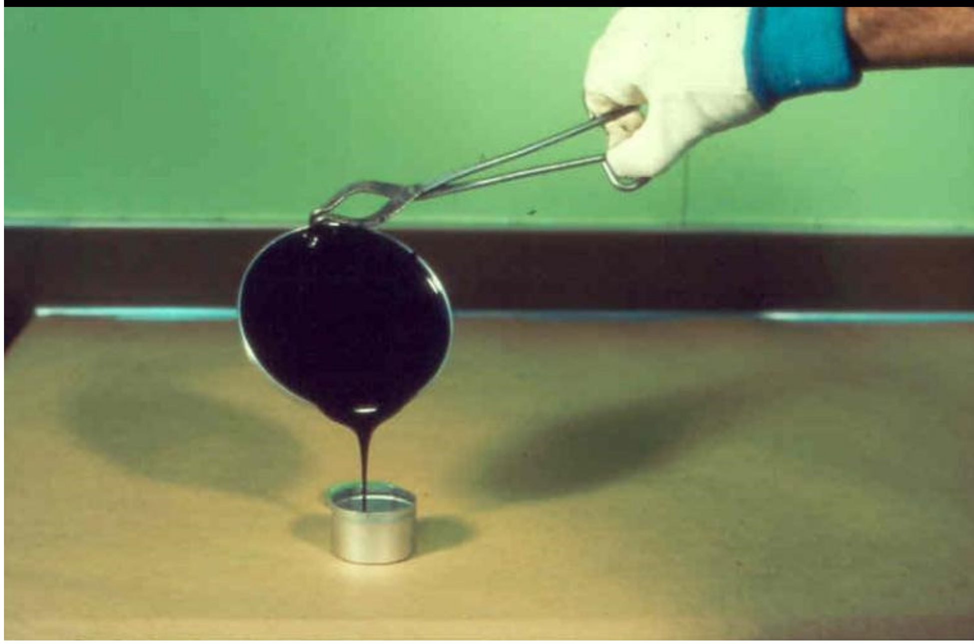
"Asphalt! Your Key to Savings, Performance and Sustainability"

March 18-19, 2014
Soaring Eagle Casino & Resort
Mt. Pleasant, Michigan

The 3 A's of Hot Mix Asphalt



Asphalt (binder), **Aggregates,**

and Air

HMA = Asphalt + Aggregates + Air

Mix Design Objective

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"…to determine the combination of asphalt cement and aggregate that will give long lasting performance…"

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

Mix Design Goals
Balancing Act

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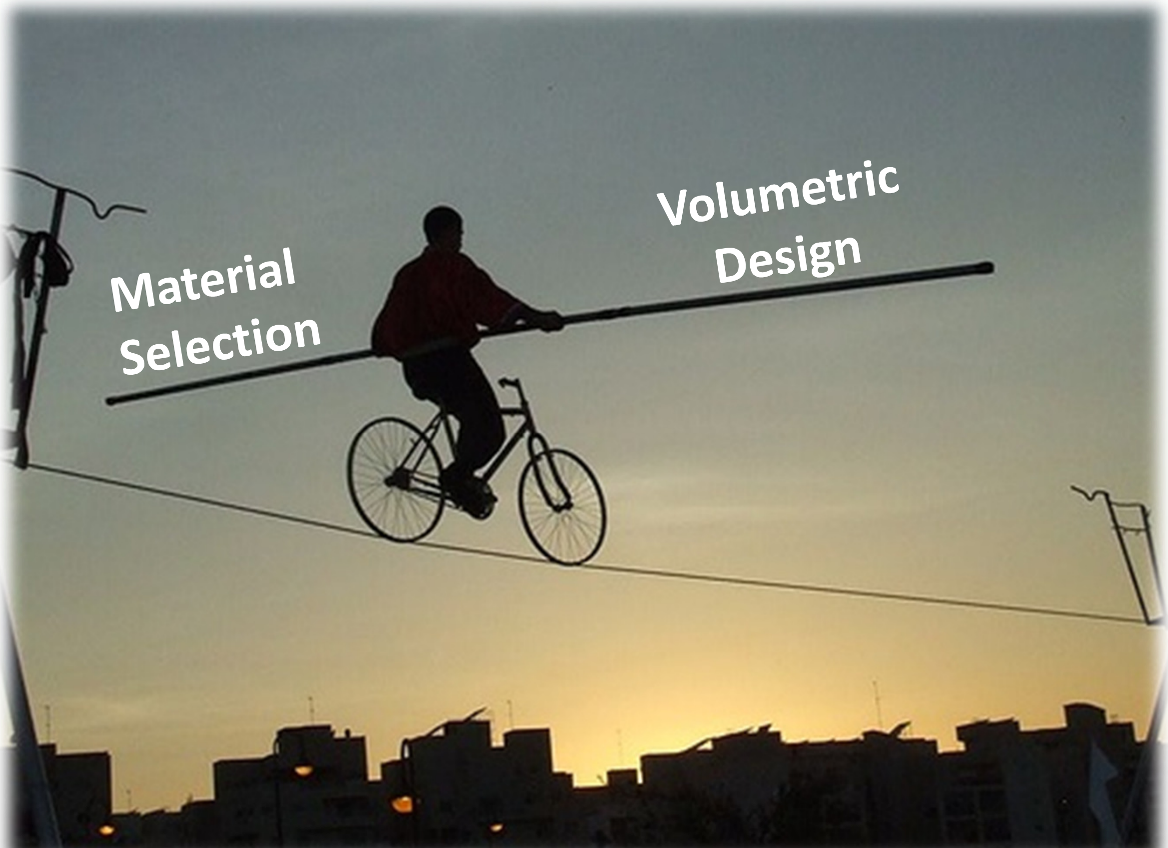
Smooth Quite Ride

Strength & Stability

No
- Rutting
- Shoving
- Flushing

Workability



Durable

No
- Cracking
- Raveling

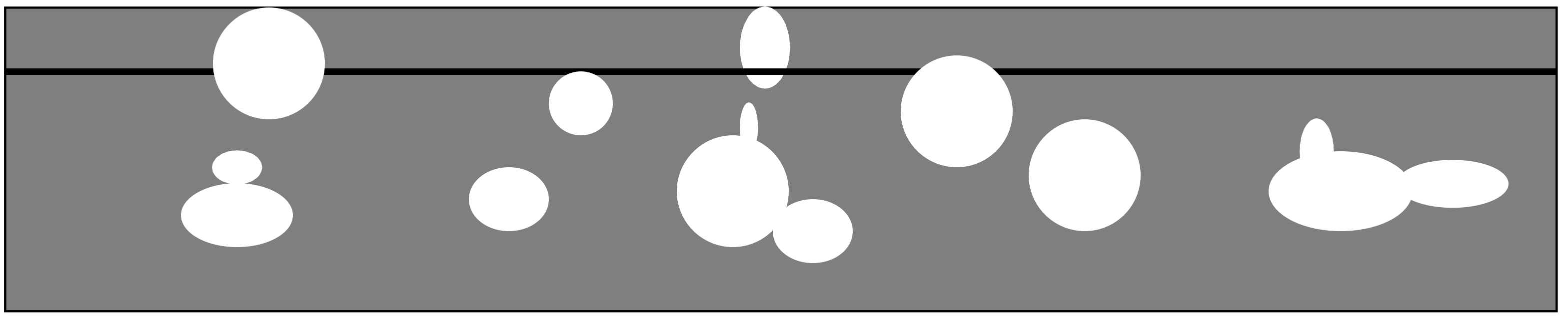
Skid Resistance

Hot Mix Asphalt Compaction

Field performance has shown air voids:

- **Below 3% are susceptible to rutting & shoving**
- **Over 5% are susceptible to raveling, oxidation**
- **4% air voids typically allows for optimal design**
    - **Not too open**
    - **Little extra compaction under traffic**

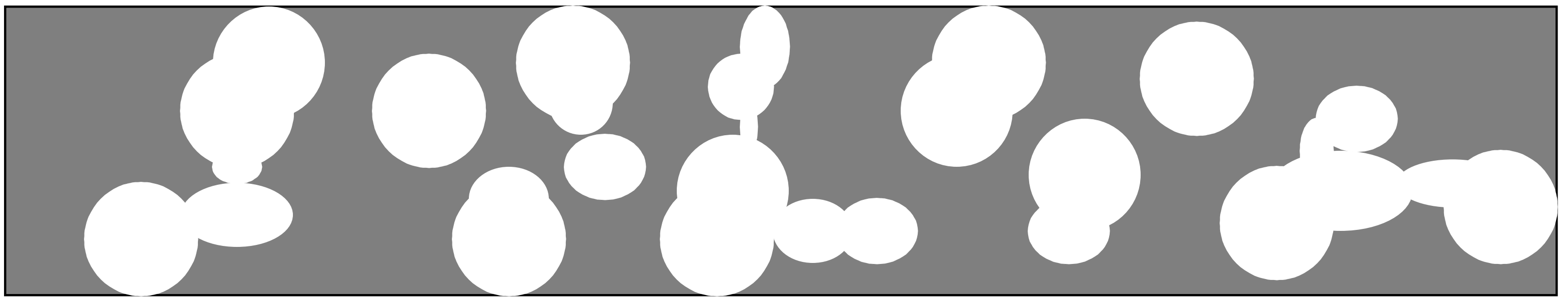
Hot Mix Asphalt Compaction



Air Voids $\leq$ **7 or 8%**

Mix generally not permeable

Hot Mix Asphalt Compaction



Air Voids > 10%

Mix generally permeable

Effect of In-Place Voids on Life

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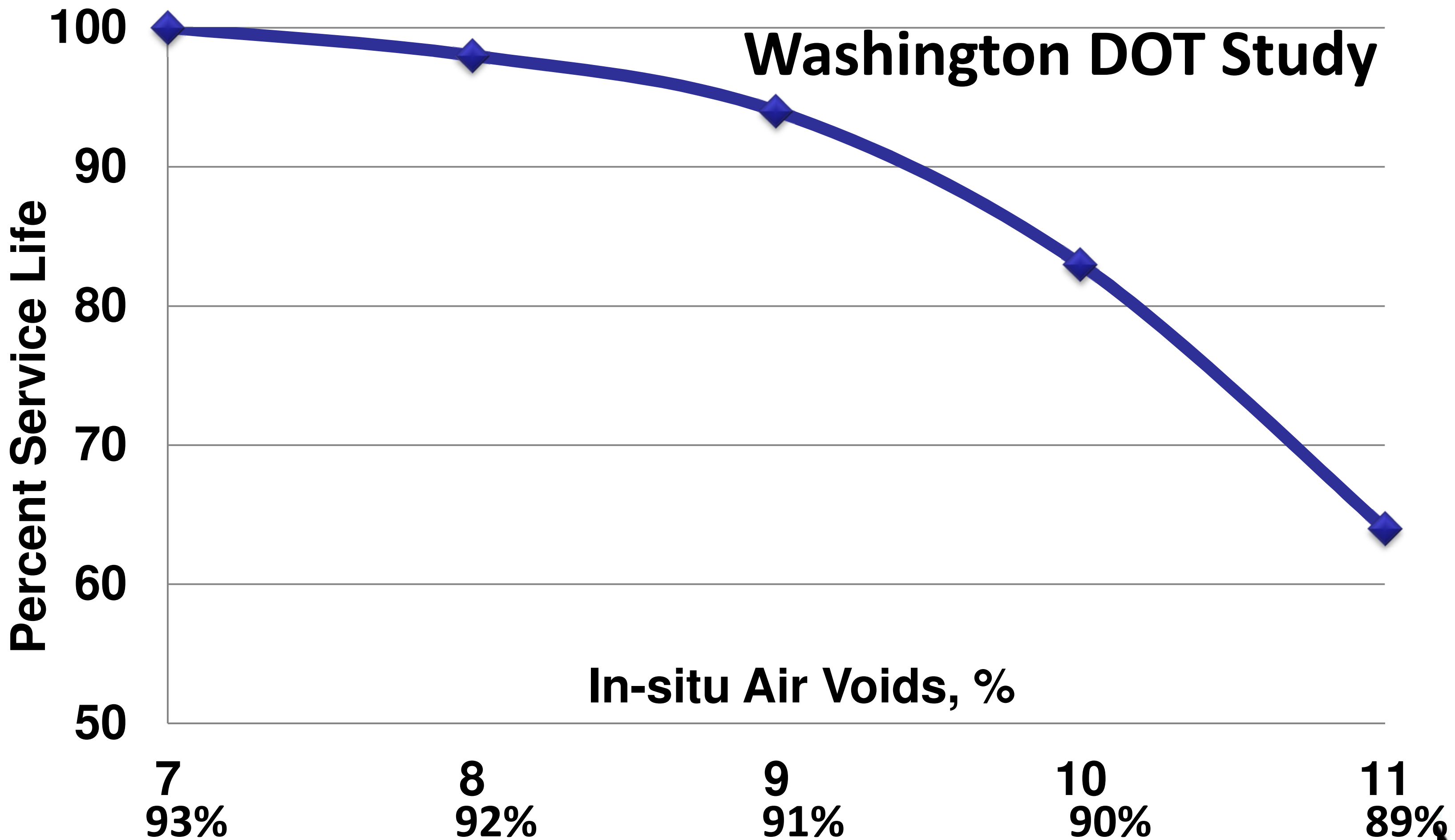
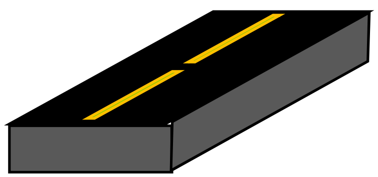


Intent of Laboratory Compaction?

