QMS-1 REVISED 08 / 01 / 12

Request for Mix Design and Job Mix Formula Approval

Contractor: ____________________
Address: ____________________
____

Date Submitted: ____________________
Proprosed Starting Date: ____________________
Specification: ____________________
*Mix Design No.: ____________________

Based on the Attached SUPERPAVE Mix Design (Itemized Below) Approval and Issuance of a Mix Design is Requested

Check Block if Attached

☒ M & T 601 Form, Report on SUPERPAVE Method of An Asphalt Mix Design

☒ M & T 602 Form, Graphical Plot of Volumetric Properties on SUPERPAVE Method of An Asphalt Mix Design

☒ M & T 603 Form, Report of Volumetric Properties on SUPERPAVE Method of An Asphalt Mix Design

☒ FHWA 0.45 Power Chart, Graphical Plot of Blended Gradation Values

☒ M & T 601A Form, Worksheet for Gmb and Gmm on SUPERPAVE Method of An Asphalt Mix Design

☒ M & T 612 Form, Worksheet for Tensile Strength Ratio

☒ M & T 613 Form, Worksheet for APA Rut Specimens

☒ Gyratory Printouts (Design, TSR and APA Rut)

☒ M & T 620 Form, Worksheet for Consensus Properties

If this Mix Design is Approved, Issuance of a Job Mix Formula Based on this Mix Design is also Requested for:

Plant Location(s) : ____________________

Comments: ____________________

☐ **New Sand Source Request**

Mix Design Technician's Signature: ____________________

Telephone No.: ____________________

Mail To Asphalt Design Engineer, 1545 Mail Service Center, Raleigh , NC 27699-1545

*To be assigned by NCDOT

M & T 601 FORM, REPORT ON SUPERPAVE METHOD OF AN ASPHALT MIX DESIGN

E SUBMITTED: ____________________ DATE APPROVED: ____________________ MD#: __________

MIX DESIGN INFORMATION	MATERIALS USED
OJECT NO.:	BINDER:
COUNTY:	ADDITIVE:
CONTRACTOR:	
PLANT & CERT. NO.:	
DESIGNED BY:	
SPECIFICATION:	
MIXTURE TYPE:	
GYRATIONS (N_{ini} / N_{des}):	
COMPACTION TEMP (°C):	
MOLD DIAMETER:	
COMPACTOR TYPE:	
TRAFFIC LEVEL:	

GRADATION OF MATERIALS USED

MATERIAL												BLEND	
PERCENT (JMF)													CONTROL POINTS
PERCENT (MD)													
SIEVES	50.0 mm												
	37.5 mm												
	25.0 mm												
	19.0 mm												
	12.5 mm												
	9.50 mm												100.0
	4.75 mm												90.0 - 100.0
	2.36 mm												65.0 - 90.0
	1.18 mm												
	.600 mm												
	.300 mm												
	.150 mm												
	.075 mm												4.0 - 8.0
Furn. Cal. Fact.:													
Bulk Dry S.G.:													
											Agg. Effective S.G.:		
Apparent S.G.:													

MIX PROPERTIES @ N DESIGN

	Opt. Pb				
% Asphalt Binder - Total Mix:		4.0	4.5	5.0	5.5
Max. Specific Gravity (G_{mm}):					
G_{mb} @ N_{des}:					
% Voids-Total Mix (VTM):					
% Solids-Total Mix:					
% Effective Binder Content (P_{be}):					
Dust to P_{be} Ratio ($P_{.075}/P_{be}$):					
By Volume of Effective P_b:					
% Solids by Vol. of Agg. Only:					
% Voids in Mineral Agg. (VMA):					
% Voids Fillied w/Binder (VFA):					
% G_{mm} @ N_{ini}:					
% G_{mm} @ N_{des}:					

Fractionation or Combination of Recycled Materials

% Recycle #1 / % Recycle #2 __________
Pb in Recycle #1 / Recycle #2 __________
Pb from Recycle #1 / Recycle #2

Total Recycled Material

Total % Recycle / Total % Virgin:
Total Pb in Recycle: __________
Total Pb from Recycle:

Pb Absorption: __________
% ASH: __________
TSR % Retained : __________
Ignition Furn. Calibr.: __________
Pb (Design): __________
Rice Specific Gravity: __________
Lab Specific Gravity: __________
Percent Air Voids: __________
Percent VMA: __________
Percent VFA: __________
DUST/AC Ratio: __________
% G_{mm} @ N_{ini}
Pb ADDED: __________
Pb from ______________ __________
Pb from ______________ __________
Pb from ______________ __________

CONSENSUS PROPERTIES	
F. Agg. Angularity:	
Sand Equivalent:	
Flat & Elongated:	
C. Agg. Angularity:	
F. Agg. Angularity:*	

*T304; Ran on Individual Natural Sand

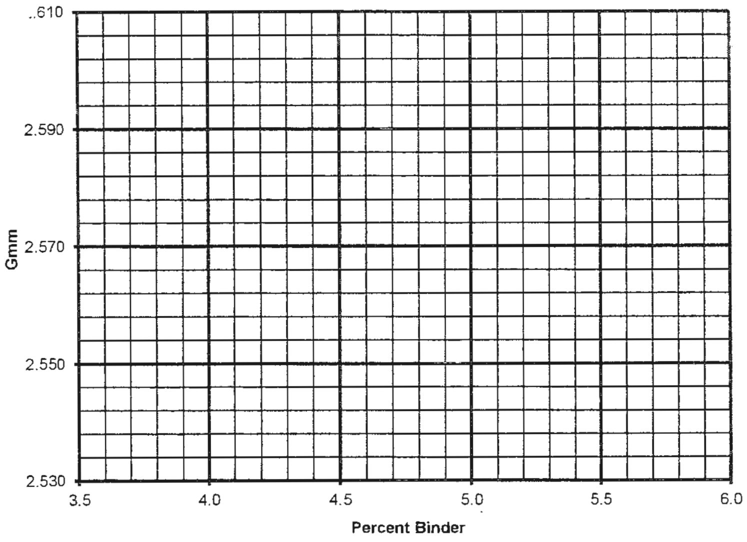
COMMENTS:

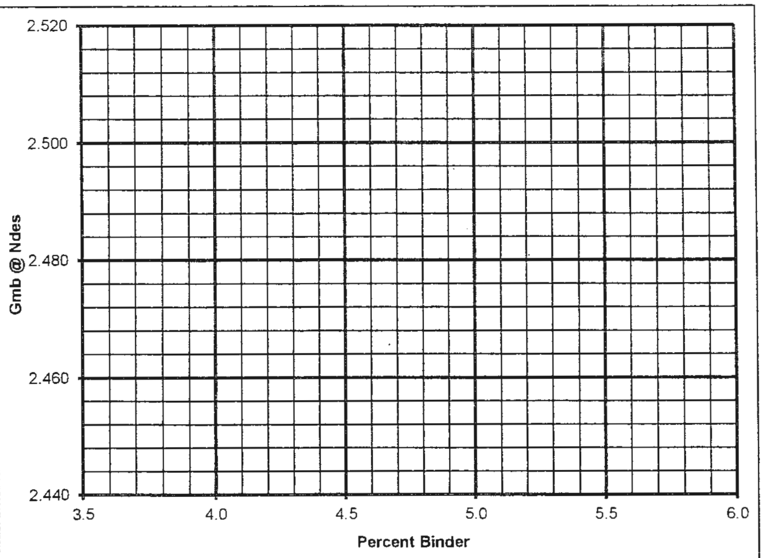
SUBMITTED BY:

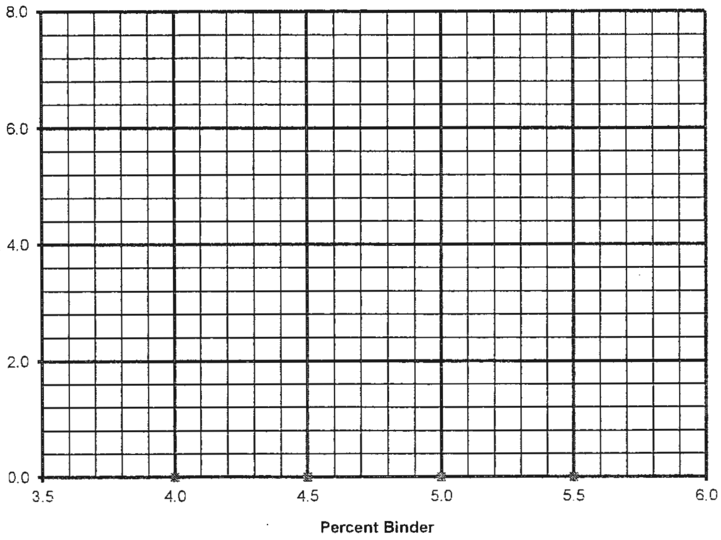
APPROVED BY:

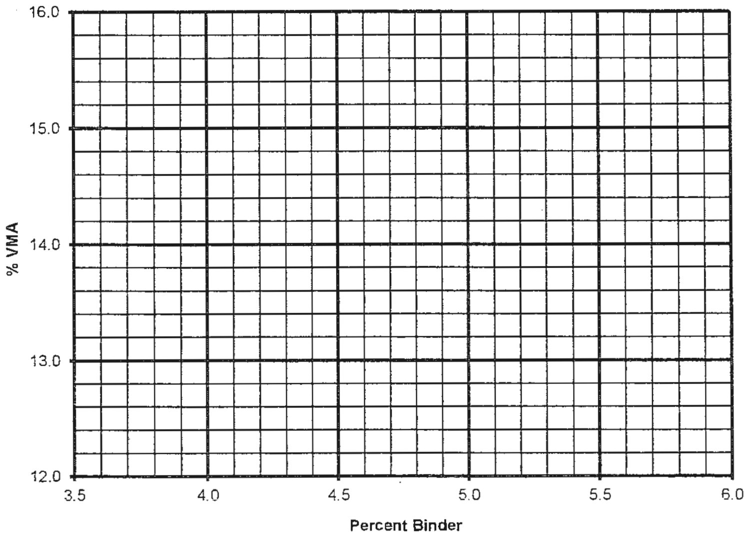
M & T 602 FORM, GRAPHICAL PLOT OF VOLUMETRIC PROPERTIES ON SUPERPAVE METHOD OF AN ASPHALT MIX DESIGN

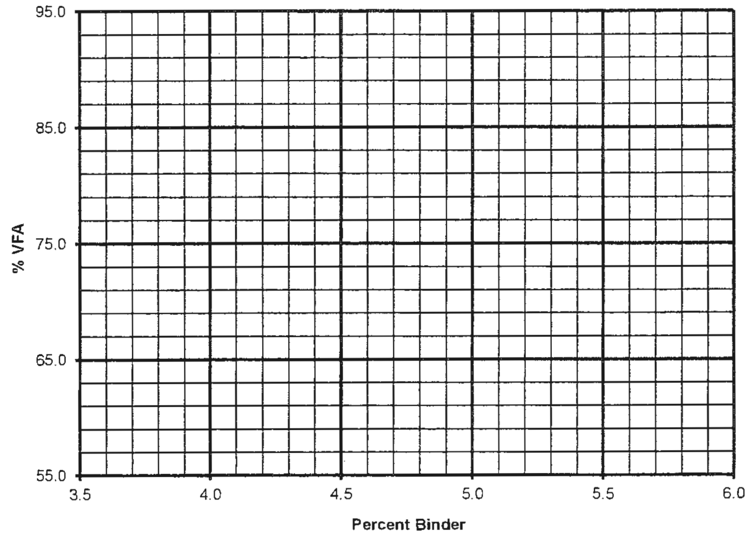
.NT & CERT. NO.: ____________ SPECIFICATION: ____________ MD #: ____________

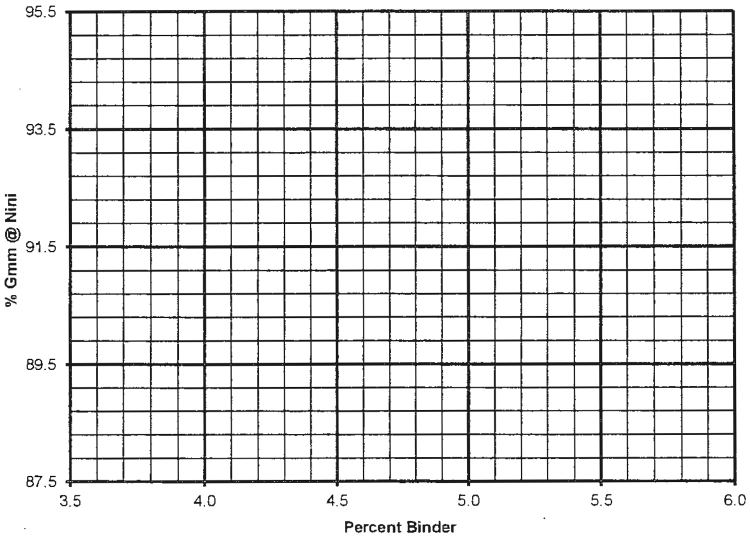












Property	Optimum Pb	Gmm @ Opt. Pb	Gmb @ Ndes	% VTM	% VMA	% VFA	% Gmm @ Nini
Spec.	----	----	----				

