VII. Superpave Mix Design

The chapter presents a full Superpave volumetric mix design example.

Volumetric mix design plays a central role in Superpave mixture design. The best way of illustrating its steps is by means of an example. This section provides the Superpave mixture design test results for a project that was constructed in 1992 by the Wisconsin Department of Transportation on IH-43 in Milwaukee. The information presented follows the logical progression of testing and data analysis involved in a Superpave mixture design and encompasses the concepts outlined in previous sections. There are four major steps in the testing and analysis process:

1. selection of materials (aggregates, binders, modifiers, etc.),
2. selection of a design aggregate structure,
3. selection of a design asphalt binder content,
4. evaluation of moisture sensitivity of the design mixture.

Selection of materials consists of determining the traffic and environmental factors for the paving project. From that, the performance grade of asphalt binder required for the project is selected. Aggregate requirements are determined based on traffic level and layer depth. Materials are selected based on their ability to meet or exceed the established criteria.

Selection of the design aggregate structure is a trial-and-error process. This step consists of blending available aggregate stockpiles at different percentages to arrive at aggregate gradations that meet Superpave requirements. Three trial blends are normally employed for this purpose. A trial blend is considered acceptable if it possesses suitable volumetric properties (based on traffic and environmental conditions) at a predicted design binder content. Once selected, the trial blend becomes the design aggregate structure.

Selection of a design asphalt binder content consists of varying the amount of asphalt binder with the design aggregate structure to obtain acceptable volumetric and compaction properties when compared to the mixture criteria, which are based on traffic and environmental conditions. This step is a verification of the results obtained from the previous step. This step also allows the designer to observe the sensitivity of volumetric and compaction properties of the design aggregate structure to asphalt content. The design aggregate structure at the design asphalt binder content becomes the job-mix formula.

Evaluation of moisture sensitivity consists of testing the designed mixture by AASHTO T283 to determine if the mix will be susceptible to moisture damage.

MATERIALS SELECTION

For the IH-43 project, design ESALs are determined to be 18 million in the design lane. This places the design in the traffic category from 10 to 30 million ESALs. Traffic level is used to determine design requirements such as number of design gyrations for compaction, aggregate physical property requirements, and mixture volumetric requirements.

The mixture in this example is an intermediate course mixture. It will have a nominal maximum particle size of 19.0 mm. It will be placed at a depth less than 100 mm from the surface of the pavement.

Binder Selection

Environmental conditions are determined from weather station data stored in the Superpave weather database. The data can be retrieved from the report *Weather Database for the Superpave Mix Design System*, SHRP-A-648A, or from the LTPPBIND software released by the Long-Term Pavement Performance (LTPP) Division of the FHWA. The project near Milwaukee has 2 weather stations:

Project Environmental Conditions and Binder Grades

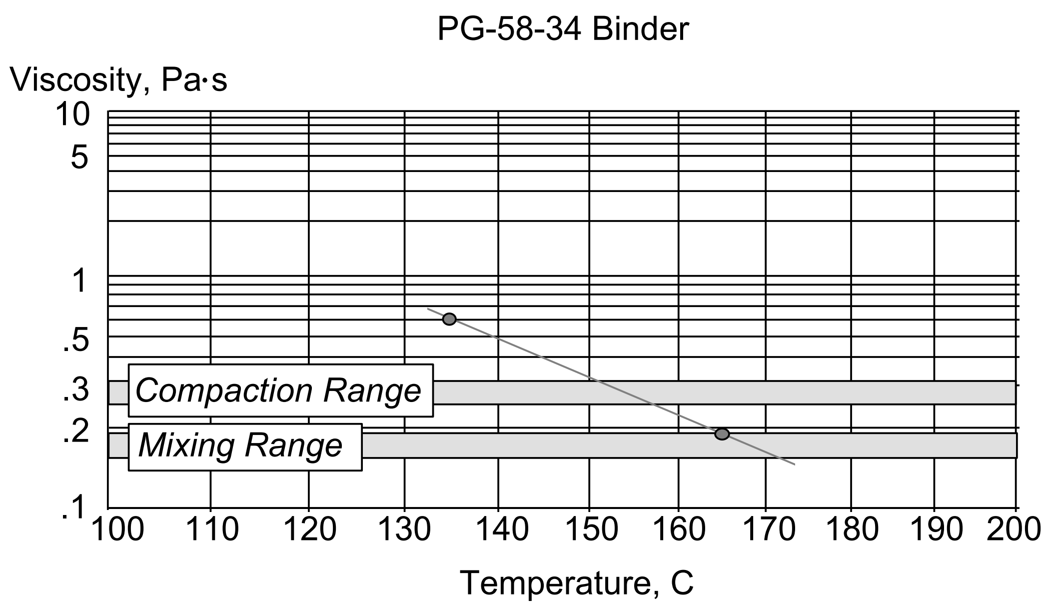
Weather Station	Min. Pvmt. Temp. (°C)	Max. Pvmt. Temp. (°C)	Binder Grade	Design Air Temp. (°C)
Low Reliability (50%)				
Milwaukee Mt. Mary	-26	51	PG 52-28	32
Milwaukee WSO AP	-25	51	PG 52-28	31
Paving Location (Assumed)	-26	51	PG 52-28	32
High Reliability (98%)				
Milwaukee Mt. Mary	-32	55	PG 58-34	36
Milwaukee WSO AP	-33	54	PG 58-34	34
Paving Location (Assumed)	-33	55	PG 58-34	35

Low and high reliability level binders are shown. Reliability is the percent probability that the actual temperature will not exceed the design pavement temperatures listed in the binder grade. In this example, the designer chooses high reliability for all conditions. Thus, a PG 58-34 binder is needed. The average Design High Air Temperature is 35°C.

Having determined the need for a PG 58-34 binder, the binder is selected and tested for specification compliance. Binder test results are:

Test	Property	Test Result	Criteria
Original Binder			
Flash Point	n/a	304°C	230°C minimum
Rotational Viscosity	135°C	0.575 Pa·s	3 Pa·s maximum
Rotational Viscosity	165°C	0.142 Pa·s	n/a
Dynamic Shear Rheometer	G*/sin δ @ 58°C	1.42 kPa	1.00 kPa minimum
RTFO-aged Binder			
Mass Loss	n/a	0.14%	1.00% maximum
Dynamic Shear Rheometer	G*/sin δ @ 58°C	2.41 kPa	2.20 kPa minimum
PAV-aged Binder			
Dynamic Shear Rheometer	G*sin δ @ 16°C	1543 kPa	5000 kPa maximum
Bending Beam Rheometer	Stiffness @ -24°C	172.0 MPa	300.0 MPa maximum
Bending Beam Rheometer	m-value @ -24°C	0.321	0.300 minimum

Comparing the test results to specifications, the designer verifies that the asphalt binder meets the requirements of a PG 58-34 grade. Specification testing requires only that rotational viscosity be performed at 135°C. Additional testing was performed at 165°C to establish laboratory mixing and compaction temperatures. The illustration of the temperature-viscosity relationship for this binder shows that the mixing temperature range is selected between 165°C and 172°C. The compaction temperature range is selected between 151°C and 157°C.



Aggregate Selection

Next, the designer selects the aggregates to use in the mixture. For this example, there are 5 stockpiles of materials consisting of three coarse materials and two fine materials. It is assumed that the mixing facility will have at least 5 cold feed bins. If fewer cold feed bins are available, fewer stockpiles will be used. The materials are split into representative samples, and a washed sieve analysis is performed for each aggregate. These test results are shown in the section on selecting design aggregate structure.

The bulk and apparent specific gravities are determined for each aggregate. These specific gravities are used in VMA calculations and may be used if trial binder contents are calculated.

Aggregate Specific Gravities		
Aggregate	Bulk Sp. Gravity	Apparent Sp. Gravity
#1 Stone	2.703	2.785
12.5 mm Chip	2.689	2.776
9.5 mm Chip	2.723	2.797
Manuf. Sand	2.694	2.744
Screen Sand	2.679	2.731

In addition to sieve analysis and specific gravity determination, Superpave requires that consensus aggregate tests be performed to assure that the aggregates selected for the mix design are acceptable. The four tests required are: coarse aggregate angularity, fine aggregate angularity, thin and elongated particles, and clay content. In addition, the specifying agency can select any other aggregate tests deemed important. These tests can include items such as soundness, toughness, and deleterious materials among others.

