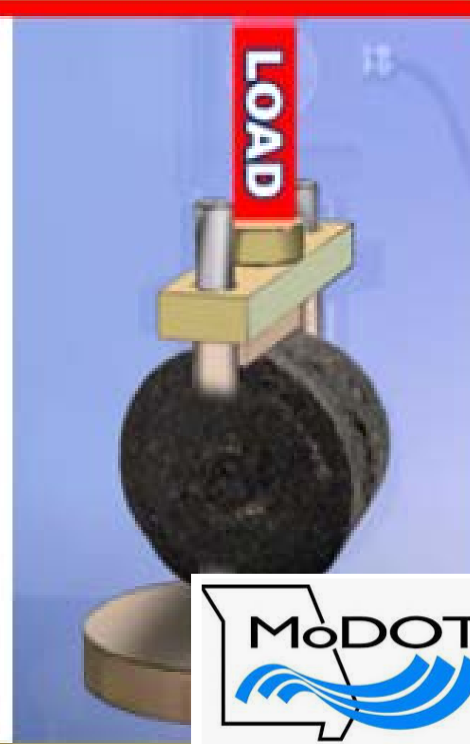
Edition 2022

Tensile Strength Ratio



MoDOT

Tensile Strength Raito

2022 – Updates

- 2022 – Entire Manual has been updated.
  - 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

MoDOT

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

7

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.

Dry Set Unconditioned

Wet Set Conditioned

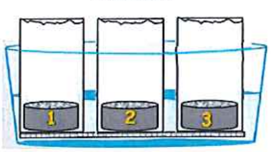
8

8

T 283 Moisture Sensitivity

3 Unconditioned Specimens

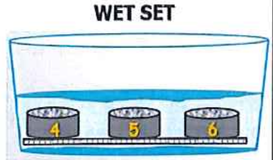
DRY SET



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

9

T 283 Moisture Sensitivity

Determine the tensile strengths of both sets of 3 specimens.

Calculate the Tensile Strength Ratio (TSR).

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

TSR = ≥ **80%** needed.

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

10

10

SCOPE

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

11

11

TSR Role in QC/QA

- Mix design/acceptance
- Field Verification of mix

12

12

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.

13

13

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.

14

14

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.

15

15

Mix Design Acceptance

- TSR ≥ 70% for ***BB and BP*** mixes
- TSR > 80% for ***Superpave*** mixes

16

16

TSR Role in QC/QA

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

17

17

Superpave TSR Pay adjustment

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

18

18

SCOPE

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

19

19

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.

20

20

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).

21

21

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.

22

22

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.

23

23

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.

24

24

Loose Mix Sampling Location

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

SAFETY: Always wear PPE when sampling asphalt.

25

TRUCK SAMPLING

Preferred

Use a platform with rails.

26

26

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.

27

27

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.

28

28

PLANT DISCHARGE SAMPLING

29

29

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.

30

30

Plant Discharge

Diverter Chute Issues

- Contamination issues from diesel used to clean the area.

31

31

MINI-STOCKPILE SAMPLING

32

32

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.

33

33

ROADWAY SAMPLING

(Use as a last resort)

34

34

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.

35

35

TSR Sampling-Roadway
Roadway Issues

- Profiler issues?
- Big hole to fill.

36

36

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).

37

37

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"

38

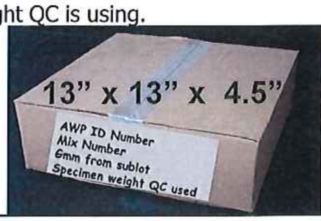
38

QA - TSR Box Information

On each full box of asphalt, write the following <u>ON THE SIDE</u> of the box:

1. AWP ID number.
2. Mix number.
3. G_{mm} from sublot 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.



39

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.

40

40

SCOPE

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

41

41

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"

42

42

AASHTO R47 Quartering Devices

43

43

SCOPE

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

44

44

Equipment

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

45

45

Equipment

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

46

46

Equipment

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

47

47

Equipment

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

48

48

SCOPE

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

49

49

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.

50

50

Estimate TSR Puck Mass

- V_{solids} = (Mass)/(specific gravity)
- $V_{air} = V_{total} - V_{solids}$
- 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.

51

51

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.

52

52

Estimate TSR Puck Mass

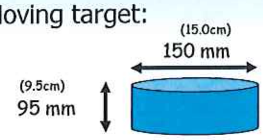
- Do a weight-volume calculation to get initial mass.
- Adjust via the most recent puck history. (say, using volumetric pucks)
- Fine-tune with experience.

53

53

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).

54

54

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.

