ASPHALTIC TERMINOLOGY, EQUATIONS & EXAMPLE CALCULATIONS

SCOPE

This IM describes the terminology and many of the equations associated with asphaltic materials. In addition, there are a number of example calculations showing how to determine various properties.

LIQUID ASPHALT TERMINOLOGY

Asphalt Cement – See **Binder**

Binder – A dark brown to black cementitious material, which occurs in nature or is obtained in petroleum processing. Also commonly referred to Asphalt Cement (AC).

Bitumen – See **Binder**

Cutback Asphalt – Liquid asphalt composed of asphalt binder and a petroleum solvent. Cutback asphalts have three types (Rapid Curing (RC), Medium Curing (MC), and Slow Curing (SC)). The petroleum solvent, also called diluents, can have high volatility (RC) to low volatility (SC).

Emulsified Asphalt – Composed of asphalt binder and water, and a small quantity of emulsifying agent, which is similar to detergent. They may be of either the Anionic, electro-negatively-charged asphalt globules, or Cationic, electro-positively-charged asphalt globules types, depending upon the emulsifying agent. Emulsified asphalt is produced in three grades (Rapid-Setting (RS), Medium-Setting (MS), and Slow-Setting (SS)).

Flux or Flux Oil – A thick, relatively nonvolatile fraction of petroleum, which may be used to soften asphalt binder to a desired consistency.

Foamed Asphalt – A combination of high temperature asphalt binder and water to produce foaming.

Gilsonite – A form of natural asphalt, hard and brittle, which is mined.

Modified Binder – These are asphalt binders, which have been physically- and/or chemically-altered (usually with an additive) to bring the characteristics of the binder to what is desired for the application. This process includes polymer modification.

Performance Graded Asphalt (PG) – The identification associated with the grading of the binder. Prior identification methods have been penetration and viscosity grading. For example, a PG 64-22 would indicate a performance-graded binder with a high temperature confidence of 64°C and a low temperature confidence of -22°C.

Viscosity – The property of a fluid or semifluid that enables it to resist flow. The higher the viscosity, the greater the resistance to flow.

AGGREGATE TERMINOLOGY

Absorption – The property of an aggregate particle to take in and hold a fluid. For our purposes usually asphalt binder or water.

Aggregate – Any hard, inert, mineral material used for mixing in graduated fragments. It includes sand, gravel, crushed stone, and slag.

Coarse Aggregate – The aggregate particles retained on the #4 (4.75 mm) sieve.

Coarse-Graded Aggregate – A blend of aggregate particles having a continuous grading in sizes of particles from coarse through fine with a predominance of coarse sizes. A gradation below the maximum density line.

Cold-Feed Gradation – The aggregate proportioning system employing calibrated bins to deliver aggregate to the dryer (see IM 508 for additional information).

Fine Aggregate – Aggregate particles passing the #4 (4.75 mm) sieve.

Fine-Graded Aggregate – A blend of aggregate particles having a continuous grading in sizes of particles from coarse through fine with a predominance of fine sizes. A gradation above the maximum density line.

Gradation – The description given to the proportions of aggregate on a series of sieves. Usually defined in terms of the % passing successive sieve sizes.

Lime – A product used to enhance the bond between aggregate and asphalt binder. It is composed of dust from crushed limestone. Hydrated lime is often specified for surface mixes.

Manufactured Sand –The predominately minus #4 (4.75 mm) material produced from crushing ledge rock or gravel.

Mineral Filler – A finely divided mineral product at least 70 percent of which will pass a #200 (75 µm) sieve. Pulverized limestone is the most commonly manufactured filler, although other stone dust, hydrated lime, Portland cement, fly ash and certain natural deposits of finely divided mineral matter are also used.

Natural Sand – A loose, granular material found in natural deposits.

Open-Graded Aggregate – A blend of aggregate particles containing little or no fine aggregate and mineral filler and the void spaces in the compacted aggregate are relatively large.

Slag – A byproduct of steel production.

Well-Graded Aggregate – Aggregate that is uniformly graded from coarse to fine.

MIX TERMINOLOGY

Asphalt Cement Concrete – See **Hot Mix Asphalt**

Asphalt Leveling Course – Lift(s) of HMA of variable thickness used to eliminate irregularities in the contour of an existing surface prior to overlay.

Asphalt Overlay – One or more lifts of HMA constructed on an existing pavement. The overlay may include a leveling course to correct the contour of the old pavement, followed by uniform course or courses to provide needed thickness.

Base Course – Lift(s) of HMA pavement placed on the subgrade or subbase on which successive layers are placed.

Binder Course – See **Intermediate Course**

Full-Depth® Asphalt Pavement – The term Full-Depth® certifies that the pavement is one in which asphalt mixtures are employed for all courses above the subgrade or improved subgrade. A Full-Depth® asphalt pavement is laid directly on the prepared subgrade.

Hot Mix Asphalt (HMA) – Asphalt binder/aggregate mixture produced at a batch or drum-mixing facility that must be spread and compacted while at an elevated temperature. To dry the aggregate and obtain sufficient fluidity of the binder, both must be heated prior to mixing – giving origin to the term "hot mix."

Intermediate Course – An HMA pavement course between a base course and a surface course.

Job Mix Formula (JMF) – The JMF is the mix design used to begin a HMA project. It is also used as the basis for the control of plant produced mixture. It sets the proportions of the aggregate and amount of asphalt binder.

Mixed-In-Place (Road Mix) – An HMA course produced by mixing mineral aggregate and cutback or emulsified asphalt at the road site by means of travel plants, motor graders, or special road-mixing equipment.

Plant Mix – A mixture, produced in an asphalt mixing facility that consists of mineral aggregate uniformly coated with asphalt binder, emulsified asphalt or cutback asphalt.