Superpave consensus aggregate criteria are applied to combined aggregate gradations rather than individual aggregate components. However, some designers find it useful to perform the aggregate tests on the individual aggregate components. This step allows the designer to use the test results in narrowing the acceptable range of blend percentages for the aggregates. It also allows for greater flexibility if multiple trial blends are attempted. The test results from the components can be used to estimate the results for a given combination of materials. The drawback to this procedure is that it takes more time to perform this additional testing. For this example, the aggregate properties are measured for each stockpile as well as for the aggregate trial blends.

Coarse Aggregate Angularity

This test is performed on the coarse aggregate particles of the aggregate stockpiles. The coarse aggregate particles are defined as particles larger than 4.75 mm.

Coarse Aggregate Angularity Test Results				
Aggregate	1+ Fractured Faces	Criterion	2+ Fractured Faces	Criterion
#1 Stone	92%	95% min	88%	90% min
12.5 mm Chip	97%		94%	
9.5 mm Chip	99%		95%	

Note that this test is not performed on the two fine aggregates, even though they have some small percentage retained on the 4.75 mm sieve. The manufactured sand has 4.5% retained and the Screen Sand has 10.5% retained on the 4.75 mm sieve.

The test results table also shows the criteria for fractured faces based on traffic (18 million ESALs) and depth from the surface (< 100 mm). The criteria change as the traffic level and layer position (relative to the surface) change. The criteria are also based on the test results from the aggregate *blend* rather than individual materials. Thus, even though the #1 Stone is below the minimum criteria, it can be used as long as the selected *blend* of aggregates meets the criteria.

Fine Aggregate Angularity

This test is performed on the fine aggregate particles of the aggregate stockpiles. The fine aggregate particles are defined as particles smaller than 2.36 mm.

Fine Aggregate Angularity		
Aggregate	% Air Voids (Loose)	Criterion
Manufactured Sand	52%	45% min
Screen Sand	40%	

Note that this test is not performed on the three coarse aggregates, even though they have a small percentage passing the 2.36 millimeter sieve. The #1 Stone has 1.9% passing, the 1/2" Chip has 2.6% passing, and the 3/8" Chip has 3.0% passing the 2.36 mm sieve. The test results table also indicates the criterion for fine aggregate angularity based on traffic and depth from the surface. Even though the

Screen Sand is below the minimum criterion, it can be used as long as the selected *blend* of aggregates meets the criterion.

Flat, Elongated Particles

This test is performed on the coarse aggregate particles of the aggregate stockpiles. The coarse aggregate particles are defined as particles larger than 4.75 mm.

Flat, Elongated Particles		
Aggregate	% Flat/Elongated	Criterion
#1 Stone	0%	10% max
12.5 mm Chip	0%	
9.5 mm Chip	0%	

Note that this test is not performed on the two fine aggregates, even though they have some small percentage retained on the 4.75 mm sieve. The manufactured sand has 4.5% retained and the Screen Sand has 10.5% retained on the 4.75 mm sieve. The test results table also indicates the criterion for percentage of flat and elongated particles, which is based on traffic only. The criterion changes as the traffic level changes. In this case, the aggregates are cubical and not in danger of failing the criterion.

Clay Content (Sand Equivalent)

This test is performed on the fine aggregate particles of the aggregate stockpiles. The fine aggregate particles are defined as particles smaller than 4.75 mm.

Clay Content (Sand Equivalent)		
Aggregate	Sand Equivalent	Criterion
Manufactured Sand	47	45 min
Screen Sand	70	

Note that this test is not performed on the three coarse aggregates, even though they have some small percentage passing the 4.75 mm sieve. The #1 Stone has 2.1% passing, the 1/2" Chip has 3.1% passing, and the 3/8" Chip has 4.8% passing the 4.75 mm sieve. The test results table also indicates the criterion for clay content (sand equivalent) based on traffic only. The criterion changes as the traffic level changes. The criterion is also based on the test results from the aggregate *blend* rather than individual materials. Both fine aggregates are above the minimum requirement, so there is reasonable expectation that the blend will also meet the clay content requirement. Once all of the aggregate testing is complete, the material selection process is complete. The next step is to select the design aggregate structure.

SELECT DESIGN AGGREGATE STRUCTURE

To select the design aggregate structure, the designer establishes trial blends by mathematically combining the gradations of the individual materials into a single gradation. The blend gradation is then compared to the specification requirements for the appropriate sieves. Gradation control is based on four control sieves: the maximum sieve, the nominal maximum sieve, the 2.36 mm sieve, and the 75 micron sieve.

The nominal maximum sieve is one sieve size larger than the first sieve to retain more than ten percent of combined aggregate. The maximum sieve size is one sieve size greater than the nominal maximum sieve. The restricted zone is an area on either side of the maximum density line. For a 19.0 mm nominal mixture, it starts at the 2.36 mm sieve and extends to the 300 micron sieve. Any proposed trial blend gradation has to pass between the control points established on the four sieves. In addition, it has to be outside of the area bounded by the limits set for the restricted zone. Some specifying agencies may allow gradations to pass through the Restricted Zone – if there is a history of successful performance or supporting test results.

Gradation Criteria for 19.0 mm Nominal Mixture			
Gradation Control Item	Sieve Size, mm	Minimum, %	Maximum, %
Control Points	25.0	100.0	
	19.0	90.0	100.0
	12.5		90.0
	2.36	23.0	49.0
	0.075	2.0	8.0
Restricted Zone	2.36	34.6	34.6
	1.18	22.3	28.3
	0.600	16.7	20.7
	0.300	13.7	13.7

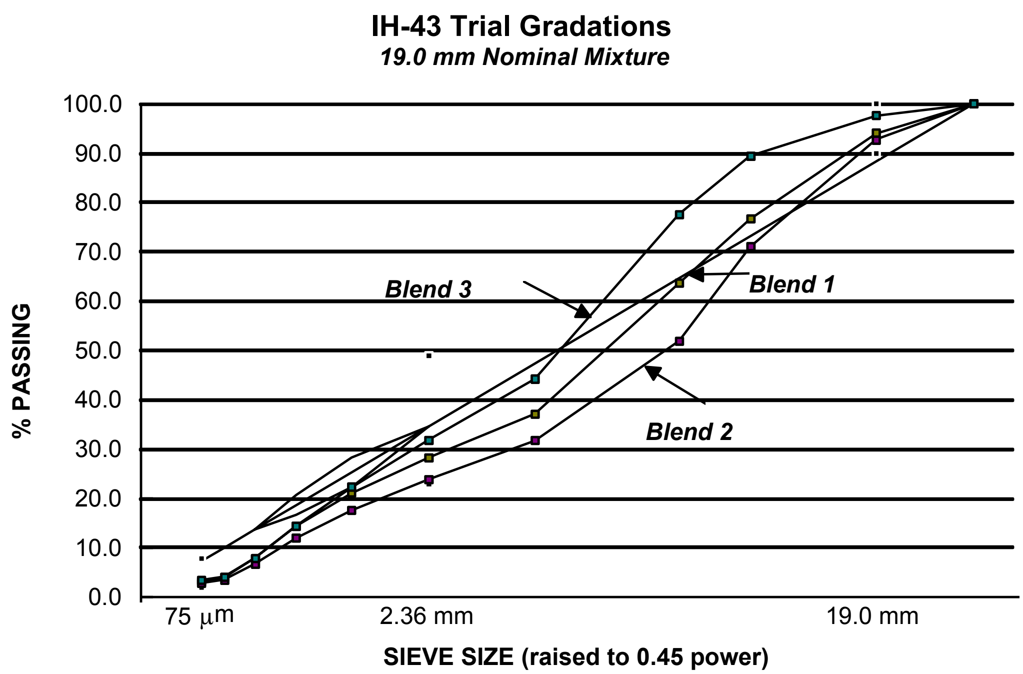
Any number of trial blends can be attempted, but three is the standard number of blends. Trial blending consists of varying stockpile percentages of each aggregate to obtain blend gradations meeting the gradation requirements for that particular mixture. For this example, three trial blends are used: an intermediate blend (Blend 1), a coarse blend (Blend 2), and a fine blend (Blend 3). The intermediate blend is combined to produce a gradation that is not close to either the gradation limits for the control sieves, or the restricted zone. The coarse blend is combined to produce a gradation that is close to the minimum criteria for the nominal maximum sieve, the 2.36 mm sieve, and the 75 micron sieve. The fine blend is combined to produce a gradation that is close to the maximum criteria for the nominal maximum sieve, and the restricted zone.