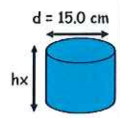
h_x in "cm" for historical pucks.
(Usually 11.5 ± 0.5 cm)

55

55

$G_{mb,est}$ Step #2

- Next, compute the G_{mb} as if there were no side voids (dimples) = $G_{mb,est}$
- $$Gmb, estimated = \frac{Avg.Mmeas}{\left(\frac{\pi d^2 (avg\ h_X)}{4}\right)}$$



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 > $G_{mb,est}$

56

56

Calculation of Mass Required For 7.0% AIR VOIDS Step # 3

- Calculate "C"

Step #1

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

Step #2

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

57

57

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

- Obtain G_{mm} for the sampled roadway mat area.
- $$V_{air} = \frac{100(G_{mm} - G_{mb})}{G_{mm}}$$

58

58

CAUTION

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

59

59

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

h = 9.5 cm for TSR pucks

60

60

Alternate Equation
Step #4, cont'd.

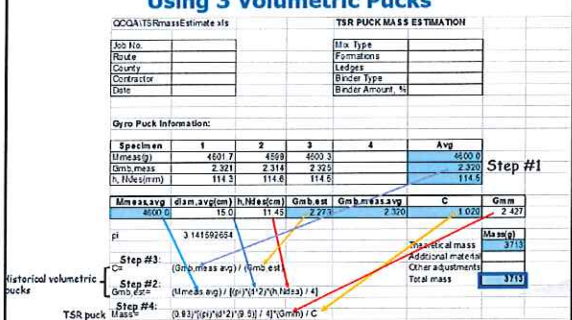
- If (d=15.0 cm) and (h = 9.5 cm):
- $Mass = \frac{1561.2\ Gmm}{C}$

61

61

Example TSR Mass
Using 3 Volumetric Pucks

ENLARGED



62

62

SCOPE

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

63

63

Example TSR Mass
Using 3 Volumetric Pucks

QCQA\TSRmassEstimate.xls

TSR PUCK MASS ESTIMATION

Job No.		Mix Type	
Route		Formations	
County		Ledges	
Contractor		Binder Type	
Date		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

Step #1

Mmeas,avg	diam,avg(cm)	h,Ndes(cm)	Gmb,est	Gmb,meas.avg	C	Gmm
4600.0	15.0	11.45	2.273	2.320	1.020	2.427

pi 3.141592654

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

Historical volumetric pucks

Step #3:
C= (Gmb,meas.avg) / (Gmb,est)

Step #2:
Gmb,est= (Mmeas,avg) / [(pi)*(d^2)*(h,Ndes) / 4]

TSR puck

Step #4:
Mass= (0.93)*[(pi)*(d^2)*(9.5)] / 4]*(Gmm) / C

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

64

64

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±3° C*** for ***16 ± 1 hrs.***

65

65

Procedure

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

66

66

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

67

67

DAILY PROCEDURE
Outline

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

68

68

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]

69

69

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).

70

70

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.

71

71

DAY 1: Determine Air Voids

- Determine G_{mb} for all 6 pucks.

(Follow AASHTO T166 - Pucks need to be tested at **25 ± 1° C**).

Note:

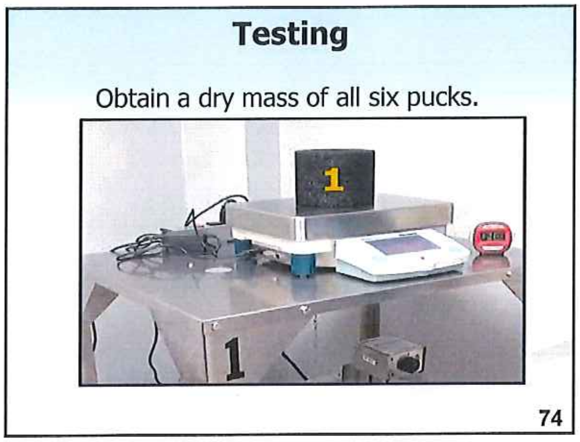
See your Bituminous Technician Manual for AASHTO T166 Bulk Specific Gravity,
And AASHTO T269 Percent Air Voids.
See your Superpave Manual for AASHTO T209 Maximum Specific Gravity.

72

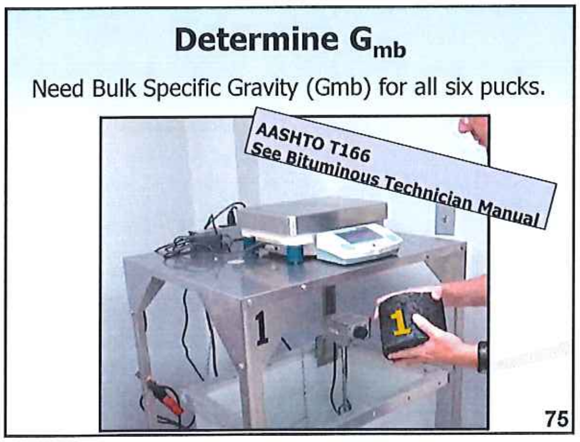
72


TSR
Unconditioned pucks (Dry Set) #1, #2, #3
1
2
3
Rice
4
5
6
Conditioned pucks (Wet Set) #4, #5, #6
73