Sand Asphalt – A mixture of sand and asphalt binder, cutback or emulsified asphalt. It may be prepared with or without special control of aggregate grading and may or may not contain mineral filler. Either mixed-in-place or plant-mix construction may be employed.

Sheet Asphalt – A hot mixture of binder with clean angular, graded sand and mineral filler.

Surface Course – The top lift(s) of HMA pavement, sometimes called asphalt wearing course.

MISCELLANEOUS TERMINOLOGY

Asphalt Joint Sealer – An asphalt product used for sealing cracks and joints in pavements and other structures.

Cold-In-Place Recycling – A method of rehabilitating the HMA surface by milling, adding a stabilizing agent, relaying and compacting in a continuous operation (see IM 504 for additional information).

Durability – The property of an asphalt paving mixture that describes its ability to resist the detrimental effects of air, water and temperature. Included under weathering are changes in the characteristics of asphalt, such as oxidation and volatilization, and changes in the pavement and aggregate due to the action of water, including freezing and thawing.

Fatigue Resistance – The ability of asphalt pavement to withstand repeated flexing caused by the passage of wheel loads.

Field Density – The density ($G_{mb\ (field)}$) of HMA based on field roller compaction.

Flexibility – The ability of an asphalt paving mixture to be able to bend slightly, without cracking, and to conform to gradual settlements and movements of the base and subgrade.

Fog Seal – A light application of emulsion diluted with water that is applied without mineral aggregate cover.

Lab Density – The density ($G_{mb\ (lab)}$) of HMA based on laboratory compaction.

Permeability – The resistance that an asphalt pavement has to the passage of air and water into or through the pavement.

Recycled Asphalt Pavement (RAP) – HMA removed and processed, generally by milling. This material may be stored and used on products in addition to virgin aggregate and binder. This is also referred to as Reclaimed Asphalt Pavement.

Seal Coat – A thin asphalt surface treatment used to waterproof and improve the texture of an asphalt wearing surface. Depending on the purpose, seal coats may or may not be covered with aggregate. The main types of seal coats are aggregate seals, fog seals, emulsion slurry seals and sand seals.

Skid Resistance – The ability of asphalt paving surface, particularly when wet, to offer friction against the tire surface.

Slurry Seal – A mixture of emulsified asphalt, fine aggregate and mineral filler, with water added to produce flowing consistency.

Specific Gravity – The weight to volume relationship of material in relation to water.

Stability – The ability of asphalt paving mixtures to resist deformation from imposed loads. Unstable pavements are marked by channeling (ruts), and corrugations (washboarding).

Surface Treatments – A broad term embracing several types of asphalt or asphalt-aggregate applications, usually less than 1 in. (25 mm) thick, to a road surface. The types range from a light application of emulsified or cutback asphalt (Fog seal) to a single or multiple surface layers made up of alternating applications of asphalt and aggregate (chip seal).

Tack Coat – A very light application of asphalt, usually asphalt emulsion diluted with water. It is used to ensure a bond between the existing pavement surface and the overlay.

CONSTRUCTION TERMINOLOGY

Batch Plant – This type of HMA production plant is used to produce individual batches of mix by making use of a pugmill (see IM 508 for additional information).

Certified Plant Inspection (CPI) – A specified method of quality control using a Certified Plant Inspector (see Section 2521 of the Standard Specification for additional information).

Cold-Feed – The device used to combine the various aggregates, in the correct proportions.

Drum Plant – This type of HMA production plant is a continuously operating plant, which mixes the aggregate, asphalt binder and RAP (if used) in the drum (See IM 508 for additional information).

Quality Management of Asphalt (QMA) – A specified quality control procedure where the contractor is responsible for the mix design and the control of the mix properties during production (see IM 511 for additional information). The agency is responsible for quality assurance and verification.

Workability – The ease with which paving mixtures may be placed and compacted.

NAMING CONVENTION

G_{sb}

Volumetric Property	*Material*	*Type*
		b = bulk
	s = stone	e = effective
G = Specific Gravity	b = binder	m = maximum theoretical
V = Volume	m = mix	a = apparent (for G) or
P = Percent	a = air	a = absorbed (for V and P)

DEFINITIONS

P_a = % of air voids in compacted hot mix asphalt mixture (percent of total volume)

P_b = % of asphalt binder in the hot mix asphalt mixture

$P_{b(RAP)}$ = % of asphalt binder in RAP material

P_s = % of combined aggregate in the hot mix asphalt mixture
= $100 - P_b$

P_{ba} = % of asphalt binder absorbed by aggregate, aggregate basis

P_{be} = effective asphalt binder, %, mixture basis

% Abs = % water absorption of the individual or combined aggregate

ABS = fraction of water absorption of the individual or combined aggregate
= % Abs/100
ABS is always used in the calculations rather than % Abs.

G_{sa} = apparent specific gravity of the aggregate

G_{se} = effective specific gravity of the combined aggregate

G_{sb} = bulk specific gravity of the aggregate (dry basis)

$G_{sb(SSD)}$ = bulk specific gravity of the aggregate (SSD basis)
Used for Portland Cement Concrete **NOT ASPHALT!!!**

G_b = specific gravity of the asphalt binder at 25°C (77°F)

G_{mm} = maximum specific gravity of the hot mix asphalt mixture. Often referred to as the Rice specific gravity, solid specific gravity or solid density.