IH-43 Trial Gradations

	#1 Stone	12.5 mm chip	9.5 mm chip	Mfg sand	Scr. sand
Blend 1	25.0%	15.0%	22.0%	18.0%	20.0%
Blend 2	30.0%	25.0%	13.0%	17.0%	15.0%
Blend 3	10.0%	15.0%	30.0%	31.0%	14.0%

Sieve						Blend 1 Gradation	Blend 2 Gradation	Blend 3 Gradation
25.0 mm	100.0	100.0	100.0	100.0	100.0	***100.0***	***100.0***	***100.0***
19.0 mm	76.1	100.0	100.0	100.0	100.0	***94.0***	***92.8***	***97.6***
12.5 mm	14.3	87.1	100.0	100.0	100.0	**76.6**	**71.1**	**89.5**
9.5 mm	3.8	26.0	94.9	100.0	99.8	**63.7**	**51.9**	**77.7**
4.75 mm	2.1	3.1	4.8	95.5	89.5	**37.1**	**31.7**	**44.3**
2.36 mm	1.9	2.6	3.0	63.5	76.7	***28.3***	***23.9***	***31.9***
1.18 mm	1.9	2.4	2.8	38.6	63.5	**21.1**	**17.6**	**22.2**
600 μm	1.8	2.3	2.6	21.9	45.6	**14.4**	**12.0**	**14.5**
300 μm	1.8	2.2	2.5	11.0	23.1	**7.9**	**6.8**	**7.9**
150 μm	1.7	2.1	2.4	5.7	8.4	**4.0**	**3.6**	**4.1**
75 μm	1.6	1.9	2.2	5.7	4.7	***3.1***	***2.9***	***3.5***

All three of the trial blends are shown graphically. Note that all three trial blends pass below the restricted zone. This is not a requirement. Superpave allows but does not recommend blends that plot above the restricted zone.



Once the trial blends are selected, a preliminary determination of the blended aggregate properties is necessary. This can be estimated mathematically from the aggregate properties.

Estimated Aggregate Blend Properties				
Property	Criteria	Trial Blend 1	Trial Blend 2	Trial Blend 3
Coarse Ang.	95%/90% min.	96%/92%	95%/92%	97%/93%
Fine Ang.	45% min.	46%	46%	48%
Thin/Elongated	10% max.	0%	0%	0%
Sand Equivalent	45 min.	59	58	54
Combined G_{sb}	n/a	2.699	2.697	2.701
Combined G_{sa}	n/a	2.768	2.769	2.767

Values for coarse aggregate angularity are shown as percentage of one or more fractured faces followed by percentage of two or more fractured faces. Based on the estimates, all three trial blends are acceptable. When the design aggregate structure is selected, the blend aggregate properties will need to be verified by testing.

SELECT TRIAL ASPHALT BINDER CONTENT

The next step is to evaluate the trial blends by compacting specimens and determining the volumetric properties of each trial blend. For each blend, a minimum of two specimens will be compacted using the SGC. The trial asphalt binder content can be estimated based on experience with similar materials. If there is no experience, the trial binder content can be determined for each trial blend by estimating the effective specific gravity of the blend and using the calculations shown below. The effective specific gravity (G_{se}) of the blend is estimated by:

$$G_{se} = G_{sb} + 0.8 \times (G_{sa} - G_{sb})$$

The factor, 0.8, can be adjusted at the discretion of the designer. Absorptive aggregates may require values closer to 0.6 or 0.5. The blend calculations are shown below:

Blend 1: $G_{se} = 2.699 + 0.8\times(2.768 - 2.699) = 2.754$

Blend 2: $G_{se} = 2.697 + 0.8\times(2.769 - 2.697) = 2.755$

Blend 3: $G_{se} = 2.701 + 0.8\times(2.767 - 2.701) = 2.754$

The volume of asphalt binder (V_{ba}) absorbed into the aggregate is estimated using this equation:

$$V_{ba} = \frac{P_s \times (1 - V_a)}{\left(\frac{P_b}{G_b} + \frac{P_s}{G_{se}}\right)} \times \left(\frac{1}{G_{sb}} - \frac{1}{G_{se}}\right)$$

where V_{ba} = volume of absorbed binder, cm^3/cm^3 of mix

P_b = percent of binder (assumed 0.05),

P_s = percent of aggregate (assumed 0.95),

G_b = specific gravity of binder (assumed 1.02),

V_a = volume of air voids (assumed 0.04 cm^3/cm^3 of mix)

Blend 1: $$V_{ba} = \frac{0.95 \times (1-0.04)}{(\frac{0.05}{1.02} + \frac{0.95}{2.754})} \times (\frac{1}{2.699} - \frac{1}{2.754}) = 0.0171 \text{ cm}^3/\text{cm}^3 \text{ of mix}$$

Blend 2: $$V_{ba} = \frac{0.95 \times (1-0.04)}{(\frac{0.05}{1.02} + \frac{0.95}{2.755})} \times (\frac{1}{2.697} - \frac{1}{2.755}) = 0.0181 \text{ cm}^3/\text{cm}^3 \text{ of mix}$$

Blend 3: $$V_{ba} = \frac{0.95 \times (1-0.04)}{(\frac{0.05}{1.02} + \frac{0.95}{2.754})} \times (\frac{1}{2.701} - \frac{1}{2.754}) = 0.0165 \text{ cm}^3/\text{cm}^3 \text{ of mix}$$

The volume of the effective binder (V_{be}) can be determined from this equation:

$V_{be} = 0.081 - 0.02931 \times [\ln(S_n)]$

where S_n = the nominal maximum sieve size of the aggregate blend (in inches)

Blend 1-3: $V_{be} = 0.081 - 0.02931 \times [\ln(0.75)] = 0.089$ cm^3/cm^3 of mix

Finally, the initial trial asphalt binder (P_{bi}) content is calculated from this equation:

$$P_{bi} = \frac{G_b \times (V_{be} + V_{ba})}{(G_b \times (V_{be} + V_{ba})) + W_s} \times 100$$

where P_{bi} = percent (by weight of mix) of binder
W_s = weight of aggregate, grams

$$W_s = \frac{P_s \times (1 - V_a)}{(\frac{P_b}{G_b} + \frac{P_s}{G_{se}})}$$

Blend 1: $$W_s = \frac{0.95 \times (1-0.04)}{(\frac{0.05}{1.02} + \frac{0.95}{2.754})} = 2.315$$

$$P_{bi} = \frac{1.02 \times (0.089 + 0.0171)}{(1.02 \times (0.089 + 0.0171)) + 2.315} \times 100 = 4.46\%$$ (by mass of mix)

Blend 2:

$$W_s = \frac{0.95 \times (1 - 0.04)}{(\frac{0.05}{1.02} + \frac{0.95}{2.755})} = 2.316$$

$$P_{bi} = \frac{1.02 \times (0.089 + 0.0181)}{(1.02 \times (0.089 + 0.0171)) + 2.316} \times 100 = 4.46\%$$ (by mass of mix)

Blend 3:

$$W_s = \frac{0.95 \times (1 - 0.04)}{(\frac{0.05}{1.02} + \frac{0.95}{2.754})} = 2.315$$

$$P_{bi} = \frac{1.02 \times (0.089 + 0.0165)}{(1.02 \times (0.089 + 0.0171)) + 2.315} \times 100 = 4.46\%$$ (by mass of mix)

Next, a minimum of two specimens for each trial blend is compacted using the SGC. Two specimens are also prepared for determination of the mixture's maximum theoretical specific gravity (G_{mm}). An aggregate weight of 4500 grams is usually sufficient for the compacted specimens. An aggregate weight of 2000 grams is usually sufficient for the specimens used to determine maximum theoretical specific gravity (G_{mm}). AASHTO T 209 should be consulted to determine the minimum sample size required for various mixtures.