73


Testing
Obtain a dry mass of all six pucks.
1
1
74

74

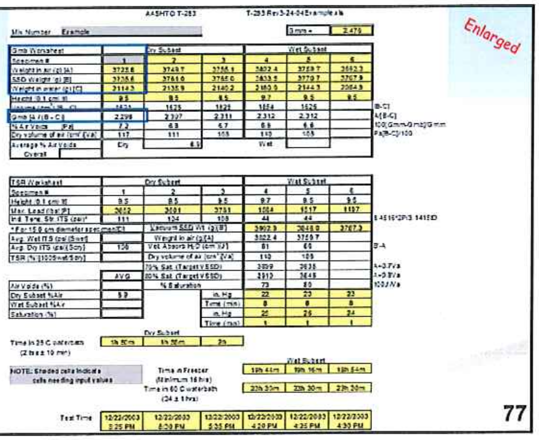

Determine G_{mb}
Need Bulk Specific Gravity (Gmb) for all six pucks.
AASHTO T166
See Bituminous Technician Manual
1
1
75

75

Maximum Specific Gravity

Maximum Specific Gravity Test "Rice" (Gmm)

76



Gmb Worksheet		Dry Subset		Wet Subset			
Specimen #	1	2	3	4	5	6	
Weight in air (g) [A]	3725.8	3749.7	3755.1	3802.4	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	2064.9	
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5	
Volume (cm³) [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	6.9	6.7	6.6	6.6		100(Gmm-Gmb)/Gmm
Dry volume of air (cm³) [Va]	117	111	109	110	108		Pa(B-C)/100
Average % Air Voids	Dry	6.9		Wet			
Overall							

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]	3612	3601	3751	1004	1517	1197	
Ind. Tens. Str. ITS (psi)*	111	124	109	44	44		[illegible]
* For 15.0 cm diameter specimen [D]		Vacuum SSD Wt. (g) [B']		3902.3	3848.0	3767.3	
Avg. Wet ITS (psi) [Swet]		Weight in air (g) [A]		3822.4	3759.7		
Avg. Dry ITS (psi) [Sdry]	130	Vol. Absorb H₂O (cm³) [J']		81	88		B'-A
TSR (%) [100Swet/Sdry]		Dry volume of air (cm³) [Va]		110	108		
		70% Sat. (Target V SSD)		3899	3835		A+0.7Va
	AVG	80% Sat. (Target V SSD)		3910	3846		A+0.8Va
Air Voids (%)		% Saturation		73	80		100J'/Va
Dry Subset %Air	6.9		in. Hg	22	20	23	
Wet Subset %Air			Time (min)	8	8	8	
Saturation (%)			in. Hg	25	26	24	
			Time (min)	1	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 values

	Wet Subset		
Time in Freezer (Minimum 16 hrs)	19h 44m	19h 16m	19h 54m
Time in 60 C waterbath (24 ± 1 hrs)	23h 30m	23h 30m	23h 30m

	1	2	3	4	5	6
Test Time	12/22/2003 3:25 PM	12/22/2003 6:20 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

77

77

Puck Bulk Specific Gravity

From Example Spreadsheet Puck #1

$$G_{mb} = \frac{A}{B - C}$$

$$G_{mb} = \frac{3725.8}{3735.6 - 2114.3}$$

G_{mb} = ***2.298***

78

78

AASHTO T-283 T-283 Rev3-24-04Example.xls

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	6.9		Wet			
Overall							

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_2O (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
	AVG	80% Sat. (Target VSSD)		3910	3846		A+0.8Va
Air Voids (%)		% Saturation		73	80		100J'/Va
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	

	Dry Subset			Wet Subset		
Time in 25 C waterbath (2 hrs ± 10 min)	1h 50m	1h 55m	2h			
Time in Freezer (Minimum 16 hrs)				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	12/22/2003 5:35 PM	12/22/2003 4:20 PM	12/22/2003 4:25 PM	12/22/2003 4:30 PM

NOTE: Shaded cells indicate cells needing input values

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

Determine %Air Voids

From Example Spreadsheet Puck #1

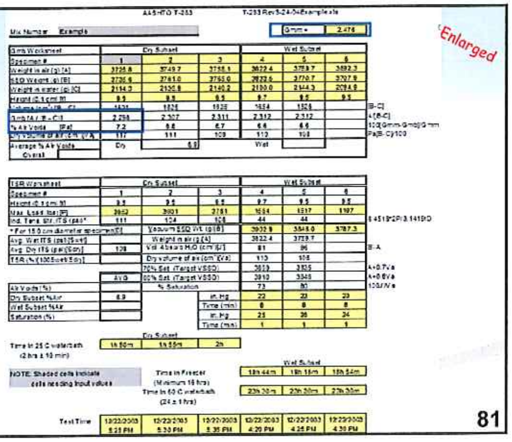
- Having tested Maximum Specific Gravity, (Rice), calculate air voids of each puck:

