Balanced Mix Design Procedure

What is Balanced Mix Design?

- Balanced Mix Design (BMD) is defined as an “asphalt mix design using performance tests on appropriately conditioned specimens that address multiple modes of distress taking into consideration mix aging, traffic, climate and location within the pavement structure.”
- Mix design procedure followed to optimize the mix to provide needed performance and balance between stability and durability.

Why Balanced Mix Design?

- Superpave implementation primarily focused on rutting. There is a need to evaluate cracking susceptibility as well.
- Current design method volumetric properties do not allow us to evaluate the impacts of individual components on mix performance.
  - Quality of binder
  - Impacts of polymer modification
  - Impact of binder grade adjustments on mix performance
  - Impacts of recycled materials
  - Impacts of additives
- Mix volumetrics are based on properties that may be unreliable
  - Aggregate bulk specific gravity (Gsb) changes over time, but is not often verified
  - Gsb of RAP is questionable

Where do we start?

- Performance test selection
- Acquire testing equipment
- Establish set testing procedures and best practices
  - Aging and curing
- Benchmarking current mixes
  - Establish baseline data for current, local materials
- Specification development
- Training, certifications, and accreditation
- Mix design trials and experimentation
- Initial Implementation
  - Pilot projects
  - Side by side comparison

Rutting Performance Tests

- Hamburg Wheel Tracker
- Asphalt Pavement Analyzer (APA)
- Flow Number Test
- High Temperature Indirect Tension (HT-IDT)
- Rapid Shear Rutting Test (IDEAL-RT)
- Stress Sweep Rutting (SSR)

Cracking Performance Tests

- Indirect Tensile Asphalt Cracking Test (IDEAL-CT)
- Illinois Flexibility Index Test (I-FIT)
- Overlay Test
- Cantabro Test
- Direct Tension Cyclic Fatigue Test
- Disc-Shaped Compact Tension Test (DCT)
- Flexural Bending Beam Fatigue
- IDT Creep Compliance and Strength Test
- NFLEX Factor
- Semi-Circular Bend Test

Rutting Performance - Influencing Factors

- Aggregate properties
  - Durability, soundness, degradation, fractured faces, surface texture
- Blend gradation/structure
  - Blend angularity
- Binder grade or polymer modification
  - Stiffer binder or polymer modification may increase rut resistance
- Asphalt binder content
  - Lower binder content
- Recycled materials
- Other additives

Cracking Performance – Influencing Factors

- Asphalt binder content
  - Higher binder content
- Binder grade or polymer modification
- Binder quality
  - Especially important for cracking performance
- Recycled materials
  - Lower amount of recycled materials
- Other additives
  - Rejuvenators, liquid anti-strip

Colorado Performance Tests

- Hamburg Wheel Tracker
  - CDOT procedure CP-L 5112
  - 4 mm max. rut depth and 10,000 passes
- IDEAL-CT
  - ASTM D8225-19
  - Simple to perform
    - Requires no cutting, gluing or fabrication
    - Existing load frames can utilize a Smart-Jig
  - Colorado CT_{Index} specification in progress
    - Based on benchmarking data and NCAT recommendation
    - Specification may vary from state to state considering aggregate sources, design specifications, aging and curing procedures, etc.

CDOT CP-L 5112 Hamburg Wheel Tracker Sample Preparation

- Laboratory Produced Mix
  - Mixing – Materials mixed in the lab shall be brought to specified mixing temperature using a forced draft oven and mixed in a mechanical mixer for 3 to 5 minutes until complete coating of the aggregates is achieved.