Specimens are mixed at the appropriate mixing temperature, which is 165°C to 172°C for the selected PG 58-34 binder. The specimens are then short-term aged by placing the loose mix in a flat pan in a forced draft oven at the compaction temperature, 151°C to 157°C, for 2 hours. Finally, the specimens are then removed and either compacted or allowed to cool loose (for G_{mm} determination).

The number of gyrations used for compaction is determined based on the traffic level.

Superpave Design Gyratory Compactive Effort

Design ESALs (millions)	Compaction Parameters		
	$N_{initial}$	N_{design}	$N_{maximum}$
< 0.3	6	50	75
0.3 to < 3	7	75	115
3 to < 10	8	100	160
≥ 30	9	125	205

The number of gyrations for initial compaction, design compaction, and maximum compaction are:

N_{ini} = 8 gyrations
N_{des} = 100gyrations
N_{max} = 160 gyrations

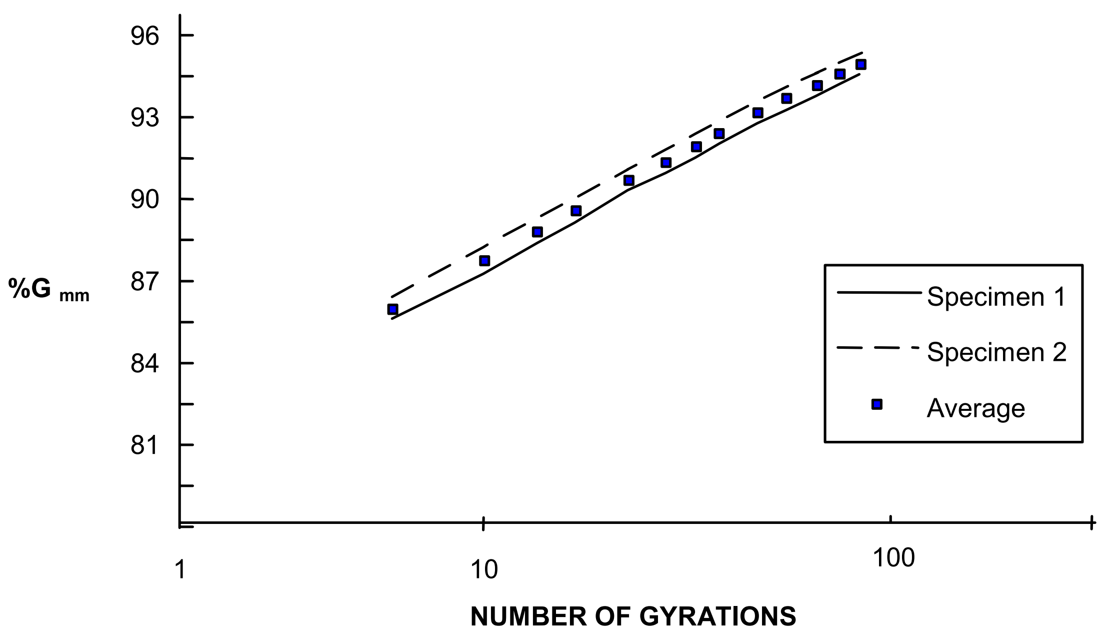
Each specimen will be compacted to the design number of gyrations, with specimen height data collected during the compaction process. This is tabulated for each Trial Blend. SGC compaction data reduction is accomplished as follows.

During compaction, the height of the specimen is continuously monitored. After compaction is complete, the specimen is extruded from the mold and allowed to cool. Next, the bulk specific gravity (G_{mb}) of the specimen is determined using AASHTO T166. The G_{mm} of each blend is determined using AASHTO T209. G_{mb} is then divided by G_{mm} to determine the % G_{mm} @ N_{des}. The % G_{mm} at any number of gyrations (N_x) is then calculated by multiplying % G_{mm} @ N_{des} by the ratio of the heights at N_{des} and N_x.

The SGC data reduction for the three trial blends is shown in the accompanying tables. The most important points of comparison are %G_{mm} at N_{ini}, N_{des}, and N_{max}, which are highlighted in these tables. Figures illustrate the compaction plots for data generated in these tables. The figures show %G_{mm} versus the logarithm of the number of gyrations.

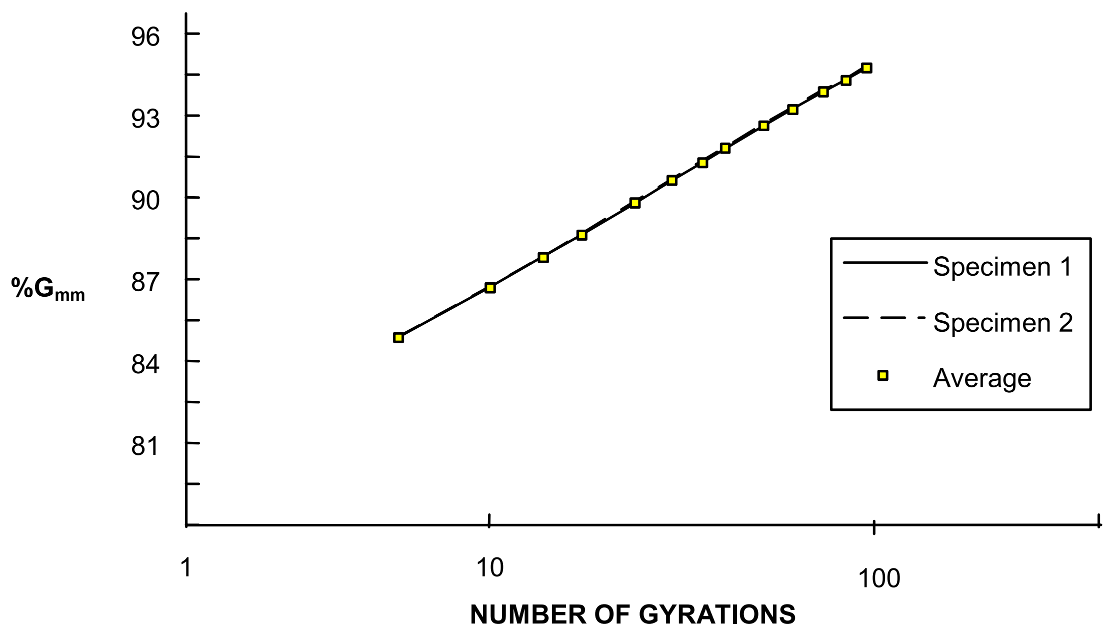
Densification Data for Trial Blend 1					
	Specimen 1		Specimen 2		AVG
Gyrations	Ht, mm	%G_{mm}	Ht, mm	%G_{mm}	%G_{mm}
5	129.0	85.2	130.3	86.2	85.7
8	127.0	86.5	128.1	87.6	**87.1**
10	125.7	87.3	126.7	88.6	88.0
15	123.5	88.9	124.7	90.1	89.5
20	122.2	89.9	123.4	91.0	90.4
30	120.1	91.4	121.5	92.4	91.9
40	119.0	92.3	120.2	93.4	92.8
50	118.0	93.0	119.3	94.2	93.6
60	117.2	93.7	118.5	94.8	94.3
80	116.0	94.7	117.3	95.8	95.2
100	115.2	95.4	116.4	96.5	**95.9**
G_{mb}	2.445		2.473		
G_{mm}	2.563		2.563		