M & T 603 FORM, REPORT OF VOLUMETRIC PROPERTIES ON SUPERPAVE METHOD OF AN ASPHALT MIX DESIGN

NT & CERT. NO.: ____________________ SPECIFICATION: ____________________ MD #: __________

P_b =	4.0			G_{mm} (calculated) =				G_{mb} @ N_{design} =				VTM @ N_{design} =	
	Specimen 1				Specimen 2				Specimen 3				
	G_{mb} (measured) =				G_{mb} (measured) =				G_{mb} (measured) =				Average
	Sample Weight (g) =				Sample Weight (g) =				Sample Weight (g) =				% G_{mm}
No. of Gyrations	Height (mm)	G_{mb} (est)	G_{mb} (corr)	% G_{mm} (corr)	Height (mm)	G_{mb} (est)	G_{mb} (corr)	% G_{mm} (corr)	Height (mm)	G_{mb} (est)	G_{mb} (corr)	% G_{mm} (corr)	corrected

P_b =	4.5			G_{mm} (calculated) =				G_{mb} @ N_{design} =				VTM @ N_{design} =	
	Specimen 1				Specimen 2				Specimen 3				
	G_{mb} (measured) =				G_{mb} (measured) =				G_{mb} (measured) =				Average
	Sample Weight (g) =				Sample Weight (g) =				Sample Weight (g) =				% G_{mm}
No. of Gyrations	Height (mm)	G_{mb} (est)	G_{mb} (corr)	% G_{mm} (corr)	Height (mm)	G_{mb} (est)	G_{mb} (corr)	% G_{mm} (corr)	Height (mm)	G_{mb} (est)	G_{mb} (corr)	% G_{mm} (corr)	corrected

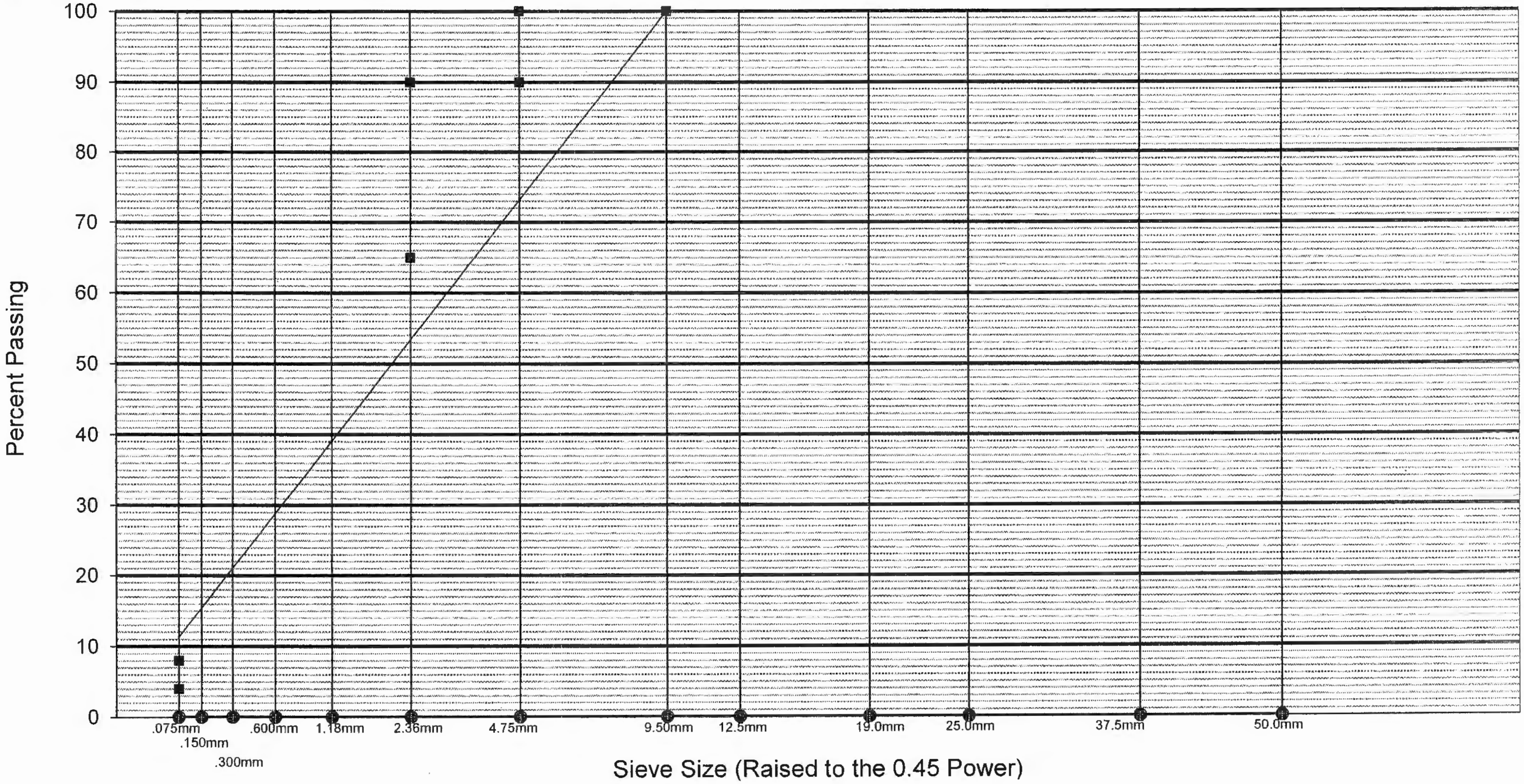
P_b =	5.0			G_{mm} (calculated) =				G_{mb} @ N_{design} =				VTM @ N_{design} =	
	Specimen 1				Specimen 2				Specimen 3				
	G_{mb} (measured) =				G_{mb} (measured) =				G_{mb} (measured) =				Average
	Sample Weight (g) =				Sample Weight (g) =				Sample Weight (g) =				% G_{mm}
No. of Gyrations	Height (mm)	G_{mb} (est)	G_{mb} (corr)	% G_{mm} (corr)	Height (mm)	G_{mb} (est)	G_{mb} (corr)	% G_{mm} (corr)	Height (mm)	G_{mb} (est)	G_{mb} (corr)	% G_{mm} (corr)	corrected

P_b =	5.5			G_{mm} (calculated) =				G_{mb} @ N_{design} =				VTM @ N_{design} =	
	Specimen 1				Specimen 2				Specimen 3				
	G_{mb} (measured) =				G_{mb} (measured) =				G_{mb} (measured) =				Average
	Sample Weight (g) =				Sample Weight (g) =				Sample Weight (g) =				% G_{mm}
of Gyrations	Height (mm)	G_{mb} (est)	G_{mb} (corr)	% G_{mm} (corr)	Height (mm)	G_{mb} (est)	G_{mb} (corr)	% G_{mm} (corr)	Height (mm)	G_{mb} (est)	G_{mb} (corr)	% G_{mm} (corr)	corrected

Opt. P_b =				G_{mm} (calculated) =				G_{mb} @ N_{design} =				VTM @ N_{design} =	
	Specimen 1				Specimen 2				Specimen 3				
	G_{mb} (measured) =				G_{mb} (measured) =				G_{mb} (measured) =				Average
	Sample Weight (g) =				Sample Weight (g) =				Sample Weight (g) =				% G_{mm}
No. of Gyrations	Height (mm)	G_{mb} (est)	G_{mb} (corr)	% G_{mm} (corr)	Height (mm)	G_{mb} (est)	G_{mb} (corr)	% G_{mm} (corr)	Height (mm)	G_{mb} (est)	G_{mb} (corr)	% G_{mm} (corr)	corrected

FHWA 0.45 POWER CHART, GRAPHICAL PLOT OF BLENDED GRADATION VALUES

PLANT & CERT. NO.: ______________ **SPECIFICATION:** ______________ **MD #:** ________



Sieve Size (Raised to the 0.45 Power)

SEIVES	**0.075 mm**	0.150 mm	0.300 mm	0.600 mm	1.18 mm	**2.36 mm**	4.75 mm	9.50 mm	12.5 mm	19.0 mm	25.0 mm	37.5 mm	50.0 mm
BLEND													

M & T 601A FORM, WORKSHEET FOR Gmm AND Gmb ON SUPERPAVE METHOD OF AN ASPHALT MIX DESIGN

PLANT & CERT. NO.: ______________________

SPECIFICATION: ______________________

MD #: __________

GYRATORY SPECIMEN DATA (Gmb) (CONVENTIONAL)							
Pb	SAMPLE #	DRY WT.	SSD WT.	WET WT.	Gmb	HT. @ Nini	HT. @ Ndes
-0.5 Pb INCREMENT				**AVGS.**			
Pb	SAMPLE #	DRY WT.	SSD WT.	WET WT.	Gmb	HT. @ Nini	HT. @ Ndes
MIDDLE Pb INCREMENT				**AVGS.**			
Pb	SAMPLE #	DRY WT.	SSD WT.	WET WT.	Gmb	HT. @ Nini	HT. @ Ndes
+0.5 Pb INCREMENT				**AVGS.**			
Pb	SAMPLE #	DRY WT.	SSD WT.	WET WT.	Gmb	HT. @ Nini	HT. @ Ndes
+1.0 Pb INCREMENT				**AVGS.**			
Pb	SAMPLE #	DRY WT.	SSD WT.	WET WT.	Gmb	HT. @ Nini	HT. @ Ndes
OPTIMUM Pb INCREMENT				**AVGS.**			

RICE DATA (Gmm) (CORELOK)		
	RICE #1	RICE #2
BAG WT(S).		
RUBBER SHEET WT(S).		
BAG(S), SHEET(S) & MIX WT.		
MIX WT.		
BAG(S), SHEET(S) & MIX WT. IN H20		
TOTAL VOLUME		
BAG & SHEET VOLUME		
MIX VOLUME		
RICE GRAVITY (Gmm)		
AVERAGE RICE GRAVITY (Gmm)		▨

M & T 601A FORM, WORKSHEET FOR Gmm AND Gmb ON SUPERPAVE METHOD OF AN ASPHALT MIX DESIGN

PLANT & CERT. NO.: ____________________ **SPECIFICATION:** ____________________ **MD #:** __________

GYRATORY SPECIMEN DATA (Gmb) (CORELOK)

Pb	SAMPLE #	BAG WT.	DRY WT.	SEALED IN H20 WT.	WT. AFTER SUBMRSN	Gmb	Ht. @ Nini	Ht. @ Ndes
-0.5 Pb INCREMENT					**AVGS.**			
Pb	SAMPLE #	BAG WT.	DRY WT.	SEALED IN H20 WT.	WT. AFTER SUBMRSN	Gmb	Ht. @ Nini	Ht. @ Ndes
MIDDLE Pb INCREMENT					**AVGS.**			
Pb	SAMPLE #	BAG WT.	DRY WT.	SEALED IN H20 WT.	WT. AFTER SUBMRSN	Gmb	Ht. @ Nini	Ht. @ Ndes
+0.5 Pb INCREMENT					**AVGS.**			
Pb	SAMPLE #	BAG WT.	DRY WT.	SEALED IN H20 WT.	WT. AFTER SUBMRSN	Gmb	Ht. @ Nini	Ht. @ Ndes
+1.0 Pb INCREMENT					**AVGS.**			
Pb	SAMPLE #	BAG WT.	DRY WT.	SEALED IN H20 WT.	WT. AFTER SUBMRSN	Gmb	Ht. @ Nini	Ht. @ Ndes
OPTIMUM Pb INCREMENT					**AVGS.**			

RICE DATA (Gmm) (CORELOK)

	RICE #1	RICE #2
BAG WT(S).		
RUBBER SHEET WT(S).		
BAG(S), SHEET(S) & MIX WT.		
MIX WT.		
BAG(S), SHEET(S) & MIX WT. IN H20		
TOTAL VOLUME		
BAG & SHEET VOLUME		
MIX VOLUME		
RICE GRAVITY (Gmm)		
AVERAGE RICE GRAVITY (Gmm)		

M&T 612 (SP)

REVISED 08 / 01 / 12

M & T 612 FORM, WORKSHEET FOR TENSILE STRENGTH RATIO

NTRACTOR:	PLANT LOCATION:	PLANT CERT. NO.:
TYPE:	MIX DESIGN NO.:	NO. OF GYRATIONS:
ANTI-STIP SUPPLIER:	ANTI-STIP TYPE:	% ANTI-STRIP DOSAGE:
DATE MIX PRODUCED:	DATE MIX COMPACTED:	DATE COMPLETED:

SPECIMEN NUMBER			1	2	3	4	5	6	7	8
DIAMETER (mm)		(a)								
HEIGHT (mm)		(b)								
DRY WEIGHT IN AIR (g.)		(c)								
SSD WEIGHT IN AIR (g.)		(d)								
WEIGHT IN WATER (g.)		(e)								
VOLUME	*(d - e)*	(f)								
GMB	*(c / f)*	(g)								
GMM (Rice)		(h)								
% VTM	*(100 * (h - g) / h)*	(i)								
AIR VOIDS' VOLUME	*(i * f) / 100*	(j)								
CALC. SSD AT 70% SAT.	*(0.70 * j) + c*									
CALC. SSD AT 80% SAT.	*(0.80 * j) + c*									

BEFORE BEING CONDITIONED 24 HOURS IN 140 °F WATER BATH

SSD WEIGHT IN AIR (g.)		(k)								
WEIGHT IN WATER (g.)		(l)								
VOLUME	*(k - l)*	(m)								
VOL. ABS. H2O	*(k - c)*	(n)								
% SATURATION	*100 * (n / j)*									
TURATED						MINUTES @		"Hg		
E AND TIME INTO 140 °F WATER BATH										
E AND TIME OUT OF 140 °F WATER BATH										

AFTER BEING CONDITIONED 24 HOURS IN A 140 °F WATER BATH AND 2 HOURS IN A 77 °F WATER BATH

DATE AND TIME OUT OF 77 °F WATER BATH										
SSD WEIGHT IN AIR (g.)		(o)								
WEIGHT IN WATER (g.)		(p)								
VOLUME	*(o - p)*	(q)								
VOLUME ABS. H2O	*(o - c)*	(r)								
% SATURATION	*100 * (r / j)*									
INTERNAL SPECIMEN TEMPERATURE (°F)										

PEAK LOAD (Newton's)		(s)								
DRY TS(kPa)	*(2000 * s) / (a * b * 3.1416)*									
WET TS(kPa)	*(2000 * s) / (a * b * 3.1416)*									

SUBSET				DRY	WET
AVERAGE % VTM					
AVERAGE SATURATION				▨	
AVERAGE TEMPERATURE					
MEDIAN TENSILE STRENGTH					
TENSILE STRENGTH RATIO					▨
QA/QC COMPARATIVE TSR					
VISUAL STRIPPING: X APPROPRIATE BOX BELOW				QA/QC JOINT TEST?	
				Circle One	
None	Minor	Moderate	Severe	Yes	No

TECHNICIAN:

HiCAMS NO.:

TECHNICIAN:

HiCAMS NO.:

LAB LOCATION:

LAB CERT. NO.:

COMMENTS:

e: Attach proposed M&T 601 form when
specimens are being submitted to QA.

M & T 613 FORM, WORKSHEET FOR APA RUT SPECIMENS

PLANT & CERT. NO.: ______________________ **SPECIFICATION:** ______________________ **MD #:** __________

APA RUT GYRATORY SPECIMEN AND VOLUMETRIC DATA							
SAMPLE #	HEIGHT	DRY WT.	SSD WT.	WET WT.	Gmb	Gmm @ OPT. % AC	VTM
1							
2							
3							
4							
5							
6							
AVGS.							

M & T 620 FORM, WORKSHEET FOR CONSENSUS PROPERTIES

NTRACTOR:	PLANT LOCATION:	PLANT CERT. NO.:
TYPE:	MIX DESIGN NO.:	TEST DATE:

FINE AGGREGATE ANGULARITY (UNCOMPACTED VOID CONTENT) (AASHTO T 304 METHOD A) (-2.36 mm)

MATERIAL SOURCE:	SOURCE LOCATION:	MATERIAL TYPE:

SAMPLE #	SAMPLE + CUP WT. (g) (A)	CUP WT. (g) (B)	SAMPLE WT. (g) (C=A-B)	CUP VOL. (mL) (D)	Gsb (E)	(F=C/E)	% VOIDS ((D-F)/ D*100)
1							
2							
3							
						AVERAGE	

SAMPLE PREPERATION:

SEIVE	**INDIVIDUAL WTS.**	**CUMMULATIVE WTS.**
1.18 mm	44 GRAMS	44 GRAMS
.600 mm	57 GRAMS	101 GRAMS
.300 mm	72 GRAMS	173 GRAMS
.150 mm	17 GRAMS	190 GRAMS

SAND EQUIVALENT (AASHTO T 176) (-4.75 mm)

MATERIAL SOURCE:	SOURCE LOCATION:	MATERIAL TYPE:

SAMPLE #	CLAY READING (A)	SAND READING (B)	SAND EQUIV. (B/A)*100
1			
2			
3			
		AVERAGE	

FLAT AND ELONGATED PARTICLE TEST (ASTM D 4791 SECT. 8.4) (+4.75 mm)

MATERIAL SOURCE:	SOURCE LOCATION:	MATERIAL TYPE:

SEIVE	% PASSING (A)	% RETAINED (B)	RATIO (D=B/C)	TOTAL WT. (g) (E)	F & E WT. (g) (F)	% F & E (G=F/E*100)	(H=G*D)
50.0 mm							
37.5 mm							
25.0 mm							
19.0 mm							
12.5 mm							
9.50 mm							
4.75 mm							
TOTAL % RETAINED (C)						**TOTAL % FLAT & ELONGATED (I)**	

CALIPER RATIO (CIRCLE)	5:1	4:1	3:1	2:1

(A) = % PASSING FROM M & T 601 FORM
(B) = % PASSING OF SEIVE ABOVE - PASSING OF SEIVE*
*Ex: % RETAINED OF 4.75 mm SEIVE = % PASSING OF 9.5 mm SEIVE - % PASSING OF 4.75 mm SEIVE
(C) = SUMMATION OF COLUMN (B)
(D) = RATIO OF % RETAINED (B) / TOTAL % RETAINED (C)
(E) = NUMBERS ARE OBTAINED BY WEIGHING APPROXIMATELY 100 PIECES OF AGGREGATE
= NUMBERS ARE OBTAINED BY WEIGHING PIECES OF AGGREGATE THAT FAIL F & E CALIPER
= F & E WT. (F) / TOTAL WT. (E)**
R A SEIVE THAT RETAINS LESS THAN 10% USE (G) VALUE FROM SEIVE ABOVE OR BELOW
(H) = % F & E (G) * RATIO (D)
(I) = SUMMATION OF COLUMN (H)

2020

ASPHALT QUALITY MANAGEMENT SYSTEM

North Carolina Department of Transportation
Materials and Tests Unit
Asphalt QMS Manual

SECTION 4

ASPHALT MIX DESIGN AND JOB MIX FORMULAS

4.1 INTRODUCTION TO MIX DESIGN

As stated in Section 2, an asphalt mixture is composed of three basic components: 1) asphalt binder, 2) aggregates and 3) air voids. Mineral filler, additives, and other modifiers are used when needed or required. The asphalt material, which can be asphalt binder, modified asphalt binder, emulsified liquid asphalt or some other form of asphaltic material, acts as a binding agent to glue the aggregate particles into a cohesive mass. Asphalt Concrete is a paving material that consist primarily of asphalt binder and mineral aggregate and is mixed in an asphalt mix plant or by some other procedure. When bound by the asphalt binder, the mineral aggregate acts as a stone framework to impart strength and toughness to the system. Because it is relatively impervious to water, the asphalt binder also functions to waterproof the mixture. Because asphalt mix contains both asphalt binder and mineral aggregate, the volumetric properties and subsequently the behavior of the mixture is affected by the properties of the individual components and how they react with each other in the system. In order to determine if the behavior and performance of the mixture under traffic will be satisfactory, a mix design must be performed to determine the proper combination of the individual materials prior to beginning mix production.

4.2 PURPOSES OF MIX DESIGNS

While there are many types of asphalt mixtures used in highway construction, there are three basic types: surface mixes, intermediate mixes and base mixes. As noted above, there are certain properties and performance characteristics that are desirable in an asphalt mix. The relative proportions of aggregate, asphalt binder, and air voids significantly affect the physical properties of the mix and ultimately, how it will perform as a finished pavement. While it would be very easy to "mix some asphalt with some rock", this very likely would result in a poor-quality mix. Designing asphalt mixes, as with other engineering materials designs, is largely a matter of selecting and proportioning materials to obtain the desired qualities and properties in the finished construction. The overall objective is to determine an economical blend and gradation of aggregates (within the specification limits) and a corresponding asphalt content that yields a mix having:

(a) Sufficient asphalt to ensure a durable pavement by thoroughly coating the aggregate particles and waterproofing and bonding them together under suitable compaction.
(b) Sufficient mix resistance to permanent deformation to satisfy the service requirement and demands of traffic without distortion or displacement.
(c) Sufficient voids in the total compacted mix to provide for a slight additional amount of compaction under traffic loading without bleeding and rutting, yet be low enough to keep out excessive air and moisture.
(d) Sufficient workability to permit efficient placement and proper compaction operations without segregation.

4.3 PERFORMANCE CHARACTERISTICS CONSIDERED IN MIX DESIGN

Asphalt pavements function properly when they are designed, produced and placed in such a manner as to give them certain desirable performance characteristics. These characteristics contribute to the quality of asphalt pavements. These include permanent deformation (rutting) resistance, durability, flexibility, fatigue resistance, skid resistance, impermeability, workability and economics.

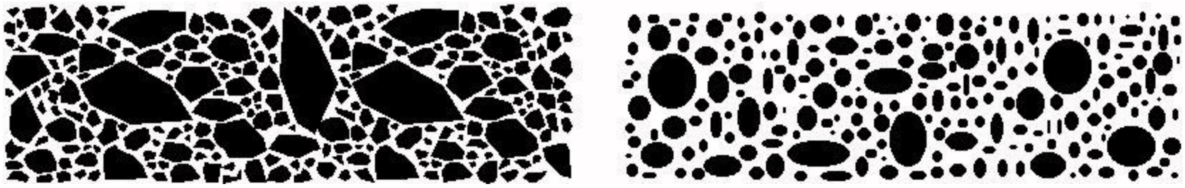
Ensuring that a paving mixture has each of these properties is a major goal of the mix-design procedure. Therefore, the technician should be aware of what each of the properties is, how it is evaluated, and what it means in terms of pavement performance. These properties are discussed below.

4.3.1 Permanent Deformation (Rut Resistance)

The ability of an asphalt mix to resist permanent deformation from imposed loads. Unstable mixes are marked by channeling (ruts), corrugations (washboarding), pushing and shoving in the pavement. Rut resistance is dependent upon both internal friction of aggregate and cohesion within the mix.

Internal friction is dependent on particle shape, surface texture, gradation of aggregate, density of mix, binder grade and quantity of asphalt. Rut resistance results from a combination of the frictional forces within the aggregate structure and the interlocking resistance of the aggregate in the mix. Frictional resistance increases with the surface roughness of the aggregate particles and with the area of particle contact. Interlocking resistance is dependent upon particle size and shape.

Figure 4-1
Contrasting Aggregate Structures



Cubical Aggregate **Rounded Aggregate**

The figure above demonstrates that with more angular (cubical) particle shape and more contact between particles greater resistance to rutting and permanent deformation is achieved. For any given aggregate, the rut resistance increases with the density of the confined particles, which is achieved by dense gradations and adequate compaction. Excessive asphalt in the mix tends to lubricate the aggregate particles and lower the internal friction of the stone framework.

Cohesion is that binding force that is inherent in the asphalt mixes. The asphalt serves to maintain contact pressures developed between aggregate particles. Cohesion varies directly with the rate of loading, loaded area, and viscosity of the asphalt. It varies inversely with the temperature. Cohesion increases with increasing asphalt content up to a maximum point and then decreases.

4.3.2 Durability

Durability is how well an asphalt mix resists disintegration by weathering and traffic. Included under weathering are changes in the characteristics of asphalt such as oxidation, volatilization and changes in the pavement and aggregate due to the action of water, including stripping, freezing and thawing. Durability is generally enhanced by high asphalt contents, dense aggregate gradations, and well-compacted, impervious mixes. One argument for an increased amount of asphalt is the resultant thicker asphalt film coating around the aggregate particles. Thicker films are more resistant to age-hardening. Another reason for an increased amount of asphalt is to reduce the pore size of the interconnected voids or to seal them off in the mix, making it more difficult for air and water to enter the interior of the mix and cause damage. To resist the action of water, the same requirements (dense-graded aggregates, high asphalt contents, and adequate compaction) apply. It is desirable to use aggregates that retain an asphalt coating in the presence of water.