G_{mb}	=	bulk specific gravity of compacted hot mix asphalt mixture
$G_{mb(corrected)}$	=	corrected G_{mb} at N_{des}, also called Lab Density.
$G_{mb(field)}$	=	bulk specific gravity of pavement cores
VMA	=	% voids in mineral aggregate, (percent of bulk volume), compacted mix
V_t	=	design target air voids, %
VFA	=	% voids filled with asphalt binder
N_{ini}	=	Number of gyrations used to measure initial compaction.
N_{des}	=	Number of gyrations used to measure design compaction. G_{mb} for Lab Density is determined at N_{des}.
N_{max}	=	Number of gyrations used to measure maximum compaction.
N_x	=	Level of compaction, where x is the number of gyrations.
R	=	temperature correction multiplier obtained from IM 350 Table 2 App. A
d_t	=	density of water at test temperature, g/cc
h_{max}	=	the height of the specimen at N_{max}, mm
h_{des}	=	the height of the specimen at N_{des}, mm
h_x	=	the height of the specimen at any gyration level N_x, mm
C_x	=	percent of compaction expressed as a percentage of G_{mm} Where x is the number of gyrations (this is normally N_{ini} or N_{max})
S	=	slope of the compaction curve
FT	=	Film Thickness, microns
SA	=	Surface Area, m^2/kg
F/B	=	Filler/Bitumen Ratio
σ_{n-1}	=	Sample Standard Deviation
$\bar{x}$	=	sample average

FORMULAS

All calculations shown have been rounded for ease of presentation. Normally calculations will involve maintaining more significant figures throughout the intermediate calculations and only rounding the final result. The values generated by the software specified by the DOT will be the accepted results for reporting purposes.

All specific gravity calculations will be reported to 3 decimal places. Binder content is reported to 2 decimal places. Percent voids, VMA and VFA are reported to 1 decimal place.

Unless noted as otherwise, the following information is given to perform the calculations. Any additional needed information will be provided with the sample calculation.

P_b = 5.75%	G_{sa} = 2.667	$G_{mb\ (field)}$ = 2.215
P_s = 100 – 5.75 = 94.25%	G_{se} = 2.659	$G_{mb\ (measured)}$ = 2.310
% Abs = 1.39	G_{sb} = 2.572	$G_{mb\ (corrected)}$ = 2.273
ABS = 1.39/100 = 0.0139	$G_{sb(SSD)}$ = 2.608	% RAP = 10.0%
G_b = 1.031	G_{mm} = 2.438	$P_{b(RAP)}$ = 5.00%

% minus #200 (75 μm) sieve = 5.0%
% frictional agg. retained on #4 (4.75 mm) = 90%
% frictional agg. of total blend = 20%
% retained on #4 (4.75 mm) of total blend = 60%

VOLUMETRIC EQUATIONS

To convert the specific gravity of asphalt binder from one temperature to another, the following two equations are used.

G_b (at 60°F) $= \dfrac{G_b \text{ (at } 77°\text{ F)}}{0.9961}$ $= \dfrac{1.031}{0.9961} = 1.035$

G_b (at 77°F) $= 0.9961 \times G_b \text{ (at } 60°\text{F)}$ $= 0.9961 \times (1.035) = 1.031$

% Abs $= \dfrac{W_a + W_b - W_c}{W_c} \text{ x } 100$ $= \dfrac{1315.7 + 690.3 - 2000.0}{2000.0} \text{ x } 100 = 0.30\%$

Where: W_a = Saturated-Surface-Dry (SSD) weight of coarse portion, 1315.7 g
W_b = Saturated-Surface-Dry (SSD) weight of fine portion, 690.3 g
W_c = Combined dry weight of coarse and fine portion, 2000.0 g

% Abs$_{(combined)}$

$$= [\% \text{ Abs}_1 \times (P_{s1})] + [\% \text{ Abs}_2 \times (P_{s2})] + [\% \text{ Abs}_3 \times (P_{s3})] + \ldots$$

$$= 0.67(0.50) + 1.23(0.05) + 2.21(0.45) = 1.39\%$$

Where: % Abs_1 = 0.67% P_{s1} = 50%
% Abs_2 = 1.23% P_{s2} = 5%
% Abs_3 = 2.21% P_{s3} = 45%

G_{sa}

$$= \frac{W \times R}{W + W_1 - W_2} = \frac{(2000.0)(1.0000)}{2000.0 + 6048.0 - 7298.1} = 2.667$$

Where: W = Weight of dry sample, 2000.0 g
W_1 = Sample weight of pycnometer filled with water at test temperature, 6048.0 g
W_2 = Sample weight of pycnometer filled with water and sample, 7298.1 g
R = Multiplier to correct temperature to 77°F = 1.0000 @ 77°F

G_{sb}

$$= \frac{G_{sa}}{1 + (ABS) \times (G_{sa})} = \frac{2.667}{1 + (0.0139)(2.667)} = 2.572$$

$G_{sb\ (combined)}$

$$= \frac{100}{\frac{P_{s1}}{G_{sb1}} + \frac{P_{s2}}{G_{sb2}} + \frac{P_{s3}}{G_{sb3}} + ..} = \frac{100}{\frac{50.0}{2.657} + \frac{5.0}{2.642} + \frac{45.0}{2.640}} = 2.649$$

Where: P_{s1} = 50.0% G_{sb1} = 2.657
P_{s2} = 5.0% G_{sb2} = 2.642
P_{s3} = 45.0% G_{sb3} = 2.640

G_{se}

$$= \frac{P_s}{\frac{100}{G_{mm}} - \frac{P_b}{G_b}} = \frac{100 - 5.75}{\frac{100}{2.438} - \frac{5.75}{1.031}} = 2.659$$

G_{mm}

$$= \frac{W \times R}{W + W_1 - W_2} = \frac{(2020.0)(1.0000)}{2020.0 + 6048.0 - 7239.5} = 2.438$$

Where: W = Sample weight of sample, 2020.0 g
W_1 = Sample weight of pycnometer filled w/water at test temperature, 6048.0 g
W_2 = Sample weight of pycnometer filled w/water and sample, 7239.5 g
R = Multiplier to correct temperature to 77°F = 1.0000 @ 77°F

To correct the density of water to 77°F the R multiplier is used. The value of R is given in the tables in IM's 350 and 380 for temperatures from 60 to 130°F. R is calculated as follows:

R $= \dfrac{d_t}{0.99707} \qquad = \dfrac{0.99707}{0.99707} = 1.0000$

Where: d_t = density of water at temperature t = 0.99707 g/cc at 77°F.

