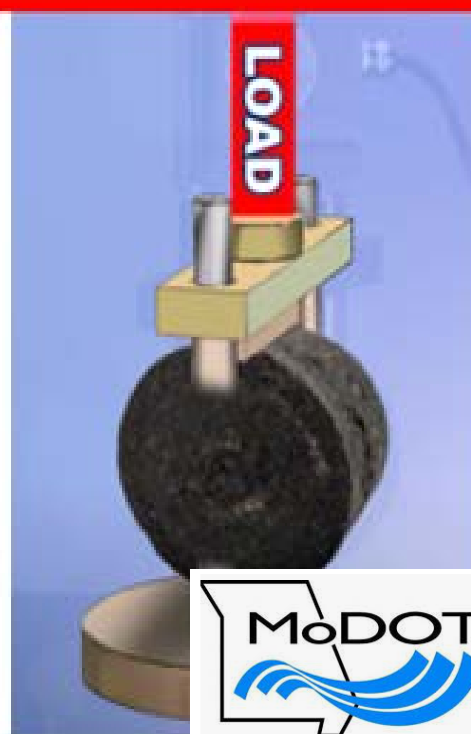




Tensile Strength Ratio



Tensile Strength Ratio

2024 Updates

- **2024 NO updates**
- **2023 Updates**
- **AASHTO T283:**
 - o **60 C Water Bath:** The thermometer for measuring the temperature of the water bath shall meet the requirements of M339M/M339 with a temperature range of at least 55 to 65°C (131 to 149°F) and an accuracy of $\pm 0.25^{\circ}\text{C}$ ($\pm 0.45^{\circ}\text{F}$) (see note 2),
 - NOTE 2: Thermometer types to use include:
 - ASTM E1 Mercury Thermometer
 - ASTM E879 thermistor thermometer
 - ASTM E1137/E1137M Pt-100 RTD platinum resistance thermometer, Class A
 - IEC 60751: 2008 Pt-100 RTD platinum resistance thermometer, Class AA
 - o **25 C Water Bath:** Meeting the requirements of M339M/M339 with a temperature range of at least 20 to 30°C (68 to 86°F) and an accuracy of $\pm 0.13^{\circ}\text{C}$ ($\pm 0.22^{\circ}\text{F}$) (see note 2),
 - NOTE 2: Thermometer types to use include:
 - ASTM E1 Mercury Thermometer
 - ASTM E879 thermistor thermometer
 - ASTM E1137/E1137M Pt-100 RTD Platinum Resistance, special order
 - IEC 60751: 2008 Pt-100 RTD platinum resistance thermometer, special order
 - o **Freezer:** Meeting the requirements of M339M/M339 with a temperature range of at least -25 to -10°C (-13 to 14°F) and an accuracy of $\pm 0.75^{\circ}\text{C}$ ($\pm 1.35^{\circ}\text{F}$) (see note 3),
 - NOTE 3: Thermometer types to use include:
 - ASTM E1 Mercury Thermometer
 - ASTM E2877 digital metal stem thermometer
 - ASTM E230/E230M thermocouple thermometer, Type T, Special Class
 - IEC 60584: thermocouple thermometer, Type T, Class 1

- o **Oven:** The thermometer for measuring the oven temperature shall meet the requirements of M339M/M339 with a range of at least 25 to 185°C (77 to 365°F) and an accuracy of $\pm 0.75^{\circ}\text{C}$ ($\pm 1.35^{\circ}\text{F}$) (see note 4),
 - NOTE 4: Thermometer types to use include:
 - ASTM E1 Mercury Thermometer
 - ASTM E230/E230M thermocouple thermometer, Type T, Special Class
 - IEC 60584: thermocouple thermometer, Type T, Class 1

2022 Updates

- 2022 – entire manual has been updated.
 - o Several updates for TSR testing – Jeff will go over this.

Course Content

Tensile Strength Raito

Updates

TSR Presentation

Background

TSR Role in QC/QA

Sampling for TSR

AASHTO R47 Reducing

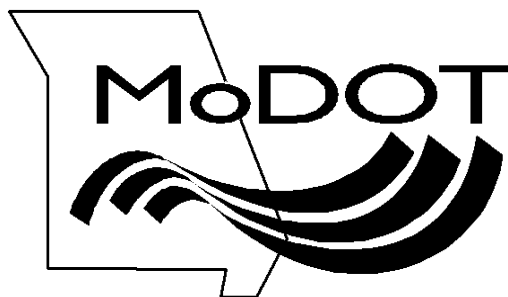
Equipment

Estimation of Puck Mass

AASHTO T283 Test for Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage.

Field Verification

TSR Proficiency



AASHTO T283 TENSILE STRENGTH RATIO (TSR)

Resistance of Compacted Asphalt Mixtures to
Moisture-Induced Damage

Revision March 4, 2022

1

What is Tensile Strength Ratio?

- Moisture Sensitivity of Asphalt Mixtures
- Affects the structural integrity of a mixture.
- Based on the ratio of the tensile strength of a set of conditioned to a set of unconditioned specimens expressed as a %.

2

2

SCOPE

- **Background** ←
- TSR Role in QC/QA
- Sampling for TSR
- Reducing AASHTO R47
- Equipment
- Estimation of Puck Mass
- Test Procedure
- Field verification

3

3

Why are we concerned with Moisture Sensitivity?

- Stripping will result if the bond is broken between the asphalt cement and aggregate.
- Resulting in pavement:
 - Rutting
 - Shoving
 - Raveling
 - Cracking

4

4

Moisture Damage (Stripping)



Left, HMA sample with no moisture damage
Right, HMA sample with moisture damage.
Notice the amount of uncoated aggregate on the right?

5

5

Stripping



6

6

AASHTO Test Methods & Specifications (Specs.)

- R35 Volumetric Design Practice
- M323 Volumetric Design Specs.
- R30 Mix Conditioning
- T312 Gyro operation
- T166 Bulk Specific Gravity of gyratory pucks
- T209 Max Specific Gravity of Voidless Mix (Rice)
- T 283 Moisture Sensitivity
- R 47 HMA Sample Splitting
- D 3549 Thickness of Specimens

7

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T 283 Moisture Sensitivity

- Measured on proposed aggregate blend and asphalt content.
- Reduced compactive effort to increase voids.
- Uses a minimum of **6 specimens**, divide into two sets a dry-set and a wet-set.



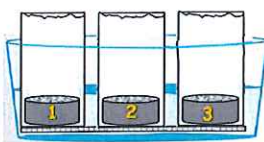
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T 283 Moisture Sensitivity

3 Unconditioned Specimens

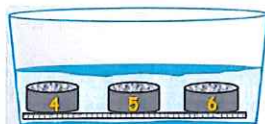
DRY SET



Place in leakproof plastic bags.
Sit in 25°C bath for 2 hrs.

3 Conditioned Specimens

WET SET



Vacuum saturate specimens
Freeze at -18°C for 16 hrs.
Soak at 60°C for 24 hrs.
Soak at 25°C for 2 hrs.

9

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T 283 Moisture Sensitivity

Determine the tensile strengths of both sets of 3 specimens.

Calculate the Tensile Strength Ratio (TSR).

$$\text{TSR} = \frac{\text{Avg. wet tensile strength}}{\text{Avg. dry tensile strength}} \times 100$$

TSR = $\geq 80\%$ needed.

Typical test results range in initial mix design: 40 - 95+ %.



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SCOPE

- Background
- **TSR Role in QC/QA** ←
- Sampling
- Reducing AASHTO R47
- Equipment
- Estimation of Puck Mass
- Test Procedure
- Field verification

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TSR Role in QC/QA

- Mix design/acceptance
- Field Verification of mix

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Non-Moisture Sensitive

- The intent is for Superpave (sect 403) and Plant mix (sect 401) to be **non-moisture-sensitive**.
 - Superpave **-must** be proven through TSR testing.
 - Plant mix **-may** be required to be proven through TSR testing.

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Section 401: BB and BP Mixes

- **401.2.1 (Standard Spec):**
- During mix design, TSR required when PI exceeds 3 for any individual aggregate fraction with 10% or more passing the #30 sieve.
- **401.9 (Standard Spec):**
During production QA checks PI once per project: if an individual aggregate fraction PI > 2 points above mix design value, TSR is required.

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Section 401: BB and BP Mixes

- **Engineering Policy Guide 401.2.3:**
Additional TSR testing is warranted if: in the field, if the PI of the fine aggregate fractions has significantly increased or the overall quality of the aggregate has changed.
- If a source has a history of stripping, MoDOT may require TSR testing during design and/or production.

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Mix Design Acceptance

- $\text{TSR} \geq 70\%$ for **BB and BP** mixes
- $\text{TSR} > 80\%$ for **Superpave** mixes

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TSR Role in QC/QA

- Mix design/acceptance
- **Field Verification of mix**

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Superpave TSR Pay adjustment

TSR	% of Contract price
≥ 90	103
75-89	100
70-74	98
65-69	97
< 65	Remove

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SCOPE

- Background
- TSR Role in QC/QA
- **Sampling for TSR** ←
- Reducing AASHTO R47
- Equipment
- Estimation of Puck Mass
- Test Procedure
- Field verification

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TSR Field Sample Timing QC/QA

- **Sample During production:** loose mix samples will be taken and quartered as described in EPG Section 403.1.5.
- **QC:** Has the option of taking loose mix samples from any point in the production process.
- **QA:** Samples should be taken from the same point as the QC, although not at the same time.

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TSR Field Sampling Frequency QC/QA

- **QC:** 1 per 10,000 tons.
- **QA:** 1 per 50,000 tons or one per mix (combination of projects).
[contract with several projects with same mix, totaling < 50,000 tons].
- **Random Locations:** By 403 spec. (per EPG not enforced).

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TSR Field Sampling - QC

- **QC:** Gets their own TSR sample, plus a retained sample for QA.
- **Location:** Truck sample, plant discharge, or behind the paver*.
 - *Behind paver, need full depth of the course. (Roadway is Last Resort)
- **Size:** 75-125 lbs., plus another 125lbs. retained for QA.