Sufficient asphalt must be incorporated in the mix to provide bonding properties adequate to resist the abrasive forces of traffic. Insufficient asphalt may result in aggregate being dislodged from the surface. This is known as raveling. Abrasion may also take place if the asphalt has become brittle. Overheating of asphalt in the mixing process is a cause of brittleness, which leads to pavement disintegration. A mix having a high asphalt content with voids completely filled with asphalt would provide the ultimate in durability. However, this would be undesirable from the standpoint of rut resistance. When placed in the roadway, the mix would rut and displace under traffic. Bleeding or flushing of asphalt to the surface would also take place, thereby reducing skid resistance. Maximum rut resistance is not reached in an aggregate mass until the amount of asphalt coating the particles has reached some critical value. Additional asphalt then tends to act as a lubricant rather than a binder, reducing rut resistance of the mix, even though durability may be increased. It is necessary to compromise by keeping the asphalt content as high as possible while maintaining adequate rut resistance.

4.3.3 Flexibility

This is the ability of an asphalt mix to conform to gradual settlements and movements of the base and subgrade. Differential settlements in the fill embankment occasionally occur. Thus, it is impossible to develop uniform density in the subgrade during construction because sections or portions of the pavement tend to compress and settle under traffic. Therefore, the asphalt pavement must have the ability to conform to localized and differential settlement without cracking. Generally, flexibility of the asphalt mix is enhanced by high asphalt content and relatively open-graded aggregates.

4.3.4 Fatigue (Cracking) Resistance

The ability of asphalt pavement to withstand repeated flexing of the pavement structure caused by the passage of wheel loads. Tests have shown that the quantity of asphalt is extremely important when considering the fatigue resistance of a pavement. As a rule, the higher the asphalt content, the greater the fatigue resistance. Tests indicate that low air-void content asphalt mixes have more fatigue resistance than higher air-void content mixes. Well-graded aggregates that permit higher asphalt content without causing flushing or bleeding in compacted pavement should be incorporated in the mix.

4.3.5 Skid Resistance

The ability of an asphalt surface, particularly when wet, to provide resistance to slipping or skidding of vehicles. The factors for obtaining high skid resistance are generally the same as those for obtaining high stability. Proper asphalt contents and aggregates with a rough surface texture are the greatest contributors. However, not only must the aggregate have a rough surface texture, it must also resist polishing. Aggregates containing non-polishing minerals with different wear or abrasion characteristics provide continuous renewal of the pavement's texture, maintaining a skid-resistant surface. Examples of non-polishing aggregates are granites, crushed gravel, silica sands and slag. An example of a polishing type aggregate is limestone. Mixes so rich in asphalt as to fill the voids in the compacted pavement will probably cause asphalt to flush to the surface, which is called bleeding. Asphalt on pavement surface can cause slippery conditions.

4.3.6 Impermeability

The ability an asphalt pavement to provide resistance to the passage of air and water into or through the pavement. While the void content may be an indication of the susceptibility of a compacted mix to the passage of air and water; of more significance is the interconnection of voids and their access to the surface. Imperviousness to air and water is extremely important from the standpoint of lasting durability.

4.3.7 Low Temperature / Shrinkage Cracking

The ability of an asphalt pavement to resist low temperature/shrinkage cracking. Low temperature/shrinkage cracking is caused by adverse environmental conditions rather than applied traffic loads. It is characterized by surprisingly consistently spaced transverse cracks (perpendicular to the direction of traffic). It is caused by a build-up of tensile stresses as the pavement shrinks due to extremely cold weather or due to shrinkage caused by oxidation (aging) of the pavement. Hard asphalt binders or binders which have hardened (oxidized) due to high void content in the as constructed mix are more prone to low temperature cracking.

4.3.8 Workability

The ease with which an asphalt mix may be placed and compacted. With careful attention to proper design and with the use of machine spreading, workability is not a problem. At times, the properties of the aggregates that promote high rut resistance make asphalt mixes containing these aggregates difficult to spread or compact and may promote segregation. Since workability problems are discovered most frequently during the paving operation, mix design adjustments should be made quickly to allow the job to proceed as efficiently as possible.

4.3.9 Economics

The cost of the in-place pavement must be considered. Mix components, production and placement costs, haul distances, safety considerations, quality, expected pavement performance and other factors need to be evaluated when selecting the final mix design.

4.4 THE MIX DESIGN PROCESS

The mix design process is based on volumetric proportioning of the asphalt and aggregate materials and laboratory compaction of trial mixes using the Gyratory Compactor. The basic mixture design procedures consist of an evaluation of the following characteristics once the type and amount of traffic and the environmental conditions under which the pavement will be expected to perform have been determined:

4.4.1 Aggregate Properties and Gradation Requirements

Aggregate physical properties for asphalt mixes are specified on the basis of both “consensus” (blend) properties and “source” (individual) properties. These criteria are discussed in more detail in Section 2. To specify gradation, the 0.45-power gradation chart is used with control points on various sieves to define a permissible gradation of the designated mix type. Control points function as master ranges through which gradations must pass. Control points are placed at the nominal maximum size sieve, an intermediate size sieve (2.36 mm), and the smallest sieve (0.075 mm). The control points vary, depending on the nominal maximum size of the mix. This chart uses a unique graphing technique to judge the cumulative particle size distribution of an aggregates blend. The vertical axis of the chart is the percent passing. The horizontal axis is an arithmetic scale of sieve sizes in millimeters, raised to the 0.45 power.

An important feature of the 0.45-power chart is the maximum density gradation. This gradation plots as a straight line from the maximum aggregate size through the origin and uses the following definitions with respect to aggregate size:

Maximum Size:	One sieve size larger than the nominal maximum size.
Nominal Maximum Size:	One sieve size larger than the first sieve to retain more than 10%

(Mix types are defined in terms of their nominal maximum aggregate size;
for example, an I 19.0C mix has a nominal maximum aggregate size of 19.0 mm.)

The maximum density gradation represents a gradation in which the aggregate particles fit together in their most dense possible arrangement. In general, this is a gradation to avoid because there will most likely be inadequate void space within the aggregate structure to allow adding adequate asphalt binder in order to develop sufficiently thick asphalt films for a durable mixture and still maintain the desired air void content. The design gradation should lie between the control points and meet the aggregate gradation requirements detailed in Table 610-2.

4.4.2 Asphalt Binder Grade Selection and Requirements

The binder grade selection process utilizes procedures that directly relate laboratory analysis with laboratory performance. In general, mix design guidelines specify that the binder grade to be used in a mix be initially selected based on the climate (average high and average low temperatures), in which the pavement will be performing. The designation, called **P**erformance **G**rading (**PG**) contains two temperatures: the average 7 day high pavement temperature and the average 7 day low temperature. The high temperature is important because rutting failure occurs when the pavement is hot and becomes soft. The low temperature number indicates the low temperature cracking properties of the binder. The lower the second number, the greater the ability the binder has to resist cracking due to shrinkage caused by freeze/thaw cycles. See Table 610-3 for the PG grade required for the various mix types specified by NCDOT.

PG 64-22 is the "standard" grade for North Carolina based on climatic conditions.

4.4.3 Mixture Volumetric Properties and Requirements

A major factor that must be taken into account when considering asphalt mixture behavior is the volumetric properties of the mixture. Mixture volumetric requirements consist of air voids (VTM), voids in the mineral aggregate (VMA), voids filled with asphalt (VFA) and effective asphalt content (P_{be}). These volumetric properties for NCDOT mixes are illustrated in Figure 4-2.

Air void content (VTM) is an extremely important property because it is used as the basis for selecting the asphalt binder content. The design air void content is usually 4.0%; however, the mix designer should always check the specifications.

Voids in the mineral aggregate (VMA) is defined as the sum of the volume of air voids and effective (i.e., unabsorbed) binder in a compacted sample. It represents the void space between the aggregate particles. Specified minimum values for VMA at the design air void content of 4.0% are a function of nominal maximum aggregate size. Table 610-3 shows mix VMA requirements.

Voids filled with asphalt (VFA) is defined as the percentage of the VMA containing asphalt binder. Consequently, VFA is the volume of effective asphalt binder expressed as a percentage of the VMA. The acceptable range of design VFA is a function of traffic level as shown in Table 610-3. Effective asphalt content (P_{be}) is defined as the total asphalt content of a paving mixture minus the portion of asphalt absorbed into the aggregate particles (see Fig. 4-3).

Obtaining the correct air void content is critical in both mix design and the in-service performance of a pavement. As discussed in Section 2, asphalt binder expands and contracts with variations in-temperature. In hot weather, air voids in the mix provide room for the expanding asphalt binder. If there are not enough voids within the mix to allow for the expansion, the asphalt binder expands to fill all existing voids, and then begins pushing the aggregate particles apart, reducing aggregate interlock and contact friction. This causes the pavement to become unstable, more susceptible to pushing, shoving, and rutting. The binder eventually may bleed or flush to the surface. This significantly reduces the skid resistance of the pavement.

Imperviousness to air and water is extremely important for the mix to be and remain durable. If the air void content is too high, the air voids may interconnect and allow water and air to penetrate into the mix. Water penetration may cause the asphalt binder to strip from the aggregate. Exposing asphalt binder to both water and air will cause it to oxidize more rapidly, causing it to become hard and brittle, and therefore resulting in early fatigue failure.

4.4.4 Dust to Effective Binder Ratio

Another mixture requirement is the dust to effective binder ratio. This is computed as the ratio of the percentage by weight of aggregate finer than the 0.075 mm sieve (by washing) to the effective asphalt content expressed as a percent by weight of total mix. Effective binder content is the total binder used in the mixture less the percentage of absorbed binder. Dust / Binder Ratio is used during the mixture design phase as a design criteria. See Table 610-3 for the required Dust / Binder Ratio for the various mix types specified by NCDOT.

4.4.5 Moisture Susceptibility

Moisture Susceptibility, also known as *stripping,* is the separation of the asphalt film from the aggregate through the action of water and may make an aggregate material unsuitable for use in asphalt paving mixes. Such material is referred to as hydrophilic (water loving). Siliceous aggregates such as quartzite and some granites are examples of aggregates that may require evaluation of stripping potential. Aggregates that exhibit a high degree of resistance to asphalt film stripping in the presence of water are usually most suitable in asphalt paving mixes. Such aggregates are referred to as hydrophobic (water hating) aggregates. Limestone, dolomite, and traprock are usually highly resistant to asphalt film stripping. Why hydrophobic or hydrophilic aggregates behave as they do is not completely understood. The explanation is not as important as the ability to detect the properties and avoid use of aggregates conductive to asphalt stripping.

The moisture susceptibility test used to evaluate asphalt mix for stripping is NCDOT-T-283. This test serves two purposes. First, it identifies whether a combination of asphalt binder and aggregate is moisture susceptible. Second, it measures the effectiveness of anti-stripping additives.

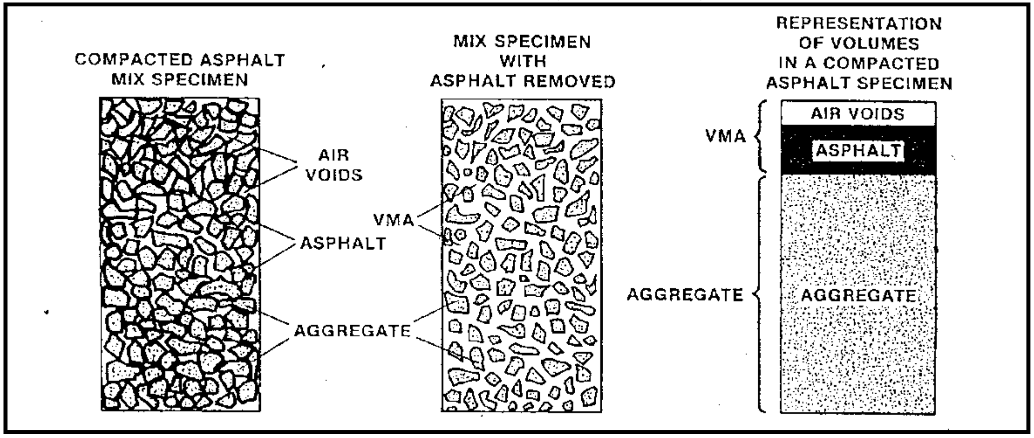
4.4.6 Permanent Deformation (Rut Resistance)

One of the major objectives of mix design is to provide pavements which would be highly resistant to permanent deformation (rut resistance). As stated earlier, rut resistance is the ability of an asphalt mix to resist permanent deformation from imposed loads. This is especially important for surface mixes since this is where the wheel loads are concentrated and the potential for rutting is greatest. The aggregate and binder specifications are established such that a rut resistant mix should be obtained; however, once a mix has been designed based on the specified criteria, the mix should be physically tested to evaluate the anticipated performance under traffic. To accomplish this objective the Department will perform rut resistance evaluation on surface mix specimens prepared by the Contractor as a part of the mix design process.