$G_{mb(measured)}$ $= \dfrac{W_1}{W_3 - W_2} \qquad = \dfrac{4800.0}{4805.6 - 2727.7} = 2.310$

Where: W_1 = Sample Dry weight, 4800.0 g
W_2 = Sample weight in water, 2727.7 g
W_3 = Sample weight in air, SSD, 4805.6 g

P_a (lab voids) $= \dfrac{G_{mm} - G_{mb(corrected)}}{G_{mm}} \times 100 \qquad = \dfrac{2.438 - 2.273}{2.438} \times 100 = 6.8\%$

P_a (field voids) $= 100 - \left[\dfrac{G_{mb(field)}}{G_{mm}} \times 100\right] \qquad = 100 - \dfrac{2.215}{2.438} \times 100 = 9.1\%$

VMA $= 100 - \left[\dfrac{G_{mb(corrected)} \times P_s}{G_{sb}}\right] \quad = 100 - \dfrac{(2.273)(94.25)}{2.572} = 16.7\%$

VFA $= \dfrac{VMA - P_a}{VMA} \times 100 \qquad = \dfrac{15.4 - 6.8}{15.4} \times 100 = 55.8\%$

P_{ba} $= \dfrac{(G_{se} - G_{sb})}{(G_{se} \times G_{sb})} \times G_b \times 100 \qquad = \dfrac{2.659 - 2.572}{(2.659)(2572)} \times 1.031 \times 100 = 1.31\%$

P_{be} $= P_b - \left[\dfrac{P_{ba} \times P_s}{100}\right] \qquad = 5.75 - \dfrac{(1.31)(94.25)}{100} = 4.52\%$

F/B $= \dfrac{\text{Total \% of minus \#200 material}}{P_{be}} \qquad = \dfrac{5.00}{4.52} = 1.11$

Where: Total % of minus #200 (75 µm) includes both virgin aggregate and RAP when used.

GYRATORY EQUATIONS

To correct G_{mb} from the measured value at N_{max} to the corrected value at N_{des}:

$G_{mb\,(corrected)}$ (lab density) $= (G_{mb\,(measured)}) \times \frac{h_{max}}{h_{des}}$ $= (2.310)\frac{117.5}{119.4} = 2.273$

Where: h_{max} = 117.5 mm h_{des} = 119.4

To find the percent of maximum specific gravity ($\%G_{mm}$) at a specific gyration (N_x):

C_x ($\%G_{mm}$) $= \frac{(G_{mb(measured)}) \times (h_{max})}{(G_{mm}) \times (h_x)} \text{ x } 100$

Given:
N_{ini} = 8 gyrations h_8 = 135.4 mm
N_{des} = 109 gyrations h_{109} = 119.4 mm
N_{max} = 174 gyrations h_{174} = 117.5 mm

C_8 $= \left(\frac{(2.310) \text{ x } (117.5\text{mm})}{(2.438) \text{ x } (135.4\text{mm})}\right) \text{ x } 100 = 82.2\%$

C_{109} $= \left(\frac{(2.310) \text{ x } (117.5\text{mm})}{(2.438) \text{ x } (119.4\text{mm})}\right) \text{ x } 100 = 93.2\%$

C_{174} $= \left(\frac{(2.310) \text{ x } (117.5\text{mm})}{(2.438) \text{ x } (117.5\text{mm})}\right) \text{ x } 100 = 94.7\%$

To find the slope of the gyratory compaction curve:

S $= \frac{(\log(N_{max}) - \log(N_{ini}))}{C_{max} - C_{ini}}$ $= \frac{(\log(174) - \log(8))}{0.947 - 0.822} = 10.7$

Where: C_{max} and C_{ini} are expressed as decimals.

RAP FORMULAS

$$\mathbf{P_{b(added)}} = \frac{[(100)\times(\text{total intended } P_b)] - [(\%\ RAP)\times(P_{b(RAP)})]}{100 - [(\%\ RAP)\times(P_{b(RAP)})\times(0.01)]}$$

$$= \frac{(100)(5.75) - (10.0)(5.00)}{100 - (10.0)(5.00)(0.01)} = 5.28\%$$

$$\mathbf{\%\ RAP_{(aggregate)}} = \frac{(\%\ RAP)\times[1.00 - (P_{b(RAP)}\times 0.01)]}{\%\ \text{virgin agg.} + [(\%\ RAP)\times(1.00 - (P_{b(RAP)}\times 0.01))]} \text{ x } 100$$

$$= \frac{(10.0)(1.00 - (5.00)(0.01))}{90.0 + (10.0)(1.00 - (5.00)(0.01))} \text{ x } 100 = 9.55\%$$

$$\mathbf{\%\ virgin\ agg.} = \frac{\%\ \text{virgin agg.}}{\%\ \text{virgin agg.} + [(\%\ RAP)\times(1.00 - (P_{b(RAP)}\times 0.01))]} \text{ x } 100$$

$$= \frac{90.0}{90.0 + (10.0)(1.00 - (5.00)(0.01))} \text{ x } 100 = 90.45\%$$

$$\mathbf{Total\ P_b} = P_{b(added)} + [(\%\ RAP)\times(P_{b(RAP)})\times(0.01)] - [(P_{b(added)})\times(\%\ RAP)\times(P_{b(RAP)})\times(0.0001)]$$

$$= 5.28 + (10.0)(5.00)(0.01) - (5.28)(10.0)(5.00)(0.0001) = 5.75\%$$

MISCELLANEOUS

Optimum P_b

$$= \frac{(\text{high voids - target voids})}{(\text{high voids - low voids})} \times (\text{high } P_b \text{ - low } P_b) + \text{low } P_b$$