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TSR Field Sampling - QA

- **QA :** Gets their own "independent" ~250 lb. sample, retains 125 lbs.
- **Location:** Truck sample, plant discharge, or behind the paver*.
 - *Behind paver, need full depth of the course. (Roadway is Last Resort)
 - Same place as QC, but at a different time.
- **Size:** Gets their own independent ~250 lb. sample, retains 125 lbs.

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CAUTION

- Filling one **bucket/box** at a time may render different characteristics. It is better to place one shovelful per bucket/box at a time.
- Should recombine and quarter.

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Loose Mix Sampling Location

- Truck
- Asphalt Plant Discharge
- Roadway*
 - *Last Resort

SAFETY: Always wear PPE when sampling asphalt.



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TRUCK SAMPLING

Preferred

Use a platform with rails.



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Truck Sampling

- Obtain at least 3 approximately equal increments from random locations.
- Remove approximately 6 inches of the surface material from the sampling area.
- Obtain a random increment from the exposed surface and place in buckets or boxes.
- Move to the next location and repeat the process until enough material is collected.
- Combine to form a sample of the required size, close the container and mark with ID.

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Truck Sampling Issues

- Possible segregation in truck bed.
- Sampling methods (e.g., length of arms) limit the position of sampling in the truck bed → non-representative sample.
- Safety issues.
- Don't leave sample boxes uncovered at this location—may get contaminated with dust and overspray of release agent.

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PLANT DISCHARGE SAMPLING



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Plant Discharge (Chop Gate-Diverter Chute)

- Divert entire production stream from drum to a loader bucket.
- Sample across the loader bucket, one shovel per box, all boxes.
- Repeat until buckets/boxes are full.
- Cool (Beware of dust).
- Close bucket/boxes.
- Write sample information the containers.

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Plant Discharge

Diverter Chute Issues

- Contamination issues from diesel used to clean the area.

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MINI-STOCKPILE SAMPLING



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Mini-Stockpile – Option 1

- About 2 tons sampled from silo discharge into a truck.
- Dumped
- Back dragged
- Obtain approximately equal increments from at least 1 foot from the edge.
- Insert the shovel, exclude underlying material.
- Place the sample increments into clean buckets or boxes, close container, identify.

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ROADWAY SAMPLING

(Use as a last resort)



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TSR Sampling-Roadway

- Before compaction
- Using a template or a square nose shovel, clearly mark out an area to be removed.
- Remove all mixture within the area.
- **Do Not** contaminate sample with underlying material.
- Place material into clean containers.
- Close or cover containers.
- Mark information on outside of containers.

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TSR Sampling-Roadway Roadway Issues

- Profiler issues?
- Big hole to fill.

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QA TSR Sample

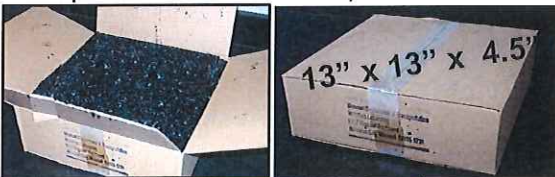
- Field QA should sample a 125 lb. sample.
 - Ship to the lab at least 4 - FULL boxes of TSR sample the size of 13" x 13" x 4.5"
 - Field QA should also retain a 125 lb. sample.
- (Do not send to Central Lab unless asked for. Discard only after issues of favorable comparison between QC and QA have been determined).*

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QA TSR Sample

- QA inspector will box up 125 lbs. of loose mix sample and ship to the Central Lab for testing
- Each box should contain a representative sample that includes all fines, etc.



*** Send to MoDOT Laboratory
4 - FULL boxes of TSR sample the size
of 13" x 13" x 4.5"

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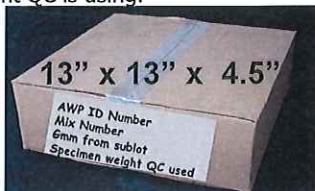
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QA - TSR Box Information

On each full box of asphalt, write the following
ON THE SIDE of the box:

1. AWP ID number.
2. Mix number.
3. G_{mm} from subplot taken (QC or QA).
4. Specimen weight QC is using.

Note: Permanent marker on the side of the box is the preferred method of labeling.



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QA TSR Sample

- Central Lab will determine the TSR puck weight to be used from testing one of the boxes.
- Central Lab will combine the remaining boxes and go through the AASHTO R47 procedure.

Communicate: Field techs and Laboratory techs. if boxes were filled one-at-a-time in the field, then the **first box** may not be the same as the other **three**. Communicate to the laboratory if the boxes were filled this way.

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SCOPE

- Background
- TSR Role in QC/QA
- Sampling for TSR
- **Reducing AASHTO R47** ←
- Equipment
- Estimation of Puck Mass
- Test Procedure
- Field verification

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Reducing

- Re-heat and combine field samples by mixing all boxes.
- **EPG:** The sample will be thoroughly mixed and quartered in accordance with AASHTO R47, or with an approved splitting/quartering device. Two opposite quarters will be retained for testing during the dispute resolution process, if necessary. The remaining two quarters will be mixed and quartered again and then tested.
- **R47, See your "Bituminous Technician Manual"**

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SCOPE

- Background
- TSR Role in QC/QA
- Sampling for TSR
- Reducing AASHTO R47
- **Equipment** ←
- Estimation of Puck Mass
- Test Procedure
- Field verification

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Equipment

- Gyrotory compactor & 150 mm diameter molds (section 403).
- Oven: room temperature up to 176 ± 3 °C.
- Balance
- Rice specific gravity equipment.

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Equipment

- Water bath at 25 ± 0.5 °C
- Water bath at 60 ± 1 °C
- Plastic bags
- Plastic wrap

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Equipment

- Vacuum desiccator
- Vacuum pump @ up to 26" mercury
- Timer
- Damp towel

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Equipment

- 10 ml graduated cylinder
- Freezer @ -18 ± 3 °C
- Load frame (2 in per min movement)
- Indirect tensile strength breaking head

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SCOPE

- Background
- TSR Role in QC/QA
- Sampling for TSR
- Reducing AASHTO R47
- Equipment
- **Estimation of Puck Mass** ←
- Test Procedure
- Field verification

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Estimate TSR Puck Mass

- Enough to fill a cylinder 150 mm diameter and 95 mm height.
- Less 7.0% air voids.
- Less side dimples.
- The calculation of required mass will be a starting point---experience will fine-tune the actual mass required.



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Estimate TSR Puck Mass

- $V_{\text{solids}} = (\text{Mass})/(\text{specific gravity})$
- $V_{\text{air}} = V_{\text{total}} - V_{\text{solids}}$
- Mix is constantly changing:
 - Bin % changes.
 - Exact %'s of each material is changing.
 - Each material has a different specific gravity.
- So, volumes of each material are changing.
- So, puck mix mass must change to keep 7.0% air voids constant.

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Estimate TSR Puck Mass

- The following slides present one method for determining mass of puck to result in 7.0% air voids & 95 ± 5 mm tall. The method is not mandatory.
- There may be equally useful methods.

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Estimate TSR Puck Mass

- Do a weight-volume calculation to get initial mass.
- Adjust via the most recent puck history. (say, using volumetric pucks)
- Fine-tune with experience.

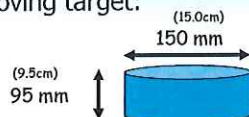


53

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Estimate TSR Puck Mass

Moving target:



Mass to get
7.0% air voids

But...character of the dimples changes:



So, adjust mass according to how the mix is behaving (info from other compacted pucks).

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Calculation of Mass Required For 7.0% AIR VOIDS

Step # 1

- From historical test data of QC or QA volumetric pucks, average several G_{mb} values appropriate for the TSR sampled mat area: $G_{mb, meas}$
- Average the mass (M_{meas}) of each of the G_{mb} pucks.
- Average the puck height (from gyro printout) h @ N_{des} (h_x) of each of the G_{mb} pucks.

h_x in "cm" for historical pucks.
(Usually 11.5 ± 0.5 cm)

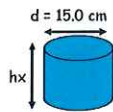
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$G_{mb, est}$ Step #2

- Next, compute the G_{mb} as if there were no side voids (dimples) = $G_{mb, est}$

$$G_{mb, estimated} = \frac{Avg. M_{meas}}{\left(\frac{\pi d^2 (avg h_x)}{4} \right)}$$



Note: d and h are in cm

- Thus, for the same mass, the volume will be larger for $G_{mb, est}$ and so $G_{mb, est}$ will be smaller (Same mass spread over a larger volume)
- So, $G_{mb, meas}$ will be $> G_{mb, est}$

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Calculation of Mass Required For 7.0% AIR VOIDS

Step # 3

- Calculate " C "

$$C = \frac{G_{mb}(measured)}{G_{mb}(estimated)} + experience$$

- $C > 1.0$
- "experience" may be adding $\sim 10g$ to account for material loss
- Apply " C " to TSR pucks

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Calculation of Mass Required For 7.0% AIR VOIDS Step # 4

- Obtain G_{mm} for the sampled roadway mat area.

$$V_{air} = \frac{100(G_{mm} - G_{mb})}{G_{mm}}$$

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CAUTION

- The G_{mm} needs to be representative - if not, the computed air voids will be wrong.

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Calculation of Mass Required For 7.0% AIR VOIDS Step # 4

- Calculate the required puck **mass** for 7.0% air voids (Mass = Vol x Sp Gravity).

$$\text{Mass} = \frac{[(0.93)(\pi)(d^2/4)(h)](G_{mm})}{C}$$

$h = 9.5 \text{ cm}$ for TSR pucks

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Alternate Equation Step #4, cont'd.