IH-43, 19.0 mm Nominal, 4.4% AC, Trial Blend 1



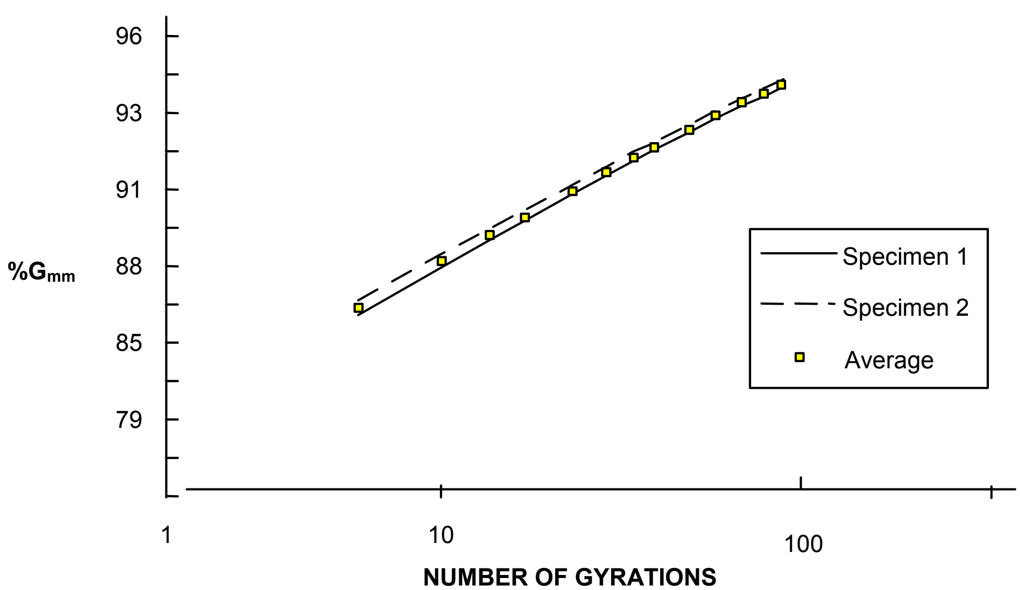
Densification Data for Trial Blend 2					
	Specimen 1		Specimen 2		AVG
Gyrations	Ht, mm	$\%G_{mm}$	Ht, mm	$\%G_{mm}$	$\%G_{mm}$
5	131.7	84.2	132.3	84.2	84.2
8	129.5	85.6	130.1	85.6	**85.6**
10	128.0	86.6	128.7	86.6	86.6
15	125.8	88.1	126.5	88.1	88.1
20	124.3	89.2	124.9	89.2	89.2
30	122.2	90.7	122.7	90.8	90.7
40	120.7	91.8	121.2	91.9	91.9
50	119.6	92.7	120.1	92.8	92.7
60	118.7	93.4	119.2	93.5	93.4
80	117.3	94.5	117.8	94.6	94.5
100	116.3	95.3	116.8	95.4	**95.4**
G_{mb}	2.444		2.447		
G_{mm}	2.565		2.565		

IH-43, 19.0 mm Nominal, 4.4% AC, Trial Blend 2



Densification Data for Trial Blend 3					
	Specimen 1		Specimen 2		AVG
Gyrations	Ht, mm	%G_{mm}	Ht, mm	%G_{mm}	%G_{mm}
5	130.9	84.4	129.5	85.2	84.8
8	127.2	85.9	127.3	86.6	**86.3**
10	127.2	86.9	125.9	87.6	87.3
15	125.1	88.3	124.1	89.0	88.7
20	123.7	89.3	122.8	89.9	89.6
30	121.8	90.7	121.0	91.2	91.0
40	120.5	91.7	119.7	92.2	91.9
50	119.6	92.5	118.7	93.0	92.7
60	118.8	93.1	118.1	93.5	93.3
80	117.6	94.0	116.9	94.4	94.2
100	116.7	94.7	116.1	95.1	**94.9**
G_{mb}	2.432		2.442		
G_{mm}	2.568		2.568		

IH-43, 19.0 mm Nominal, 4.4% AC, Trial Blend 3



EVALUATE TRIAL BLENDS

The average $\%G_{mm}$ is determined for N_{ini} (8 gyrations) and N_{des} (100 gyrations) for each trial blend. This data is taken directly from the compaction data tables. The summary of these values for Trial Blends 1, 2, and 3 is:

Determination of $\%G_{mm}$ at N_{ini} and N_{des} for Trial Blends		
Trial Blend	$\% G_{mm}$ @ N_{ini}	$\%G_{mm}$ @ N_{des}
1	87.1	95.9
2	85.6	95.4
3	86.3	94.9

The $\%G_{mm}$ for N_{max} must also be evaluated. Two additional specimens can be compacted to N_{max} for each of the trial blends or just the selected trial blend can be checked. (In this example, the second approach is utilized. The N_{max} verification, for the example, is discussed later in this chapter.)

The percent of air voids and voids in the mineral aggregate (VMA) are determined at N_{des}. The percent air voids is calculated using this equation:

$$\%\text{Air Voids} = 100 - \%G_{mm} @ N_{des}$$

Blend 1: %Air Voids = 100 - 95.9 = 4.1%
Blend 2: %Air Voids = 100 - 95.4 = 4.6%
Blend 3: %Air Voids = 100 - 94.9 = 5.1%

The percent voids in the mineral aggregate is calculated using this equation:

$$\%VMA = 100 - \left(\frac{\%G_{mm} @ N_{des} \times G_{mm} \times P_s}{G_{sb}}\right)$$

Blend 1: $$\%VMA = 100 - \left(\frac{95.9\% \times 2.563 \times 0.956}{2.699}\right) = 12.9\%$$

Blend 2: $$\%VMA = 100 - \left(\frac{95.4\% \times 2.565 \times 0.956}{2.697}\right) = 13.3\%$$

Blend 3: $$\%VMA = 100 - \left(\frac{94.9\% \times 2.568 \times 0.956}{2.701}\right) = 13.7\%$$

Compaction Summary of Trial Blends					
Blend	%AC	$\%G_{mm}$ @ N=8	$\%G_{mm}$ @ N=100	%Air Voids	%VMA
1	4.4	87.1	95.9	4.1	12.9
2	4.4	85.6	95.4	4.6	13.3
3	4.4	86.3	94.9	5.1	13.7

The table above shows the compaction summary of the trial blends. The central premise in Superpave volumetric mix design is that the correct amount of asphalt binder is used in each trial blend so that each blend achieves exactly 96% of G_{mm} or 4% air void content at N_{des}. Clearly, this did not happen for any of the three IH-43 trial blends. Because the trial blends exhibit different air void contents at N_{des}, the other volumetric and compaction properties cannot be properly compared. For example, Trial Blend 1 contained slightly too little asphalt to achieve 4 % air voids at N_{des}. Instead, it had 4.1% air voids. The VMA of Trial Blend 1 is too low. The designer must ask the question, "If I had used the asphalt content in Trial Blend 1 to achieve 4% air voids at N_{des}, would the VMA and other required properties improve to acceptable levels?"

Providing an answer to this question is an important step in volumetric mix design. To answer this question, an estimated asphalt binder content to achieve 4% air voids (96% G_{mm} at N_{des}) is determined for each trial blend using this formula:

$$P_{b,estimated} = P_{bi} - (0.4 \times (4 - V_a))$$

where
$P_{b,estimated}$ = estimated percent binder
P_{bi} = initial (trial) percent binder
V_a = percent air voids at N_{des}

Blend 1: $P_{b,estimated} = 4.4 - (0.4 \times (4 - 4.1)) = 4.4\%$
Blend 2: $P_{b,estimated} = 4.4 - (0.4 \times (4 - 4.6)) = 4.6\%$
Blend 3: $P_{b,estimated} = 4.4 - (0.4 \times (4 - 5.1)) = 4.8\%$

The volumetric (VMA and VFA) and mixture compaction properties are then estimated at this asphalt binder content using the equations below. These steps are solely aimed at answering the question, "What would have been the trial blend properties if I had used the right amount of asphalt to achieve 4% air voids at N_{des}?" It is by these steps that a proper comparison among trial blends can be accomplished.