In addition to the required mix design submittal forms, the Contractor will prepare and deliver six (6) Gyratory Compactor specimens to the Department's Central Asphalt Laboratory for the following surface mix types: S4.75A, S9.5B, S9.5C, and S9.5D. The Contractor will prepare these specimens using lab produced mix in accordance with NCDOT-T-312. These specimens shall be compacted to a height of 75 ± 2 mm and to a void content (VTM) of 4.0% ± 0.5% **(except, S4.75A rut specimens should be compacted to a VTM of 5.0% ± 0.5%)**. These specimens will be tested for rutting susceptibility using the Asphalt Pavement Analyzer in the Materials and Tests Central facility. The maximum rut depth allowed for the various surface mixes is specified in Table 610-3.

MIXTURE VOLUMETRIC PROPERTIES AND RELATIONSHIPS

Figure 4-2
Illustration of VMA in a Compacted Mix Specimen



(Note: For simplification the volume of absorbed asphalt is not shown.)

4.5 NCDOT MIX DESIGN PROCEDURES

The Contractor is required to design the asphalt mix and to obtain an approved Job Mix Formula (JMF) issued by the Department. A mix design and proposed JMF targets for each required mix type and combination of aggregates must be submitted both in writing and in electronic format to the NCDOT Asphalt Mix Design Engineer for review and approval at least 10 days (at least 20 days for OGFC and UWBC mixes) prior to start of asphalt mix production.

The mix design must be prepared in an approved mix design laboratory by a certified Mix Design Technician. The design laboratory must be approved by the Asphalt Mix Design Engineer prior to submission of the mix design. The mix design shall be prepared in accordance with AASHTO R 35, “Superpave Volumetric Design for Asphalt Mixtures” as modified by the Department, recommended procedures in the latest edition of the Asphalt Institute publication “MS-2: Asphalt Mix

Design Methods" and the latest edition of Department mix design computer programs, policies, procedures, and forms. The request for the AMD/JMF approval will be submitted to the Asphalt Mix Design Engineer on Form QMS-1 with attached design data, proposed JMF target values, and forms as noted. In addition, the Contractor is required to submit the design data in electronic form using the Department's mix design program.

Prepare all proposed mix design data in accordance with Department policies and procedures including but not limited to, the following information:

(1) Source and percentage of each aggregate component to be used in the design aggregate blend gradation, including RAP and RAS.
(2) Percentage of asphalt binder in RAP and RAS.
(3) Gradation of each aggregates component, including RAP and RAS.
(4) The following aggregate properties: current bulk specific gravity (G_{sb}), current apparent specific gravity (G_{sa}) and absorption of the individual aggregate components to be used when tested in accordance with AASHTO T84 and T85, except report the effective bulk specific gravity (G_{se}) of RAP and RAS aggregate as determined by NCDOT-T-209. Report coarse aggregate angularity, fine aggregate angularity, flat and elongated percentages, and sand equivalent for the total aggregate blend.
(5) Source(s), modification method, and percent of modifier by weight of asphalt binder, if modified.
(6) Supplier, source, grade, and equi-viscous mixing and compaction temperatures of the asphalt binder. Include a copy of the binder producer's Certificate of Analysis (COA) showing test data for rotational viscometer testing in accordance with ASTM D4402 corresponding to the following recommended viscosity ranges:

Range for mixing = 0.150 to 0.190 Pa-s
Range for compaction = 0.250 to 0.310 Pa-s

When PG 76-22 or other modified binders are used, base the temperatures on the documented supplier's recommendations.
(7) Brand name, manufacturer, shipping point, and percentage of anti-strip additive used in the mix design. Determine TSR data in accordance with NCDOT-T-283.
(8) Target value for percent passing each standard sieve for the design aggregate gradation. Data will show the percent passing for all standard sieves listed in Table 610-2 for the specified mix type. Show the percentages in units of one percent of aggregate passing, except for the 0.075 mm (No. 200) sieve, show in units to one-tenth of one percent. Base percentages on the dry weight of aggregate determined in accordance with NCDOT-T-11 and NCDOT-T-27.
(9) Volumetric properties of the compacted mixture calculated on the basis of the mixture's maximum specific gravity as determined by NCDOT-T-209. The mixture shall be aged in accordance with AASHTO R 30 and the bulk specific gravity of specimens determined by NCDOT-T-166 or NCDOT-T-331, for each asphalt content tested. Determine and report properties in accordance with the requirements of AASHTO R 35 except as modified herein, and Department Mix Design Policies and Procedures.
(10) Graphical plots of percent asphalt binder by total weight of mix (P_b) versus the following properties at the design number of gyrations, N_{des}, specified:

(a) SGC bulk gravity, G_{mb} @ N_{des}
(b) % G_{mm} @ N_{ini}
(c) Voids in total Mix (VTM)
(d) Voids Filled with Asphalt (VFA)
(e) Voids in Mineral Aggregate (VMA)
(f) % Compaction vs. Log of Gyrations

(11) Graphical plot of the design aggregate gradation (design blend) on FHWA 0.45 power chart showing the applicable control points, and maximum density line. Plot all standard sieves for the applicable mix type.
(12) Proposed target value of asphalt binder content by weight of total mix and specification design properties at that percentage.
(13) TSR test data in accordance with NCDOT-T-283.

When the mix design is submitted, include the original recording charts detailing the TSR results to the Asphalt Mix Design Engineer in accordance with Section 7.14. In addition, when requested by the Asphalt Mix Design Engineer, the Contractor must submit representative samples of each mix component, including RAP, RAS, mineral filler, asphalt binder, chemical anti-strip additive and hydrated lime to the Department's mix design laboratory.

In addition, the Contractor will prepare and deliver six (6) Gyratory Compactor specimens to the Department's Central Asphalt Laboratory for the following surface mix types: S4.75A, S9.5B, S9.5C, and S9.5D. These specimens are used for rut testing.

4.6 THE JOB MIX FORMULA

All asphalt plant mixes, either virgin or recycled, be proportioned and graded such that they meet the requirements of a job mix formula approved and issued by the Department. This job mix formula will be based on a mix design performed by the Contractor and approved by the Materials and Tests Asphalt Lab. Once the Asphalt Mix Design Engineer has evaluated and/or confirmed the data, the mix design will be approved if it meets specifications. The mix design and job mix formula target values must be within the design criteria for the particular type of asphalt mixture specified. The source and grades of material, blend proportions of each of the various aggregates used, specific gravity information, and other applicable data and notes will be given on the formula. Specific details on "Master" job mix formula procedures are discussed below.

Once the JMF has been approved and production is ready to begin, the component materials must be combined in such proportions that the completed mixture meets the specification requirements for the particular mix type specified. During production the materials are heated and blended together in an asphalt mix plant such that the mixture is uniformly mixed and coated with asphalt binder. The mixture is then transported to the roadway where it is spread, finished and compacted to the required grades, thickness and typical section required by the plans and contract.

The job mix formula (JMF) gradation target values will be established within the design criteria specified for the particular type of asphalt mixture to be produced. The JMF asphalt binder content will be established at the percentage which will produce voids in total mix (VTM) at the midpoint of the specification design range for VTM, unless otherwise approved. The formula for each mixture will establish the following: blend percentage of each aggregate fraction, the percentage of reclaimed aggregate, if applicable, a single percentage of combined aggregate passing each required sieve size, the total percentage (by weight of total mixture) and grade of asphalt binder required for that mix type as in Table 610-3 unless otherwise approved by the Engineer, the percentage and grade of asphalt binder actually to be added to the mixture (for recycled mixtures), the percentage of chemical anti-strip additive to be added to the asphalt binder or percentage of hydrated lime to be added to the aggregate, the temperature at which the mixture is to be discharged from the plant, the required field density, and other volumetric properties.

The mixing temperature during production at the asphalt plant will be established on the job mix formula. The mixing temperature is based on the grade of asphalt binder required for a specific mix type as in Table 610-3, unless otherwise approved by the Engineer. The mixing temperatures will be different depending on which grade of asphalt binder is being used.

At the end of this section are examples of the currently approved computer-generated mix design forms and supporting mix design data forms for the Contractor's use in preparing and submitting Mix Design/JMF request. The Contractor is required to use and therefore, must obtain from the Department, at no charge, the Mix Design computer spreadsheet program that will perform the calculations and generate the completed forms once the appropriate data has been entered. To obtain a copy of this spreadsheet, contact the Asphalt Mix Design Engineer at (919) 329-4060.

TABLE 610-2
AGGREGATE GRADATION CRITERIA
(Percent Passing Control Points)

Standard Sieves (mm)	**Mix Type (Nominal Max. Aggregate Size)**							
	4.75 mm		**9.5 mm**^{A}		**19.0 mm**		**25.0 mm**	
	Min	Max	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*
50.0	-	-	-	-	-	-	-	-
37.5	-	-	-	-	-	-	100	-
25.0	-	-	-	-	100	-	90.0	100
19.0	-	-	-	-	90.0	100	-	90.0
12.5	100.0	-	100	-	-	90.0	-	-
9.50	95.0	100.0	90.0	100	-	-	-	-
4.75	90.0	100.0	-	90.0	-	-	-	-
2.36	-	-	32.0^{B}	67.0^{B}	23.0	49.0	19.0	45.0
1.18	30.0	60.0	-	-	-	-	-	-
0.075	6.0	12.0	4.0	8.0	3.0	8.0	3.0	7.0

A. For the final surface layer of the specified mix type, use a mix design with an aggregate blend gradation above the maximum density line on the 2.36 mm and larger sieves.

B. For Type S9.5B, the percent passing the 2.36 mm sieve shall be a minimum of 60% and a maximum of 70%.

TABLE 610-3
MIX DESIGN CRITERIA

Mix Type	Design ESALs millions [A]	Binder PG Grade	Compaction Levels		Max. Rut Depth (mm)	Volumetric Properties [B]			
			G_{mm} @			VMA	VTM	VFA	%G_{mm}
			N_{ini}	N_{des}		% Min.	%	Min.-Max.	@ N_{ini}
S4.75A	< 1	64 - 22	6	50	11.5	16.0	4.0 - 6.0	65 - 80	≤ 91.5
S9.5B	0 - 3	64 - 22	6	50	9.5	16.0	3.0 - 5.0	70 - 80	≤ 91.5
S9.5C	3 - 30	64 - 22	7	65	6.5	15.5	3.0 - 5.0	65 - 78	≤ 90.5
S9.5D	> 30	76 - 22	8	100	4.5	15.5	3.0 - 5.0	65 - 78	≤ 90.0
I19.0C	ALL	64 - 22	7	65	-	13.5	3.0 - 5.0	65 - 78	≤ 90.5
B25.0C	ALL	64 - 22	7	65	-	12.5	3.0 - 5.0	65 - 78	≤ 90.5
	Design Parameter					Design Criteria			
All Mix Types	Dust to Binder Ratio ($P_{0.075}$ / P_{be})					0.6 - 1.4 [C]			
	Tensile Strength Ratio (TSR) [D]					85% minimum [E]			

A. Based on 20-year design traffic.

B. Volumetric Properties based on specimens compacted to N_{des} as modified by the Department.

C. Dust to Binder Ratio ($P_{0.075}$ / P_{be}) for Type S4.75A is 1.0 - 2.0.

D. NCDOT-T-283 (No Freeze-Thaw cycle required).

E. TSR for Type S4.75A & B25.0C mixes is 80% minimum.

TABLE 610-4
MAXIMUM RECYCLED BINDER REPLACEMENT PERCENTAGE (RBR%)

Recycled Material	Intermediate & Base Mixes	Surface Mixes	Mixes Using PG 76-22
RAS	23%	20%	18%
RAP or RAP/RAS Combination	45%	40%	18%

TABLE 610-5
BINDER GRADE REQUIREMENTS (BASED ON RBR%)

Mix Type	%RBR ≤ 20%	21% ≤ %RBR ≤ 30%	%RBR > 30%
S4.75A, S9.5B, S9.5C I19.0C, B25.0C	PG 64-22	PG 64-22 [A]	PG 58-28
S9.5D, OGFC	PG 76-22 [B]	n/a	n/a

A. If the mix contains any amount of RAS, the virgin binder shall be PG 58-28.

B. Maximum Recycled Binder Replacement (%RBR) is 18% for mixes using PG 76-22 binder.

4.7 NCDOT "MASTER" JOB MIX FORMULA PROCEDURES

Once a mix design for a specified mix type has been approved, and if the Asphalt Mix Design Engineer is in concurrence with the design and proposed target values, the JMF data will be entered into the NCDOT HiCAMS computer system. This "Master" JMF will be for a specific plant and will serve for all projects on which that given JMF for the specified mix type is to be used. The Contractor will then place one copy of this AMD/JMF assembly on file at the asphalt plant QC field laboratory for use by all QMS personnel. It is suggested that a bulletin board, preferably with a glass enclosure or a durable notebook with transparent plastic sheeting be used for this purpose. In situations where the JMF is to be used for DOT work and no lab is present, the JMF should be placed on file in the plant control room.