- If ($d=15.0$ cm) and ($h = 9.5$ cm):
- $Mass = \frac{1561.2 \text{ Gmm}}{C}$

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Example TSR Mass Using 3 Volumetric Pucks

ENLARGED

GCQA:TSRmassEstimate.xls

TSR PUCK MASS ESTIMATION

Job No.		Mat. Type	
Route		Formations	
County		Leaves	
Contractor		Binder Type	
Date		Binder Amount, %	

Dry Puck Information:

Specimen	1	2	3	4	Avg
Umass(g)	4601.7	4589	4603.3		4600.0
Gmm mass	2.391	2.314	2.325		2.330
h, H(h)(mm)	114.3	114.6	114.5		114.5

Step #1

Umassavg	(Umass avg)(h, H(h))	Gmm avg	Gmm massavg	C	Gmm
4600.0	15.0	11.45	2.330	1.020	2.427

Step #2

Historical volumetric pucks

Step #3:

Step #4:

TSR puck mass =

$$0.83 \left(\frac{Umassavg}{h} \right) \left(\frac{h}{h_{std}} \right)^2 \left(\frac{h_{std}}{h} \right) \left(\frac{Gmm}{Gmm_{std}} \right)^2$$

Theoretical mass
 Adjusted mass
 (air adjustments)
 Total mass

Mo wet(g)

3713

3713

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SCOPE

- Background
- TSR Role in QC/QA
- Sampling for TSR
- Reducing AASHTO R47
- Equipment
- Estimation of Puck Mass
- ***Test Procedure***
- Field verification

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[illegible]

Example TSR Mass

Using 3 Volumetric Pucks

QCQA\TSRmassEstimate.xls		TSR PUCK MASS ESTIMATION			
Job No.					
Route				Mix Type	
County				Formations	
Contractor				Ledges	
Date				Binder Type	
				Binder Amount, %	
Gyro Puck Information:					
Specimen	1	2	3	4	Avg
Mmeas(g)	4601.7	4598	4600.3		4600.0
Gmb, meas	2.321	2.314	2.325		2.320
h, Ndes(mm)	114.3	114.6	114.5		114.5
Mmeas, avg	diam, avg(cm)	h, Ndes(cm)	Gmb, est	Gmb, meas, avg	C
4600.0	15.0	11.45	2.273	2.320	1.020
pi	3.141592654				
Step #3: C=	$\frac{(Gmb, meas, avg)}{(Gmb, est)} \times \frac{[(pi) \times (d^2) \times (h, Ndes) / 4]}{(Mmeas, avg)}$				
Step #2: Gmb, est=	$(0.93) \times [(pi) \times (d^2) \times (9.5)] / 4 \times (Gmm) / C$				
Step #4: Mass=	$(0.93) \times [(pi) \times (d^2) \times (9.5)] / 4 \times (Gmm) / C$				
TSR pucks					

Step #1

Historical volumetric pucks

TSR pucks

Mass(g)	3713
Theoretical mass	
Additional material	
Other adjustments	
Total mass	3713

TSR Field Test Procedure Overview

- Determine TSR puck weights
- Compact pucks, run specific gravity
- Run Rice specific gravity
- Calculate air voids
- Break dry pucks
- Condition wet pucks
- Break wet pucks
- Calculate TSR
- Inspect conditioned pucks

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During Mix Design In Addition to Field Verification Steps (One extra day for lab mix at front end)

- Mixture prepared in lab
- After mixing, place mixture in a pan (one specimen per pan) and cool at **room temperature** for **2.0 ± 0.5 hrs.**
- Place in oven on perforated shelf (or on spacers) at **$60 \pm 3^\circ \text{C}$** for **16 ± 1 hrs.**

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Procedure

- The following slides relate to TSR testing of **field** samples and to **lab-mixed** samples after the first day.

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DAILY PROCEDURE

Outline

- Day 1:
 - Sample, quarter, heat to compaction temperature *[for lab-mixed, heating time is 2 hr. ± 10 min.]*
 - Compact pucks
 - Run Rice gravity
 - Determine G_{mb} of pucks
 - Calculate air voids
 - Group into two sets of 3
 - Saturate the Wet set
 - Put Wet set into freezer
 - Set aside Dry set

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DAILY PROCEDURE

Outline

- Day 2:
 - Start high temperature conditioning of Wet set.
- Day 3:
 - Test strength of Dry and Wet set
 - Calculate TSR

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TEST PROCEDURE: Day 1

- Warm the mix to soften it for quartering, *(no specified temperature or time)*, then quarter.
- Reheat the mix to *compaction temperature ± 3 °C*.
(Field mix: *no specified time*; Lab mix: *2 hr. ± 10 min.*)
- Compact: use sufficient mix to achieve **7.0 ± 0.5%** air voids in a 95 ± 5 mm tall puck.
 - **Note:** SMA mixes require 6.0 ± 0.5% air voids.
- Determine Rice gravity (G_{mm}).
[Must be representative of TSR mix]

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DAY 1

- Set gyro to "Height control" mode.
- Compact 6+ pucks.
(Actually, will make one or more trial pucks; may also wish to compact several extra pucks).



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Tender Pucks

- Extrude the puck from the mold.
- Remove mold lid and 1st paper disc.
- Cool for few minutes for stability before handling.
Pucks will be tender while hot!
- Without distorting the puck, move it from gyratory to a cooling table.
In this move, flip the puck over before sitting it down on the cooling table to remove the 2nd paper disc.
- ID the puck
- Allow to cool at **room- temperature.**
- Determine air voids by AASHTO T166.

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DAY 1: Determine Air Voids

- Determine G_{mb} for all 6 pucks.
(Follow AASHTO T166 - Pucks need to be tested at **$25 \pm 1^\circ \text{C}$**).

Note:

See your Bituminous Technician Manual for AASHTO T166 Bulk Specific Gravity,
And AASHTO T269 Percent Air Voids.
See your Superpave Manual for AASHTO T209 Maximum Specific Gravity.

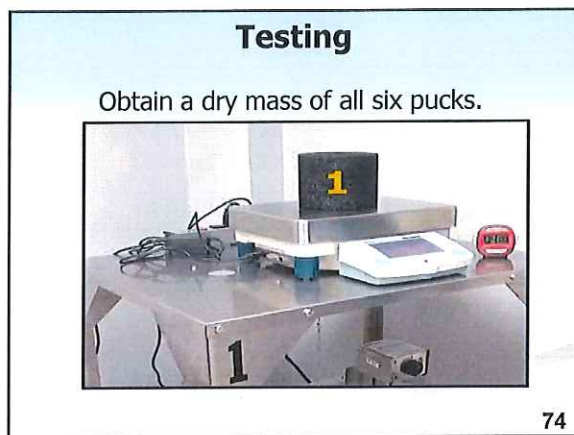


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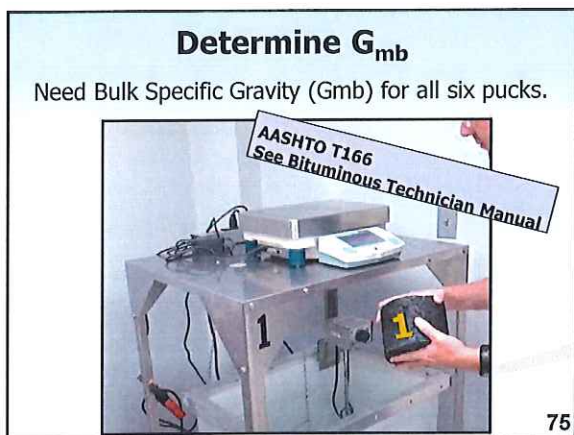
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Maximum Specific Gravity Test "Rice" (Gmm)



Apply a vacuum of 27.5 ± 2.5 mmHg for 15 ± 2 minutes

Enlarged

From Example Spreadsheet Puck #1

$$G_{mb} = 2.298$$



- AC mixed with agg. and compacted into sample

$$G_{mb} = \frac{\text{Mass agg. and AC}}{\text{Vol. agg., AC, air voids}}$$

Mix Number

Example

Gmm =

2.476

Gmb Worksheet

Specimen #	Dry Subset		Wet Subset		
	1	2	3	4	5
Weight in air (g) [A]	3725.8	3749.7	3755.1	3822.4	3759.7
SSD Weight (g) [B]	3735.6	3761.0	3765.0	3833.5	3770.7
Weight in water (g) [C]	2114.3	2135.9	2140.2	2180.0	2144.3
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5
Volume (cm ³) [B - C]	1621	1625	1625	1654	1626
Gmb [A / (B - C)]	2.298	2.307	2.311	2.312	2.312
% Air Voids [Pa]	7.2	6.8	6.7	6.6	6.6
Dry volume of air (cm ³) [Va]	117	111	108	110	108
Average % Air Voids	Dry	6.9			
Overall		Wet			

[B-C]

A/[B-C]

100[Gmm-Gmb]/Gmm

Pa[B-C]/100

TSR Worksheet

Specimen #	Dry Subset		Wet Subset		
	1	2	3	4	5
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5
Max. Load (lbs) [P]	3852	3601	3761	1564	1517
Ind. Tens. Str.:ITS (psi)*	111	104	108	44	44
* For 15.0 cm diameter specimen[D]	Vacuum SSD Wt. (g)[B']		3902.9	3846.0	3787.3
Avg. Wet ITS (psi)[Swet]	Weight in air (g)[A]		3822.4	3759.7	
Avg. Dry ITS (psi)[Sdry]	Vol. Absorb H ₂ O (cm ³)[J']		81	86	
TSR (%) [100Swet/Sdry]	Dry volume of air (cm ³)[Va]		110	108	
Air Voids (%)	70% Sat. (Target VSSD)		3899	3835	
	80% Sat. (Target VSSD)		3910	3846	
	% Saturation		73	80	
Dry Subset %Air	AVG		22	23	23
Wet Subset %Air	6.9		8	8	8
Saturation (%)			25	26	24
			Time (min)	1	1

6.4516*2P/3.1415tD

B'-A

A+0.7Va

A+0.8Va

100J'/Va

Dry Subset

Time in 25 C waterbath
(2 hrs ± 10 min)

1h 50m

1h 55m

2h

Wet Subset

NOTE: Shaded cells indicate
cells needing input values

Time in Freezer

(Minimum 16 hrs)

Time in 60 C waterbath

(24 ± 1 hrs)

19h 44m

19h 16m

18h 54m

23h 30m

23h 30m

23h 30m

Test Time

12/22/2003

5:25 PM

12/22/2003

5:30 PM

5:35 PM

12/22/2003

4:20 PM

4:25 PM

4:30 PM

12/22/2003

4:20 PM

4:25 PM

4:30 PM

AIR VOIDS

$$P_a = \frac{G_{mm} - G_{mb}}{G_{mm}} \times 100$$

- P_a = % air voids
- G_{mm} = Maximum specific gravity of the voidless mix (Rice sp gravity)
- G_{mb} = Spec. gravity of the compacted mix