Table 1

Asphalt Grade	Mixing Temperature	Compaction Temperature
PG 58-28	154° C (310° F)	138° C (280° F)
PG 58-34	154° C (310° F)	138° C (280° F)
PG 64-22	163° C (325° F)	149° C (300° F)
PG 64-28	163° C (325° F)	149° C (300° F)
PG 70-28	163° C (325° F)	149° C (300° F)
PG 76-28	163° C (325° F)	149° C (300° F)
	± 2.8° C (5°F)	

CDOT CP-L 5112 Hamburg Wheel Tracker Sample Preparation

- Splitting – Lab mixed material shall be placed in open pans. The amount of material needed for each specimen is determined by calculating the grams of mix needed to attain an air void target of 7% (± 0.5%). The pans should contain less than 77 kg/m^2 of material.
- Aging - The mixed material shall be short-term aged by placing the open pans in a forced draft oven at the compaction temperature (Table 1) for 2 hours to age the material before compaction. If it is known that the material being designed will stay at elevated temperatures in the field for longer than 2 hours, then the aging time can be increased.

CDOT CP-L 5112 Hamburg Wheel Tracker Sample Preparation

- Compacting – Material shall be compacted into slabs or by utilizing Superpave gyratory samples.
  - Slabs shall be compacted to 7% (± 0.5%) throughout the sample and have dimensions of 12.5 in. (320 mm) long and 10.25 in. (260 mm) wide. A slab thickness of 1.5 in. (38 mm) to 4 in. (100 mm) can be used. The slab thickness shall be at least twice the maximum nominal aggregate size. Mounting procedures are outlined in CP-L 5112
  - Superpave gyratory samples should be molded to 7% (± 0.5%) air voids in accordance with T 324-04.
  - All samples shall be cooled at room temperature on a clean, flat surface until cool to the touch
- Bulking – Bulk specific gravity testing shall be performed in accordance with CP 44.

CP-L 5112 Hamburg Wheel Tracker – Test Procedure

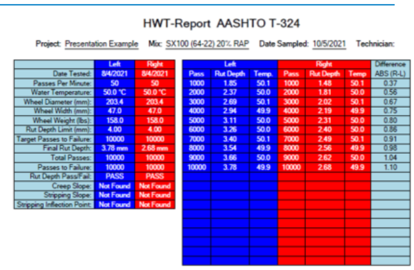
- Select test temperature based on SHRP High Temp PG as follows:

SHRP High Temp PG	Test Temp
58	45° C
64	50° C
70	55° C
76	55° C

- Saw cut ends of specimens and place into molds. Ensure that there is no gap greater than ¼".
- Insert molds into machine
- Fill the wheel tracking device with hot water
- Once the water has been at testing temperature for 45 minutes, lower the wheels onto the slabs.
- Begin Test
- Run the test until 10,000 cycles have occurred.

CP-L 5112 Hamburg Wheel Tracker – Test Report

- Test report shall include the following:
  - Total number of passes
  - Maximum impression (rut depth)
  - Test temperature
  - Sample(s) air voids
  - Creep slope
  - Strip slope
  - Stripping inflection point (SIP)

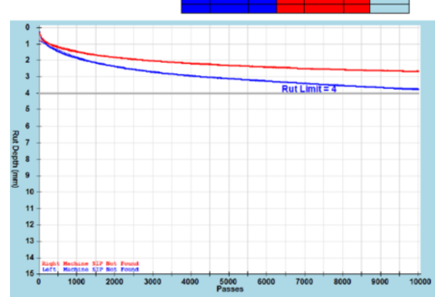


HWT-Report AASHTO T-324

Project: Presentation Example Mix: SX100 (64-22) 20% RAP Date Sampled: 10/5/2021 Technician:

	Left	Right
Date Tested:	8/4/2021	8/4/2021
Passes Per Minute:	50	50
Water Temperature:	50.0 °C	50.0 °C
Wheel Diameter (mm):	203.4	203.4
Wheel Width (mm):	47.0	47.0
Wheel Weight (lbs):	158.0	158.0
Rut Depth Limit (mm):	4.00	4.00
Target Passes to Failure:	10000	10000
Final Rut Depth:	3.78 mm	2.68 mm
Total Passes:	10000	10000
Passes to Failure:	10000	10000
Rut Depth Pass/Fail:	PASS	PASS
Creep Slope:	Not Found	Not Found
Stripping Slope:	Not Found	Not Found
Stripping Inflection Point:	Not Found	Not Found