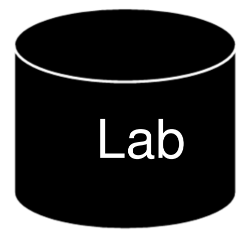
Simulate the in-place density of HMA after it has endured several years of traffic in the roadway

In-place Density



Future Traffic

Design Density



Air Voids

15-25% Before Rolling

6 – 9% After Rolling

Air Voids

3 – 5% Marshall

4% Superpave

Clarification of Terms

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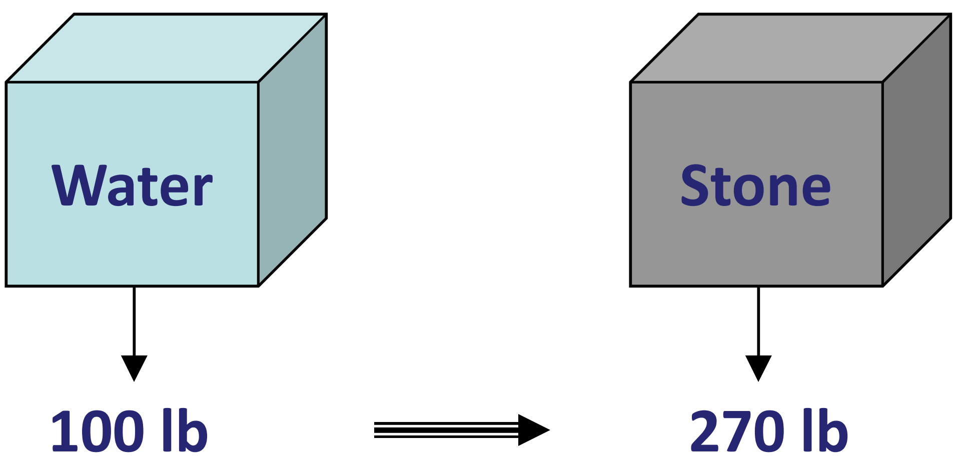
- Density: weight per volume (i.e. 140 pcf)
- Percent Relative Compaction:
  - Comparing a measured density to a target density
  - i.e. in place density of 94% TMD
- All industries have jargon
  - Shorthand to simplify communications
- Density is asphalt industry jargon
  - For percent relative compaction
  - i.e. 94% density really means 94% TMD

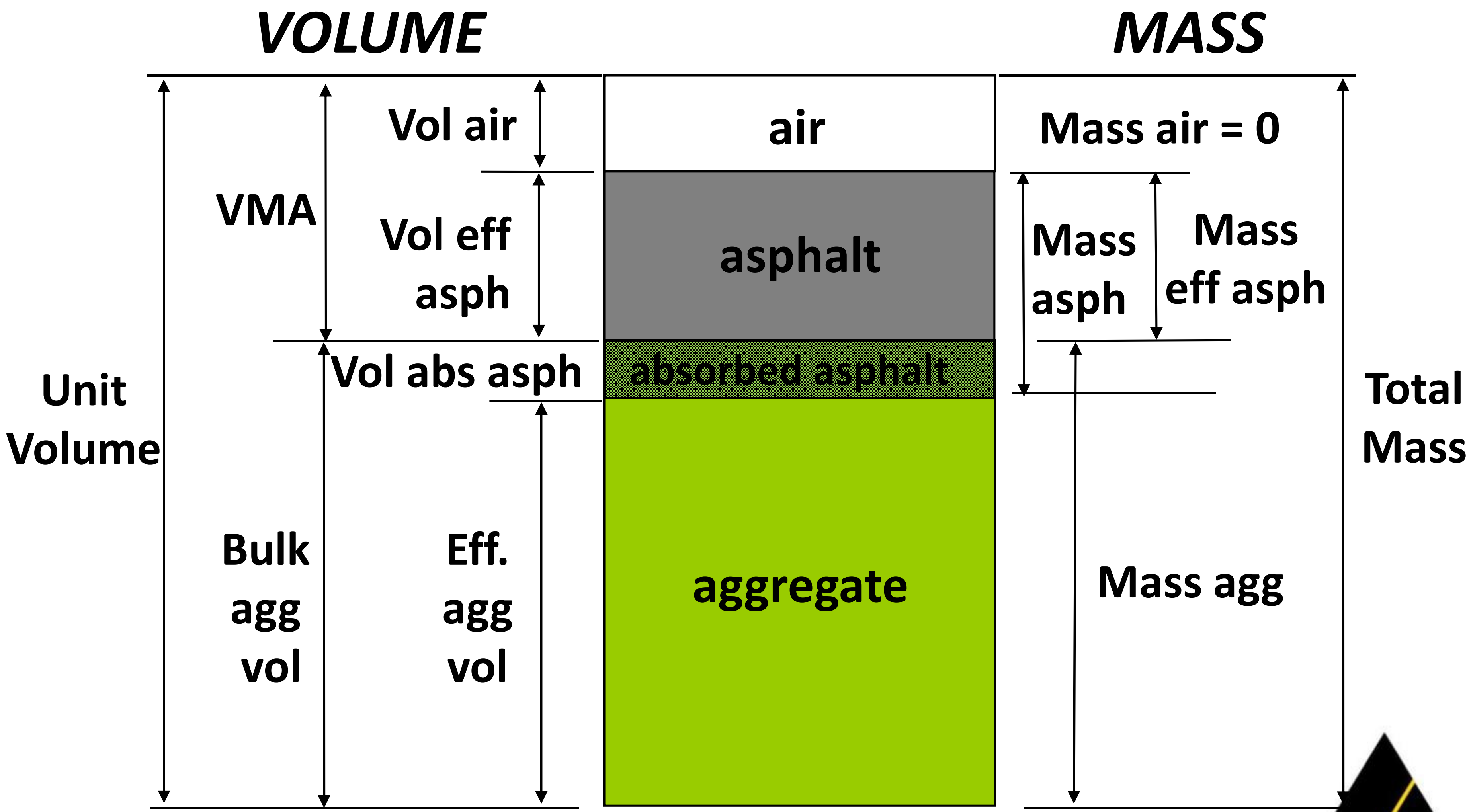
Specific Gravity

- Ratio of a material's weight to the weight of an equal volume of water
  - Dimensionless number (no units attached)

Specific Gravity = 2.70 means that the rock weighs 2.70 times an equal volume of water