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

$$Pa = \frac{2.476 - 2.298}{2.476} \times 100 = \textit{7.2 \%}$$

80

80



81

81

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	6.9		Wet			
Overall							

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_2O (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
	AVG	80% Sat. (Target VSSD)		3910	3846		A+0.8Va
Air Voids (%)		% Saturation		73	80		100J'/Va
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	

	Dry Subset			Wet Subset		
Time in 25 C waterbath (2 hrs ± 10 min)	1h 50m	1h 55m	2h			
Time in Freezer (Minimum 16 hrs)				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	12/22/2003 5:35 PM	12/22/2003 4:20 PM	12/22/2003 4:25 PM	12/22/2003 4:30 PM

NOTE: Shaded cells indicate cells needing input values

AIR VOIDS
Two Similar Groups "Wet" and "Dry"

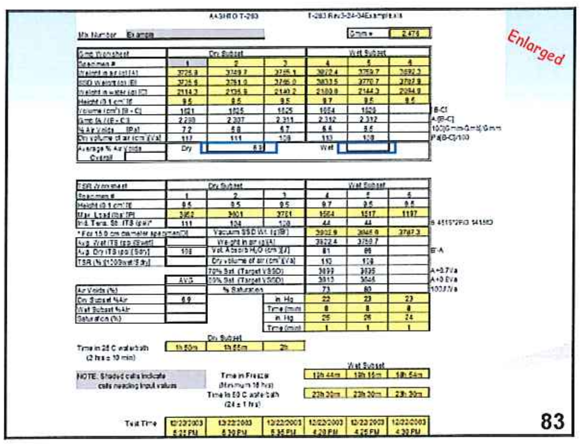
- Group the pucks into 2 groups such that average air voids of each group is about equal.

$$Pa, avg. = \frac{Pa1 + Pa2 + Pa3}{3}$$

- Testing pucks at extreme end of allowable voids may lead to poor QC/QA comparison.

82

82



83

TSR – Unconditioned (Dry)

84

84

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	6.9		Wet			
Overall							

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_2O (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
	AVG	80% Sat. (Target VSSD)		3910	3846		A+0.8Va
Air Voids (%)		% Saturation		73	80		100J'/Va
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	

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

NOTE: Shaded cells indicate cells needing input values

	Wet Subset		
Time in Freezer (Minimum 16 hrs)	19h 44m	19h 16m	18h 54m
Time in 60 C waterbath (24 ± 1 hrs)	23h 30m	23h 30m	23h 30m

	1	2	3	4	5	6
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

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

87

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 (≥ 1″ cover and ≥ 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

Apply Vacuum

91

91

Vacuum Saturation

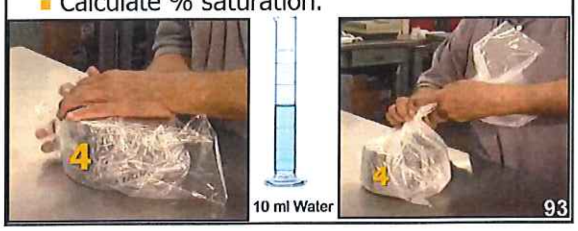
- Slowly remove vacuum.
- Let puck set in water for 5-10 minutes. During this time, the puck is pulling water in. Don't shortcut this step.
- Remove puck, quickly surface dry with a damp towel.

92

92

Day 1, Cont'd. Wet Pucks

- Determine the saturated surface dry weight. (T166 Bulk Specific Gravity)
- If in the **70 -80% saturation** weight range, wrap in plastic wrap, place in plastic bag, add **10 ± 0.5 ml water**, seal.
- Calculate % saturation.



93

93

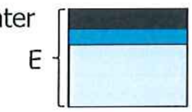
Calculation of % Saturation From Example Spreadsheet Puck #4

E (puck volume) = B - C

B = puck SSD weight

C = puck weight in water

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



E = 3833.5 – 2180.0 = ***1654 cm^3***

94

94

Determine % Air voids Puck #4

- Calculate air voids of each puck:

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

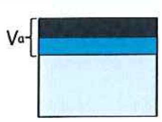
$$P_a = \frac{2.476 - 2.312}{2.476} \times 100 = \mathbf{6.6\ \%}$$

95

95

Open Voids Puck #4

$$Va\ (volume\ of\ air\ voids) = \frac{(Pa)\,E}{100}$$



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

V_a = ***110 cm^3***

96

96

AASHTO T-283 T-283 Rev3-24-04Example.xls

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	6.9		Wet			
Overall							

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_2O (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
	AVG	80% Sat. (Target VSSD)	3910	3846		A+0.8Va
Air Voids (%)		% Saturation	73	80		100J'/Va
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	