Where: Target voids = 4.0

	P_b	P_a	
(low P_b =)	4.75	5.5	(= high voids)
(high P_b =)	5.75	3.0	(= low voids)
	6.75	1.2	

Since the target voids of 4.0% falls between 5.5 and 3.0 they are the high voids and low voids respectively. The asphalt contents associated with those voids are used as the low P_b and high P_b respectively.

$$= \frac{(5.5 - 4.0)}{(5.5 - 3.0)} \text{ x } (5.75 - 4.75) + 4.75 = 5.35\%$$

% Moisture

$$= \frac{\text{Wet Wt. Sample - Dry Wt. Sample}}{\text{Dry Wt. Sample}} \text{ x } 100$$

Where: Wet Wt. Sample = 2100.0 g
Dry Wt. Sample = 2000.0 g

$$= \frac{2100.0 - 2000.0}{2000.0} \text{ x } 100 = 5.0\%$$

To adjust the height of a G_{mb} specimen to reach the intended height, the following equation is used.

Adjusted sample weight

$$= \frac{(\text{trial sample weight}) \times (\text{intended height})}{\text{trial sample height}}$$

$$= \frac{(4775.0)(115.0)}{109.5} = 5014.8$$

G_{sb} (from $G_{sb(SSD)}$)

$$= \frac{G_{sb(SSD)}}{1 + ABS} \qquad = \frac{2.608}{1 + 0.0139} = 2.572$$

$$\textbf{\% Frictional Agg.} = \frac{(\%\text{ frictional agg. retained on \#4 })\times(\%\text{ frictional agg. of total blend})}{(\%\text{ retained on \#4 of total blend})}$$

For example: The aggregate blend contains 20% quartzite as the Type 2 friction class aggregate, the quartzite gradation shows 90% **retained** on the #4 sieve, and the combined gradation of the blend shows 60% **retained** on the #4 sieve:

$$= \frac{(90)(20)}{60} = 30\%$$

Percent of Lab Density $= \dfrac{G_{mb(field)}}{G_{mb(corrected)}} \text{ x } 100$ $\qquad = \dfrac{2.215}{2.273} \text{ x } 100 = 97.4\%$

Min. P_b $= \dfrac{[(G_b)(G_{se})(VMA - V_t) + (G_b)(100 - VMA)(G_{se} - G_{sb})]}{(G_b)(G_{se})(VMA - V_t) + (G_b)(100 - VMA)(G_{se} - G_{sb}) + (G_{se})(G_{sb})(100 - VMA)} \text{ x } 100$

$$= \frac{[(1.031)(2.659)(15.4 - 4.0) + (1.031)(100 - 15.4)(2.659 - 2.572)]}{(1.031)(2.659)(15.4 - 4.0) + (1.031)(100 - 15.4)(2.659 - 2.572) + (2.659)(2.572)(100 - 15.4)} \text{ x } 100 = 6.29\%$$

You have 13,000 grams of aggregate and 650 grams of asphalt binder. Determine the asphalt binder content (P_b) of the mixture.

$P_{b\ (mix\ basis)}$ $= \dfrac{W_b}{W_s + W_b} \text{ x } 100$ $\qquad = \dfrac{650}{13000 + 650} \text{ x } 100 = 4.76\%$

Where: W_b = Weight of the asphalt binder, g
W_s = Weight of the aggregate, g
$P_{b\ (mix\ basis)}$ = Percent binder of the mix, mix basis

You have 13,000 grams of aggregate. You want to prepare a mixture having 5.5% asphalt binder content based on the total mix. Determine the weight of the asphalt binder you need to add to the aggregate.

$W_{b\ (mix\ basis)}$ $= \dfrac{(P_b)\times(W_s)}{(P_s)}$ $\qquad = \dfrac{(5.5)(13000)}{100 - (5.5)} = 756.6$

Where: $W_{b\ (mix\ basis)}$ = Weight of the added binder, mix basis, g
W_s = Weight of the aggregate, g

QUALITY INDEX (QI) EXAMPLE:

Given: lab. lot average $G_{mb(corrected)}$ = 2.408
field G_{mb} of individual cores: 2.319, 2.316, 2.310, 2.298, 2.242, 2.340, and 2.345.
% of lab density = 94%, 95%, or 96%. For this example 95% is used.

Determine the average field density (G_{mb}) of the seven cores.

$$\bar{x} = \frac{2.319 + 2.316 + 2.310 + 2.298 + 2.242 + 2.340 + 2.345}{7} = 2.310$$

The sample standard deviation is determined as follows:

$$\sigma_{n-1} = \sqrt{\frac{\sum (x - \bar{x})^2}{n - 1}} = \sqrt{\frac{0.007}{7 - 1}} = 0.034$$

Where: x = individual sample value
n = number of samples
$\bar{x}$ = average of all samples

The Quality Index for density shall be determined according to the following calculation:

$$\textbf{Q.I. (Density)} = \frac{(\text{Avg. } G_{mb})_{\text{FIELD LOT}} - ((\%\text{ Density})_{\text{SPECIFIED}} \text{ x } (\text{Avg. } G_{mb})_{\text{LAB LOT}})}{(\text{Std. Dev. } G_{mb})_{\text{FIELD LOT}}}$$

$$\textbf{QI} = \frac{2.310 - (0.95)(2.408)}{0.034} = 0.66$$

The QI is less than 0.72. Check for outliers. To test for a suspected outlier result, apply the appropriate formula.

$$\textbf{Suspected High Outlier} = \frac{\text{Highest } G_{mb} - \text{Avg. } G_{mb}}{\sigma_{n-1}} = \frac{2.345 - 2.310}{0.034} = 1.03$$

$$\textbf{Suspected Low Outlier} = \frac{\text{Avg. } G_{mb} - \text{Lowest } G_{mb}}{\sigma_{n-1}} = \frac{2.310 - 2.242}{0.034} = 1.99$$

The highest density or lowest density shall not be included if the suspected outlier result is more than 1.80 for seven samples. The quality index shall then be recalculated for the remaining six samples.