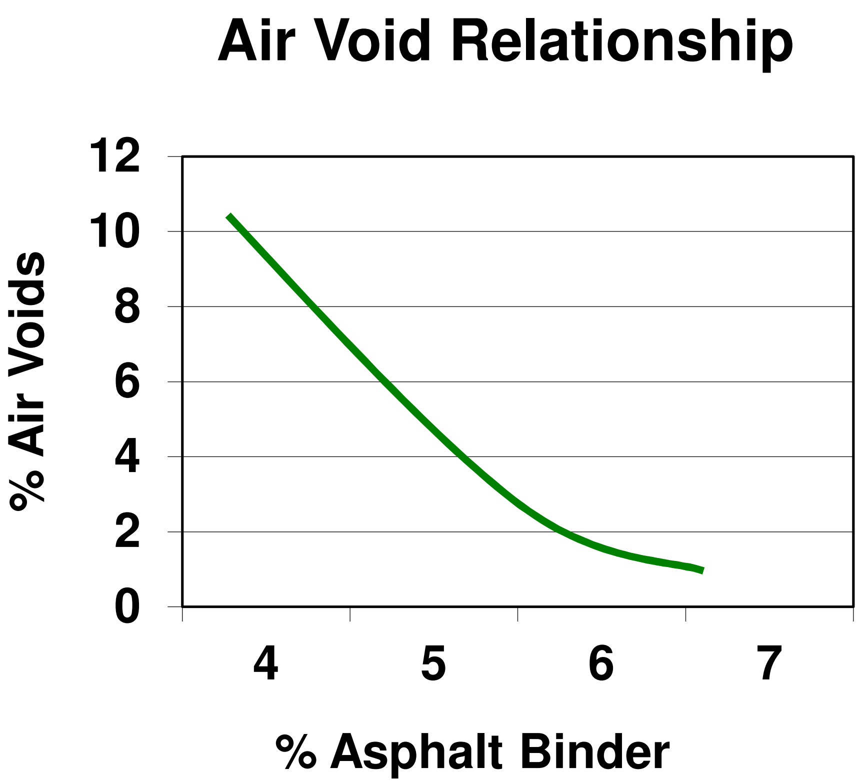


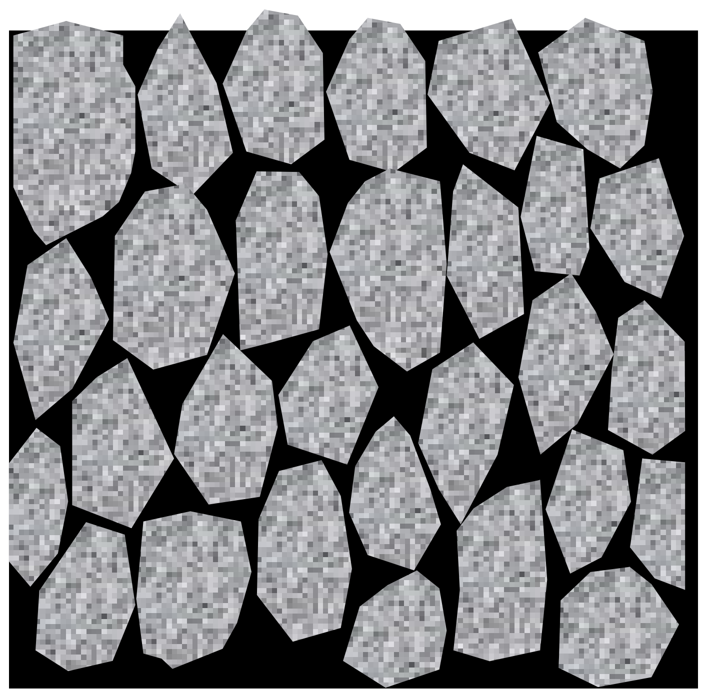
Component Diagram



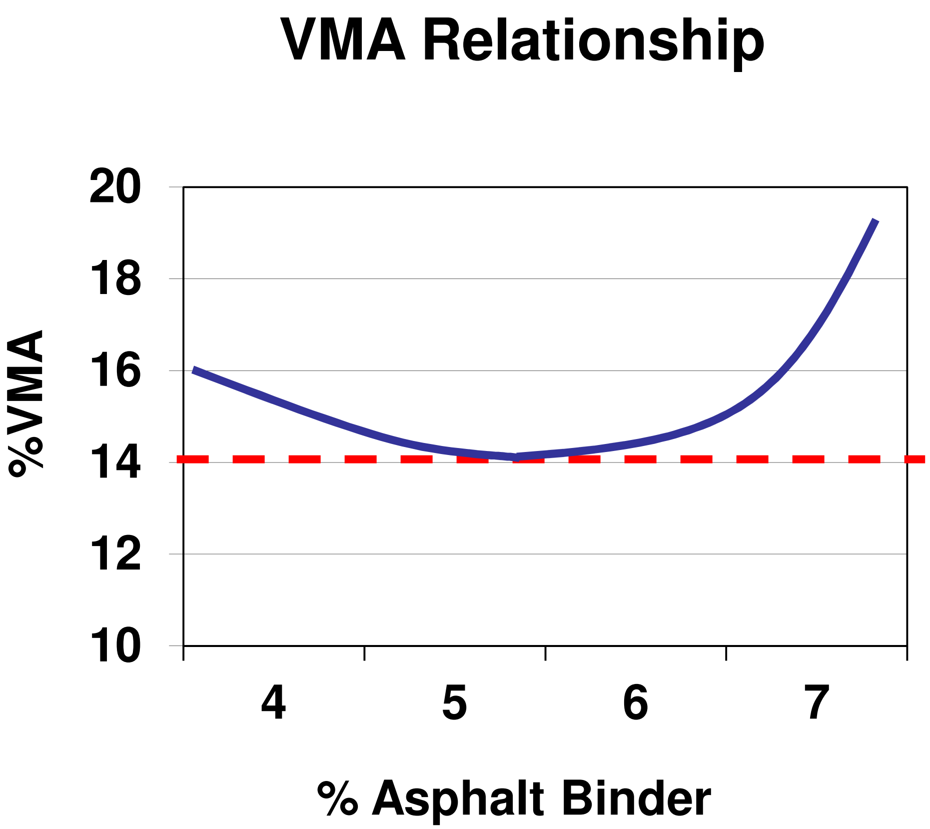
SP-2, Fig. 4.2

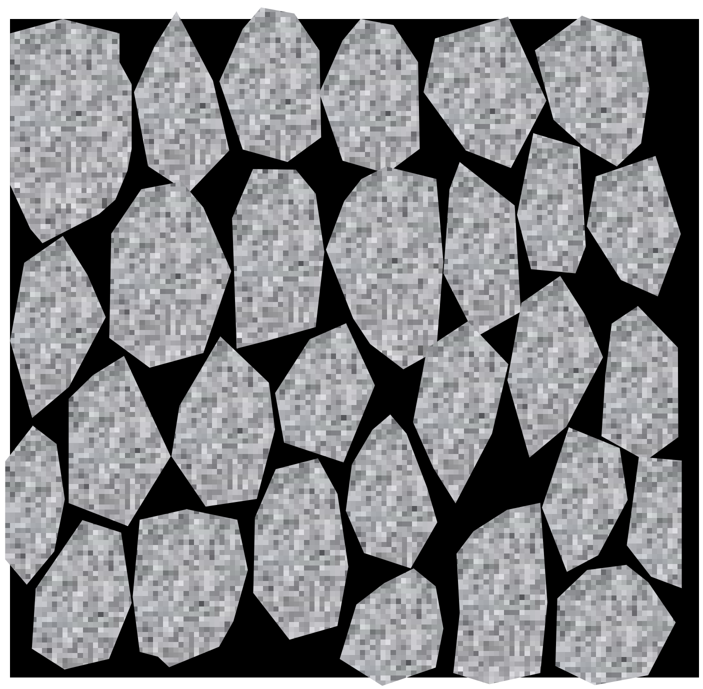
Air Voids


Air Void Relationship
12
10
8
6
4
2
0
% Air Voids
4
5
6
7
% Asphalt Binder



VMA and %AC





Minimum VMA Requirements

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Nominal Maximum Aggregate Size, mm (in)	*Minimum VMA, percent*
9.5 (3/8)	15.0
12.5 (1/2)	14.0
19.0 (3/4)	13.0
25.0 (1.0)	12.0
37.5 (1.5)	11.0

SP-2, Table 5.2

Marshall Method, History

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- **Originally developed by Bruce G. Marshall at the Mississippi Highway Department (late 1930's)**
- **U.S. Army Corps of Engineers further refined the procedure (during and after WW II)**
- **Subsequently adopted by FAA and most state DOT's**
- ***Most state DOT's are now using Superpave procedures***

Laboratory Mixing/ Compaction Temperatures

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Rotational Viscometer

- For neat (unmodified) asphalt binders, determine equiviscous temperatures
- Mixing: 0.17 ± 0.02 Pa-s (170 +/- 20 cSt)
- Compaction: 0.28 ± 0.03 Pa-s (280 +/- 30 cSt)
- For polymer-modified asphalts, obtain recommendation from binder supplier

Testing of Specimens

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- **Theoretical Maximum Specific Gravity of Mixture**
  - **“Zero” air voids**
  - **Tested on Loose Mix**
  - **Dry Weight in Air**
  - **Vacuum and vibrating to get all air out**
  - **Submerged Weight in Water**

Preparation of Marshall Test Specimens

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- Marshall hammer
  - Compact specimens
  - 10 lbs hammer
  - 18” drop
  - ASTM D 1559 requires a manually-operated hammer
  - Mechanical hammers must be correlated with the standard
- Compact with 50 or 75 blows per side depending on design

Testing of Specimens

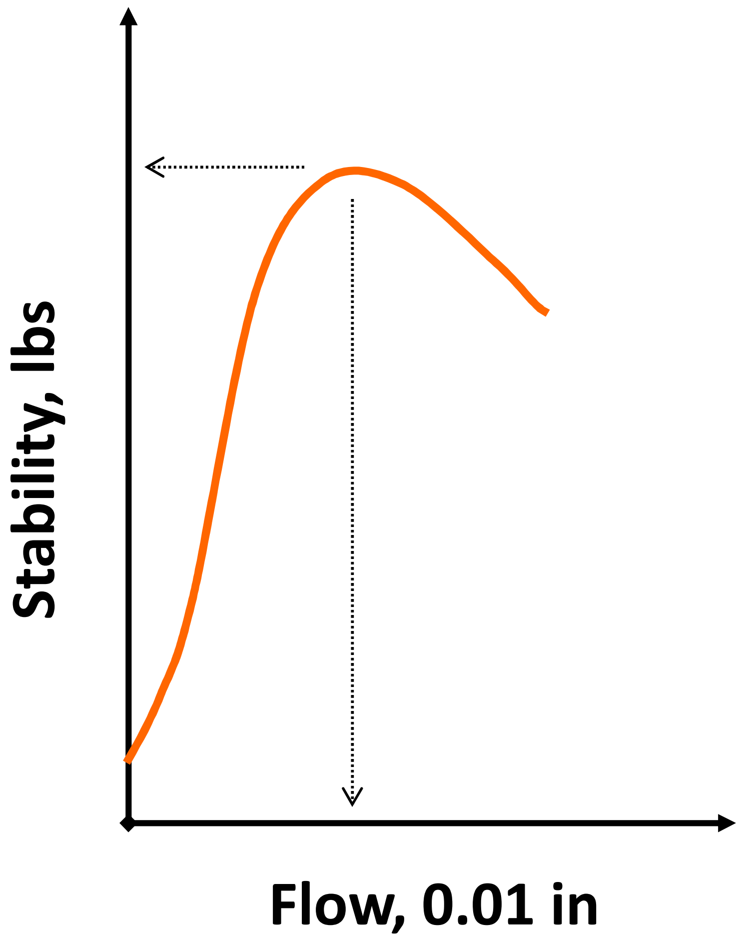
- Bulk Specific Gravity of Compacted Specimens
- Stability and Flow Test (ASTM D 1559)
- Density and Voids Analysis
  - Theoretical Maximum Specific Gravity of Mixture
  - Volumetrics: V_a, VMA, VFA

Testing of Marshall Specimens

Stability and Flow

- Specimens soaked at 60℃ for 30 - 40 min.
- Blot dry with towel
- Test within 30 sec.
  - Compression Load at 2 in/min
  - Record Peak Load vs. Deflection

Stability vs. Flow



- Stability = maximum load
- Flow = deformation where load begins to decrease
- Multiply stability by correlation ratio for specimen height & volume
- Average the stability and flow values at each asphalt content (average of 3 specimen)

Interpretation of Marshall Test Data

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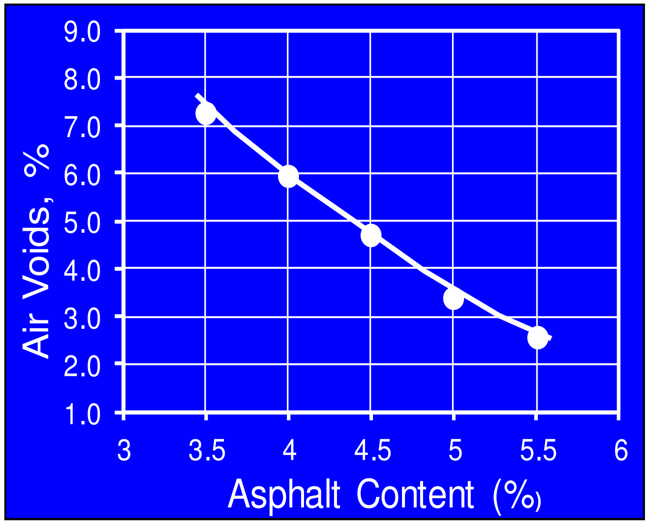
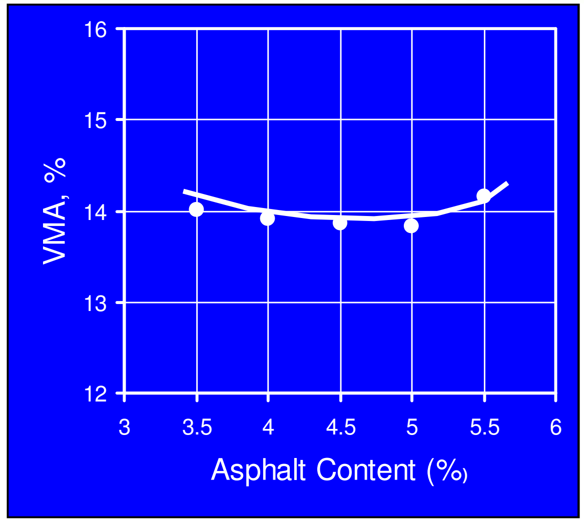
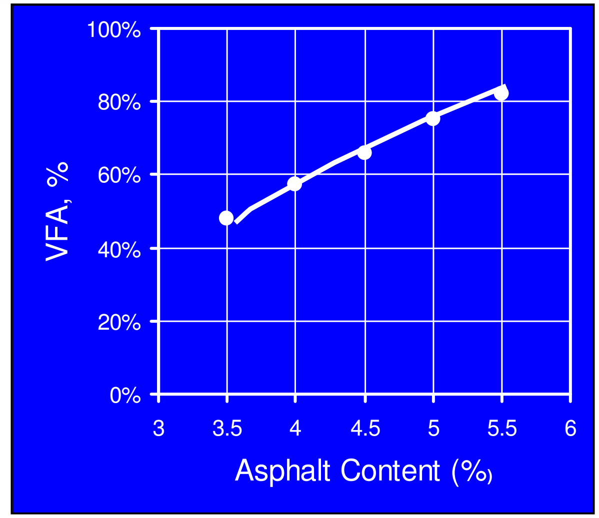
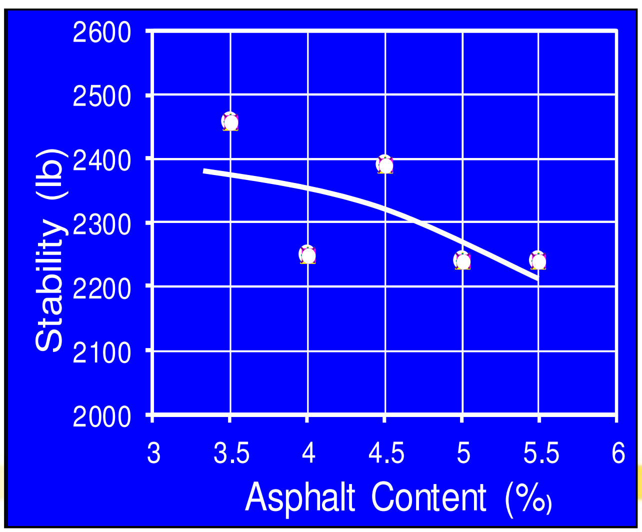
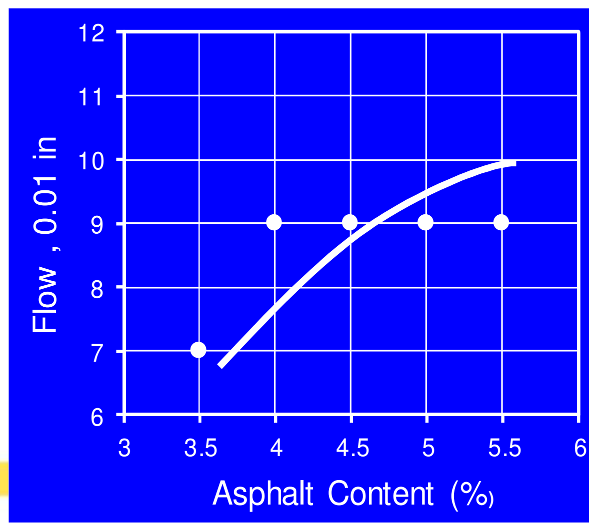