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

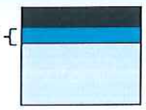
NOTE: Shaded cells indicate cells needing input values

	Wet Subset		
Time in Freezer (Minimum 16 hrs)	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	12/22/2003 5:35 PM	12/22/2003 4:20 PM	12/22/2003 4:25 PM	12/22/2003 4:30 PM

% Saturation
Puck #4

$$\%Saturation = \frac{100\,J'}{Va}$$



J' (volume of absorbed water) = B' – A

B' = SSD weight after saturation

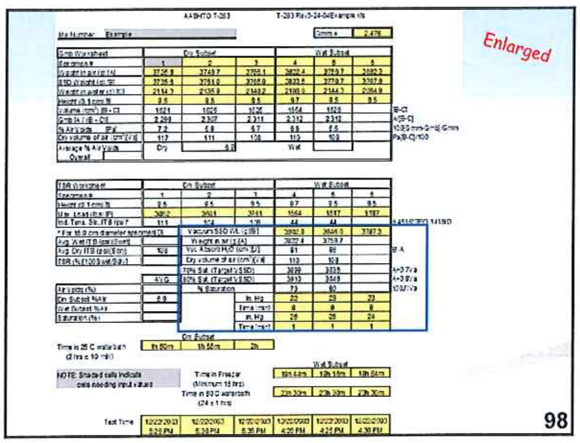
A = puck dry weight in air ["A" from G_{mb} testing]

J' = 3902.9 – 3822.4 = ***81 cm³***

$$\text{\% Saturation} = \frac{100\,(81)}{110} = \mathbf{73\%}$$

97

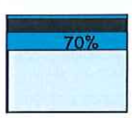
97



98

Pre-Determined Weights
Specimen #4

- Note: for water, M ≈ V
- At 70% saturation:
  - M_{70} = A + 0.7 (V_a)
  - M_{70} = 3822.4 + 0.7 (110) = ***3899 g***



- At 80% saturation:
  - M_{80} = A + 0.8 (V_a)
  - M_{80} = 3822.4 + 0.8 (110) = ***3910 g***

99

99

% 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 ± 3 °C*** for ***at least 16 hrs***. Verify temperature throughout the freezer.
- Do not allow specimens to drain after saturation but prior to freezing.

10 ml Water

101

101

DAY 2: Wet Pucks

- Remove the pucks from freezer, remove from bag, and thaw pucks in a water bath at ***60° ± 1 C*** for ***24 ± 1 hr***. Minimum 1 in. water cover above specimens. Unwrap plastic wrap as soon as the film thaws.

102

102

Wet Pucks

In this 60º bath there are 3 different wet sets, being tested. Busy lab today!

103

103

Day 3 Dry and Wet Strength

104

104

Determine Thickness (t) ASTM D3549

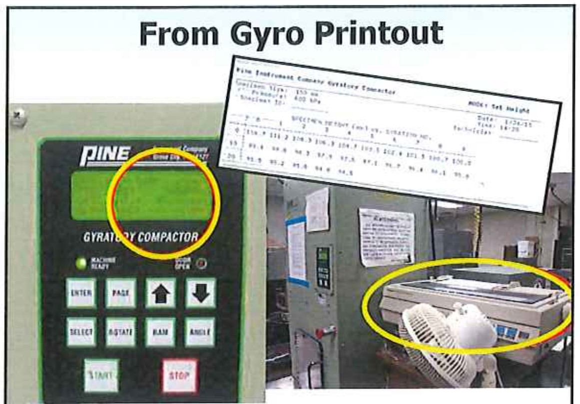
- Use calipers: to measure ***dry pucks***
  - Average of 4 points around the perimeter.
  - Caliper method is more accurate than printout method if puck swells.

Or use puck height from gyro printout.

105

105

From Gyro Printout



106

106

From Gyro Printout

Pine Instrument Company Gyratory Compactor MODE: Set Height

Specimen Size: 150 mm Date: 1/24/15
Pressure: 600 kPa Time: 14:25
Specimen ID: ________ Technician: ________

SPECIMEN HEIGHT (mm) vs. GYRATION NO.

	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	[illegible]	97.1	96.7	96.4	96.1	95.8
20	95.5	95.2	95.0	94.8	94.5					

107

107

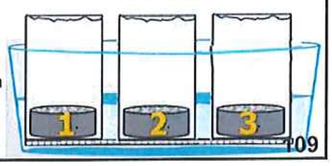
108

108

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 ± 0.5 C*** for ***2 hrs. ± 10 min.***
- Water level must be Above the puck by at least **1 inch**.

Note: This creates an air bath Inside the bag.



109

109

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.