For VMA:

$$\%VMA_{estimated} = \%VMA_{initial} + C \times (4 - V_a)$$

where: $\%VMA_{initial}$ = %VMA from trial asphalt binder content
C = constant (either 0.1 or 0.2)
Note: C = 0.1 if V_a is less than 4.0%
C = 0.2 if V_a is greater than 4.0%

Blend 1: $\%VMA_{estimated} = 12.9 + (0.2 \times (4.0 - 4.1)) = 12.9\%$
Blend 2: $\%VMA_{estimated} = 13.3 + (0.2 \times (4.0 - 4.6)) = 13.2\%$
Blend 3: $\%VMA_{estimated} = 13.7 + (0.2 \times (4.0 - 5.1)) = 13.5\%$

For VFA:

$$\%VFA_{estimated} = 100\% \times \frac{(\%VMA_{estimated} - 4.0)}{\%VMA_{estimated}}$$

Blend 1: $$\%VFA_{estimated} = 100\% \times \frac{(12.9 - 4.0)}{12.9} = 69.0\%$$

Blend 2: $$\%VFA_{estimated} = 100\% \times \frac{(13.2 - 4.0)}{13.2} = 69.7\%$$

Blend 3: $$\%VFA_{estimated} = 100\% \times \frac{(13.5 - 4.0)}{13.5} = 70.4\%$$

For $\%G_{mm}$ at N_{ini}:

$$\%G_{mm\ estimated} @ N_{ini} = \%G_{mm\ trial} @ N_{ini} - (4.0 - V_a)$$

Blend 1: $\%G_{mm\ estimated} @ N_{ini} = 87.1 - (4.0 – 4.1) = 87.2\%$
Blend 2: $\%G_{mm\ estimated} @ N_{ini} = 85.6 - (4.0 – 4.6) = 86.2\%$
Blend 3: $\%G_{mm\ estimated} @ N_{ini} = 86.3 - (4.0 – 5.1) = 87.4\%$

Finally, there is a required range on the dust proportion. This criteria is constant for all levels of traffic. It is calculated as the percent by mass of the material passing the 0.075 mm sieve (by wet sieve analysis) divided by the effective asphalt binder content (expressed as percent by mass of mix). The effective asphalt binder content is calculated using:

$$P_{be,\ estimated} = -(P_s \times G_b) \times \left(\frac{G_{se} - G_{sb}}{G_{se} \times G_{sb}}\right) + P_{b,\ estimated}$$

Blend 1: $$P_{be,\ estimated} = -(95.6 \times 1.02) \times \left(\frac{2.754 - 2.699}{2.754 \times 2.699}\right) + 4.4 = 3.7\%$$

Blend 2: $$P_{be,\ estimated} = -(95.4 \times 1.02) \times \left(\frac{2.755 - 2.697}{2.755 \times 2.697}\right) + 4.6 = 3.8\%$$

Blend 3: $$P_{be,\ estimated} = -(95.2 \times 1.02) \times \left(\frac{2.754 - 2.701}{2.754 \times 2.701}\right) + 4.8 = 4.1\%$$

Dust Proportion is calculated using:

$$DP = \frac{P_{.075}}{P_{be,\ estimated}}$$

Blend 1: $$DP = \frac{3.1}{3.7} = 0.84$$

Blend 2: $$DP = \frac{2.9}{3.8} = 0.76$$

Blend 3: $$DP = \frac{3.5}{4.1} = 0.85$$

The dust proportion must typically be between 0.6 and 1.2.

Dust Proportion of Trial Blends		
Blend	Dust Proportion	Criterion
Trial Blend 1	0.84	0.6 - 1.2
Trial Blend 2	0.76	
Trial Blend 3	0.85	

These tables show the estimated volumetric and mixture compaction properties for the trial blends at the asphalt binder content that should result in 4.0% air voids at N_{des}:

Estimated Mixture Volumetric Properties @ N_{des}						
Blend	Trial %AC	Est. %AC	%Air Voids	%VMA	%VFA	D.P.
1	4.4	4.4	4.0	12.9	69.0	0.84
2	4.4	4.6	4.0	13.2	69.7	0.76
3	4.4	4.8	4.0	13.5	70.4	0.85

Estimated Mixture Compaction Properties			
Blend	Trial %AC	Est. %AC	%G_{mm} @ N = 8
1	4.4	4.4	87.2
2	4.4	4.6	86.2
3	4.4	4.8	87.4

Estimated properties are compared against the mixture criteria. For the design traffic and nominal maximum particle size, the volumetric and densification criteria are:

% Air Voids	4.0%
% VMA	13.0% (19.0 mm nominal mixture)
% VFA	65% - 75% (10-30 $\times$ 10^6 ESALs)
% G_{mm} @ N_{ini}	less than 89%
Dust Proportion	0.6 - 1.2

After establishing all the estimated mixture properties, the designer can observe the values for the trial blends and decide if one or more are acceptable, or if further trial blends need to be evaluated.

Blend 1 is unacceptable based on a failure to meet the minimum VMA criteria. Both Blends 2 and 3 are acceptable. The VMA, VFA, D. P., and N_{ini} criteria are met. For this example, Trial Blend 3 is selected as the design aggregate structure.

What could be done at this point if none of the blends were acceptable? Additional combinations of the current aggregates could be tested, or additional materials from different sources could be obtained and included in the trial blend analysis.

SELECT DESIGN ASPHALT BINDER CONTENT

Once the design aggregate structure is selected, Trial Blend 3 in this case, specimens are compacted at varying asphalt binder contents. The mixture properties are then evaluated to determine a design asphalt binder content.

A minimum of two specimens are compacted at each of the following asphalt contents:

- estimated binder content
- estimated binder content ± 0.5%, and
- estimated binder content + 1.0%.

For Trial Blend 3, the binder contents for the mix design are 4.3%, 4.8%, 5.3%, and 5.8%. Four asphalt binder contents are a minimum in Superpave mix design.

A minimum of two specimens is also prepared for determination of maximum theoretical specific gravity at the estimated binder content. Specimens are prepared and tested in the same manner as the specimens from the “Select Design Aggregate Structure” section.

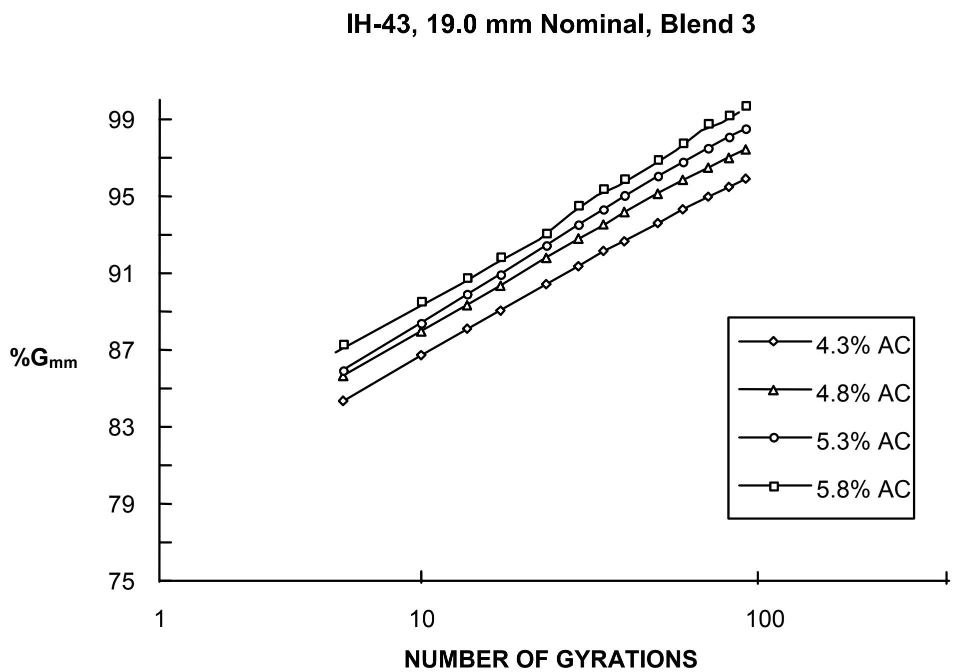
The following tables indicate the test results for each trial asphalt binder content. The average densification curves for each trial asphalt binder content are graphed for comparative illustration.