This is the JMF that both the Contractor QC and the DOT QA personnel will be using for producing and testing the mixture, respectively. This JMF will possibly be used for a significant period of time and must be kept in a safeguarded manner. This posted copy will be readily available to all QC/QA personnel and will also serve for all projects until voided or revisions are authorized by the Asphalt Mix Design Engineer or his representative.

When the Contractor is ready to begin producing mixture, he will advise the Pavement Specialist which JMF he intends to produce. Inasmuch as there will very likely be several valid JMF's for a given mix type at each plant using different material sources and combinations, the Contractor must use caution to ensure that the appropriate materials as required by the formula are being used. In addition, he must ensure that the latest version of the formula is being used and the correct JMF number is being recorded on weight tickets. The Department will compare its test results with this JMF for compliance with specifications.

As a JMF is revised in the field for whatever reasons, the Asphalt Mix Design Engineer will send to the Contractor an updated copy showing the revisions and the effective date. The Contractor must make certain that these updated copies are posted in the field lab as quickly as possible and that the voided copies are removed. (There may be situations where verbal approval is given by the Asphalt Laboratory prior to the actual posting of the JMF data). While it would be desirable to have the valid JMF posted at the plant at all times, it is realized that delays due to mailing will occur. Verbal approval can be given in these situations, but everyone must strive to keep this to a minimum. Master Job Mix Formulas for the standard mix types covered by the specifications will not be issued directly by the Asphalt Mix Design Engineer for a specific project unless some special circumstance exists.

Included in this Manual are examples of both virgin mix JMF's and recycled mix JMF's. Note that the owner's name, plant location, and plant certification number shown on the JMF are the same as shown on the plant certification certificate. JMF's will indicate a specific anti-strip additive supplier, brand, and rate and must be used unless otherwise approved by the Engineer.

4.8 COMPOSITION OF RECYCLED MIXTURES (JOB MIX FORMULA)

When the Contractor elects to use a recycled mixture on a project, he must submit to the Department's Materials and Tests Unit his proposed mix design and JMF target values in accordance with Article 610-3 of the Standard Specifications and this Manual. The reclaimed asphalt materials (RAP or RAS) shall be tested for the following properties: (1) asphalt content, (2) aggregate gradation, (3) aggregate effective specific gravity, and (4) performance grade (PG) of the RAP/RAS asphalt (shown in blending charts), when required.

The gradation of the reclaimed aggregates is analyzed to determine the gradation of the virgin aggregates required. Using the gradation of the aggregate from the RAP material and the new aggregates, the approved design lab will design a combined gradation meeting the specifications. The asphalt content of the RAP material is used to determine the amount of asphalt binder to be added in the recycled mixture. The performance grade parameters of the asphalt in the RAP/RAS material will determine the required grade of the additional asphalt binder in the recycled mixture. The new asphalt binder added to the recycled mix serves two purposes. It increases the total asphalt content to meet the requirements of the mix and it blends with the aged asphalt in the reclaimed portion of the mix to yield an asphalt meeting the desired specifications.

Reclaimed Asphalt Pavement (RAP) or Reclaimed Asphalt Shingles (RAS) may be incorporated into asphalt plant mixes in accordance with Article 1012-1 and the following applicable requirements. However, use of RAP materials is not allowed in Open Graded Friction Course (OGFC) mixes or Ultra-Thin Bonded Wearing Course (UBWC) mixes. Use of RAS materials is not allowed in Ultra-Thin Bonded Wearing Course (UBWC) mixes. RAS material may constitute up to 6% by weight of total mixture, except for Open Graded Friction Course (OGFC) mixes, which are limited to 5% RAS by weight of total mixture. Also, when the percentage of RAP is greater than 30% by weight of total mixture, use Fractionated RAP (FRAP) meeting the requirements of Subarticle 1012-1(F)(c).

When RAP, RAS, or a combination of both is used in asphalt mixtures, the recycled binder replacement percentage (RBR%) shall not exceed the amounts specified in Table 610-4 for the mix type. For recycled mixtures, the virgin binder Performance Grade (PG) grade to be used is specified in Table 610-5 for the mix type based on the recycled binder replacement percentage (RBR%).

If the Contractor wishes to submit mix designs containing recycled material amounts exceeding the specified maximums, additional testing will be required to verify the Performance Grade (PG) of the reclaimed binder. Also, the Contractor has the option to have additional testing performed to determine if the mix can be approved using a virgin binder grade different than specified in Table 610-5. The Engineer will determine if the binder grade is acceptable for use based on the test data submitted with the mix design. If the mix design is acceptable, the Engineer will establish and approve the grade and percentage of virgin asphalt binder to be used.

If a change in the source of RAP or RAS be made, a new mix design and JMF may be required in accordance with Article 1012-1. Samples of the completed recycled mixture may be taken by the Department on a random basis to determine the PG grading on the recovered asphalt binder in accordance with **AASHTO M 320/M 332.** If the grading is determined to be a value other than required for the specified mix type, the Engineer may require the Contractor to adjust any combination of the grade, the percentage of additional asphalt binder or the blend of reclaimed material 1 to bring the grade to the specified value.

Once the total asphalt demand has been determined, the amount of new asphalt binder to be added in the recycled mixture is then calculated. This quantity equals the calculated asphalt demand minus the percentage of asphalt in the reclaimed asphalt pavement. Trial mix designs are then made using the mix design procedures to determine the estimated design asphalt content. The same design criteria are used for recycled mixes as are used with virgin mixes of the same type.

The Job Mix Formula will establish the percentage of reclaimed aggregate, the percentage of each additional aggregate required, a single percentage of combined aggregate passing each sieve size, the total percentage of asphalt binder in the mixture, a single percentage of additional asphalt material to be added, the percentage of chemical anti-strip additive to be added to the additional asphalt material or percentage of hydrated lime to be added to the aggregate, a single temperature at which the mixture is to be discharged from the plant, the required field density, and other volumetric properties. In addition, the Job Mix Formula will establish the blend ratio and percent binder in the RAP. Should a change in the source of virgin aggregate be made, a new job mix formula will be required before the new mixture is produced. Should a change in the source or properties of the RAP be made, a new mix design and/or JMF may be required based on the requirements of Article 1012-1 of the Standard Specifications (see Section 8.3). Samples of the completed recycled asphalt mixture may be taken by the Department on a random basis to determine the performance grading on the recovered asphalt binder in accordance with AASHTO M 320/M 332. If the viscosity is determined to be out of this specified range, the Engineer may require the Contractor to adjust the additional asphalt material formulation and/or blend of reclaimed material to bring the viscosity within the allowable range.

4.9 PROJECT FILE JOB MIX FORMULA PROCEDURES

Job Mix Formulas (JMF) are maintained in the Highway Construction and Materials System (HiCAMS), including revised and voided JMF's. HiCAMS automatically pulls information from the JMF to calculate the quantity of asphalt binder to be paid based upon the quantity of plant mix material placed and JMF in effect at the time the work is performed. Since copies of those JMF can be obtained at any time, the Resident Engineer is not required to maintain paper copies of the JMF within the project Files.

When a given JMF is revised, the void date will be entered on the voided formula by the Asphalt Mix Design Engineer and this date will appear on all copies obtained through the computer after that date. The new or revised JMF will show the new number assigned and the effective date. This new JMF will be entered into the computer system and the cycle repeated as noted in the "Master" JMF procedures. Again, it is critical that the QC technician has the correct JMF number and shows same on his daily reports. If the JMF is revised, the technician at the plant will be advised of the new JMF number at that time and will note the revised number and date on the copy posted at the plant. This revised JMF will be used until the Contractor receives and posts the new JMF at the plant.

A listing of all Job Mix Formulas issued to a specific asphalt plant can be obtained from the Materials and Tests Asphalt Laboratory. It should be noted that this listing shows all Job Mix Formulas issued to a plant including any "voided" formulas. Therefore, everyone must be careful to assure that the Contractor is using the most current JMF and not a voided formula.

4.9.1 Mix Type Designations

	Virgin	***Recycled***
Asphalt Concrete Surface Course, Type SA-1	SA-1	RSA-1
Asphalt Concrete Surface Course, Type S 4.75 A	S 4.75A	RS 4.75A
Asphalt Concrete Surface Course, Type S 9.5 B	S 9.5B	RS 9.5B
Asphalt Concrete Surface Course, Type S 9.5 C	S 9.5C	RS 9.5C
Asphalt Concrete Surface Course, Type S 9.5 D	S 9.5D	RS 9.5D
Asphalt Concrete Intermediate Course, Type I 19.0 C	I 19.0C	RI 19.0C
Asphalt Concrete Base Course, Type B 25.0 C	B 25.0C	RB 25.0C

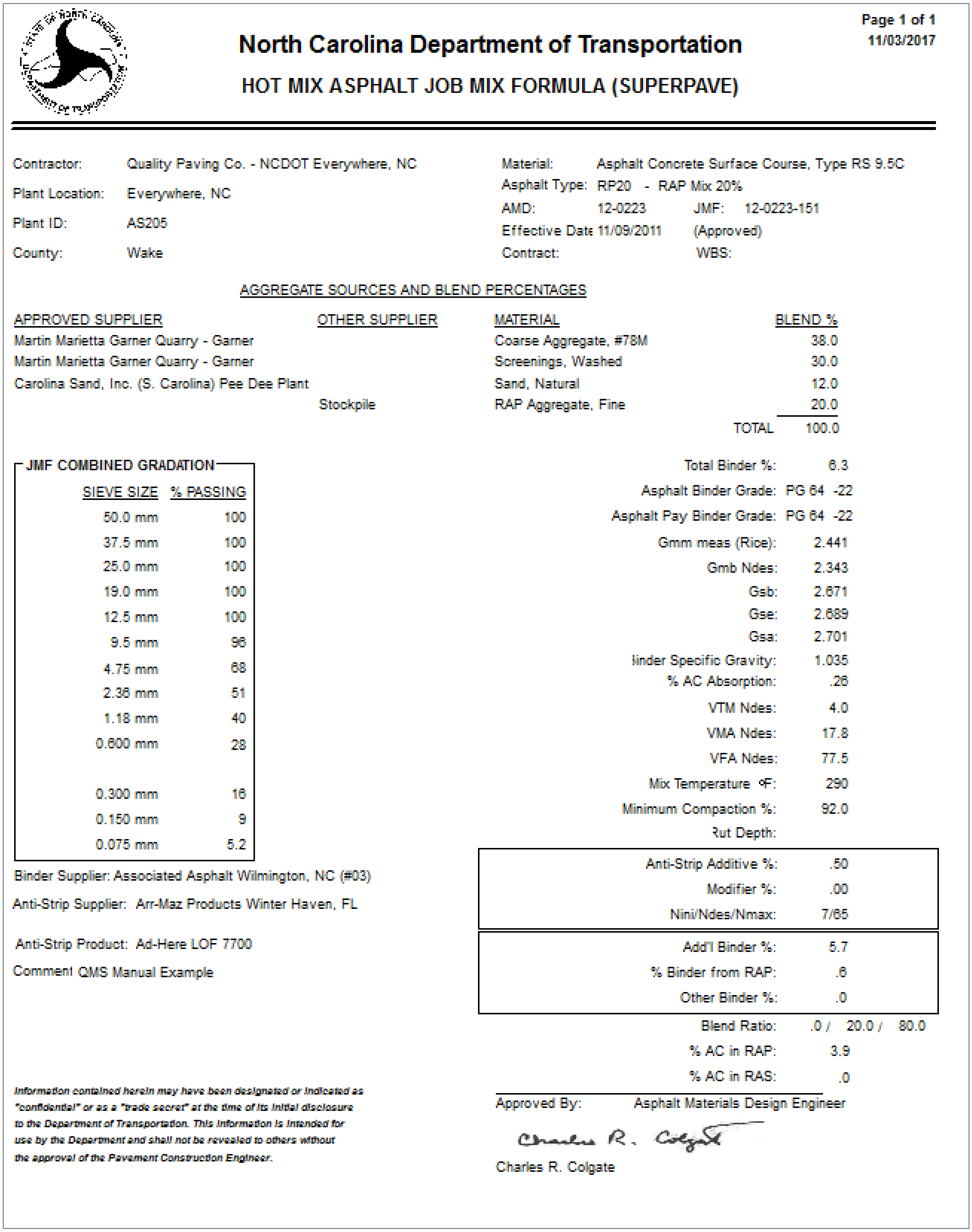
4.9.2 Job Mix Formula Numbering System

Job Mix Formula numbers will be 9 digits with a 4 character code at the end. This is the number shown on the JMF posted at the plant and shown on all appropriate reports. Job Mix Formulas are accessible via HiCAMS.