- **Plot averages versus asphalt content**





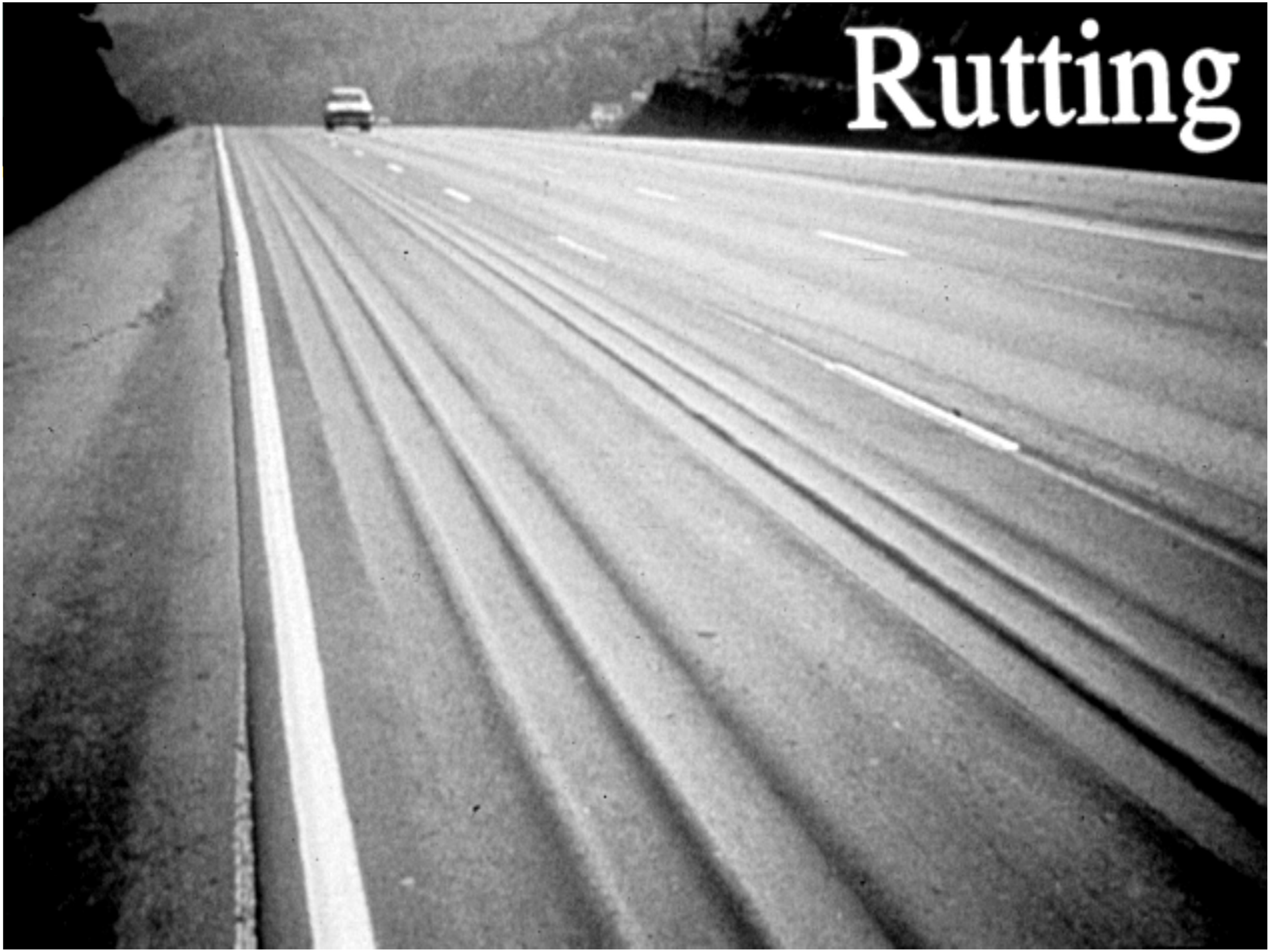
Moisture Sensitivity

AASTHO T-282

- 6 specimens compacted to 6 – 8% air voids
  - 3 conditioned and 3 unconditioned
- Conditioned specimens
  - 55 to 80 percent saturation
  - Freeze-thaw cycle
  - 24 hour soak in 60℃ water bath
  - Cooled to 25℃ and broken on IDT Tester
- Unconditioned specimens
  - Left undisturbed until broken on IDT Tester
- TSR ≥ 75%

Mix Design (JMF) Report
Marshall Mix Design

a. Gradation (% passing)
b. Asphalt content (%)
c. Binder grade (PG 64-22 etc)
d. No. of blows
e. Mixing temp.
f. Compaction temp.
g. Discharge temperature
h. Temp/vis plot for asphalt cement
i. Combined gradation plot on 0.45 power chart
j. Plots of stability, flow, air voids, VMA, & unit weight vs asphalt content
k. % natural sand
l. % fractured faces
m. % elongated particles
n. TSR
o. Anti-strip additive (type, amount)


Rutting

Superpave

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- Strategic Highway Research Program (SHRP)
  - Superpave, which stands for
    - <u>Su</u>perior
    - <u>Per</u>forming Asphalt
    - <u>Pave</u>ments
  - Performance-based specification
    - Asphalt grades are called
      - Performance Graded (PG) Binders

Superpave

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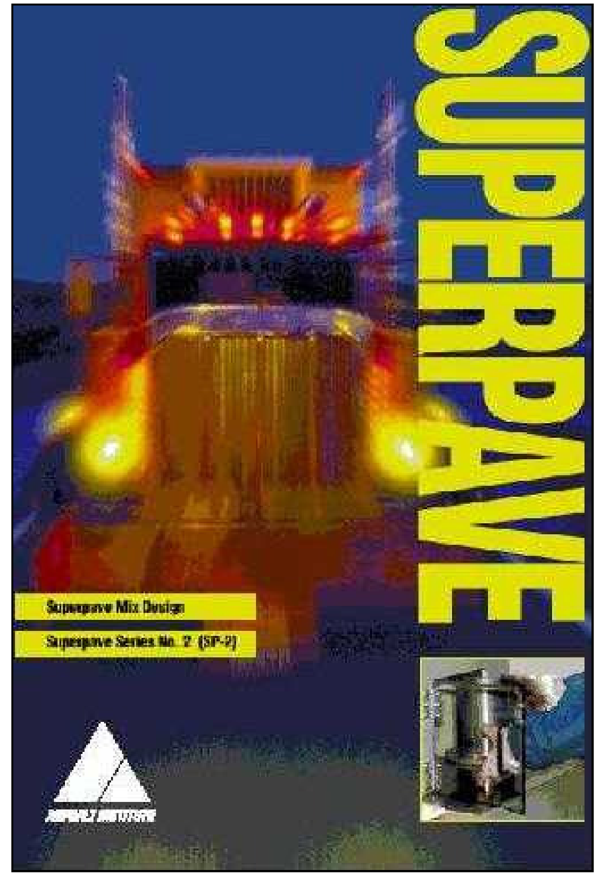
- **Asphalt Institute SP-2**
  Superpave Mix Design

- **Asphalt Institute *MS-2***

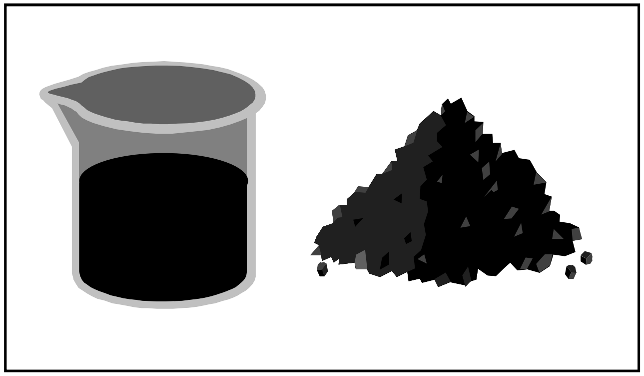
- ***2014***
  Asphalt Mix Design Procedures
  - ***Combines SP-2 & MS-2***
  - ***Marshall/Hveem in appendix***



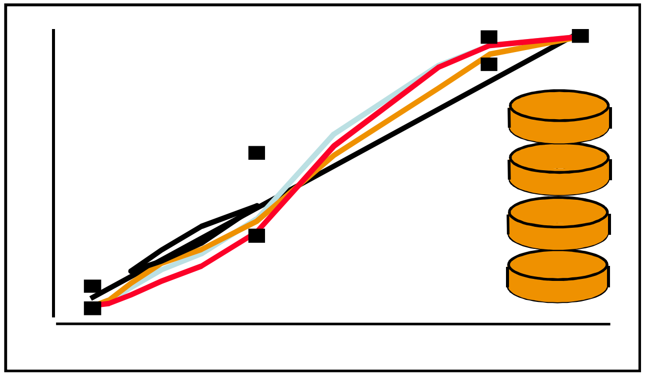
Superpave vs. Marshall

- **Similarities:**
  - **Emphasis on volumetric properties**
  - **Can select compactive effort during lab molding**
- **Biggest differences:**
  - **Laboratory molding procedure**
  - **Strength test**
  - **Ability to establish design parameters**
- **Effects:**
  - **Ability to evaluate aggregate structure**
  - **Ability to accommodate large-stone mixtures**
  - **More repeatable specimen molding**