79

79

- 80

Determine %Air Voids

From Example Spreadsheet Puck #1

- Having tested Maximum Specific Gravity, (Rice), calculate air voids of each puck:

$$P_a = \frac{G_{mm} - G_{mb}}{G_{mm}} \times 100$$
$$P_a = \frac{2.476 - 2.298}{2.476} \times 100 = 7.2 \%$$

80

80

[illegible]

Mix Number

Example

Gmm =

2.476

Gmb Worksheet			Dry Subset			Wet Subset		
Specimen #	1	2	3	4	5	6		
Weight in air (g) [A]	3725.8	3749.7	3755.1	3822.4	3759.7	3692.3		
SSD Weight (g) [B]	3735.6	3761.0	3765.0	3833.5	3770.7	3707.9		
Weight in water (g) [C]	2114.3	2135.9	2140.2	2180.0	2144.3	2094.9		
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5		
Volume (cm ³) [B-C]	1621	1625	1625	1654	1626			[B-C]
Gmb [A / (B - C)]	2.298	2.307	2.311	2.312	2.312			A/[B-C]
% Air Voids [Pa]	7.2	6.8	6.7	6.6	6.6			100[Gmm-Gmb]/Gmm
Dry volume of air (cm ³) [Va]	117	111	108	110	108			Pa[B-C]/100
Average % Air Voids	Dry			Wet				
Overall	6.9							

TSR Worksheet			Dry Subset			Wet Subset		
Specimen #	1	2	3	4	5	6		
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5		
Max. Load (lbs) [P]	3852	3601	3761	1564	1517	1197		
Ind. Tens. Str.:ITS (psi)*	111	104	108	44	44			6.4516*2P/3.1415tD
* For 15.0 cm diameter specimen[D]	Vacuum SSD Wt. (g) [B']			3902.9	3846.0	3787.3		
Avg. Wet ITS (psi)[Swet]	Weight in air (g) [A]			3822.4	3759.7			
Avg. Dry ITS (psi)[Sdry]	108	Vol. Absorb H ₂ O (cm ³) [J']			81	86		B'-A
TSR (%) [100Swet/Sdry]	Dry volume of air (cm ³) [Va]			110	108			
Air Voids (%)	70% Sat. (Target VSSD)			3899	3835			A+0.7Va
	80% Sat. (Target VSSD)			3910	3846			A+0.8Va
	% Saturation			73	80			100J'/Va
Dry Subset %Air	6.9	in. Hg			22	23		
Wet Subset %Air		Time (min)			8	8		
Saturation (%)		in. Hg			25	26		
		Time (min)			1	1		

Dry Subset

Time in 25 C waterbath
(2 hrs ± 10 min)

1h 50m

1h 55m

2h

NOTE: Shaded cells indicate
cells needing input valuesTime in Freezer
(Minimum 16 hrs)

Wet Subset

19h 44m

19h 16m

18h 54m

Time in 60 C waterbath
(24 ± 1 hrs)

23h 30m

23h 30m

23h 30m

Test Time

12/22/2003

5:25 PM

12/22/2003

5:30 PM

5:35 PM

12/22/2003

4:20 PM

4:25 PM

12/22/2003

4:30 PM

4:30 PM

Mix Number

Example

Gmm =

2.476

Gmb Worksheet		Dry Subset			Wet Subset		
Specimen #	1	2	3	4	5	6	
Weight in air (g) [A]	3725.8	3749.7	3755.1	3822.4	3759.7	3692.3	
SSD Weight (g) [B]	3735.6	3761.0	3765.0	3833.5	3770.7	3707.9	
Weight in water (g) [C]	2114.3	2135.9	2140.2	2180.0	2144.3	2094.9	
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5	
Volume (cm ³) [B - C]	1621	1625	1625	1654	1626		
Gmb [A / (B - C)]	2.298	2.307	2.311	2.312	2.312		
% Air Voids [Pa]	7.2	6.8	6.7	6.6	6.6		
Dry volume of air (cm ³) [Va]	117	111	108	110	108		
Average % Air Voids	Dry	6.9		Wet			
Overall							

[B-C]

A/[B-C]

100[Gmm-Gmb]/Gmm

Pa[B-C]/100

TSR Worksheet		Dry Subset			Wet Subset		
Specimen #	1	2	3		4	5	6
Height (0.1 cm) [t]	9.5	9.5	9.5		9.7	9.5	9.5
Max. Load (lbs) [P]	3852	3601	3761		1564	1517	1197
Ind. Tens. Str.:ITS (psi)*	111	104	108		44	44	
* For 15.0 cm diameter specimen[D]			Vacuum SSD Wt. (g)[B']		3902.9	3846.0	3787.3
Avg. Wet ITS (psi)[Swet]			Weight in air (g)[A]		3822.4	3759.7	
Avg. Dry ITS (psi)[Sdry]	108		Vol. Absorb H ₂ O (cm ³)[J']		81	86	
TSR (%) [100Swet/Sdry]			Dry volume of air (cm ³)[Va]		110	108	
			70% Sat. (Target VSSD)		3899	3835	
			80% Sat. (Target VSSD)		3910	3846	
	AVG		% Saturation		73	80	
Air Voids (%)							
Dry Subset %Air	6.9		in. Hg		22	23	23
Wet Subset %Air			Time (min)		8	8	8
Saturation (%)			in. Hg		25	26	24
			Time (min)		1	1	1

6.4516*2P/3.1415tD

B'-A

A+0.7Va

A+0.8Va

100J'/Va

Dry Subset

Time in 25 C waterbath
(2 hrs ± 10 min)

1h 50m

1h 55m

2h

Wet Subset

NOTE: Shaded cells indicate
cells needing input valuesTime in Freezer
(Minimum 16 hrs)

19h 44m

18h 54m

Time in 60 C waterbath
(24 ± 1 hrs)

23h 30m

23h 30m

Test Time

12/22/2003
5:25 PM12/22/2003
5:30 PM12/22/2003
5:35 PM12/22/2003
4:20 PM12/22/2003
4:25 PM12/22/2003
4:30 PM

Unconditioned "Dry Set" (#1, #2, #3)

- The unconditioned set should be set aside at room temperature until the conditioned set is ready for strength testing.

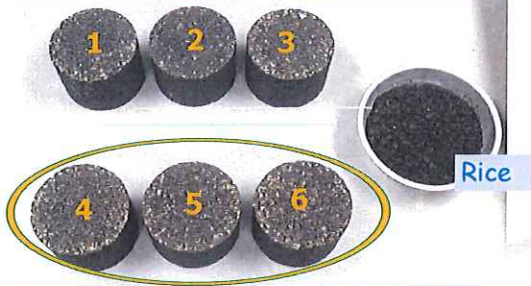


85

85

TSR – Unconditioned (Wet)

Unconditioned pucks (Dry Set) #1, #2, #3



Conditioned pucks (Wet Set) #4, #5, #6

86

86

Day 2, Cont'd.

Wet Pucks (#4, #5, #6)

- Overview: Vacuum saturate the 3 other pucks that are to be "conditioned".



87

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**Vacuum Saturation
Wet Pucks (#4, #5, #6)**

- Permissible range: **70-80%**
- Pre-calculate partially saturated puck weights at 70 and 80%.
- By iteration, progressively vacuum & weigh at intervals until puck weight is in the permissible weight range.

88

88

Day 1: Wet Pucks (#4, #5, #6)

- Determine the surface dry weight.
- Calculate the degree of saturation.



89

89

Vacuum Saturation, cont'd.

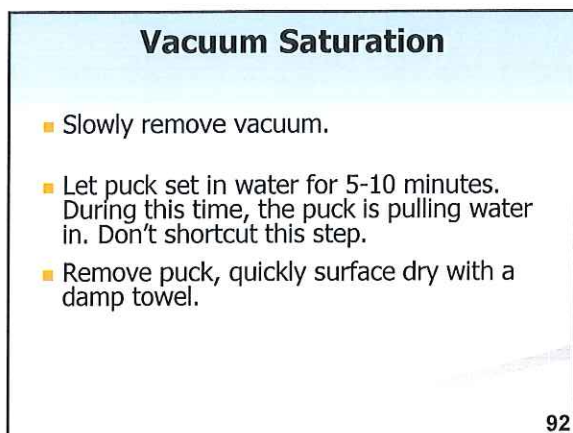
- Place puck in vacuum chamber and submerge in water ($\geq 1''$ cover and $\geq 1''$ above chamber bottom).
- Apply 10-26" (suggested 23") mercury vacuum for 5-10 (suggested 8) minutes (it's more important to achieve vacuum than stay within time limits).
- This step is pulling air out of the puck and creating a vacuum inside the puck.
- If use high/fast vacuum, may get uneven saturation—poor QC/QA comparison.