Left			Right			Difference
Pass	Rut Depth	Temp.	Pass	Rut Depth	Temp	ABS (R-L)
1000	1.85	50.1	1000	1.48	50.1	0.37
2000	2.37	50.0	2000	1.81	50.0	0.56
3000	2.69	50.1	3000	2.02	50.1	0.67
4000	2.94	49.9	4000	2.19	49.9	0.75
5000	3.11	50.0	5000	2.31	50.0	0.80
6000	3.26	50.0	6000	2.40	50.0	0.86
7000	3.40	50.1	7000	2.49	50.1	0.91
8000	3.54	49.9	8000	2.56	49.9	0.98
9000	3.66	50.0	9000	2.62	50.0	1.04
10000	3.78	49.9	10000	2.68	49.9	1.10



ASTM D8225-19 Cracking Tolerance Index Sample Preparation

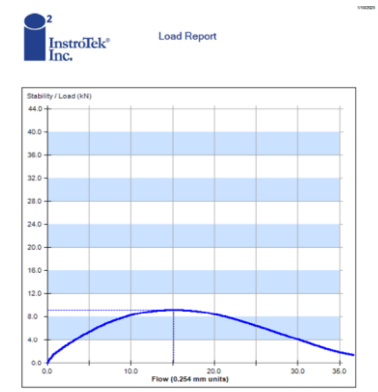
- Laboratory mixed, laboratory compacted samples (LMLC)
  - Specimen size – For mixtures with a NMAS of 19mm or smaller, the specimens shall be 150 ± 2 mm in diameter and 62 ± 1 mm in thickness; for the mixtures with a NMAS of 25 mm or larger, specimens shall be 150 ± 2 mm in diameter and 95 ± 1mm in thickness.
  - Aging – LMLC loose mix shall be conditioned for 4 hours at 135 ± 3°C in accordance with AASHTO R 30.
    - D8225-19 states that the acceptable CT_{Index} requirements are dependent on aging method used and should be adjusted for LMLC vs. PMLC.
  - Compacting – Samples shall be compacted utilizing a Superpave gyratory compactor. Other compactors are acceptable as long as specimens meet dimension requirements
    - The amount of material needed for each specimen is determined by calculating the grams of mix needed to attain an air void target of 7% (± 0.5%).
    - A minimum of 3 specimens shall be prepared

ASTM D8225-19 Cracking Tolerance Index Test Procedure

- Precondition molded test specimens in an environmental chamber or water bath at 25 ± 1°C.
- Ensure contact surfaces are clean and free of debris
- Insert the specimen in the fixture and ensure that the specimen is centered and making uniform contact on the support.
- Apply load to the specimen at a rate of 50 ± 2.0 mm/min.
- Stop the test when the load drops below 100N
- During the testing, record the time, load, and displacement at a minimum sampling rate of 40 data points per second.
- Testing shall be completed in 4 minutes or less after removal from conditioning.

ASTM D8225-19 Cracking Tolerance Index Test Report

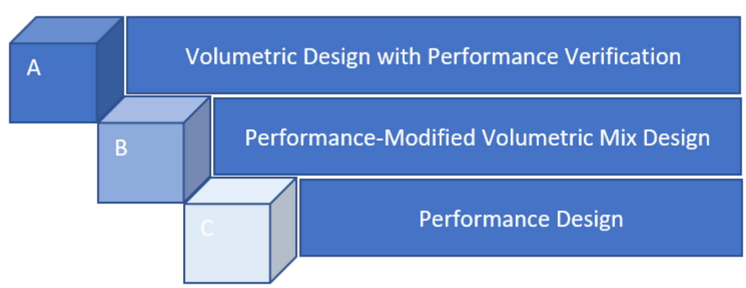
- Test report shall include the following:
  - Asphalt mixture type.
  - Test temperature, °C.
  - Specimen preparation method and aging condition.
  - Specimen air voids, %.
  - Specimen thickness, mm.
  - Specimen diameter, mm.
  - Displacement, l75, mm.
  - Post-peak slope, |m75|, N/m.
  - Failure energy, Gf, Joules/m2.
  - Work of failure, Wf, Joules.
  - Cracking tolerance index, CT_{Index}.