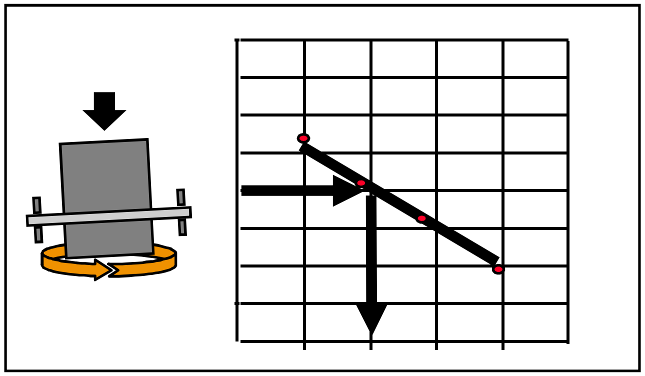
Superpave Design Method



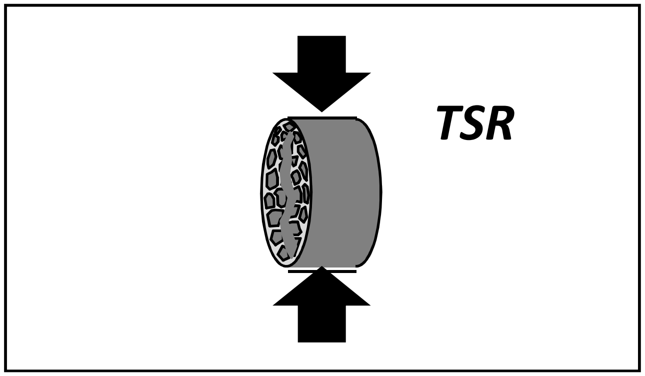
1. Materials Selection



2. Design Aggregate Structure



3. Design Binder Content



4. Moisture Sensitivity

Asphalt Binder Properties

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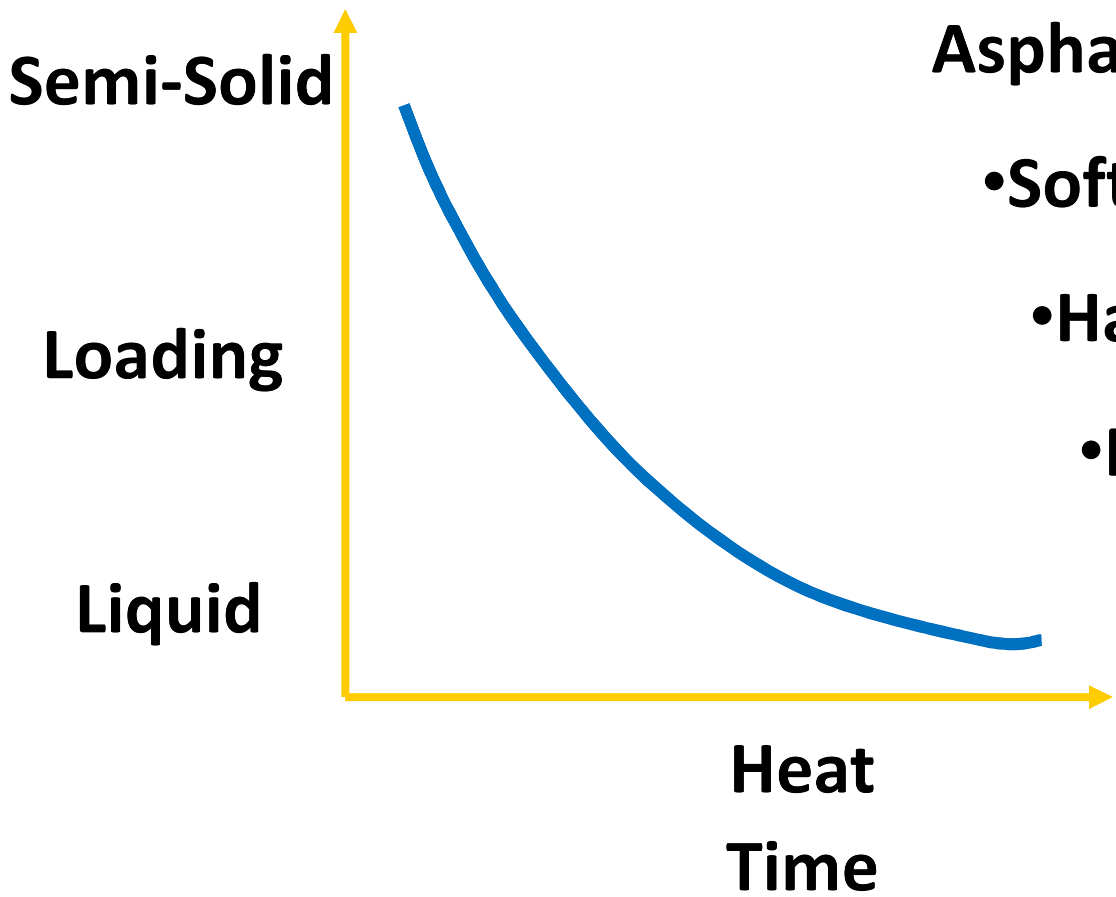

Asphalt is a *thermoplastic*

- Softens as it is heated
- Hardens as it cools
- Rate of Loading

Historic Specifications

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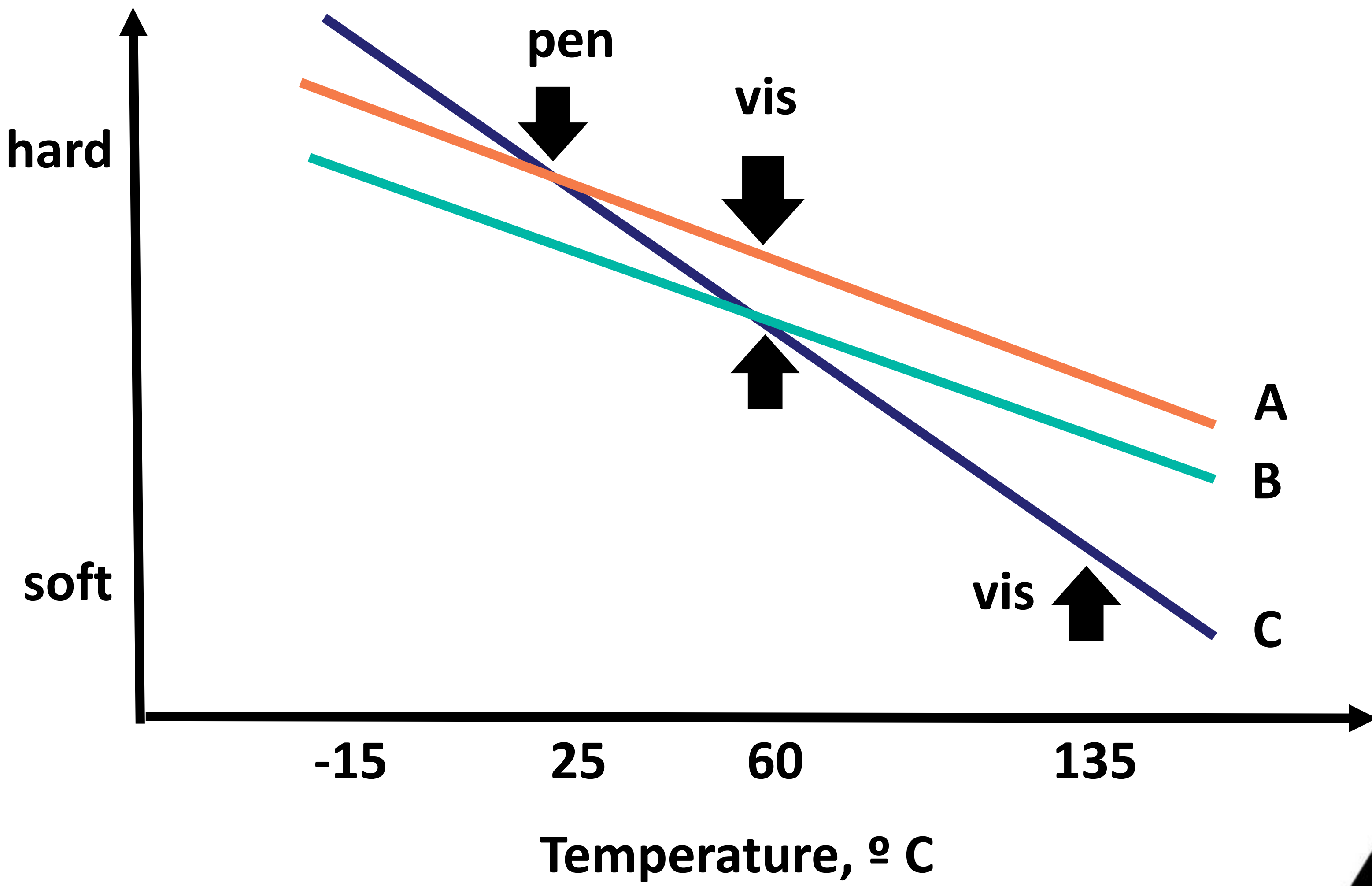
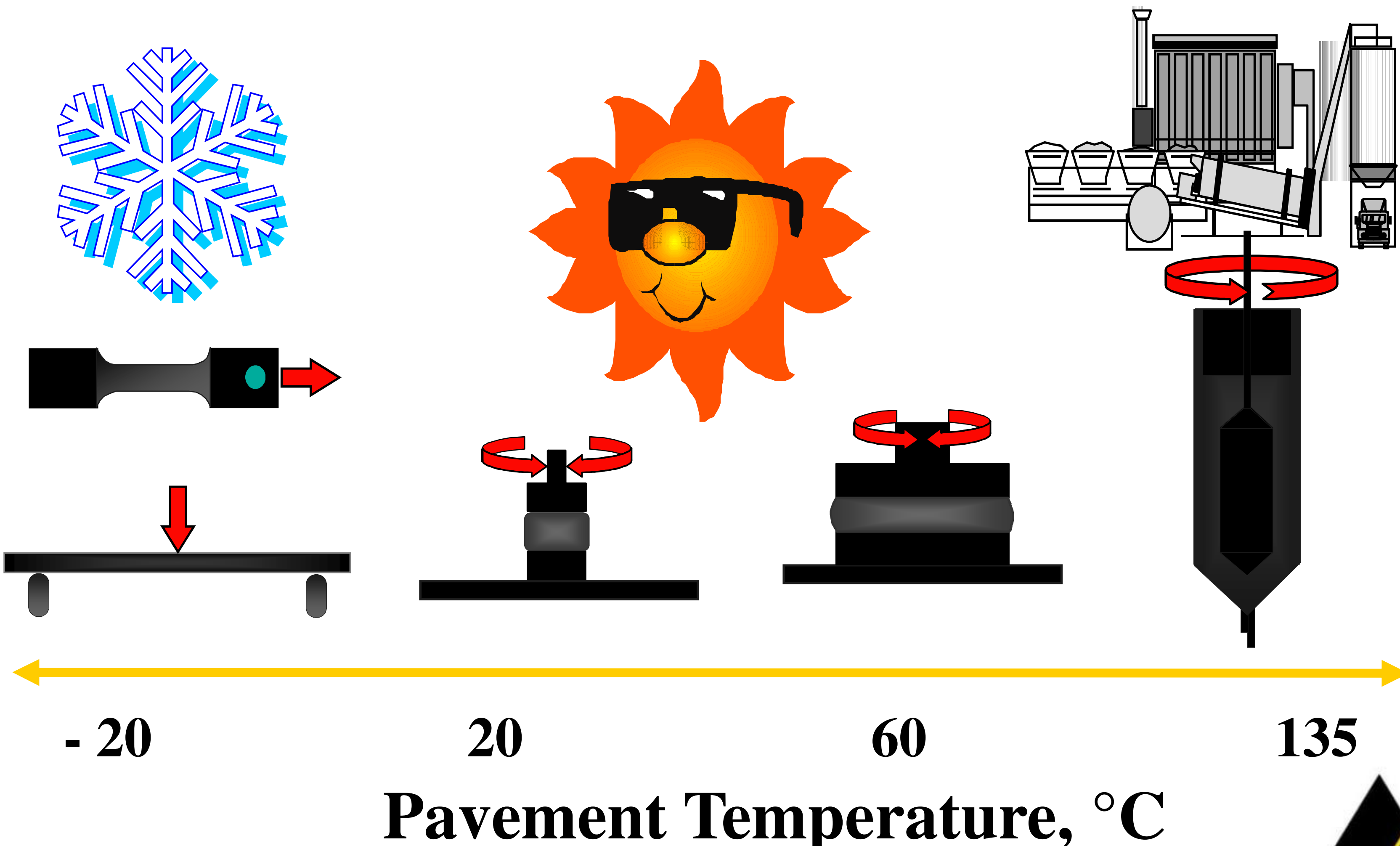


Binder Testing Philosophy



PG Binders

147.2 F -7.6 F

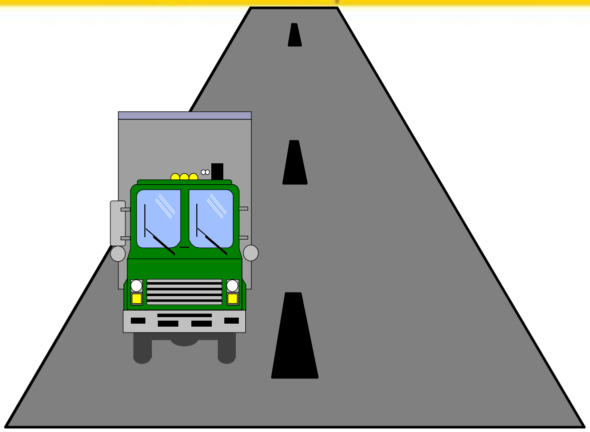
PG 64-22

"Performance Grade"