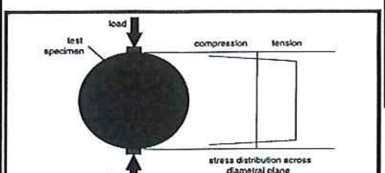
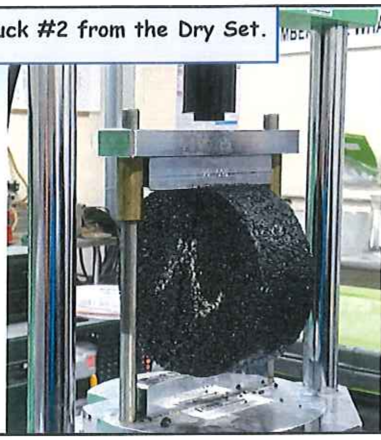


Figure 7.4 Indirect Tensile Test

111

111

Testing Puck #2 from the Dry Set.



112

112

Calculations: Dry Tensile Strength

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

$$S_1 = \frac{2P}{\pi t D}$$

P= load (lbs.)

t = dry puck thickness (in.)

D= puck diameter (6 in.)

π= 3.14159

113

113

OR Using metric puck measurements:

Indirect Tensile Strength "**Dry**", S_1 (psi)

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

P = load (lbs.)

t = puck thickness (cm)

D = puck diameter (15.0 cm)

π= 3.14159

114

114

Puck #1

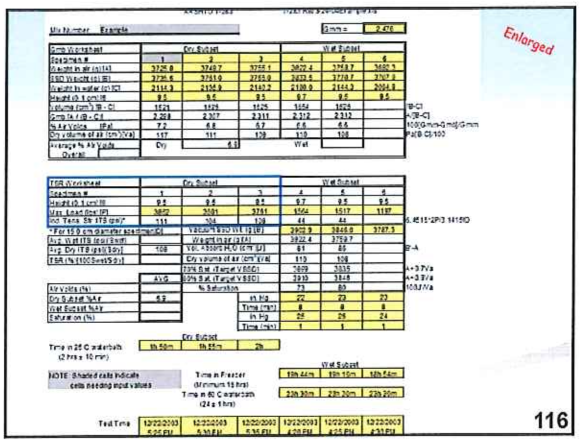
$$S = \frac{2(3852 \text{ lbs.})(6.4516)}{\pi(9.5 \text{ cm})(15.0 \text{ cm})}$$

S = 111 psi

π = 3.14159

115

115



116

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.)

π = 3.14159

117

117

AASHTO T-283 T-283 Rev3-24-04Example.xls

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	6.9		Wet			
Overall							

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]

Avg. Wet ITS (psi)[Swet]		Vacuum SSD Wt. (g)[B']	3902.9	3846.0	3787.3	
Avg. Dry ITS (psi)[Sdry]	108	Weight in air (g)[A]	3822.4	3759.7		
TSR (%)[100Swet/Sdry]		Vol. Absorb H_2O (cm^3)[J']	81	86		B'-A
		Dry volume of air (cm^3)[Va]	110	108		
		70% Sat. (Target VSSD)	3899	3835		A+0.7Va
	AVG	80% Sat. (Target VSSD)	3910	3846		A+0.8Va
Air Voids (%)		% Saturation	73	80		100J'/Va
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	

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

NOTE: Shaded cells indicate cells needing input values

	Wet Subset		
Time in Freezer (Minimum 16 hrs)	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	12/22/2003 5:35 PM	12/22/2003 4:20 PM	12/22/2003 4:25 PM	12/22/2003 4:30 PM

OR
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

118

Puck #4

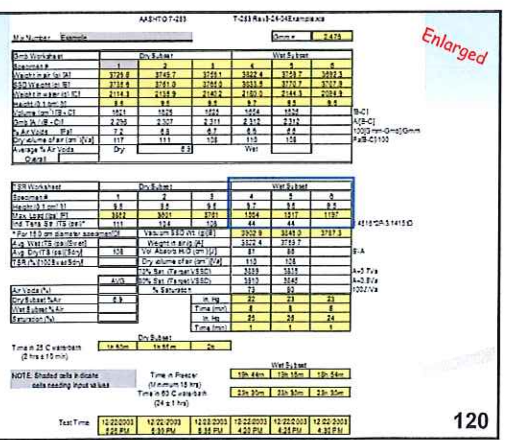
- $S = \dfrac{2(1564 \text{ lbs.})(6.4516)}{\pi(9.7 \text{ cm})(15.0 \text{ cm})}$

- S = 44 psi

$\pi = 3.14159$

119

119



120

120

AASHTO T-283 T-283 Rev3-24-04Example.xls

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	6.9		Wet			
Overall							

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_2O (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
	AVG	80% Sat. (Target VSSD)		3910	3846		A+0.8Va
Air Voids (%)		% Saturation		73	80		100J'/Va
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	