The suspected low outlier result is greater than 1.80 for seven samples, therefore the core with the lowest density, 2.242, is an outlier.

Recalculate the QI for the remaining six densities (excluding the outlier).

Avg. G$_{mb\ (field\ lot)(new)}$ = 2.321 **$\sigma_{n-1\ (new)}$** = 0.018

QI$_{(new)}$ $$= \frac{2.321 - (0.95)(2.408)}{0.018} = 1.88$$

<u>GRADATION EXAMPLE (Combined Gradation)</u>:

Assume the proportions of the individual aggregates are as follows: 50% ¾” Minus, 5% ⅜” Chips, and 45% Nat. Sand. Then using the following gradations for the individual aggregates, determine the combined gradation.

% Passing

Sieve Size	19 mm	12.5 mm	9.5 mm	4.75 mm	2.36 mm	1.18 mm	600 µm	300 µm	150 µm	75 µm
3/4" Minus	100	90	75	43	21	17	15	12	9.8	7.4
3/8" Chip	100	100	70	32	5	1.8	1.5	1.1	0.9	0.7
Nat. Sand	100	100	100	100	80	65	40	9	1.0	0.5
combined	______	______	______	______	______	______	______	______	______	______

To determine the combined gradation, take each individual material % Passing times the percentage of that material in the blend. For example, take the 50% of the 3/4” Minus material times the % Passing for that material and do the same thing with each of the other aggregates to get the following:

3/4" Minus	50.0	45.0	37.5	21.5	10.5	8.5	7.5	6.0	4.9	3.7
3/8" Chip	5.0	5.0	3.5	1.6	0.3	0.1	0.1	0.1	0.0	0.0
Nat. Sand	45.0	45.0	45.0	45.0	36.0	29.3	18.0	4.1	0.5	0.2

Next, sum the individual sieve sizes to get the combined gradation. This will result in the following combined gradation.

Combined	100.0	95.0	86.0	68.1	46.8	37.9	25.6	10.2	5.4	3.9

FILM THICKNESS EXAMPLE:

SIEVE ANALYSIS % PASSING													
Sieve	in. (mm)	1 (25.0)	3/4 (19.0)	1/2 (12.5)	3/8 (9.5)	#4 (4.75)	#8 (2.36)	#16 (1.18)	#30 (0.600)	#50 (0.300)	#100 (0.150)	#200 (0.075)	
Combined Grading		100	100	95	86	68	47	38	26	10	5.4	3.9	
Surface Area Coefficient						0.0041	0.0082	0.0164	0.0287	0.0614	0.1229	0.3277	TOTAL
Surface Area	(m^2/kg)	0.41				0.28	0.39	0.62	0.75	0.61	0.66	1.28	5.00

The surface area is found by taking the % Passing times the Surface Area Coefficient. The Surface Area for the material above the #4 sieve is a constant 0.41. The total surface area is found by adding all of the individual surface area values.

FT $= \frac{P_{be}}{SA} \times 10 \qquad = \frac{4.52}{5.00} \times 10 = 9.0$

SA (for each sieve) $= (\%\ \text{Passing})(\text{Surface Area Coefficient})$

$= (38)(0.0164) = 0.62$ (for the #16 sieve above)

Where: The Surface Area Coefficients are constants.

BATCHING EXAMPLE:

You have been directed to prepare a 13,000-gram batch of aggregate composed of the aggregates used above with the same proportions. The ¾" Minus has been split into four size fractions by sieving on the 12.5 mm, 9.5 mm and 4.75 mm sieves. The ⅜" Chip has been split into three size fractions by sieving on the 9.5 mm and 4.75 mm sieves. The Nat. Sand is one size fractions passing the 4.75 mm sieve. Complete the following batching sheet by determining the mass of each aggregate needed, the percentage of each size fraction and the weight of each size fraction.

Weight ¾" Minus @ 50% = __________ grams

Sieve	% Passing	Size Fraction	% In Size Fraction	Weight Needed Each Fraction	Cumulative Weight
19 mm	100				
12.5 mm	90	-19 + 12.5	________	________	________
9.5 mm	75	-12.5 + 9.5	________	________	________
4.75 mm	43	-9.5 + 4.75	________	________	________
		-4.75	________	________	________
			________		

Weight ⅜" Chip @ 5% = __________grams

Sieve	% Passing	Size Fraction	% In Size Fraction	Weight Needed Each Fraction	Cumulative Weight
12.5 mm	100				
9.5 mm	70	-12.5 + 9.5	________	________	________
4.75 mm	32	-9.5 + 4.75	________	________	________
		-4.75	________	________	________
			________		

Weight Nat. Sand @ 45% = __________grams

Sieve	% Passing	Size Fraction	% In Size Fraction	Weight Needed Each Fraction	Cumulative Weight
4.75 mm	100	-4.75	________	________	________
			________		

The weight of each material is found by taking the percentage of the blend each material is times the total batch weight. For example, the weight of the ¾" Minus is found by taking 50% of the 13,000 gram batch, or 6,500 grams.

The % In Size Fraction column is found by subtracting the % Passing from one size by the previous size % Passing. For example, the % In Size Fraction for the –19 + 12.5 Size Fraction is found by subtracting 90% Passing the 12.5 mm sieve from 100% Passing the 19 mm sieve.

This process is repeated for each size fraction. The last line in the % In Size Fraction column is found by adding each of the individual values above it. The total should be 100.0%.