Average 7-day max pavement temperature

Minimum pavement temperature

Loading Rate of Loading



- Example
  - Mainline pavement
    PG 64-22 ← *70 mph*
  - Toll booth
    PG 70-22 ← Slow
  - Weigh Stations
    PG 76-22 ← Stopping

Modification above +90

Materials Selection

Asphalt Binder

- 4 – 7% of the mix
- "Glue" or "muscle" provides
  - Waterproofing
  - Flexibility
  - Durability

Aggregate

- 93 to 96% of the mix
- Acts as the skeleton
- Provides
  - Skid resistance
  - Stability
  - Workability

Aggregate Tests

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- **Basic Tests**
  - **Sieve analysis**
    - **Size distribution**
  - **Coarse aggregate bulk specific gravity (Gsb) & absorption**
    - **Weight in comparison of equal volume of water**
  - **Fine aggregate bulk specific gravity (Gsb) and absorption**
    - **Weight in comparison of equal volume of water**

Coarse Aggregate Angularity

Traffic/Depth Criteria

Design Traffic Level	ESAL's	% Crushed 1-FF/2-FF ≤ 100 mm	% Crushed 1-FF/2-FF > 100 mm
F	< 300,000	55/-	-/-
E	300,000 to < 3,000,000	75/-	50/-
D	3,000,000 to < 10,000,000	85/80	60/-
C	10,000,000 to < 30,000,000	95/90	80/75
B	≥ 30,000,000	100/100	100/100

Measured on plus 4.75mm (#4) material

Fine Agg. Angularity (FAA)

Test

Fine Agg. Angularity (FAA)

Traffic/Depth Criteria

Design Traffic Level	ESAL's	FAA ≤ 100 mm	FAA > 100 mm
F	< 300,000	-	-
E	300,000 to < 3,000,000	40	40
D	3,000,000 to < 10,000,000	45	40
C	10,000,000 to < 30,000,000	45	40
B	≥ 30,000,000	45	45

Sand Equivalent (SE)

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- Measured on minus 4.75mm
  - (#4) sieve
- Test limits or requirements
  - Traffic level
- Also called Clay Content

Sand Equivalent (SE)

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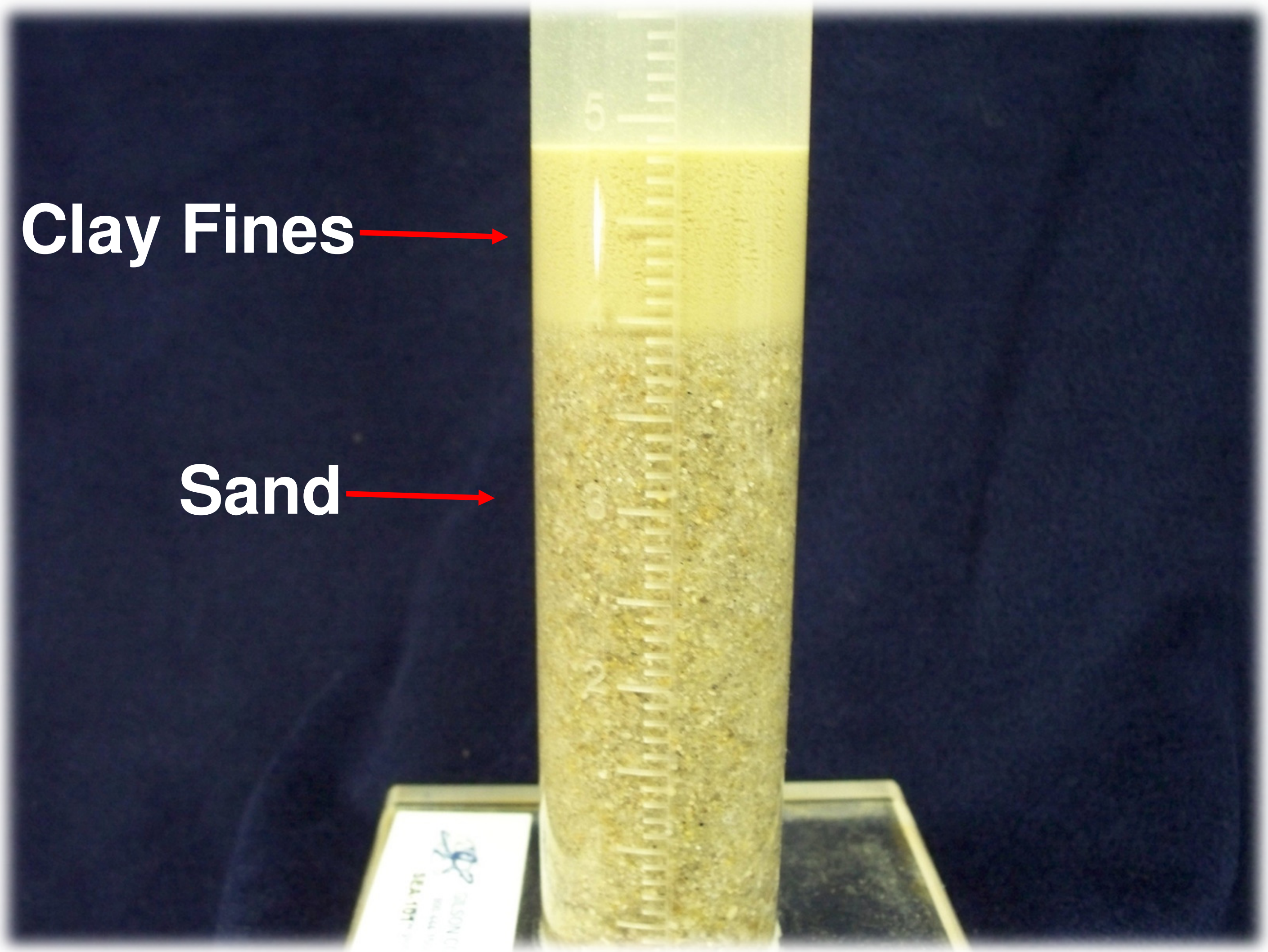

Sand Equivalent (SE)

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Design Traffic Level	ESAL's	Minimum Sand Equivalent
F	< 300,000	40
E	300,000 to < 3,000,000	40
D	3,000,000 to < 10,000,000	45
C	10,000,000 to < 30,000,000	45
B	≥ 30,000,000	50

Flat & Elongated (F&E)

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- Measured on + 4.75 mm Material
- Based on Dimensional Ratio of Particles
  - max to min dimension < 5
- Use ASTM D4791
- Requirements depend on
  - All traffic level
  - 10 % maximum

Flat & Elongated (F&E)

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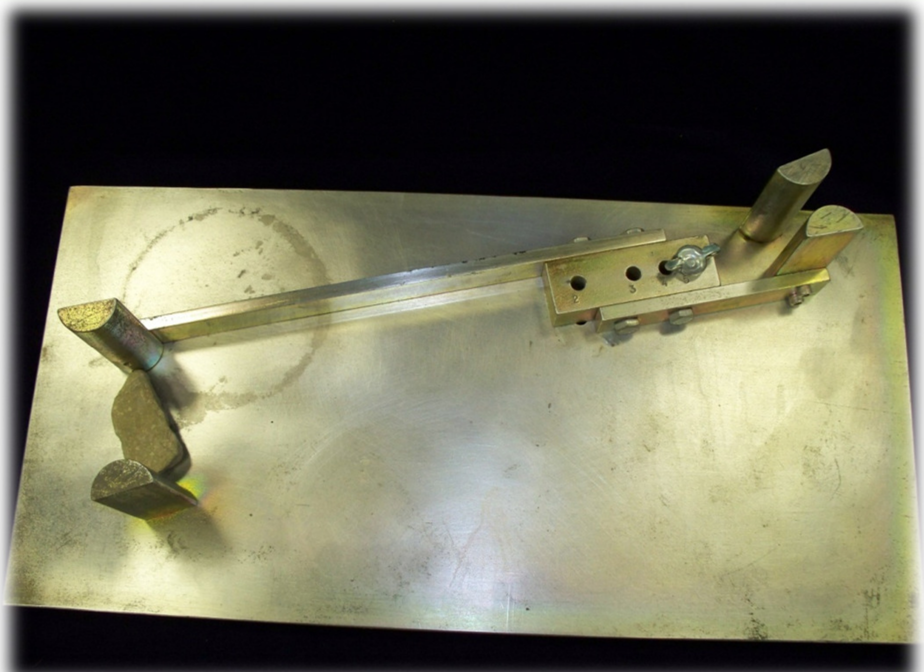
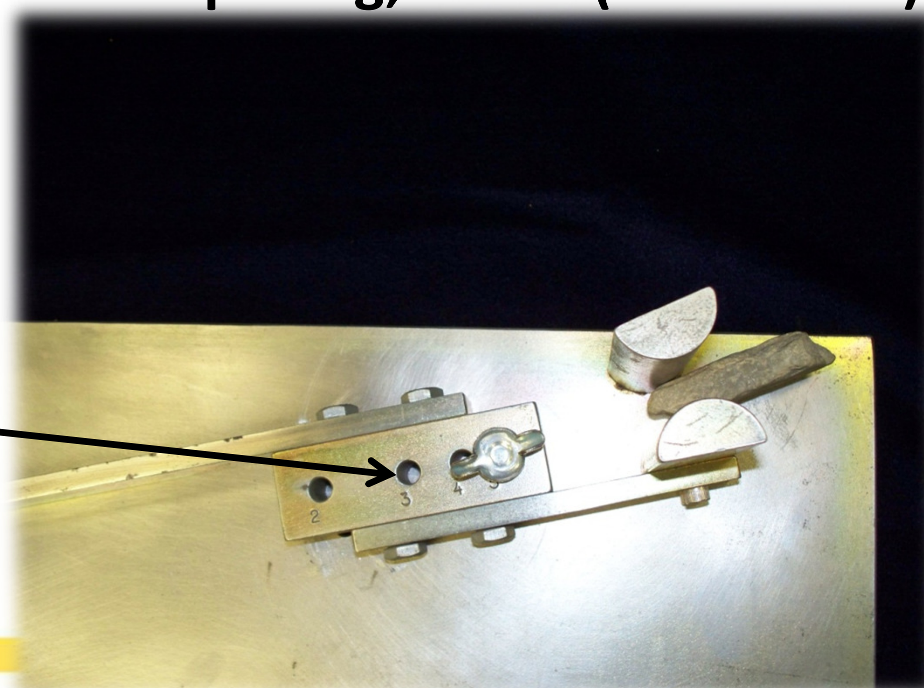


Insert agg and leave caliper open

If same agg passes through other opening, it fails (i.e. too flat)