90

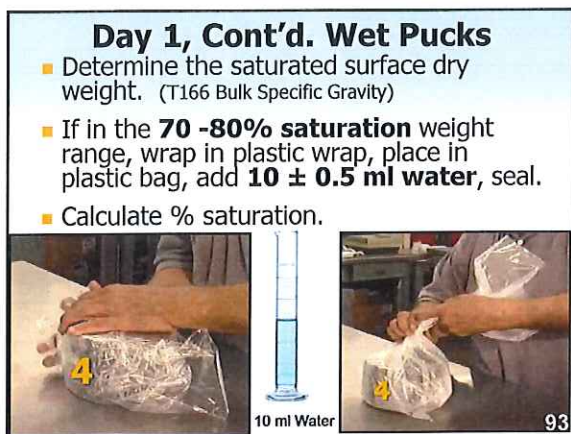
90



91



92



93

Calculation of % Saturation From Example Spreadsheet Puck #4

E (puck volume) = B - C

B = puck SSD weight

C = puck weight in water

["B" & "C" from G_{mb} testing]:

E



$$E = 3833.5 - 2180.0 = 1654 \text{ cm}^3$$

94

94

Determine % Air voids Puck #4

■ Calculate air voids of each puck:

$$P_a = \frac{G_{mm} - G_{mb}}{G_{mm}} \times 100$$

$$P_a = \frac{2.476 - 2.312}{2.476} \times 100 = 6.6 \%$$

95

95

Open Voids Puck #4

$$V_a (\text{volume of air voids}) = \frac{(P_a) E}{100}$$



$$V_a = \frac{(6.6) (1654 \text{ cm}^3)}{100}$$

$$V_a = 110 \text{ cm}^3$$

96

96

Mix Number	Example
Gmm =	2.476

Gmb Worksheet		Dry Subset			Wet Subset		
Specimen #	1	2	3		4	5	6
Weight in air (g) [A]	3725.8	3749.7	3755.1		3822.4	3759.7	3692.3
SSD Weight (g) [B]	3735.6	3761.0	3765.0		3833.5	3770.7	3707.9
Weight in water (g) [C]	2114.3	2135.9	2140.2		2180.0	2144.3	2094.9
Height (0.1 cm) [t]	9.5	9.5	9.5		9.7	9.5	9.5
Volume (cm ³) [B - C]	1621	1625	1625		1654	1626	
Gmb [A / (B - C)]	2.298	2.307	2.311		2.312	2.312	
% Air Voids [Pa]	7.2	6.8	6.7		6.6	6.6	
Dry volume of air (cm ³) [Va]	117	111	108		110	108	
Average % Air Voids	Dry	6.9			Wet		
Overall							

[B-C]
A/[B-C]
100[Gmm-Gmb]/Gmm
Pa[B-C]/100

TSR Worksheet		Dry Subset			Wet Subset		
Specimen #	1	2	3		4	5	6
Height (0.1 cm) [t]	9.5	9.5	9.5		9.7	9.5	9.5
Max. Load (lbs) [P]	3852	3601	3761		1564	1517	1197
Ind. Tens. Str.:ITS (psi)*	111	104	108		44	44	
* For 15.0 cm diameter specimen[D]		Vacuum SSD Wt. (g)[B']			3902.9	3846.0	3787.3
Avg. Wet ITS (psi)[Swet]		Weight in air (g)[A]			3822.4	3759.7	
Avg. Dry ITS (psi)[Sdry]	108	Vol. Absorb H ₂ O (cm ³)[J']			81	86	B'-A
TSR (%) [100Swet/Sdry]		Dry volume of air (cm ³) [Va]			110	108	
		70% Sat. (Target VSSD)			3899	3835	A+0.7Va
		80% Sat. (Target VSSD)			3910	3846	A+0.8Va
Air Voids (%)	AVG	% Saturation			73	80	100J'/Va
Dry Subset %Air	6.9	in. Hg			22	23	
Wet Subset %Air		Time (min)			8	8	
Saturation (%)		in. Hg			25	26	
		Time (min)			1	1	

6.4516*2P/3.1415tD

Time in 25 C waterbath (2 hrs ± 10 min)		Dry Subset		Wet Subset	
		1h 50m	1h 55m	2h	
NOTE: Shaded cells indicate cells needing input values		Time in Freezer (Minimum 16 hrs)		19h 44m	
		Time in 60 C waterbath (24 ± 1 hrs)		23h 30m	
				23h 30m	

Test Time	12/22/2003	12/22/2003	12/22/2003	12/22/2003	12/22/2003
	5:25 PM	5:30 PM	5:35 PM	4:20 PM	4:25 PM
					18h 54m
					23h 30m
					23h 30m

% Saturation (wet pucks)

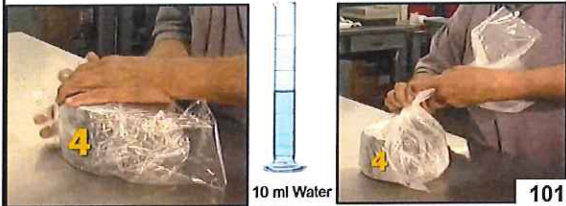
- If the saturation is **less than 70%, re-vacuum** at 26" mercury vacuum for 1 minute.
 - Slowly remove vacuum.
 - Let puck set in water for 5-10 minutes.
(if this is omitted, QA & QC may not compare).
- Check saturation.
- Repeat, as necessary .
- If the saturation is **greater than 80%**, puck is **considered destroyed** and must be discarded.

100

100

DAY 1, Cont'd. (wet pucks)

- When saturation is 70-80%, wrap the pucks in plastic wrap, place in bag with 10ml water, seal, and place in freezer at $-18 \pm 3^{\circ}\text{C}$ for **at least 16 hrs.** Verify temperature throughout the freezer.
- Do not allow specimens to drain after saturation but prior to freezing.



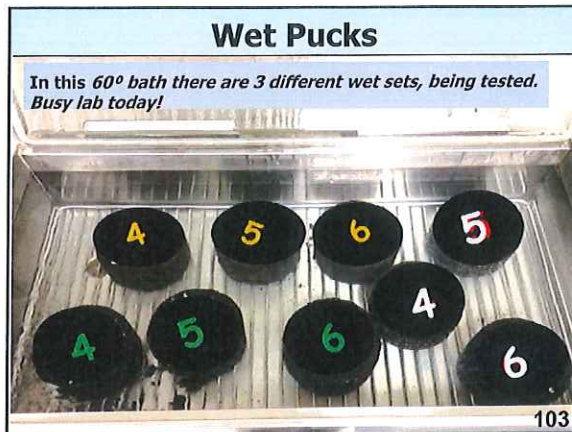
101

DAY 2: Wet Pucks

- Remove the pucks from freezer, remove from bag, and thaw pucks in a water bath at $60^{\circ} \pm 1^{\circ}\text{C}$ for $24 \pm 1\text{ hr}$. Minimum 1 in. water cover above specimens. Unwrap plastic wrap as soon as the film thaws.



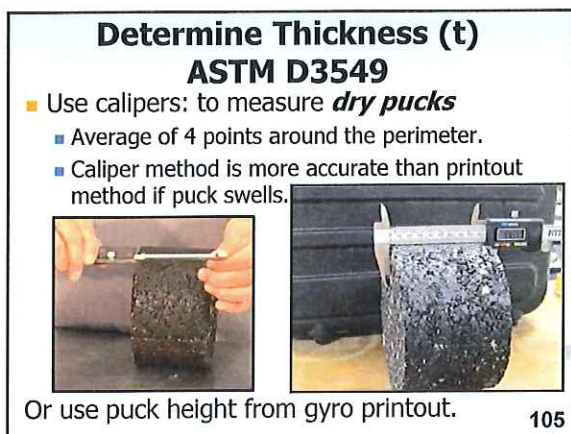
102



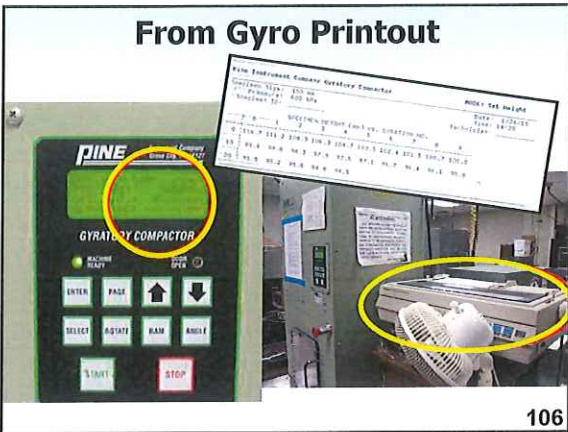
103



104



105



106

From Gyro Printout

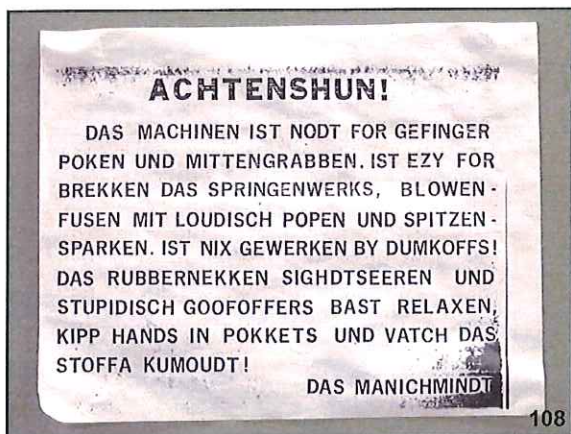
Pine Instrument Company Gyro Compactor

Specimen Size: 150 mm
Pressure: 600 kPa
Specimen ID: _____

MODE: Set Height
Date: 1/24/15
Time: 14:25
Technician: _____

	0	1	2	3	4	5	6	7	8	9
0	116.7	111.2	108.3	106.3	104.7	103.5	102.4	101.5	100.7	100.0
10	99.4	98.8	98.3	97.9	97.5	97.1	96.7	96.4	96.1	95.8
20	95.5	95.2	95.0	94.8	94.5					

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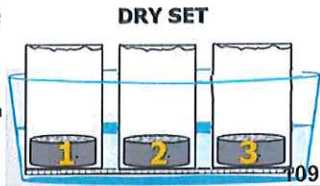
DAY 3: Dry Pucks

- 3 Unconditioned pucks.
- Place each "dry puck" into a heavy-duty leak-proof plastic bag.
- Place into a water bath at $25 \pm 0.5^\circ\text{C}$ for 2 hrs. $\pm$ 10 min.

3 Unconditioned Specimens

- Water level must be Above the puck by at least 1 inch.

Note: This creates an air bath Inside the bag.



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DAY 3: Dry Pucks

- Remove pucks from Water and determine Puck thickness (t). Then to on to testing.

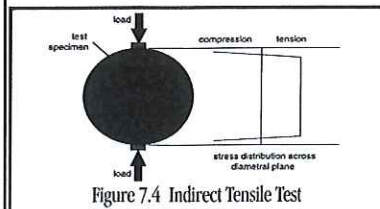


110

110

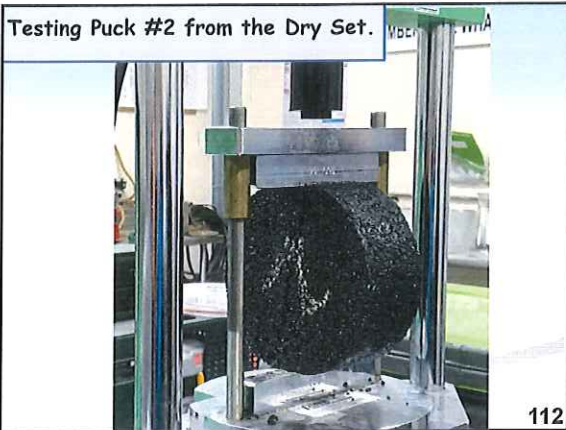
DAY 3, Cont'd. Dry Pucks

- Test for indirect tensile strength (S_1):
 - Apply load at 2" travel per minute.
 - Record maximum load.