Project ID: Presentation Example			Specimen ID: 1056-1		
Date / Time:	05/03/00 07:38		Stability (Peak Load):	9.17 kN	2061 lbf
Specimen Diameter:	150.0 mm	5.9 in.	IDT Strength:	627.5 kPa	91.0 PSI
Specimen Thickness:	62.0 mm	2.44 in.	Peak Displacement:	3.8 mm	0.15 in.
Starting Load:	-0.01 kN	-3 lbf	Flow (0.254 mm units):	15.1	
Stopping Load:	0.09 kN	21 lbf	Failure Energy:	6161 Joules / m²	
Max Specific Gravity:	2.500		Strain Energy to Peak:	24.37 Joules	
% Voids:	7.0%		Temperature:	22 °C	71.6 °F
% AC:	5.45%		IDEAL-CT Index:	145.7	
Displacement at 75%:	6.1 mm		Post-Peak Slope (75%):	-1716 N/mm	

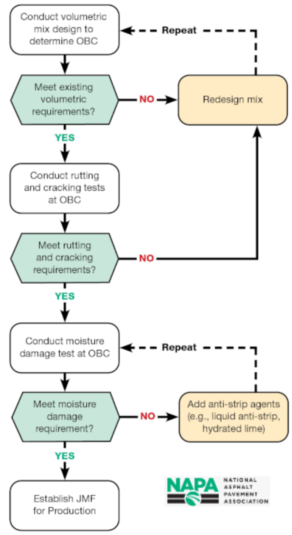
Technician: EB   Signature: ____________

BMD Mix Design Approaches



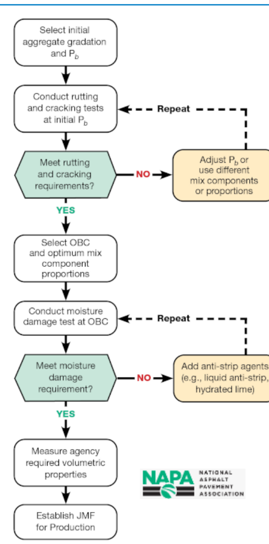
Approach A: Volumetric Design with Performance Verification

- Most conservative approach
- Requires full compliance with the existing volumetric requirements along with performance requirements
- Lowest innovation potential



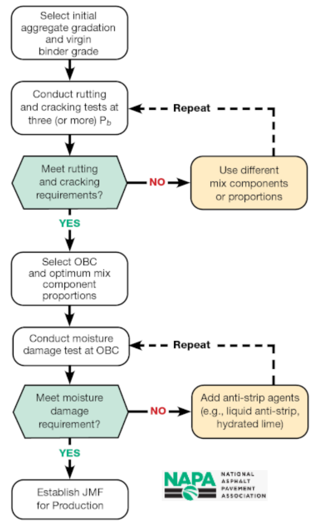
Approach B: Performance-Modified Volumetric Design

- Uses current Superpave design approach or existing design to determine and initial aggregate structure and binder content.
- May allow some of the volumetric properties to be relaxed and long as performance criteria are satisfied
- Mix design modifications used for performance modification are not limited to binder content.
- Allows for more innovation potential than approach A.



Approach C: Performance Design

- No requirement on volumetric properties.
- Relies on mixture performance testing for design optimization.
- Least conservative approach allowing for the most innovation potential.