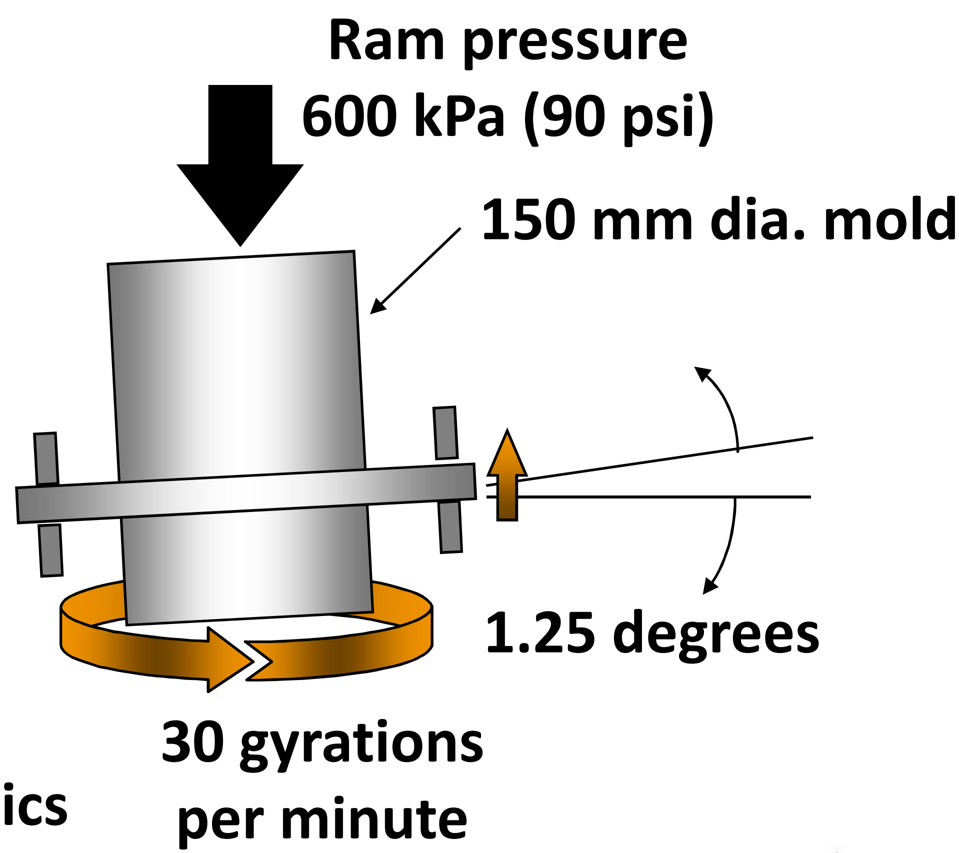


5:1 criteria

- Some states now 3:1

Superpave Gyratory Compactor

- Basis
  - Texas Gyratory
  - French operational characteristics
- 150 mm (6 in) diameter
  - up to 37.5 mm (1 ½ in) nominal size
- Height recording
  - Allows consideration of densification characteristics



Superpave Gyratory Compactors (SGC)

Original SGC

- **Research Accuracy**
- **Large Stationary**

Popular Gyratory Compactors

Pine AFG1 & G2

Pine AFGC125X

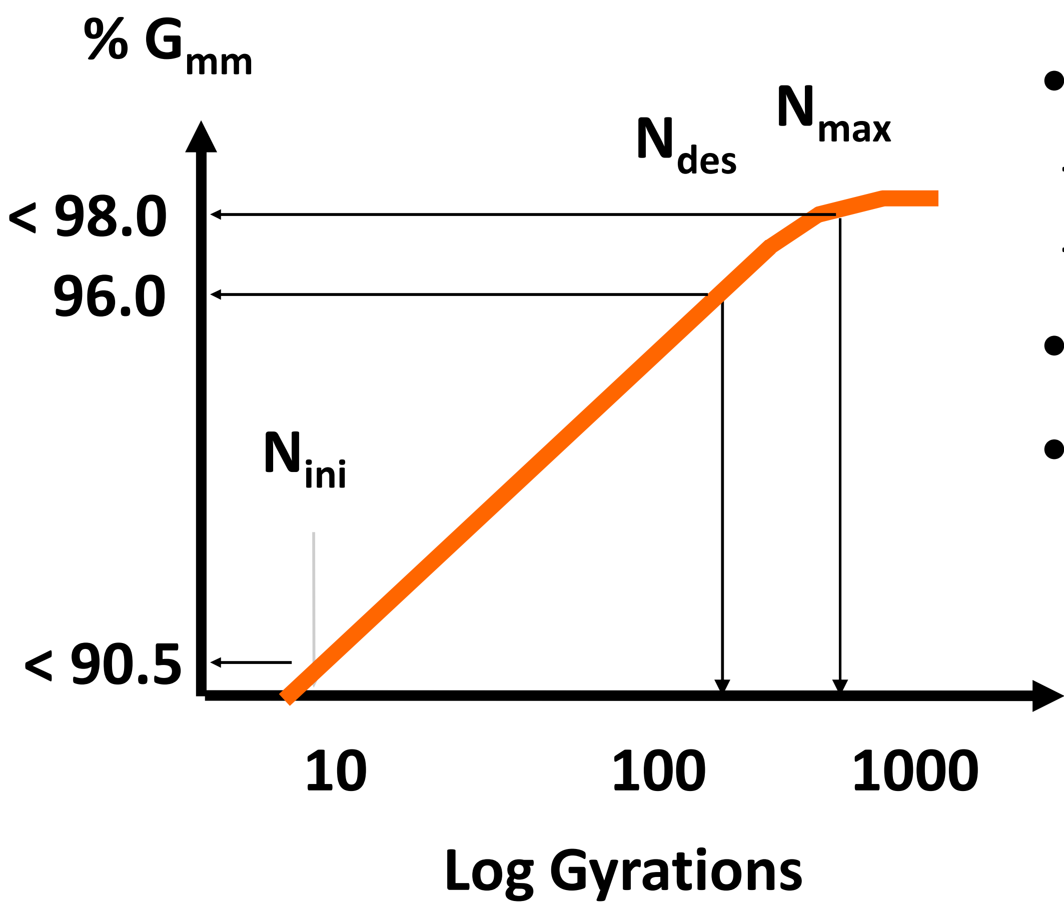
Troxler 4141

Troxler 5850

Pine AFB1

Troxler 4140

SGC Compaction Parameters



- N_{des} selected according to:
  - Climate
  - Traffic
- N_{ini} avoids tenderness
- N_{max} avoids plastic mix (min 2% Air Voids)

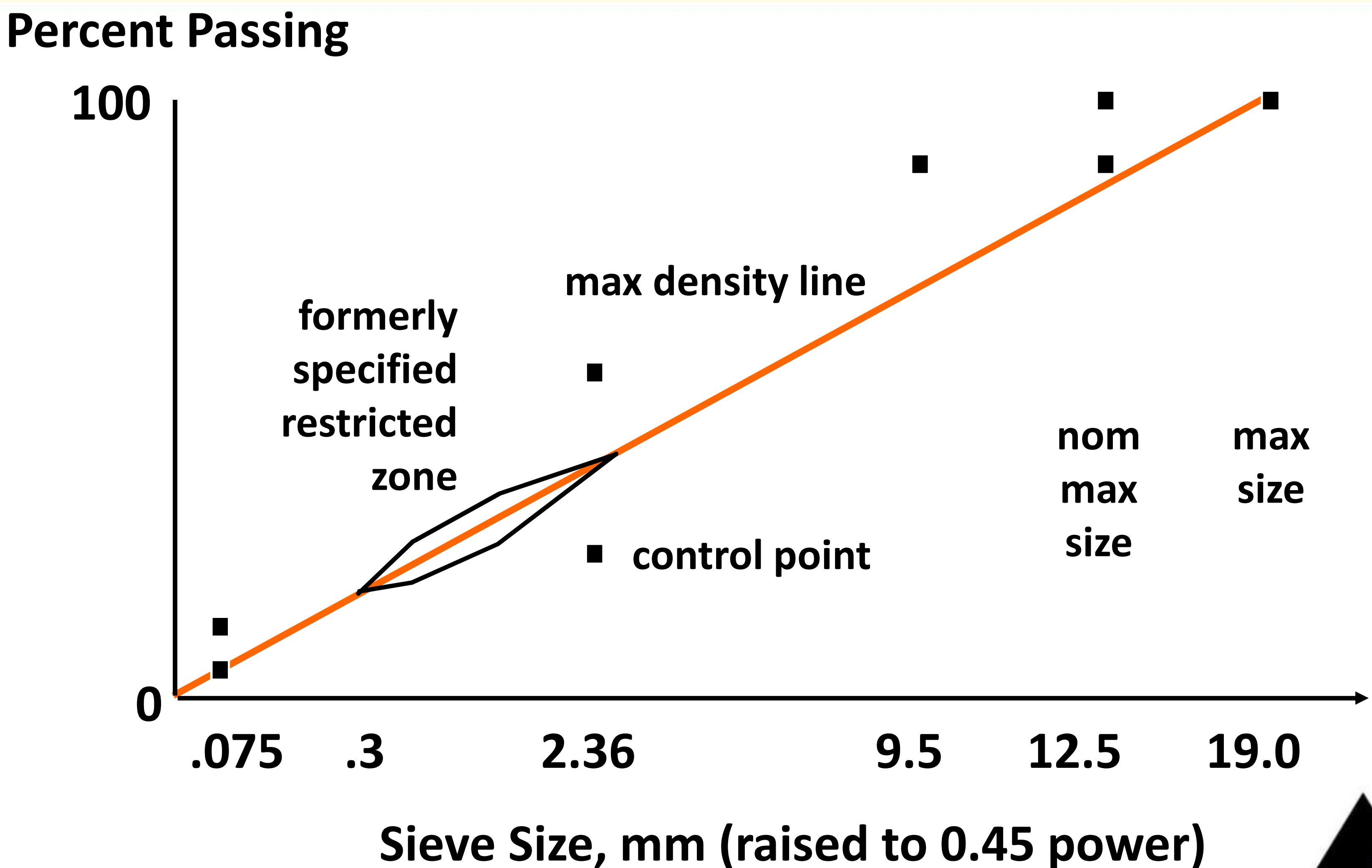
AASHTO R-35 Recommendations

M-ESALs, 20 yrs	N_{ini}	N_{des}	N_{max}
< 0.3	6	50	75
0.3 - 3	7	75	115
3 – 30	8	100	160
> 30	9	125	205

Design Aggregate Structure-Goal

- Identify combination of aggregates that:
  - Resists tenderness and deformation
    - During construction
    - Under traffic
  - Retains enough space within the compacted aggregate structure to accommodate the appropriate asphalt binder and air contents

Gradation



Percent Passing
100
0
formerly specified restricted zone
max density line
control point
nom max size
max size
.075
.3
2.36
9.5
12.5
19.0
Sieve Size, mm (raised to 0.45 power)

Design Aggregate Structure

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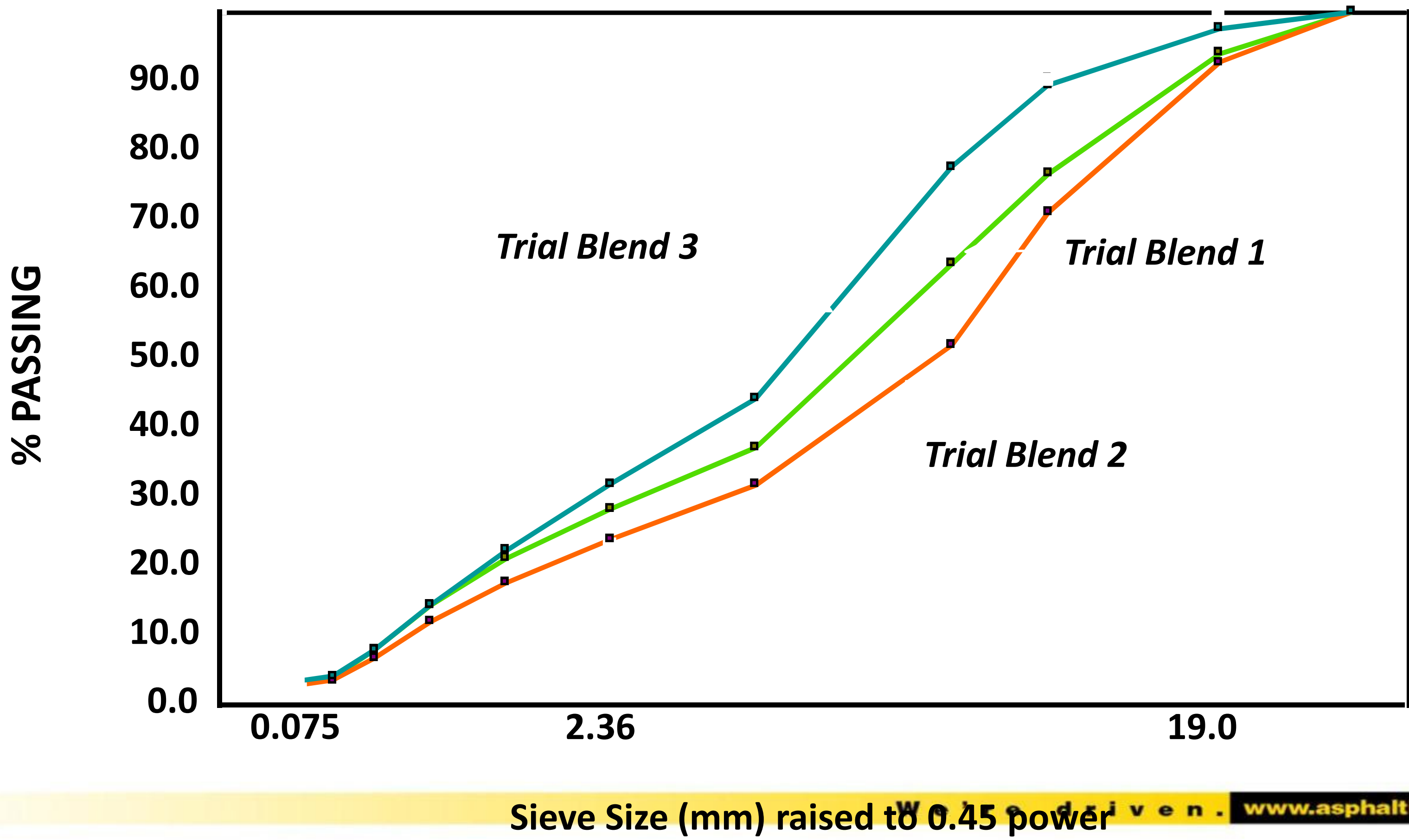
- **Establish Trial Blends**