111

111



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Calculations: Dry Tensile Strength

- Calculate dry indirect tensile strength, S_1 (psi):

$$S_1 = \frac{2P}{\pi tD}$$

P = load (lbs.)

t = dry puck thickness (in.)

D = puck diameter (6 in.)

$\pi = 3.14159$

113

113

OR Using metric puck measurements:

Indirect Tensile Strength "Dry", S_1 (psi)

$$S_1 = \frac{2P}{\pi tD} \times 6.4516$$

P = load (lbs.)

t = puck thickness (cm)

D = puck diameter (15.0 cm)

$\pi = 3.14159$

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Puck #1

$$S = \frac{2(3852 \text{ lbs.})(6.4516)}{\pi(9.5 \text{ cm})(15.0 \text{ cm})}$$

$$S = 111 \text{ psi}$$

$$\pi = 3.14159$$

115

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Enlarged

Property	Unit	Value	Unit	Value
Compressive Strength	psi	3852	MPa	266.8
Tensile Strength	psi	111	MPa	7.6
Modulus of Elasticity	psi	1.1e6	MPa	75.8
Poisson's Ratio		0.3		
Thermal Expansion Coefficient	1/°F	6.5e-6	1/°C	1.2e-5
Thermal Conductivity	Btu-in/hr-ft²-°F	0.001	W/m-K	0.14
Electrical Resistivity	ohm-in	1.0e-10	ohm-m	1.6e-11
Electrical Conductivity	ohm-in	1.0e+10	ohm-m	1.6e+11
Dielectric Constant		1.0		
Dielectric Loss		0.0		
Volume Fraction		0.0		
Surface Area	in²	1.0	m²	0.000645
Perimeter	in	3.14	m	0.020
Mass	lb	0.0001	kg	1.5e-5
Density	lb/in³	0.0001	kg/m³	1.5
Specific Gravity		0.0001		
Young's Modulus	psi	1.1e6	MPa	75.8
Shear Modulus	psi	4.2e5	MPa	29.0
Bulk Modulus	psi	1.1e6	MPa	75.8
Poisson's Ratio		0.3		
Thermal Expansion Coefficient	1/°F	6.5e-6	1/°C	1.2e-5
Thermal Conductivity	Btu-in/hr-ft²-°F	0.001	W/m-K	0.14
Electrical Resistivity	ohm-in	1.0e-10	ohm-m	1.6e-11
Electrical Conductivity	ohm-in	1.0e+10	ohm-m	1.6e+11
Dielectric Constant		1.0		
Dielectric Loss		0.0		
Volume Fraction		0.0		
Surface Area	in²	1.0	m²	0.000645
Perimeter	in	3.14	m	0.020
Mass	lb	0.0001	kg	1.5e-5
Density	lb/in³	0.0001	kg/m³	1.5
Specific Gravity		0.0001		

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Calculations Wet Tensile Strength

- Wet indirect tensile strength, S_2 (psi).

$$S_2 = \frac{2P}{\pi t' D}$$

P = load (lbs.)

t' = wet puck thickness (in.)

D = puck diameter (6 in.)

$$\pi = 3.14159$$

117

117

Mix Number	Example	Gmm =	2.476
------------	---------	-------	-------

Gmb Worksheet		Dry Subset			Wet Subset		
Specimen #	1	2	3	4	5	6	
Weight in air (g) [A]	3725.8	3749.7	3755.1	3822.4	3759.7	3692.3	
SSD Weight (g) [B]	3735.6	3761.0	3765.0	3833.5	3770.7	3707.9	
Weight in water (g) [C]	2114.3	2135.9	2140.2	2180.0	2144.3	2094.9	
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5	
Volume (cm ³) [B - C]	1621	1625	1625	1654	1626		
Gmb [A / (B - C)]	2.298	2.307	2.311	2.312	2.312		
% Air Voids [Pa]	7.2	6.8	6.7	6.6	6.6		
Dry volume of air (cm ³) [Va]	117	111	108	110	108		
Average % Air Voids	Dry	6.9		Wet			
Overall							

[B-C]
A/[B-C]
100[Gmm-Gmb]/Gmm
Pa[B-C]/100

TSR Worksheet		Dry Subset		Wet Subset		
Specimen #	1	2	3	4	5	6
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5
Max. Load (lbs) [P]	3852	3601	3761	1564	1517	1197
Ind. Tens. Str.:ITS (psi)*	111	104	108	44	44	
* For 15.0 cm diameter specimen[D]		Vacuum SSD wt. (g)[B']		3902.9	3846.0	3787.3
Avg. Wet ITS (psi)[Swet]		Weight in air (g)[A]		3822.4	3759.7	
Avg. Dry ITS (psi)[Sdry]	108	Vol. Absorb H ₂ O (cm ³)[J']		81	86	
TSR (%) [100Swet/Sdry]		Dry volume of air (cm ³)[Va]		110	108	
		70% Sat. (Target VSSD)		3899	3835	
	AVG	80% Sat. (Target VSSD)		3910	3846	
		% Saturation		73	80	
Air Voids (%)		in. Hg		22	23	23
Dry Subset %Air	6.9	Time (min)		8	8	8
Wet Subset %Air		in. Hg		25	26	24
Saturation (%)		Time (min)		1	1	1

6.4516*2P/3.1415tD

B'-A
A+0.7Va
A+0.8Va
100J/Va

Time in 25 C waterbath (2 hrs ± 10 min)	1h 50m	1h 55m	2h
--	--------	--------	----

NOTE: Shaded cells indicate cells needing input values	Time in Freezer (Minimum 16 hrs)		Time in 60 C waterbath (24 ± 1 hrs)	
	19h 44m		23h 30m	
	23h 30m		23h 30m	

Test Time	12/22/2003 5:25 PM	12/22/2003 5:30 PM	12/22/2003 5:35 PM	12/22/2003 4:20 PM	12/22/2003 4:25 PM	12/22/2003 4:30 PM

Using metric puck measurements:

- Wet indirect tensile strength, S_2 (psi).

$$S_2 = \frac{2P}{\pi t' D} \times 6.4516$$

P = load (lbs.)

t' = puck thickness (cm)

D = puck diameter (15.0 cm)

$$\pi = 3.14159$$

118

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Puck #4

- $$\blacksquare S = \frac{2(1564 \text{ lbs.})(6.4516)}{\pi(9.7 \text{ cm})(15.0 \text{ cm})}$$

- $S = 44 \text{ psi}$

$$\pi = 3.14159$$

119

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Enlarged

120

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Mix Number

Example

Gmm =

2.476

Gmb Worksheet

Specimen #	Dry Subset			Wet Subset		
	1	2	3	4	5	6
Weight in air (g) [A]	3725.8	3749.7	3755.1	3822.4	3759.7	3692.3
SSD Weight (g) [B]	3735.6	3761.0	3765.0	3833.5	3770.7	3707.9
Weight in water (g) [C]	2114.3	2135.9	2140.2	2180.0	2144.3	2094.9
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5
Volume (cm ³) [B - C]	1621	1625	1625	1654	1626	
Gmb [A / (B - C)]	2.298	2.307	2.311	2.312	2.312	
% Air Voids [Pa]	7.2	6.8	6.7	6.6	6.6	
Dry volume of air (cm ³) [Va]	117	111	108	110	108	
Average % Air Voids	Dry			Wet		
Overall	6.9					

[B-C]
A/[B-C]
100[Gmm-Gmb]/Gmm
Pa[B-C]/100

TSR Worksheet

Specimen #	Dry Subset			Wet Subset		
	1	2	3	4	5	6
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5
Max. Load (lbs) [P]	3852	3601	3761	1564	1517	1197
Ind. Tens. Str.:ITS (psi)*	111	104	108	44	44	
* For 15.0 cm diameter specimen [D]	Vacuum SSD Wt. (g) [B']			3902.9		
Avg. Wet ITS (psi) [Swet]	Weight in air (g) [A]			3822.4		
Avg. Dry ITS (psi) [Sdry]	Vol. Absorb H ₂ O (cm ³) [J]			81		
TSR (%) [100Swet/Sdry]	Dry volume of air (cm ³) [Va]			110		
	70% Sat. (Target VSSD)			3899		
	80% Sat. (Target VSSD)			3910		
	% Saturation			73		
Air Voids (%)	AVG			22		
Dry Subset %Air	6.9			23		
Wet Subset %Air				8		
Saturation (%)				25		
	Time (min)			1		

5.4516*2P/3.1415tD

B'-A

A+0.7Va

A+0.8Va

100J'/Va

Dry Subset

Time in 25 C waterbath (2 hrs ± 10 min)	1h 50m	1h 55m	2h
--	--------	--------	----

Wet Subset

	19h 44m	19h 16m	18h 54m
--	---------	---------	---------

Time in Freezer

(Minimum 16 hrs)

Time in 60 C waterbath

(24 ± 1 hrs)

	23h 30m	23h 30m	23h 30m
--	---------	---------	---------

NOTE: Shaded cells indicate
cells needing input values

Test Time

12/22/2003	12/22/2003	12/22/2003	12/22/2003
5:25 PM	5:30 PM	5:35 PM	4:30 PM

Calculations: TSR

- Calculate TSR:

$$TSR = \frac{S_2}{S_1} \times 100$$

S_2 = Average of conditioned (wet) pucks tensile strength.

S_1 = Average of unconditioned (dry) pucks tensile strength.