Ex: xx-yyyy-abc-defg where:
xx = Calendar Year
yyyy = Sequential number assigned by HiCAMS System

a = plant number, (1 for 1st plant 2 for a 2nd plant, etc.)
b = anti-strip percentage (2 for 0.25%, 5 for 0.5% etc.)
c = JMF revision number
defg = Code for Mix Type (see the following Table)

CODE	**Mix Type Description**	**CODE**	**Mix Type Description**
HMAC	*Hot-Mix Asphalt Concrete [Default]*	WMDB	Warm Mix Astec Double Barrel Green
		WM3G	Warm Mix Evotherm 3G
MRAS	Manufacturer RAS	WMU3	Warm Mix Evotherm U3
PRAS	Post-Consumer RAS	WMUF	Warm Mix Gencor Ultrafoam
RPAS	RAP-RAS Mixture	WMHT	Warm Mix Honeywell Titan
		WMAC	Warm Mix Ad-Here 62-40 + CecaBase RT
RP15	RAP Mix 15%	WMLC	Warm Mix LOF6500 + CecaBase RT
RP20	RAP Mix 20%	WMAB	Warm Mix Maxam AquaBlack
RP21	RAP Mix 21%	WMAF	Warm Mix Meeker AquaFoam
RP25	RAP Mix 25%	WMHG	Warm Mix Meridian Hydrogreen
RP30	RAP Mix 30%	WMSB	Warm Mix Sasol Sasobit
RP40	RAP Mix 40%	WMAD	Warm Mix PQ Corp. Advera
RP45	RAP Mix 45%	WMTX	Warm Mix Terex WMA
DC78	Permeable Asphalt Drainage Course, Type P-78M	UBWC	Ultra-thin Bonded Wearing Course
DC57	Permeable Asphalt Drainage Course, Type P-57		
MCS2	Micro-surfacing, Type II	FC1A	OGFC Type FC-1 w/Additive
MCS3	Micro-surfacing, Type III	FC1F	OGFC Type FC-1 w/Fibers
SSTB	Slurry Seal, Type B	FC1S	OGFC Type FC-1 w/Shingles
SSTC	Slurry Seal, Type C		



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11/03/2017

North Carolina Department of Transportation

HOT MIX ASPHALT JOB MIX FORMULA (SUPERPAVE)

Contractor: Quality Paving Co. - NCDOT Everywhere, NC
Plant Location: Everywhere, NC
Plant ID: AS205
County: Wake

Material: Asphalt Concrete Surface Course, Type RS 9.5C
Asphalt Type: RP20 - RAP Mix 20%
AMD: 12-0223 JMF: 12-0223-151
Effective Dat 11/09/2011 (Approved)
Contract: WBS:

AGGREGATE SOURCES AND BLEND PERCENTAGES

APPROVED SUPPLIER	OTHER SUPPLIER	MATERIAL	BLEND %
Martin Marietta Garner Quarry - Garner		Coarse Aggregate, #78M	38.0
Martin Marietta Garner Quarry - Garner		Screenings, Washed	30.0
Carolina Sand, Inc. (S. Carolina) Pee Dee Plant		Sand, Natural	12.0
	Stockpile	RAP Aggregate, Fine	20.0
		TOTAL	100.0

JMF COMBINED GRADATION

SIEVE SIZE	% PASSING
50.0 mm	100
37.5 mm	100
25.0 mm	100
19.0 mm	100
12.5 mm	100
9.5 mm	96
4.75 mm	68
2.36 mm	51
1.18 mm	40
0.600 mm	28
0.300 mm	16
0.150 mm	9
0.075 mm	5.2

Total Binder %:	6.3
Asphalt Binder Grade:	PG 64 -22
Asphalt Pay Binder Grade:	PG 64 -22
Gmm meas (Rice):	2.441
Gmb Ndes:	2.343
Gsb:	2.671
Gse:	2.689
Gsa:	2.701
Binder Specific Gravity:	1.035
% AC Absorption:	.26
VTM Ndes:	4.0
VMA Ndes:	17.8
VFA Ndes:	77.5
Mix Temperature °F:	290
Minimum Compaction %:	92.0
Rut Depth:	
Anti-Strip Additive %:	.50
Modifier %:	.00
Nini/Ndes/Nmax:	7/65
Add'l Binder %:	5.7
% Binder from RAP:	.6
Other Binder %:	.0
Blend Ratio:	.0 / 20.0 / 80.0
% AC in RAP:	3.9
% AC in RAS:	.0

Binder Supplier: Associated Asphalt Wilmington, NC (#03)
Anti-Strip Supplier: Arr-Maz Products Winter Haven, FL

Anti-Strip Product: Ad-Here LOF 7700
Comment QMS Manual Example

Information contained herein may have been designated or indicated as "confidential" or as a "trade secret" at the time of its initial disclosure to the Department of Transportation. This information is intended for use by the Department and shall not be revealed to others without the approval of the Pavement Construction Engineer.

Approved By: Asphalt Materials Design Engineer

Charles R. Colgate

Charles R. Colgate

4.10 ASPHALT MIX DESIGN AND TESTING CALCULATIONS/FORMULAS

(from Asphalt Institute's, SP-2, 3rd ed.)

1. **Combined Aggregate Bulk Specific Gravity** **(G_{sb}):**

$$G_{sb} = BSG = \frac{100}{\frac{\%\,Agg.\#1}{BSG\,Agg.\#1} + \frac{\%\,Agg.\#2}{BSG\,Agg.\#2} + \cdots + \frac{\%\,Agg.\#n}{BSG\,Agg.\#n}} = \frac{P_1 + P_2 + \cdots + P_n}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + \cdots + \frac{P_n}{G_n}}$$

2. **Effective Specific Gravity of Aggregate Using Rice MSG** **(G_{se}):**

$$G_{se} = Eff.SG = \frac{100 - \%\,Binder}{\frac{100}{Max.SG} - \frac{\%\,Binder}{Binder\ SG}} = \frac{P_{mm} - P_b}{\frac{P_{mm}}{G_{mm}} - \frac{P_b}{G_b}} \qquad where, P_{mm} = 100$$

3. **Maximum Specific Gravity of Mix With Different Binder Contents** **(G_{mm}):**

$$G_{mm} = Max.SG = \frac{100}{\frac{\%\,Agg.}{Agg.Eff.SG} + \frac{\%\,Binder}{Binder\ SG}} = \frac{P_{mm}}{\frac{P_s}{G_{se}} + \frac{P_b}{G_b}} \qquad where, P_{mm} = 100$$

4. **% Asphalt Absorption by Weight of Total Aggregate** **(P_{ba}):**

$$P_{ba} = 100\left[\frac{(Eff.SG) - (Agg.Bulk\ SG)}{(Agg.Bulk\ SG)(Eff.SG)}\right](Binder\ SG) = 100\left[\frac{G_{se} - G_{sb}}{(G_{sb})(G_{se})}\right]G_b$$

5. **% Effective Binder Content (by Weight of Total Mixture)** **(P_{be}):**

$$P_{be} = \%\,Binder - \left[\frac{\%\,Abs.Binder}{100}(\%\,Agg.)\right] = P_b - \left[\frac{P_{ba}}{100}(P_s)\right]$$

6. **Percent Voids in Mineral Aggregate (VMA) in Compacted Mixture:**

$$VMA = 100 - \left[\frac{(Lab\ SG)(\%\,Agg.)}{Agg.Bulk\ SG}\right] = 100 - \left(\frac{G_{mb}P_s}{G_{sb}}\right) \qquad where, P_s = \%Agg.\,by\ wt.\,of\ total\ mix$$

Note: NCDOT Mix Composition is by Weight of Total Mixture: *Example: 6.0% binder is by weight of total mixture.*

7. **Percent Air Voids (V_a) in Compacted Mixture or Voids in Total Mix (VTM):**

$$VTM = 100\frac{(Max.SG - Lab\ SG)}{(Max\ SG)} = 100\left(\frac{G_{mm} - G_{mb}}{G_{mm}}\right)$$

8. **% Voids Filled with Asphalt (VFA) in Compacted Mixture:**

$$VFA = 100\frac{\%\,Vol.Binder\ (effective)}{\%\,VMA} = 100\frac{(VMA - VTM)}{VMA}$$

9. **Bulk Specific Gravity of Compacted Mix Specimen or Core (G_{mb}):**

$$G_{mb} = \frac{Weight\ in\ Air}{(SSD\ Weight - Weight\ in\ Water)} = \frac{A}{B - C} \qquad (from\ T\ 166)$$

10. **Unit Weight Total Mix (γ_m):**

$$\gamma_m = Unit\ Weight\ (lb/ft^3) = (Mix\ SG)(\gamma_{water}) = G_{mb}(62.4) \qquad where, Unit\ Wt.of\ Water\ (\gamma_{water}) = 62.4\ lb/ft^3$$

11. **% Solids by Volume Total Mix (P_{solids}):**

$$P_{solids} = \frac{Lab\ SG}{Max\ SG} \times 100 = \frac{G_{mb}}{G_{mm}} \times 100$$

12. **Percent Asphalt Absorption by Weight of Total Mixture (P'_{ba}):**

$$P'_{ba} = (\%\ Binder\ Absorption\ by\ Wt.of\ Agg.)\frac{(\%\ Agg.)}{100} = P_{ba}\left(\frac{P_s}{100}\right) \quad where, P_s = \%\ Agg.by\ wt.of\ total\ mix$$

13. **Percent by Volume of Effective Binder (V_{be}):**

$$V_{be} = \%\ Vol.(eff.)Binder = \frac{(\%\ eff.Binder\ by\ Wt.)(Lab\ SG)}{(Binder\ SG)} = \frac{(P_{be})(G_{mb})}{G_b}$$

14. **% Solids by Volume of Aggregate Only ($P_{(solids-agg.only)}$):**

$$P_{solids-agg.only} = \%\ Solids\ by\ Volume\ Total\ Mix - \%\ Volume\ (Effective)Binder = P_{solids} - V_{be}$$

15. **% Binder (Back Calculated from Rice SG) (P_b)*:**

$$P_b = \frac{(100)(Binder\ SG)\left[\left(\frac{Eff.SG}{Max.SG}\right) - 1\right]}{(Eff.SG - Binder\ SG)} = \frac{100\ G_b\left[\left(\frac{G_{se}}{G_{mm}}\right) - 1\right]}{(G_{se} - G_b)}$$

*Note: Cannot be used when Eff. S.G. is computed from the same Rice Test.

17. **General Voids In Mineral Aggregate Relationship:**

$$VMA = \%\ Air\ Voids + \%\ Eff.Binder\ by\ Vol. = VTM + V_{be}$$

18. **Dust/Binder Ratio $P_{0.075}/P_{be}$:**

$$Dust/Binder\ Ratio = \frac{P_{0.075}}{P_{be}}$$

Where: $P_{0.075}$ = % Passing 0.075mm (#200) Sieve by Washing
P_{be} = % Effective Binder by Wt. of Total Mixture

4.11 ASPHALT Specialty Mixes Tables

1. OPEN GRADED ASPHALT FRICTION COURSE

REFER TO STANDARD SPECIFICATIONS SECTION 650

TABLE 650-1
OGFC DESIGN CRITERIA

Grading Requirements	Total Percent Passing
Sieve Size (mm)	*Type FC-1 Modified*
19.0	-
12.5	100
9.5	75 – 100
4.75	25 - 45
2.36	5 - 15
0.075	1.0 – 3.0
Asphalt Binder Grade	PG 76-22
Binder Content %	5.5 -8.0
Mixing temperature at the Asphalt Plant	300 – 325°F
Air Voids, % minimum	18.0
Cantabro Loss, % maximum	20.0
Draindown, % maximum	0.3

2. PERMEABLE ASPHALT DRAINAGE COURSE (TYPES P-78M AND P-57)

REFER TO STANDARD SPECIFICATIONS SECTION 652

TABLE 652-1
PERMEABLE ASPHALT DRAINAGE COURSE
GRADATION AND MIX DESIGN CRITERIA

Sieve Size (mm)	Total Percent Passing	
	Type P-78M	Type P-57
37.5	-	100
25.0	-	95-100
19.0	100	-
12.5	95-100	22-60
9.5	75-100	-
4.75	20-45	10-20
2.36	3-15	5-10
0.075	1.0 - 3.0	1.0 – 3.0
Asphalt Binder Content, %	2.5 - 3.5	2.0 – 3.0
Mixing temperature at Plant	240 - 270°F	260 - 290°F

3. ULTRA-THIN BONDED WEARING COURSE

REFER TO STANDARD SPECIFICATIONS SECTION 661

TABLE 661-1
UBWC GRADATION CRITERIA

Sieves (mm)	% Passing by Weight
12.5	100
9.50	85-100
4.75	28-44
2.36	17.34
1.18	13-23
0.600	8-18
0.300	6-13
0.15	4-10
0.075	3.0 - 7.0

TABLE 661-2
UBWC MIX DESIGN CRITERIA

Property	Requirement
Asphalt Content, %	5.0 (minimum)
Draindown Test, AASHTO T 305	0.1% max
Moisture Sensitivity, AASHTO T 283[A]	85% mln
Application Rate, lb/sy	70 lb/sy
Approximate Application Depth, in.	5/8”
Asphalt PG Grade, AASHTO M 320	PG 70-28 or PG 76-22

SECTION 7

ASPHALT MIXTURE SAMPLING AND TESTING

7.1 INTRODUCTION

Sampling and testing of asphalt mix are two of the most important functions performed by QC/QA technicians to assure that a quality product is obtained. Data derived from sampling and testing during production and placement of the mixture are used to control the production process and to determine whether or not the final product meets specification requirements. For these reasons, sampling and testing techniques and procedures must be followed exactly to ensure that results give a true picture of mix quality and characteristics. In addition to performing other responsibilities, a competent QC/QA technician must be able to get representative samples, conduct field tests, interpret the test data, relay the test results to appropriate parties and maintain accurate and adequate records and reports.