The Weight Needed Each Fraction is found by taking the % In Size Fraction value and multiplying it by the total mass of that aggregate. For example, for the ¾" Minus material, there is 10% in the –19 + 12.5 size fraction. Take this 10% times the mass of 6,500 grams to get the Weight Needed value of 650 grams.

The Cumulative Weight is found by taking the first value in the Weight Needed column and placing it in the first spot for the Cumulative Weight column. For example, there was 650 grams needed in the previous example. This value would go on the first line of the Cumulative Weight column. Each successive line requires adding the corresponding Weight Needed value with the previous Cumulative Weight value. Below are the solutions for the example shown above.

Weight ¾" Minus @ 50% = 6500.0 grams

Sieve	% Passing	Size Fraction	% In Size Fraction	Weight Needed Each Fraction	Cumulative Weight
19 mm	100				
12.5 mm	90	-19 + 12.5	10.0	650.0	650.0
9.5 mm	75	-12.5 + 9.5	15.0	975.0	1625.0
4.75 mm	43	-9.5 + 4.75	32.0	2080.0	3705.0
		-4.75	43.0	2795.0	6500.0
			100.0		

Weight ⅜" Chip @ 5% = 650.0 grams

Sieve	% Passing	Size Fraction	% In Size Fraction	Weight Needed Each Fraction	Cumulative Weight
12.5 mm	100				
9.5 mm	70	-12.5 + 9.5	30.0	195.0	6695.0
4.75 mm	32	-9.5 + 4.75	38.0	247.0	6942.0
		-4.75	32.0	208.0	7150.0
			100.0		

Weight Nat. Sand @ 45% = 5850.0 grams

Sieve	% Passing	Size Fraction	% In Size Fraction	Weight Needed Each Fraction	Cumulative Weight
4.75 mm	100	-4.75	100.0	5850.0	13000.0
			100.0		

The Cumulative Weight at the end of the batching should always equal the desired total batch weight.

Determine the tons of asphalt binder used in the mix for a given day using the following information:

Weights of all Binder @ 60°F = 8.67 lbs./gal.
Beginning tank stick 18,000 gal. @ 296°F
28.0 tons Binder hauled in during the day's run
Ending tank stick 16,000 gal. @ 296°F
Volume correction factor for correcting Binder @ 296°F to Binder @ 60°F = 0.9200

The difference between the beginning and ending tank stick readings is the first place to start. There were 2,000 gal. of binder used plus all of the binder hauled in during the day.

To combine these quantities, they must be converted to tons. First the gallons used must be corrected to 60°F. Since the temperature is the same for the beginning and ending tank stick readings the correction can be done on the difference between the two readings. If the temperatures were different for the two readings, the temperature correction would need to be done on the individual readings before the difference is determined.

2,000 gal binder @ 296°F $= (2000 \text{ gal @ } 296\,°\text{F}) \times 0.9200 = 1840 \text{ gal @ } 60\,°\text{F}$

This value must then be converted to the tons of binder.

1840 gal @ 60°F $= \dfrac{(1840 \text{ gal}) \times (8.67 \text{ lbs./gal.})}{2000 \text{ lbs./ton}} = 7.98 \text{ tons}$

This value in addition to the 28.0 tons of binder hauled in during the day is the amount used in the mix that day.

Tons of binder used in mix $= 28.0 \text{ tons} + 7.98 \text{ tons} = 35.98 \text{ tons binder}$

DETERMINING CORRECTION FACTORS FOR COLD FEED VS. IGNITION OVEN

		Sieve Sizes - Percent Passing												Surface
		1 1/2"	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200	Area
SU4-30D	Ign. Oven	100.0	100.0	99.0	89.0	77.0	47.0	31.0	20.0	14.0	8.6	6.4	5.2	4.60534
4-A	Cold-Feed	100.0	100.0	99.0	89.0	76.0	47.0	29.0	19.0	13.0	7.8	5.6	4.4	4.13424
Correction Factor		0.0	0.0	0.0	0.0	-1.0	0.0	-2.0	-1.0	-1.0	-0.8	-0.8	-0.8	-0.5

The correction factor is determined by taking the percent passing an ignition oven sieve and subtracting it from the percent passing of the corresponding cold-feed sieve. For example, there is 31 percent passing the number #8 sieve for the ignition oven and 29 percent passing the #8 sieve for the cold-feed. The correction factor for this sieve size is -2.0. The correction factor is applied to the ignition oven test results for I.M. 216 comparison.

This same procedure is used regardless of using a single gradation or multiple gradations to determine the correction factors. If multiple gradations are used, the correction factor is determined for each individual result and the resulting correction factors averaged for each sieve.

QUALITY INDEX (QI) EXAMPLE %G_{mm} Method:

Given: Field G_{mb} of individual cores: 2.319, 2.316, 2.310, 2.298, 2.242, 2.340, 2.345, 2.310.
Lot Average G_{mm} = 2.501

Determine the average field density (G_{mb}) of the eight cores.

$$\bar{x} = \frac{2.319 + 2.316 + 2.310 + 2.298 + 2.242 + 2.340 + 2.345 + 2.310}{8} = 2.310$$

The sample standard deviation (σ_{n-1}) of G_{mb} for the field lot is determined as follows:

$$\sigma_{n-1} = \sqrt{\frac{\sum (x - \bar{x})^2}{n - 1}} = \sqrt{\frac{0.007}{8 - 1}} = 0.032$$

Where:
x = individual sample value
n = number of samples
$\bar{x}$ = average of all samples

The Quality Index for field voids shall be determined according to the following calculation:

QI (Field Voids) $= \dfrac{(\text{Avg. } G_{mb})_{\text{FIELD LOT}} - (0.915 \times \text{Lot Avg. } G_{mm})}{(\text{Std. Dev. } G_{mb})_{\text{FIELD LOT}}}$

Example:

QI (Field Voids) $= \dfrac{2.310 - (0.915)(2.501)}{0.032} = 0.67$

If the QI results in less than 100% pay check for outliers. To test for a suspected outlier result, apply the appropriate formula.