Report TSR to the nearest whole %

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Calculations: TSR

- Specimen #6 ITS is 35 psi, so the average (#4, #5, #6) wet S_2 = 41 psi

$$TSR = \frac{41}{108} \times 100$$

$$TSR = 37.96 = 38\%$$

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445-0101-203 1-203 Rev. 3/24-540x117mm-10

Job Number: Example 2-279

Condition	1	2	3	4	5	6
Conditioned (Wet)	37.1	37.1	37.1	37.1	37.1	37.1
Unconditioned (Dry)	37.1	37.1	37.1	37.1	37.1	37.1
Average (Wet)	37.1	37.1	37.1	37.1	37.1	37.1
Average (Dry)	37.1	37.1	37.1	37.1	37.1	37.1
TSR	100	100	100	100	100	100

Enlarged

Condition	1	2	3	4	5	6
Conditioned (Wet)	37.1	37.1	37.1	37.1	37.1	37.1
Unconditioned (Dry)	37.1	37.1	37.1	37.1	37.1	37.1
Average (Wet)	37.1	37.1	37.1	37.1	37.1	37.1
Average (Dry)	37.1	37.1	37.1	37.1	37.1	37.1
TSR	100	100	100	100	100	100

NOTE: Shaded cells indicate cells needing input values

Test Time: 12/22/2003 12:20:00 12/22/2003 12:20:00 12/22/2003 12:20:00 12/22/2003 12:20:00 12/22/2003 12:20:00

123

123

Mix Number

Example

Gmm = 2.476

Gmb Worksheet		Dry Subset		Wet Subset	
Specimen #		1	2	3	6
Weight in air (g) [A]		3725.8	3749.7	3755.1	3692.3
SSD Weight (g) [B]		3735.6	3761.0	3765.0	3707.9
Weight in water (g) [C]		2114.3	2135.9	2140.2	2094.9
Height (0.1 cm) [t]		9.5	9.5	9.5	9.5
Volume (cm ³) [B - C]		1621	1625	1625	1626
Gmb [A / (B - C)]		2.298	2.307	2.311	2.312
% Air Voids [Pa]		7.2	6.8	6.7	6.6
Dry volume of air (cm ³) [Va]		117	111	108	108
Average % Air Voids		6.9			
Overall		Wet			

[B-C]
A/[B-C]
100[Gmm-Gmb]/Gmm
Pa[B-C]/100

TSR Worksheet		Dry Subset		Wet Subset	
Specimen #		1	2	3	6
Height (0.1 cm) [t]		9.5	9.5	9.5	9.5
Max. Load (lbs) [P]		3852	3601	3761	1197
Ind. Tens. Str.:ITS (psi)*		111	104	108	
* For 15.0 cm diameter specimen[D]		Vacuum SSD Wt. (g) [B']			
Avg. Wet ITS (psi) [Swet]		Weight in air (g) [A]			
Avg. Dry ITS (psi) [Sdry]		Vol. Absorb H ₂ O (cm ³) [J']			
TSR (%) [100Swet/Sdry]		Dry volume of air (cm ³) [Va]			
		70% Sat. (Target VSSD)			
		80% Sat. (Target VSSD)			
		% Saturation			
Air Voids (%)		in. Hg			
Dry Subset %Air		Time (min)			
Wet Subset %Air		in. Hg			
Saturation (%)		Time (min)			
		1			
		1			

6.4516*2P/3.1415tD

B'-A

A+0.7Va

A+0.8Va

100J'/Va

Dry Subset

1h 50m 1h 55m 2h

Time in 25 C waterbath
(2 hrs ± 10 min)

Wet Subset

19h 44m 19h 16m 18h 54m

NOTE: Shaded cells indicate
cells needing input valuesTime in Freezer
(Minimum 16 hrs)Time in 60 C waterbath
(24 ± 1 hrs)

23h 30m 23h 30m 23h 30m

Test Time

12/22/2003 5:25 PM	12/22/2003 5:30 PM	12/22/2003 5:35 PM	12/22/2003 4:20 PM	12/22/2003 4:25 PM	12/22/2003 4:30 PM
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Suspected Strength Outlier

- If attributable to an air void content different from other 2 pucks, leave in the set.
- If a mystery, calculate if statistically is an outlier (ASTM E178)-if so, pitch and do one of the following:
 - Substitute another puck if compacted extra pucks.
 - Test a new set of 3.
 - Go with 2 pucks in the set.
 - Prepare and test a substitute puck---must be assured that the material is the same as what was used for the other pucks.

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OUTLIER EVALUATION
ASTM E 178
Applies to test values: TSR

1. If the largest test value (x_{max}) in the set is suspected to be an outlier, calculate the t-statistic:

$$t = \frac{(x_{max} - x_{avg})}{S}$$

Where x_{avg} = average
 S = standard deviation

2. If the smallest test value (x_{min}) in the set is suspected to be an outlier, calculate the t-statistic:

$$t = \frac{(x_{avg} - x_{min})}{S}$$

3. Compare the largest calculated t-statistic to the critical t-statistic. The critical t-statistic depends on the desired significance level and the number of test results in the set. MoDOT has set the significance level at 5%. If the evaluation is of an outlier either being too high, or too low, the following is a table of t-critical values. Typically, there are 3 TSR replicate specimens:

No. of tests	t @ 5% in tail
3	1.153
4	1.463
5	1.672
6	1.822
7	2.038
8	2.022
9	2.119
10	2.178

If the calculated t-statistic is greater than t_{critical}, consider the test result to be an outlier.

Enlarged

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Example

- Triplicate dry set: 111, 108, 104 psi
- Average = 107.7 psi
- Standard deviation = 3.51 psi
- $t_{max} = (x_{max} - x_{avg})/S$
- $= (111 - 107.7)/3.51 = 0.940$
- $t_{min} = (x_{avg} - x_{min})/S$
- $= (107.7 - 104)/3.51 = 1.054$
- From table: $t_{critical} = 1.153$
- Is 111 an outlier? (Is $0.940 > 1.153$?) No
- Is 104 an outlier? (Is $1.054 > 1.153$?) No

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OUTLIER EVALUATION

ASTM E 178

Applies to test values: TSR

1. If the largest test value ($x_{\max}$) in the set is suspected to be an outlier, calculate the t-statistic:

$$t = \frac{(x_{\max} - x_{\text{avg}})}{S}$$

Where x_{avg} = average

S = standard deviation

2. If the smallest test value ($x_{\min}$) in the set is suspected to be an outlier, calculate the t-statistic:

$$t = \frac{(x_{\text{avg}} - x_{\min})}{S}$$

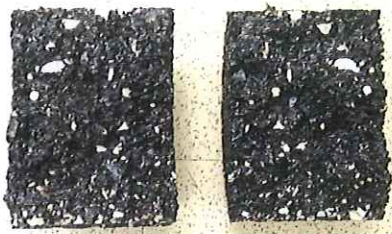
3. Compare the largest *calculated t-statistic* to the *critical t-statistic*. The *critical t-statistic* depends on the desired significance level and the number of test results in the set. MoDOT has set the significance level at 5%. If the evaluation is of an outlier either being too high, or too low, the following is a table of t-critical values. Typically, there are 3 TSR replicate specimens:

No. of tests	t @ 5% in tail
3	1.153
4	1.463
5	1.672
6	1.822
7	2.938
8	2.032
9	2.110
10	2.176

If the *calculated t-statistic* is greater than $t_{\text{critical}} (\alpha = 5\%)$, consider the test result to be an outlier.

Inspect

- Rate the degree of moisture damage on a scale of 0 to 5, with 5 being the greatest amount of stripping.



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SCOPE

- Background
- TSR Role in QC/QA
- Sampling for TSR
- Reducing AASHTO R47
- Equipment
- Estimation of Puck Mass
- Test Procedure
- **Field Verification** ←

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Comparison: QC to QA

TSR -favorable comparison is when QA and QC results are within 10% of each other.

If the difference is 5 to 10%, TSR's are evaluated by MoDOT field office.

If difference is >10%, initiate dispute resolution.

QC and QA retained samples may have to be kept for extended periods.

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Common Errors/ Unfavorable Comparison

- Shaking saturated puck to "adjust" saturated mass.
- Using pucks out of the acceptable air void range (7.0 ± 0.5 or $6.0 \pm 0.5\%$).
- Proper water tank temperature not maintained (25 and 60°C).
- Using puck that has been over or under saturated instead of discarding or applying additional vacuum.

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Common Errors/ Unfavorable Comparison

- Using incorrect maximum specific gravity to calculate voids and % saturation.
- Specimen in water bath for the incorrect amount of time.
- Not cleaning breaking apparatus when dirty.
- Not annually verifying breaking machine.

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Common Errors/ Unfavorable Comparison

- Not molding specimens at correct temperature (if cool, may break aggregate).
- Not aging lab specimens, the correct time & temperature (lab-mixed only).
- Not adding 10 ml of water prior to freezing.
- Allowing specimens to drain after saturation but prior to freezing.

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Common Errors/ Unfavorable Comparison

- Using vacuum out of allowable range (10-26 in. Hg).
- Not allowing specimen to "rest" 5-10 minutes after vacuum period.
- Exceeding time of vacuum.
- Not air-drying T166-tested unconditioned pucks for 24 hrs. prior to breaking.
- Sample contaminated with dust, release agent overspray, etc.

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Common Errors/ Unfavorable Comparison

- Improper filling of sample into boxes.
- Improper mixing and splitting procedures.
- One or more mixture re-warmings.
- Testing pucks at extreme ends of allowable range of voids [6.5, 7.5] may result in poor QC/QA comparison.
- QC and QA not sampling at the same location-type (roadway vs plant) TSR and Rice gravity.

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APPENDIX

Sample Splitting

135

135

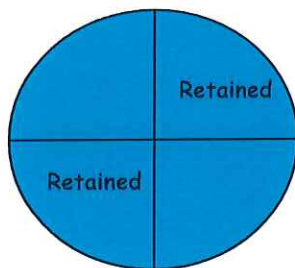
TSR Sample Quartering

- *Sample for TSR is quartered per AASHTO R 47.*
- *Opposing 2 quarters are removed and combined for the retained split.*
- Combine remaining 2 quarters.
- Quarter again.
- Combine opposite quarters, producing 2 piles.
- Quarter each pile. Now have 8 splits.
- Pull 6 pucks.
- Pull Rice if necessary.

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Opposing 2 quarters are removed and combined for the retained split.