Densification Data for Blend 3, 4.3% Asphalt Binder					
	Specimen 1		Specimen 2		AVG
Gyrations	Ht, mm	$\%G_{mm}$	Ht, mm	$\%G_{mm}$	$\%G_{mm}$
5	131.3	83.9	131.0	84.7	84.3
8	129.0	85.4	128.8	86.1	**85.7**
10	127.5	86.4	127.4	87.1	86.7
15	125.4	87.8	125.5	88.4	88.1
20	124.0	88.8	124.2	89.3	89.1
30	122.1	90.2	122.4	90.6	90.4
40	120.9	91.1	121.1	91.6	91.4
50	119.9	91.9	120.1	92.4	92.1
60	119.1	92.5	119.4	92.9	92.7
80	117.9	93.4	118.3	93.8	93.6
100	117.0	94.1	117.4	94.5	**94.3**
G_{mb}	2.430		2.440		
G_{mm}	2.582		2.582		

Densification Data for Blend 3, 4.8% Asphalt Binder					
	Specimen 1		Specimen 2		AVG
Gyrations	Ht, mm	$\%G_{mm}$	Ht, mm	$\%G_{mm}$	$\%G_{mm}$
5	130.4	85.8	130.8	85.5	85.7
8	128.2	87.2	128.8	86.9	**87.1**
10	126.8	88.2	127.4	87.8	88.0
15	124.8	89.6	125.5	89.1	89.4
20	123.5	90.6	124.1	90.1	90.3
30	121.5	92.1	122.1	91.5	91.8
40	120.3	93.0	120.8	92.6	92.8
50	119.3	93.7	119.9	93.3	93.5
60	118.5	94.4	119.0	94.0	94.2
80	117.2	95.4	117.9	94.9	95.1
100	116.4	96.1	117.0	95.6	**95.8**
G_{mb}	2.462		2.449		
G_{mm}	2.562		2.562		

Densification Data for Blend 3, 5.3% Asphalt Binder					
	Specimen 1		Specimen 2		AVG
Gyrations	Ht, mm	%G_{mm}	Ht, mm	%G_{mm}	%G_{mm}
5	132.0	86.0	132.6	85.8	85.9
8	129.8	87.5	130.4	87.4	**87.4**
10	128.3	88.5	128.9	88.4	88.4
15	126.2	90.0	126.7	89.8	89.9
20	124.8	91.0	125.2	90.9	91.0
30	122.8	92.5	123.2	92.4	92.4
40	121.4	93.5	121.7	93.5	93.5
50	120.3	94.4	120.7	94.3	94.3
60	119.5	95.1	119.9	95.0	95.0
80	118.2	96.1	118.6	96.0	96.0
100	117.3	96.8	117.7	96.7	**96.8**
G_{mb}	2.461		2.458		
G_{mm}	2.542		2.542		

Densification Data for Blend 3, 5.8% Asphalt Binder					
	Specimen 1		Specimen 2		AVG
Gyrations	Ht, mm	%G_{mm}	Ht, mm	%G_{mm}	%G_{mm}
5	130.4	87.4	131.5	87.2	87.3
8	128.6	88.7	129.4	88.6	**88.6**
10	127.4	89.5	128.0	89.6	89.5
15	125.4	90.8	126.2	90.8	90.8
20	124.0	91.9	124.9	91.8	91.8
30	122.4	93.1	123.1	93.1	93.1
40	120.5	94.6	121.3	94.5	94.5
50	119.4	95.5	120.2	95.4	95.4
60	118.9	95.9	119.5	96.0	95.9
80	117.6	96.9	118.2	97.0	96.9
100	116.7	97.7	117.2	97.8	**97.8**
G_{mb}	2.464		2.467		
G_{mm}	2.523		2.523		



Average Densification Curves for Blend 3, Varying Asphalt Binder Content

Mixture properties are evaluated for the selected blend at the different asphalt binder contents, by using the densification data at N_{ini} (8 gyrations) and N_{des} (100 gyrations). These tables show the response of the mixture's compaction and volumetric properties with varying asphalt binder contents:

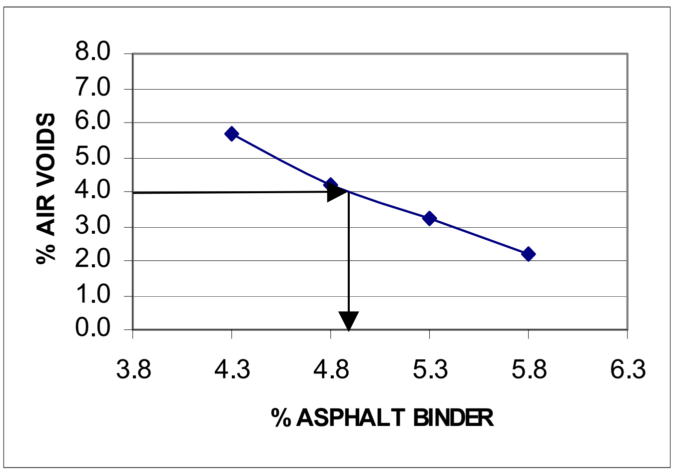
%AC	$\%G_{mm}$ @ N=8	$\%G_{mm}$ @ N=100
4.3%	85.8%	94.3%
4.8%	87.1%	95.8%
5.3%	87.4%	96.8%
5.8%	88.6%	97.8%

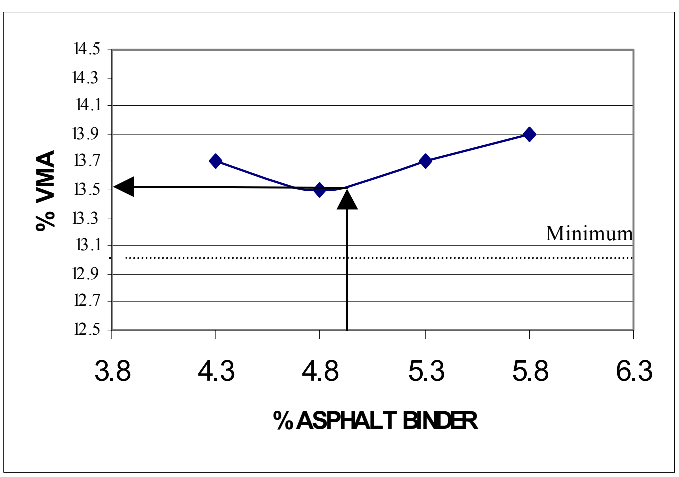
Summary of Blend 3 - Mix Volumetric Properties at N_{des}				
%AC	%Air Voids	%VMA	%VFA	Dust Proportion
4.3%	5.7%	13.7%	58.4%	1.21
4.8%	4.2%	13.5%	68.9%	1.05
5.3%	3.2%	13.7%	76.6%	0.91
5.8%	2.2%	13.9%	84.2%	0.82

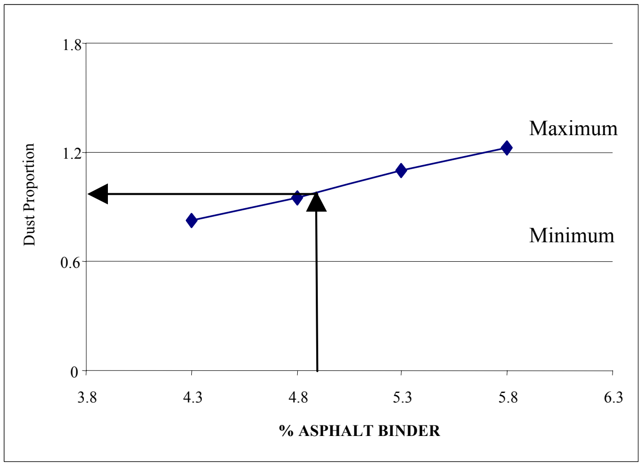
The volumetric properties are calculated at the design number of gyrations (N_{des}) for each trial asphalt binder content. From these data points, the designer can generate graphs of air voids, VMA, and VFA versus asphalt binder content. The design asphalt binder content is established at 4.0% air voids.