Design Aggregate Structure

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- Select Design Aggregate Structure
  - Select most promising blend that meets all compaction and mixture requirements
  - What to do if none of the trial blends meet?
    - Recombine aggregates for further trial blends
    - If available, select different aggregate types or sources
      - Often, fine aggregates are the key

Superpave Volumetric Requirements

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- Minimum Voids in Mineral Aggregate (VMA)
  - Based on nominal maximum aggregate size
- Voids filled with asphalt (VFA)
  - Range depends on traffic
- Air voids (P_a)
  - Design at 4%
- Dust/effective asphalt ratio
  - Between 0.6 and 1.6

Specimen Preparation

- Specimen Height
  - Mix Design - 115 mm (4700 g)
  - Mix Analysis - 140 mm (5500 g)
  - Moisture Sens. - 95 mm (3500 g)
- Loose Specimen for Max. Theor. (Rice)
  - varies with nominal max size
    - 19 mm (2000 g minimum)
    - 12.5 mm (1500 g minimum)

Design Binder Content

- Once design aggregate structure is selected
  - Optimum asphalt content must be established
- Eight (8) gyratory specimens are compacted
  - 2 reps @ 4 asphalt contents
- Determine compaction & mix properties for each specimen
- Averages are plotted to determine optimum values

Design Binder Content

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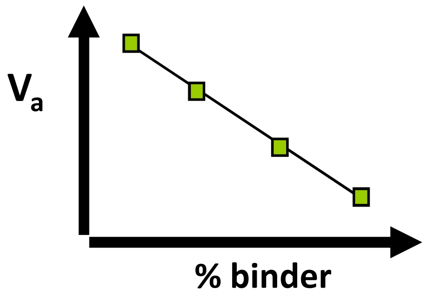
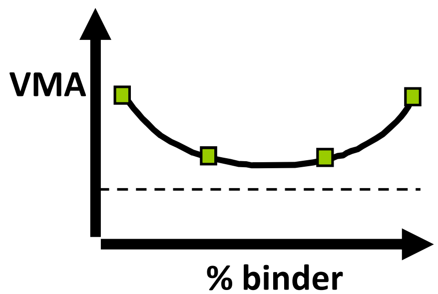
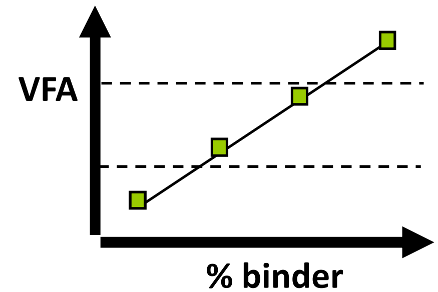
Air Voids



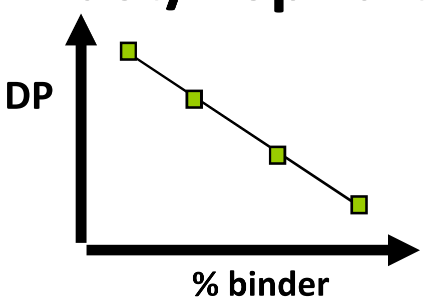
VMA



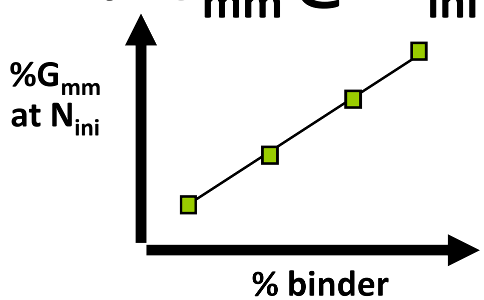
VFA



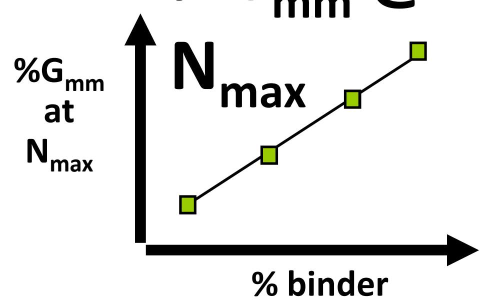
Dust/Asphalt



$\%G_{mm}$ @ N_{ini}



$\%G_{mm}$ @ N_{max}



Moisture Sensitivity

Same as Marshall

- **AASHTO T-283**
- **TSR ≥ 80%**

Hamburg Wheel (wet)

- **Pass/Fail Empirical Test**
- **Stripping susceptibility**
- **Rutting resistance**

When Selecting Mixtures

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- Consider lift thickness, construction constraints when selecting mixture classification
- Lift thickness should be at least
  - 3 times the maximum size
  - 4 times the nominal maximum size
- This is particularly important for coarse (below restricted zone) Superpave mixtures

Guidelines to Increase VMA

VMA = Air Voids + Eff. Asphalt Content

- Allows for space for adequate film thickness to provide
  - Adhesion
  - Mixture cohesion
  - Durability
- VMA is strongly influenced by the packing characteristics of the aggregate particles
- AI Class:
  - VMA is in the fine fraction
  - Achieving Volumetrics and Compactability
  - AKA "Bailey Method"
  - At headquarters annual in Feb & March

Guidelines to Increase VMA

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Aggregate gradation effect - changing the particle size distribution can influence the amount of space in the aggregate skeleton

- **Move gradation away from Maximum Density Line (MDL) on 0.45 curve**
- **Lower the minus #200 content**
- **Incorporate / increase "washed screenings," or "manufactured sand"**
- **Rescreen the "screenings" stockpile**

Production Considerations

For plant-produced mix, VMA is generally lower than laboratory mix design

- Degradation of aggregate during drying and mixing
- Return of baghouse fines to mixture
- Incomplete drying of aggregate during plant mixing
- Variable absorption, effective asphalt content

Absorption Impact on Volumetrics

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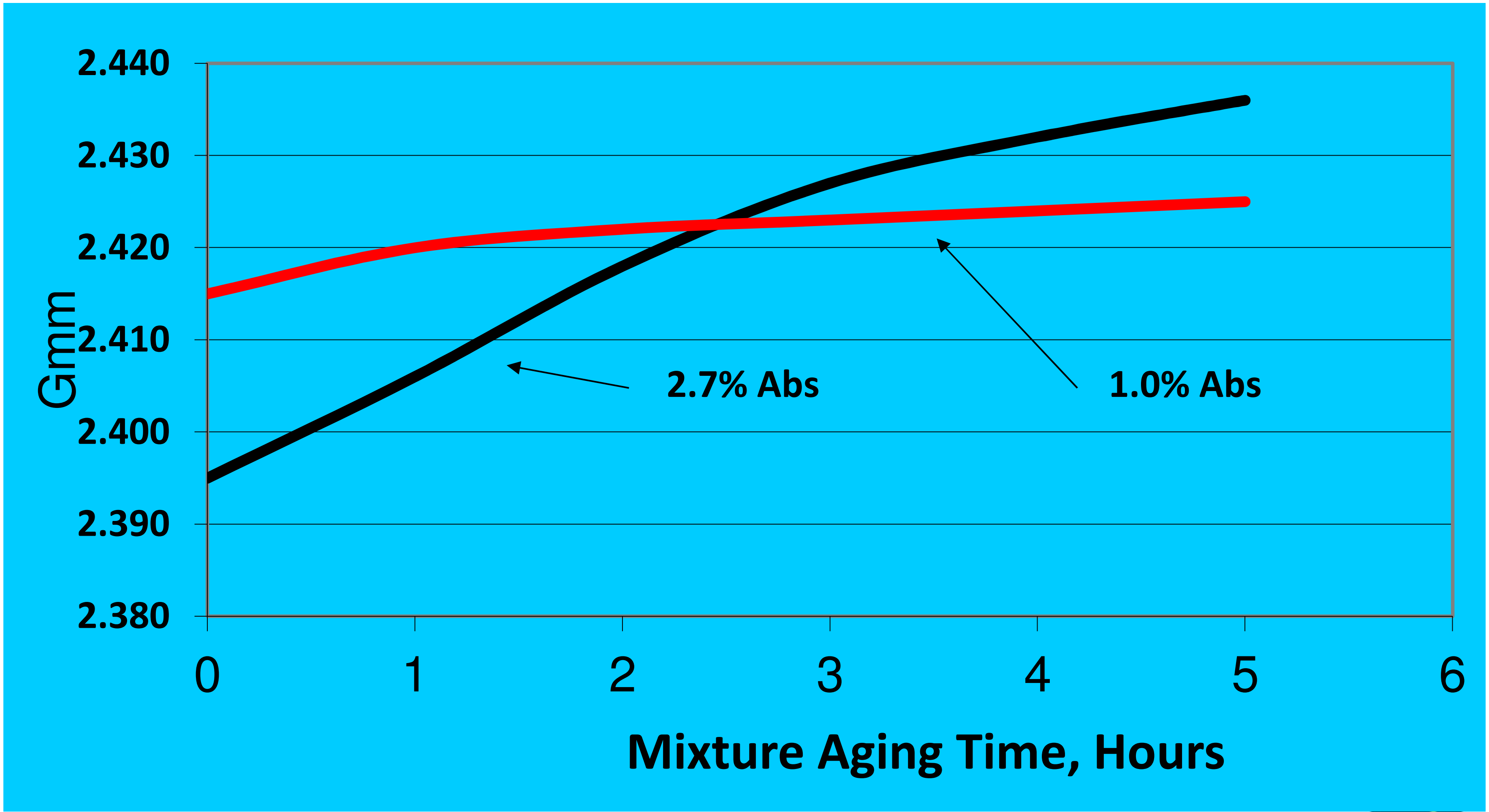

Problems resulting from VMA "Collapse"

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- Low lab-molded air voids for plant-produced mix
  - Can make it very difficult to achieve in-place density requirements
- Mixture not cohesive, prone to segregation
  - Particularly if -#200 increases, dries out the mix and reduces effective asphalt content.
- Retained moisture can cause a "tender zone" problem with coarse-graded mixtures

Suggestions

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- Consider changes in volumetric properties that normally occur during plant production during materials selection and mix design
  - Use experience with similar materials
  - Add baghouse fines in mix design
- Adjust production to maintain design air voids
  - Add/Waste dust

Mix Design Training

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Asphalt Institute *Mix Design Technology Course*

- **Hands-on laboratory design course covering Superpave and Marshall, includes mix-design software. Every January and February in KY.**
- **Certification exam / Certification available.**
- **http://www.asphaltinstitute.org**

Optimizing Volumetrics and Compactibility

Utilizing the "Bailey Method"

Every February and March in KY.

- **3 Day Class covers principles and spreadsheets**
- **"I've learned more about adjusting VMA in this course than I have learned in the last 28 years."**
- **"Been doing mix designs for 15 yrs & this class confirmed 95% of what I believed to be true & set me straight on the other 5%."**
- **"Last year, we lost around $250,000 in deducts for Voids, VMA, and Compaction. To date, using the Bailey Method, we are up $300,000 in incentives on half the number of projects"**

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Thanks,

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