	Dry Subset			Wet Subset		
Time in 25 C waterbath (2 hrs ± 10 min)	1h 50m	1h 55m	2h			
Time in Freezer (Minimum 16 hrs)				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	12/22/2003 5:35 PM	12/22/2003 4:20 PM	12/22/2003 4:25 PM	12/22/2003 4:30 PM

NOTE: Shaded cells indicate cells needing input values

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 %

121

121

Calculations: TSR

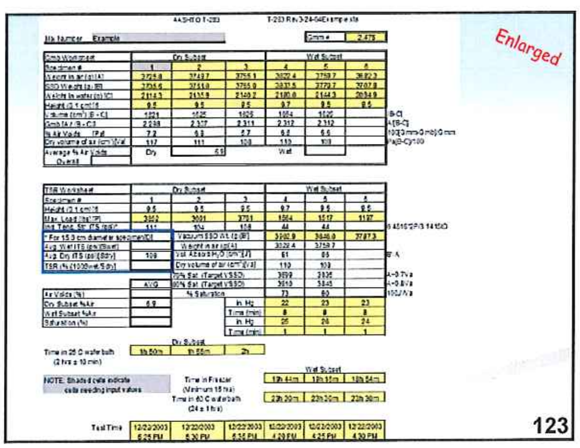
- Specimen #6 ITS is 35 psi, so the average (#4, #5, #6) wet S_2 = 41 psi

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

TSR = 37.96 = 38%

122

122


AASHTO T-283 T-283 Rev 3-24-04Example.xls

Mix Number Example Gmm = 2.475

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	3682.3	
SSD Weight (g)(B)	3735.6	3751.0	3755.0	3837.5	3779.7	3707.8	
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 (cm³)(B-C)	1621	1625	1625	1654	1635		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 (cm³)(Va)	117	111	109	110	108		Pa(B-C)/100
Average % Air Voids	Dry	6.9		Wet			
Overall							

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 (lbf)(P)	3362	3091	3191	1564	1517	1137	
Ind. Tens. Str. ITS (psi)*	111	104	109	44	44		[illegible]
* 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_2O (cm³)(J')		81	86		B'-A
TSR (%)(100Swet/Sdry)		Dry volume of air (cm³)(Va)		110	108		
		70% Sat. (Target VSSD)		3899	3835		A+0.7Va
	AVG	80% Sat. (Target VSSD)		3910	3846		A+0.8Va
Air Voids (%)		% Saturation		73	80		100J'/Va
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	

	Dry Subset		
Time in 25 C water bath (2 hrs ± 10 min)	1h 50m	1h 55m	2h

NOTE: Shaded cells indicate cells needing input values

	Wet Subset		
Time in Freezer (Minimum 16 hrs)	18h 44m	18h 15m	18h 54m
Time in 60 C water bath (24 ± 1 hrs)	23h 30m	23h 30m	23h 30m

Test Time						
	12/22/2003 6:25 PM	12/22/2003 6:30 PM	12/22/2003 6:35 PM	12/22/2003 4:20 PM	12/22/2003 4:25 PM	12/22/2003 4:30 PM

123

123

AASHTO T-283 T-283 Rev3-24-04Example.xls

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	6.9		Wet			
Overall							

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_2O (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
	AVG	80% Sat. (Target VSSD)		3910	3846		A+0.8Va
Air Voids (%)		% Saturation		73	80		100J'/Va
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	

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

NOTE: Shaded cells indicate cells needing input values

	Wet Subset		
Time in Freezer (Minimum 16 hrs)	19h 44m	19h 16m	18h 54m
Time in 60 C waterbath (24 ± 1 hrs)	23h 30m	23h 30m	23h 30m

	1	2	3	4	5	6
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

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.

124

124

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	2.938
8	2.032
9	2.110
10	2.176

If the calculated t-statistic is greater than t[illegible], consider the test result to be an outlier

Enlarged

125

125

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

126

126

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:**

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

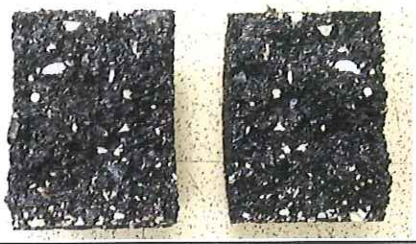
3. **Compare the largest *calculated t-statistic* to the *critical t-statistic*. The *critical t-statistic* depends on the desired significance level and the number of test results in the set. MoDOT has set the significance level at 5%. If the evaluation is of an outlier either being too high, or too 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	2.938
8	2.032
9	2.110
10	2.176

If the *calculated t-statistic* is greater than $t_{critical\ (\alpha = 5\%)}$, 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.



127

127

SCOPE

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

128

128

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.

129

129

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 ± 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.

130

130

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.

131

131

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.

132

132

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.

133

133

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.