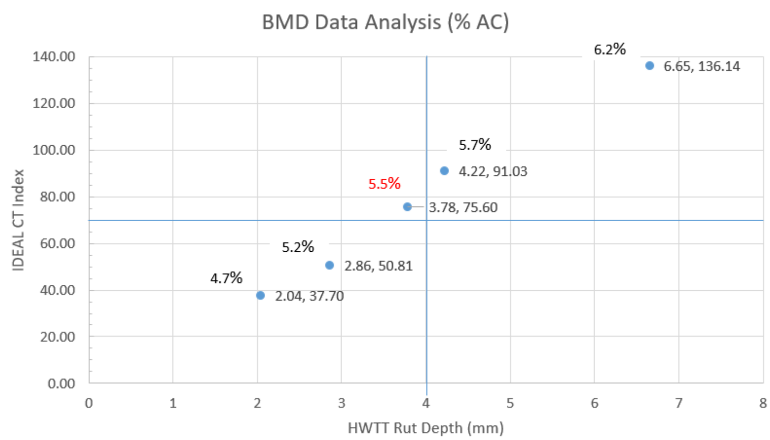


Mix Design Example

- Approach A: Volumetric Design with Performance verification
- SX 75
- 64-28 Binder
- 20% RAP
- Current Superpave design methodology
  - 4 design points 0.5% intervals to establish optimum binder content
- Volumetric Properties at optimum:

Properties at Optimum		Specifications
Asphalt Content (%AC):	5.50	
Bulk Specific Gravity (Gmb):	2.402	
Max. Specific Gravity (Gmm):	2.494	
Aggregate Effective Specific Gravity (Gse):	2.718	
Theoretical Max Unit Wt. (pcf):	155.6	
Air Voids @ N-Design (%Va):	3.7	3.5 to 4.5
Voids in Mineral Aggregate (%VMA):	14.8	14.6 min. @ 3.7 voids
Voids Filled with Asphalt (%VFA):	75.0	65-75
Dust to Asphalt Ratio (D/A):	1.17	0.6-1.2
Hveem Stability:	42	30 min.

Mix Design Example



Mix Design Example

- Lottmans (CP-L 5109)

Effect of Moisture on Hot Mix Asphalt		
Method:	***CDOT (CP-L 5109)***	
Asphalt Content (%):	**5.50**	
Additive Type:	***Lime***	
Air Voids (%):	**6.9**	***6.0 to 8.0***
Saturation (%):	**86.5**	
Indirect Tensile Strength (Wet) (psi):	**116**	
Indirect Tensile Strength (Dry) (psi):	**118**	***30 min.***
Tensile Strength Ratio (%):	**98**	***80 min.***

- Design meets all Superpave volumetric requirements along with performance testing requirements.
- Blend meets requirements for moisture induced damage (CP-L 5109)

Potential Challenges

- Relatively high standard deviation and coefficient of variation on within-lab Ideal-CT results
  - MM benchmark testing
    - 5 specimens per sample
    - 12.4 average standard deviation
      - 13.5 (ASTM D8225-19)
    - 17.7% CV
      - 10 to 20% on average based on NCAT experience
      - 18% CV on NCAT Round Robin
  - While acceptable, these values need to be taken into account when establishing specifications and tolerances.
- Multi-lab repeatability
  - Differences in machine manufacturers
  - Comparison testing needed (Round Robin?)
- Acquisition of equipment by all contractors and consulting laboratories

Potential Challenges

- Cost
  - Equipment
  - Potential material cost increase
  - Potential mix cost increase
- Material availability
  - Current local aggregates
  - Specialized aggregates or other materials for BMD may not be an option or come at an increased cost.
- Misleading data
  - Leaning on data from other states can be risky. It is up to each state to determine specifications and criteria based on data from local mixes and materials
    - Specifications and data shared with customers should be based on local mixes using local materials

Next Steps

- Continued benchmark testing
- Comparison testing
  - Multiple lab comparisons
  - Comparisons between machine manufacturers
  - CDOT Round Robin
- Continued mix design trials and experimentation
- Finalized BMD design method for Colorado
- CDOT performance testing specifications
  - Must be established before mix designs can be completed and finalized
- Pilot projects

Questions??