137

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- Note-you will need about 175 lbs. if you do this step—if not, 75 lbs. will work.

138

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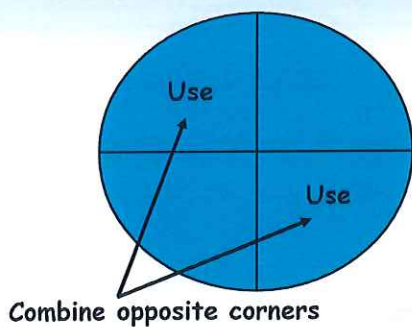
TSR Sample Quartering

- Sample for TSR is quartered per AASHTO R47.
- Opposing 2 quarters are removed and combined for the retained split.
- **Combine remaining 2 quarters.**
- Quarter again.
- Combine opposite quarters, producing 2 piles.
- Quarter each pile. Now have 8 splits.
- Pull 6 pucks.
- Pull Rice if necessary.

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Combine remaining 2 quarters



140

140

Sample Size

- Need ~ 175 lbs. to follow this whole procedure.
- Need ~ 75 lbs. if you skip the first 3 steps.

141

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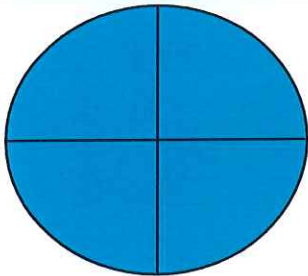
TSR Sample Quartering

- Sample for TSR is quartered per AASHTO R 47.
- Opposing 2 quarters are removed and combined for the retained split.
- Combine remaining 2 quarters.
- **Quarter again.**
- Combine opposite quarters, producing 2 piles.
- Quarter each pile. Now have 8 splits.
- Pull 6+ pucks.
- Pull Rice if necessary.

142

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Quarter Again



143

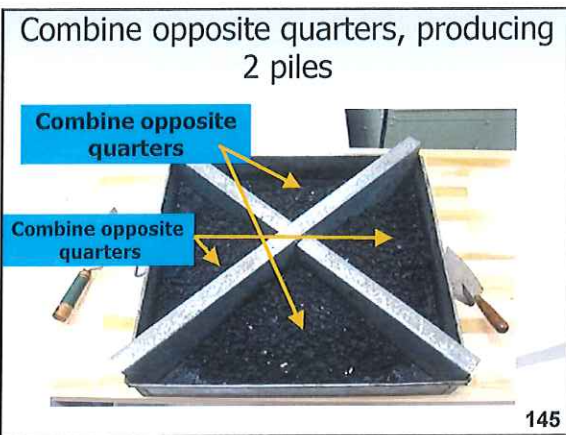
143

TSR Sample Quartering

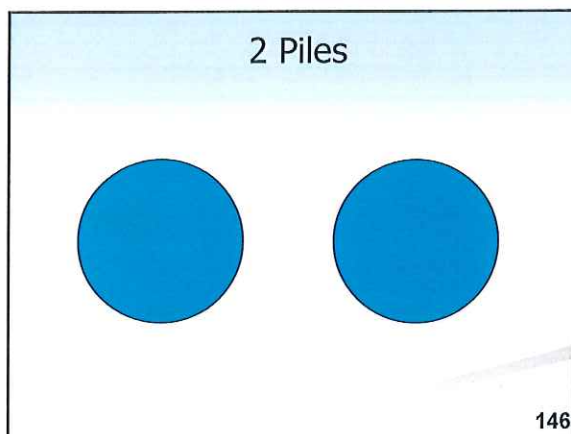
- Sample for TSR is quartered per AASHTO R47.
- Opposing 2 quarters are removed and combined for the retained split.
- Combine remaining 2 quarters.
- Quarter again.
- **Combine opposite quarters, producing 2 piles.**
- Quarter each pile. Now have 8 splits.
- Pull 6 pucks.
- Pull Rice if necessary.

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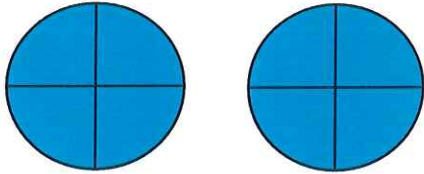
TSR Sample Quartering

- Sample for TSR is quartered per AASHTO R 47
- Opposing 2 quarters are removed and combined for the retained split.
- Combine remaining 2 quarters
- Quarter again
- Combine opposite quarters, producing 2 piles
- **Quarter each pile. Now have 8 splits.**
- Pull 6 pucks.
- Pull Rice if necessary.

147

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Quarter each pile. Now have 8 splits.



148

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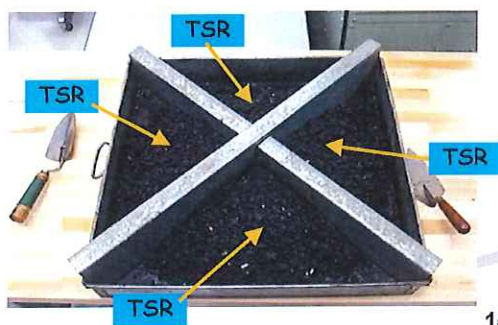
TSR Sample Quartering

- Sample for TSR is quartered per AASHTO R 47
- Opposing 2 quarters are removed and combined for the retained split.
- Combine remaining 2 quarters.
- Quarter again.
- Combine opposite quarters, producing 2 piles.
- Quarter each half again. Now have 8 splits.
- **Pull 6 pucks.**
- **Pull Rice if necessary.**

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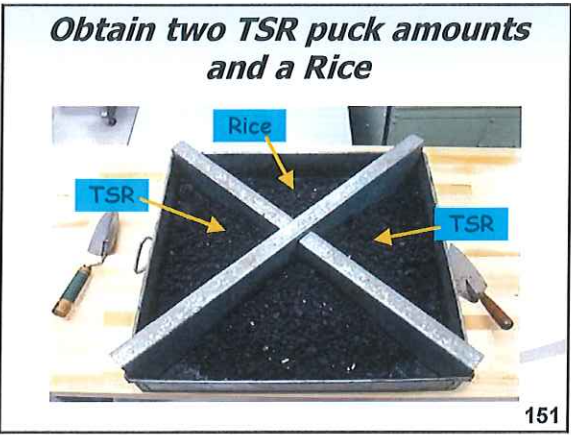
149

Obtain four TSR puck amounts

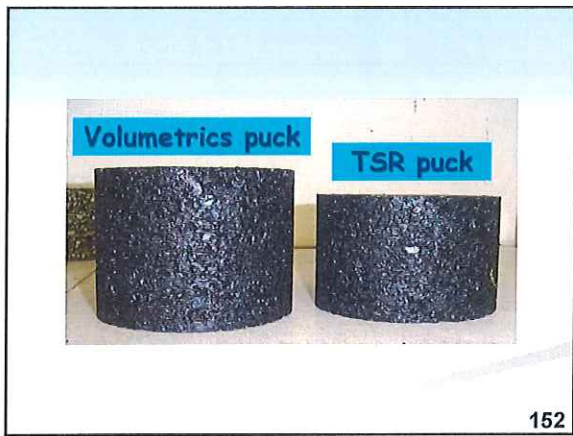


150

150



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TENSILE STRENGTH RATIO CERTIFICATION

PROFICIENCY EXAMINATION

Revised 2022

Applicant_____

Employer_____

TENSILE STRENGTH RATIO (TSR) TECHNICIAN CERTIFICATION PROFICIENCY CHECKLIST

AASHTO T 283

Revised: 03/22/2022

Trial#	1	2	R
Sample Preparation and Grouping:			
1. Obtained field-mixed asphalt mixture sample in accordance with AASHTO R97 with enough material to complete all tests.			
2. Compact ≥ 6 pucks to spec: 95 ± 5 mm thick and $7.0 \pm 0.5\%$ air voids.			
3. Determine specimen thickness (t)			
4. Obtain G_{mb} (bulk specific gravity) for each puck.			
5. Using an associated G_{mm} (Rice) using AASHTO T209, calculate % air voids for each puck.			
6. Sort into 2 groups of 3 pucks each so that <u>average air voids of each group</u> are approximately equal.			
“Dry” (Non-conditioned) Testing:			
7. Before proceeding, be sure pucks have air-dried for 24 ± 3 hrs. <u>after</u> G_{mb} determination.			
8. Place each dry puck in its own water-proof bag. Place bagged dry pucks in warm-water bath for 2 hrs. ± 10 min. with 1” of water above surface of specimens.			
9. Test each puck in indirect tension; record maximum load for each. Calculate tensile strength for each.			
10. <u>Calculate average tensile strength</u> for dry set of pucks (S_{dry}).			
“Wet” (Conditioned) Testing:			
11. Place puck in vacuum vessel with at least 1” of water below and above the puck; subject to vacuum saturation for 5-10 min. within specified vacuum range.			
12. Remove vacuum; keep puck submerged for another 5-10 min.			
13. Having already zeroed out a piece of plastic wrap on the balance, remove puck, quickly surface-dry it, and place it on the balance.			
14. Determine degree of saturation (i.e., is the weight displayed on the balance within the range needed?).			
15. If saturation $< 70\%$, repeat vacuum procedure using more time and/or vacuum.			
16. If saturation $> 80\%$, discard specimen.			
17. If degree of saturation is 70-80%, tightly wrap plastic film around puck, place sealed puck in plastic bag along with 10 ml water, seal outer bag and place in freezer for at least 16 hrs.			

18. Remove pucks from freezer and plastic bag; quickly place pucks into hot-water bath for 24 ± 1 hr. (1" of water above surface of specimens); remove plastic wrap as soon as possible.			
19. After 24 ± 1 hr. in hot-water bath, transfer pucks to warm-water bath for 2 hrs. ± 10 min.			
20. Obtain specimen thickness (t') then test each puck in indirect tension; record maximum load for each. Calculate tensile strength for each.			
21. <u>Calculate average tensile strength</u> for conditioned set of pucks ($S_{\text{conditioned}}$).			
22. Calculate TSR: $\text{TSR} = \frac{S_{\text{conditioned}}}{S_{\text{dry}}} \times 100\%$ (to nearest whole number)			
Pass?			
Fail?			

Examiner _____ Date _____

Reviewer _____ Date _____