134

134

APPENDIX

Sample Splitting

135

135

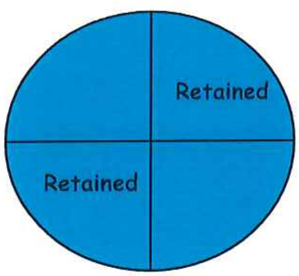
TSR Sample Quartering

- ***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.

136

136

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



137

137

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

138

138

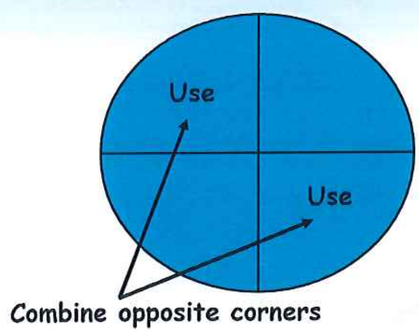
TSR Sample Quartering

- 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.

139

139

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

141

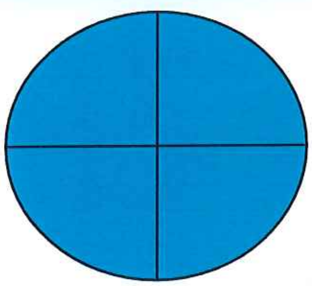
TSR Sample Quartering

- 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

142

Quarter Again



143

143

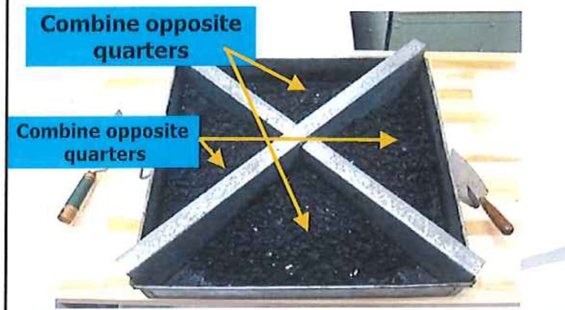
TSR Sample Quartering

- 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.

144

144

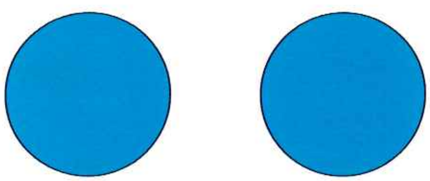
Combine opposite quarters, producing 2 piles



145

145

2 Piles



146

146

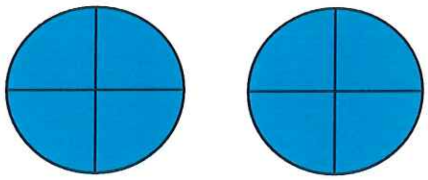
TSR Sample Quartering

- 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

147

Quarter each pile. Now have 8 splits.



148

148

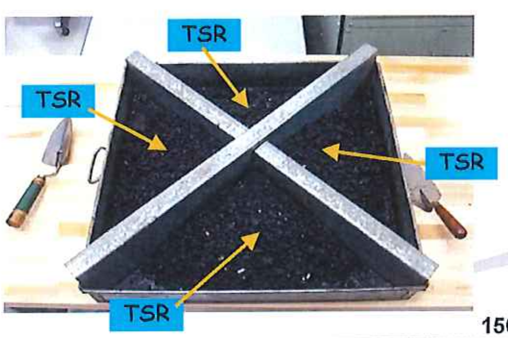
TSR Sample Quartering

- 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.***

149

149

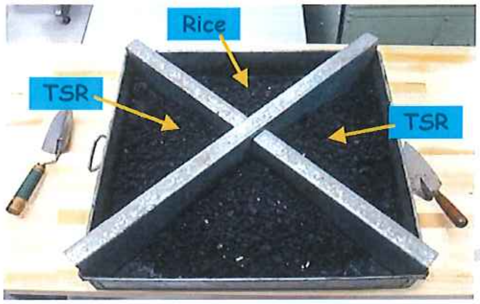
Obtain four TSR puck amounts



150

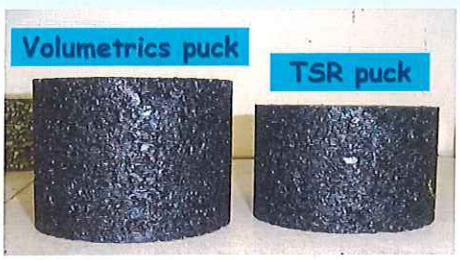
150

Obtain two TSR puck amounts and a Rice



151

151



152

152

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 ± 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. Calculate average tensile strength for conditioned set of pucks ($S_{conditioned}$).			
22. Calculate TSR: $TSR = \frac{S_{conditioned}}{S_{dry}} \times 100\%$ (to nearest whole number)			
Pass?			
Fail?			

Examiner____Date_______________

Reviewer____Date______________