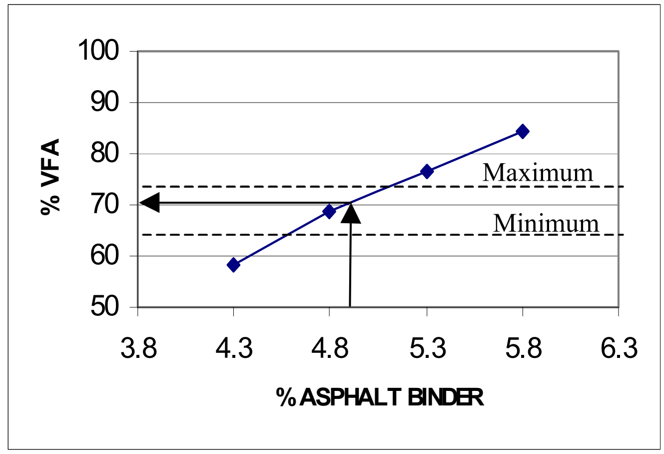
In this example, the design asphalt binder content is 4.9% - the value that corresponds to 4.0% air voids at N_{des} = 100 gyrations. All other mixture properties are checked at the design asphalt binder content to verify that they meet criteria.

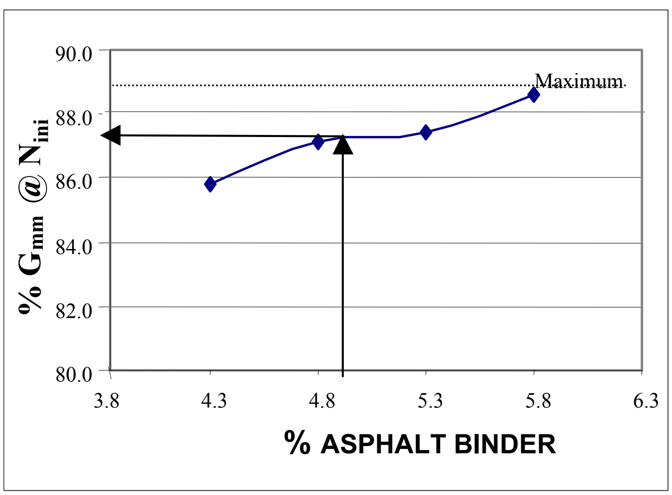
Design Mixture Properties at 4.9% Binder Content		
Mix Property	Result	Criteria
% Air Voids	4.0%	4.0%
%VMA	13.5%	13.0% min.
%VFA	71.0%	65% - 75%
Dust Proportion	1.00	0.6 - 1.2
$\%G_{mm}$ @ N_{ini} = 8	87.2%	less than 89%






Dust Proportion
1.8
1.2
0.6
0
Maximum
Minimum
3.8
4.3
4.8
5.3
5.8
6.3
% ASPHALT BINDER


% VFA
100
90
80
70
60
50
Maximum
Minimum
3.8
4.3
4.8
5.3
5.8
6.3
% ASPHALT BINDER


% Gmm @ Nini
90.0
88.0
86.0
84.0
82.0
80.0
Maximum
3.8
4.3
4.8
5.3
5.8
6.3
% ASPHALT BINDER

N_{MAX} VERIFICATION

Superpave specifies a maximum density of 98% at N_{max}. Specifying a maximum density at N_{max} prevents design of a mixture that will compact excessively under traffic, become plastic, and produce permanent deformation. Since N_{max} represents a compactive effort that would be equivalent to traffic much greater than the design traffic, excessive compaction will not occur. After selecting the trial blend (#3) and selecting the design asphalt binder content (5.0%), two additional specimens are compacted to N_{max} (160 gyrations).

The table shows the compaction data.

N_{max} Densification Data for Blend 3, 4.9% Asphalt Binder

	Specimen 1		Specimen 2		AVG
Gyrations	Ht, mm	%G_{mm}	Ht, mm	%G_{mm}	%G_{mm}
5	130.4	85.8	130.8	85.5	85.7
8	128.2	87.2	128.8	86.9	87.1
10	126.8	88.2	127.4	87.8	88.0
15	124.8	89.6	125.5	89.1	89.4
20	123.5	90.6	124.1	90.1	90.3
30	121.5	92.1	122.1	91.5	91.8
40	120.3	93.0	120.8	92.6	92.8
50	119.3	93.7	119.9	93.3	93.5
60	118.5	94.4	119.0	94.0	94.2
80	117.2	95.4	117.2	95.4	95.1
100	116.4	96.1	117.0	95.6	95.8
125	115.6	96.8	116.2	96.2	96.5
150	115.0	97.3	115.5	96.8	97.0
160	114.5	97.7	115.0	97.2	97.5
G_{mb}	2.495		2.490		
G_{mm}	2.554		2.554		

Blend 3, with %G_{mm} @ N_{max} equal to 97.5, satisfies the Superpave criteria.

EVALUATE MOISTURE SENSITIVITY

The final step in the Superpave mix design process is to evaluate the moisture sensitivity of the design mixture. This step is accomplished by performing AASHTO T 283 testing on the design aggregate blend at the design asphalt binder content. Specimens are compacted to approximately 7% air voids. One subset of three specimens is considered control specimens. The other subset of three specimens is the conditioned subset. The conditioned subset is subjected to vacuum saturation followed by an optional freeze cycle, followed by a 24 hour thaw cycle at 60° C. All specimens are tested to determine their indirect tensile strengths. The moisture sensitivity is determined as a ratio of the tensile strengths of the conditioned subset divided by the tensile strengths of the control subset. The table shows the moisture sensitivity data for the mixture at the design asphalt binder content.

Moisture Sensitivity Data for Blend 3 at 4.9% Design Asphalt Binder Content

SAMPLE		1	2	3	4	5	6
Diameter, mm	D	150.0	150.0	150.0	150.0	150.0	150.0
Thickness, mm	t	99.2	99.4	99.4	99.3	99.2	99.3
Dry mass, g	A	3986.2	3981.3	3984.6	3990.6	3987.8	3984.4
SSD mass, g	B	4009.4	4000.6	4008.3	4017.7	4013.9	4008.6
Mass in Water, g	C	2329.3	2321.2	2329.0	2336.0	2331.5	2329.0
Volume, cc (B-C)	E	1680.1	1679.4	1679.3	1681.7	1682.4	1679.6
Bulk Sp Gravity (A/E)	F	2.373	2.371	2.373	2.373	2.370	2.372
Max Sp Gravity	G	2.558	2.558	2.558	2.558	2.558	2.558
% Air Voids(100(G-F)/G)	H	7.2	7.3	7.2	7.2	7.3	7.3
Vol Air Voids (HE/100)	I	121.8	123.0	121.6	121.7	123.4	122.0
Load, N	P				20803	20065	20354
Saturated							
SSD mass, g	B'	4060.9	4058.7	4059.1			
Mass in water, g	C'	2369.4	2373.9	2372.8			
Volume, cc (B'-C')	E'	1691.5	1684.8	1686.3			
Vol Abs Water, cc (B'-A)	J'	74.7	77.4	74.5			
% Saturation (100J'/I)		61.3	62.9	61.3			
% Swell (100(E'-E)/E)		0.7	0.3	0.4			
Conditioned							
Thickness, mm	t"	99.5	99.4	99.4			
SSD mass, g	B"	4070.8	4074.9	4074.8			
Mass in water, g	C"	2373.7	2380.3	2379.0			
Volume, cc (B"-C")	E"	1697.1	1694.6	1695.8			
Vol Abs Water, cc (B"-A)	J"	84.6	93.6	90.2			
% Saturation (100J"/I)		69.5	76.1	74.2			
% Swell (100(E"-E)/E)		1.0	0.9	1.0			
Load, N	P"	16720	16484	17441			
Dry Str. (2000P/(tDp))	S_{td}				889	858	870
Wet Str. (2000P"/(t"Dp))	S_{tm}	713	704	745			

Average Dry Strength (kPa)	872
Average Wet Strength (kPa)	721
%TSR	82.6%

The minimum criteria for tensile strength ratio 80%. The design blend (82.6%) exceeded the criteria. The Superpave volumetric mix design is now complete for the intermediate mixture for IH-43.