Suspected High Outlier $= \dfrac{\text{Highest } G_{mb} - \text{Avg. } G_{mb}}{\sigma_{n-1}} = \dfrac{2.345 - 2.310}{0.032} = 1.09$

Suspected Low Outlier $= \dfrac{\text{Avg. } G_{mb} - \text{Lowest } G_{mb}}{\sigma_{n-1}} = \dfrac{2.310 - 2.242}{0.032} = 2.13$

The highest density or lowest density shall not be included if the suspected outlier result is more than 2.00 for eight samples. The quality index shall then be recalculated for the remaining seven samples.

The suspected low outlier result is greater than 2.00 for eight samples, therefore the core with the lowest density, 2.242, is an outlier.

Recalculate the QI for the remaining seven densities (excluding the outlier).

Avg. $G_{mb\ (\text{field lot})(\text{new})} = 2.320$ $\sigma_{n-1\ (\text{new})} = 0.020$

$QI_{(\text{new})} = \dfrac{2.320 - (0.915) \times (2.501)}{0.020} = 1.58$

DETERMINING ABSOLUTE AVERAGE DEVIATION (AAD) FOR LAB VOIDS

AAD is calculated by determining the absolute difference between the target and the individual test results and then averaging those values.

Example:

Target Voids P_a = 4.0
Individual P_a = 3.8, 4.2, 4.1, 3.7, 3.5

Sample	Difference	Deviation from Target	Absolute Deviation from Target
1	(4.0 - 3.8)	0.2	0.2
2	(4.0 - 4.1)	-0.1	0.1
3	(4.0 - 4.2)	-0.2	0.2
4	(4.0 - 3.7)	0.3	0.3
5	(4.0 - 3.5)	0.5	0.5

AAD (Lab Voids) $= \frac{0.2 + 0.1 + 0.2 + 0.3 + 0.5}{5} = 0.3$

DETERMINATION OF PERCENT WITHIN LIMITS (PWL)

Field Voids

Calculate the QI for field voids. Using Table 6 in AASHTO R 9-97 Appendix C and the QI value, the PWL can be determined using a sample size of N=8. A sample size of N=8 is always used regardless of the actual number of samples. The program provided by the Iowa DOT will calculate the PWL automatically using a best fit equation between QI values.

Lab Voids

Based on the weekly lot of HMA produced with a minimum of eight test values, determine the average and standard deviation for the air voids.

Quality Index for Air Voids Upper Limit (QI_U)

QI_U $$= \frac{(\text{Target } P_a + 1) - \text{Avg. } P_a}{\text{Std. Dev. } P_a}$$

Quality Index for Air Voids Lower Limit (QI_L)

QI_L $$= \frac{\text{Avg. } P_a - (\text{Target } P_a - 1)}{\text{Std. Dev. } P_a}$$

Using Table 6 in AASHTO R 9-97 Appendix C and a sample size of N=8 determine the upper and lower QI limits. A sample size of N=8 is always used regardless of the actual number of samples. The program provided by the Iowa DOT will calculate the PWL automatically using a best fit equation between QI values. No rounding is done until the final PWL is determined.

Example:

Given the following weekly lot air void information and a target air void of 4.0% determine the upper and lower limits for the QI for air voids: 3.1, 3.9, 4.2, 4.5, 4.5, 4.1, 4.3, 4.5

$P_{a(avg)}$ $$= \frac{3.1 + 3.9 + 4.2 + 4.5 + 4.5 + 4.1 + 4.3 + 4.5}{8} = 4.1375$$

Std. Dev. P_a $$= \sqrt{\frac{\sum (x - \bar{x})^2}{n - 1}} \qquad = \sqrt{\frac{1.55875}{8 - 1}} = 0.471888$$

QI_U $$= \frac{(4.0 + 1) - 4.1375}{0.471888} = 1.827763$$

QI_L $$= \frac{4.1375 - (4.0 - 1)}{0.471888} = 2.410528$$

Using Table 6 from AASHTO R 9-97 Appendix C a sample size of N=8 and the QI_U and QI_L find the corresponding PWL for the QI_U and QI_L. A sample size of N=8 is always used regardless of the actual number of samples. In this case the PWLs determined by the best fit equation for the QI_U and QI_L are 98.2 and 100.0 respectively.

The PWL used for pay factor determination is based on a combination of the PWLs calculated from the QI_U and QI_L.

Example:

PWL $= (PWL_U + PWL_L) - 100 \qquad = (98.2 + 100.0) - 100 = 98.2$

PWL Table for N=8 (from AASHTO R 9-97 Appendix C Table 6)

QI	PWL	QI	PWL	QI	PWL	QI	PWL	QI	PWL
0.00	50.00	0.50	68.43	1.00	83.96	1.50	94.44	2.00	99.24
0.05	51.89	0.55	70.16	1.05	85.26	1.55	95.17	2.05	99.45
0.10	53.78	0.60	71.85	1.10	86.51	1.60	95.84	2.10	99.61
0.15	55.67	0.65	73.51	1.15	87.70	1.65	96.45	2.15	99.74
0.20	57.54	0.70	75.14	1.20	88.83	1.70	97.01	2.20	99.84
0.25	59.41	0.75	76.72	1.25	89.91	1.75	97.51	2.25	99.91
0.30	61.25	0.80	78.26	1.30	90.94	1.80	97.96	2.30	99.96
0.35	63.08	0.85	79.76	1.35	91.90	1.85	98.35	2.35	99.98
0.40	64.89	0.90	81.21	1.40	92.81	1.90	98.69	2.40	100.00
0.45	66.67	0.95	82.61	1.45	93.65	1.95	98.99	2.45	100.00

Note: For QI values less than zero, subtract the table value from 100.