Once the job mix formula is issued and before actual construction begins, Mix Verification tests must be performed to determine any differences which may exist between the properties of the asphalt mix designed in the laboratory and the same asphalt mix produced in a batch or drum mix plant. Even though the same material sources are used, quite frequently the plant-produced mix may exhibit different mix properties from that indicated by the mix design. QC testing of the mixture during production is essential to ensure that a satisfactory mix is being obtained. In addition, the Department will perform QA sampling and testing as specified in this manual.

The JMF based on the mix design produced in the laboratory should be treated only as a “start-up” JMF. As production begins, the desired properties of the mix should be checked and monitored on the plant produced, field lab compacted asphalt mixture. Tests that should be performed during manufacture and placement include: aggregate gradations, cold feed calibrations, asphalt binder content, volumetric properties, temperature, theoretical maximum density, in-place density, smoothness and visual inspections, and others as necessary. All of the mix properties on the plant-produced mix should be within the ranges required by the JMF and also within the tolerances set by the QMS Specifications. If the test results on the plant-produced mix indicate compliance with the QMS Specifications, the plant may continue to operate. If one or more of the mix properties is outside the desired range, appropriate actions, as described elsewhere in this Manual, shall be taken immediately.

In addition to sampling and testing performed by QC/QA technicians, assessments will be performed by the Materials and Tests Unit’s Independent Assurance (IA) personnel. The Independent Assurance (IA) program ensures that the personnel performing QMS testing remain proficient. If the assessment finds problems with the technician’s proficiency, corrective action will be required, and the technician will be reassessed (see Section 1.4 for details of the Technician Assessment Program). This program also assures that the laboratory equipment used in the testing is properly maintained and calibrated. This is achieved by taking samples (typically a split sample) at either the QC or QA lab and testing those samples at a Materials and Tests Unit facility. The results are compared to a correlation rating system derived from statistical analysis of previous comparative tests. If the results of the comparative samples are within the Excellent/Good range, no investigation is required. If the results are in the Fair/Poor range, an investigation is initiated by IA personnel in an attempt to determine the reason for the disparity. This investigation shall include but is not limited to: analysis of all calculations performed and procedures used by the QC/QA personnel, investigation of the testing equipment used, and the personnel performing the IA testing. Analysis of all test results, and if necessary, re-sampling and testing under observation, are other investigation tools available. The IA personnel will normally coordinate their visits with the QC/QA technician in order to prevent unnecessary sampling. Full cooperation should be given to the IA personnel to insure that their sampling requirements are met.

This Section describes in detail the sampling and testing frequencies, procedures and test methods utilized by NCDOT. As everyone is aware, there is much concern by the Division of Highways, the Federal Highway Administration and Asphalt Industry Representatives about the quality of asphalt pavement construction in North Carolina. Full cooperation and efforts by all parties is necessary in order to assure that pavements are produced and constructed so as to perform as intended. If the Resident Engineer, QMS Technician, Contractor or others should have questions or need further clarification about the guidelines, procedures, or instructions noted in this Manual, please contact the Materials and Tests Unit at any time. All forms and worksheets utilized for Sampling and Testing of mix and aggregates are contained in Section 12 along with detailed instructions.

7.2 QMS CERTIFIED FIELD LABORATORY

For a contract with 5,000 or more total tons (metric tons) of mix, the Contractor shall furnish and maintain a certified laboratory at the plant site. The laboratory shall be furnished with the necessary space for equipment and supplies for performing contractor quality control testing. A minimum of 320 square feet, exclusive of toilet facilities is required for all QC labs. A 500 square feet facility is suggested. There should also be an accurate organizational chart, updated annually, with phone numbers for QC personnel posted in the QC Lab.

For a contract with less than 5,000 total tons (metric tons) of asphalt mix, the Contractor may conduct the quality control testing in a certified off-site laboratory. The Contractor may utilize private testing labs and technicians provided the Department has certified them. The Contractor is still required to have a QMS Level I certified technician at the plant site while producing mix for a NCDOT QMS project.

The laboratory testing equipment shall meet the requirements of the test methods herein and outlined in Section 7.3. Laboratory equipment furnished by the Contractor or his representative shall be properly calibrated and maintained. In the event of a malfunction of laboratory equipment, which cannot be corrected within twenty-four (24) hours, another certified offsite laboratory may be used if approved by the Engineer. The Contractor shall document and maintain calibration results of all equipment at the QC laboratory. See Section 7.2.2 for QMS Lab Equipment Calibration Requirements. The Engineer shall be allowed to inspect measuring and testing devices to confirm both calibration and condition. If at any time the Engineer determines that the equipment is not operating properly or is not within the limits of dimensions or calibration described in the applicable test method, the Engineer may stop production until corrective action is taken.

The Contractor shall notify the Pavement Specialist as to when the QC lab is ready for inspection and certification. This should be done as much as possible in advance of the paving operation (approx. 10 days) so that the Pavement Specialist can complete the QC Lab Certification Checklist and submit it to the Engineer for approval and certification. Once the field lab is certified, a copy of the checklist and certification will be forwarded to the Contractor. This certification shall be posted in the field lab at all times. The paving operations shall not begin until the lab is certified.

The Department will maintain a number of M&T Asphalt Laboratories throughout the state for performing Quality Assurance (QA) testing. These labs will be for the purpose of performing all necessary tests in monitoring the Contractor's QC process and for maintaining all documentation of this process.

7.2.1 QMS Lab Required Equipment List For Asphalt Mix Testing

The Asphalt Mix Design Engineer maintains a listing of the required equipment for a QMS Lab. Copies of this list are distributed anytime updates are made.

REQUIRED EQUIPMENT FOR QMS CERTIFIED LABORATORIES

QUANTITY	**DESCRIPTION**
1 each	Computer with Internet Access & capable of data input to the Department's QAP System.
1 each	Fax Machine or Scanner (for electronic transmittal of QMS Forms)
1 each	Infrared Thermometer (0° - 400°F, minimum)
1 each	Digital Thermometer (0° - 400°F, minimum) with Probe
1 each	Thermostatically Controlled Hot Plate & Frying Pan
	OR Electric Skillet (Optional, if using Ovens for Drying)
1 each	Sieve Shaker w/ Timer (able to accommodate both 8" & 12" diameter sieves)
1 each	Mechanical Aggregate Washer (Optional)
1 set	Electronic Balances (12,000-gram minimum capacity with center suspension point)
1 each	Stainless Steel Weighing Cradle
1 set	Electronic Balances (8,000-gram minimum capacity)
1 each	Vacuum Pump
1 each	Manometer
1 set	Vacuum Pycnometer & Lid with Two Vacuum Hose Connections for Rice Gravity
1 each	Mechanical Agitation Device for Rice Sample
1 each	Electric Timer with 15 Minute Capacity or more
1 each	Thermostatic Heater for Water Container
1 each	Immersion Circulation Pump

1 each	Temperature Chart Recorder w/ remote probe OR Digital Data Logger with temperature display and USB interface for data download
2 each	Electric Fans, 16” (406 mm) minimum
1 each	Water Trap for Vacuum Pump
1 each	Bleeder Valve for Vacuum Pump Line
1 each	Refrigerator, Apt. Size or Larger
4 each	Metal or Plastic Buckets, 5 gal. (19 L)
1 each	Plastic Water Container w/ Overflow, 24” diameter minimum or 24” x 18” x 18” minimum
1 each	Stainless Steel Bowl, 5 qt. (5.0 L)
1 each	Stainless Steel Bowl, 8 qt. (8.0 L)
1 each	Square Shovel or Modified Shovel with approx. 2 - 4 inch sides for Sampling
1 each	Metal Top Splitting Table, 3 ½ ft. x 3 ½ ft. minimum
6 each	Metal Mix Sample Pans, 12 ½” x 10 ½” minimum
1 each	Shop Vac
1 set	Calibration Weights
1 each	Trowel, Straight Sided (Optional)
1 set	Spatulas (1 @ 4” & 1 @ 6”)
1 each	Flat Bottom Sampling Scoop
1 each	Metal Quartering Template – w/ sides of sufficient height that form a 90° angle OR Acceptable Alternate
2 each	Large Spoons, 8” min. length
1 pair	Rubber Gloves
2 pair	Welder’s Gloves
2 each	Assortment of Brushes for cleaning sieves
- - -	Clean Rags
- - -	Wetting Agent (any dispersing agent such as liquid dish washing detergent, or soap which will promote the separation of fine material.)
- - -	Permanent Paint Marking Pens
- - -	Large Cloth Sample Bags (Good Condition)
- - -	Lab Oven(s) minimum 10.0 CF capacity. Must be forced air convection, thermostatically controlled & operable.
1 each	Approved Ignition Furnace (meeting the requirements of AASHTO T 308)
1 each	NCDOT Approved 150mm Gyratory Compactor w/Printer (meeting the requirements of AASHTO T 312)
1 each	150 mm Gyratory Specimen Extractor (unless built into the compactor)
3 each	150 mm Gyratory Specimen Molds (See section 7.2.2 (A-8))
4 each	12” x 15” (305 mm x 380 mm) Metal Mix Sample Pans
1 each	Ruler (for measuring core sample height)
1 set	12-inch Diameter Sieves (with cover & pan)

1	50.0 mm	1	19.0 mm	1	4.75 mm	1	0.600 mm	2*	0.075 mm
1	37.5mm	1	12.5 mm	1	2.36 mm	1	0.300 mm		
1	25.0 mm	1	9.50 mm	2*	1.18 mm	1	0.150 mm		

*Additional sieves required for washed gradation (1.18 mm & 0.075 mm nest) may be 8” diameter.

The following will be required for TSR testing at each Lab used for Mix Designs:

1 each	Loading Jack or Test Press with Calibration Spring (capable of printing hardcopy graphs such as a chart recorder or downloadable to a computer for printout)
1 each	150 mm TSR Breaking Head
1 each	Hot Water Bath with Agitator
1 each	Infrared Thermometer (0° - 400°F, minimum)

7.2.2 QMS Lab Equipment Calibration Requirements

Laboratory equipment furnished by the Contractor or his representative shall be properly calibrated and maintained as specified below. QC process control may require additional equipment verifications to ensure accurate test results.

The Contractor shall document and maintain all QC records, forms and calibrations for a minimum of 3 years after completion. It is recommended that all records be kept in one (1) binder. This binder shall be readily available for review by the Department or its representative. Periodically, each lab may be audited by the Department or its representative. The audit will consist of a review of calibration records and random verifications of equipment for compliance. In the event a plant does no NCDOT work for an extended period of time and these checks are not performed, this period of inactivity should be documented in the QC diary.

Test methods and forms listed *(Italics)* are available through the NCDOT Materials and Tests Unit in Raleigh at (919) 329-4060. If the M&T Forms listed are not utilized, then the replacement form must include the identical information listed on the referenced M&T Forms and be labeled clearly for each piece of equipment verified/calibrated.

The gyratory compactor and ignition furnace time and date stamp shall be checked daily to ensure accurate information is displayed on the printout. The time and date shall be accurate and consistent with the time and date displayed within 5-10 minutes of the time printed on the certified weight certificate (load tickets).

A. Gyratory Compactors and Molds

1. Standardization on the compactor shall be performed every 12 months and must be performed by the manufacturer or a certified representative (certified by manufacturer). This standardization must include internal angle verification. Paperwork (or certification sticker affixed to device) shall be provided showing the following information:
    a. Date of standardization/verification and maintenance
    b. Value for internal angle
    c. Type of internal angle device used
    d. Individual Mold Diameter Measurements
    e. Personnel who performed standardization/verification
    f. Any repair work performed
2. Internal Angle shall be standardized every 12 months as per AASHTO T 344 (1.16 ± 0.02°)
3. Pressure shall be standardized every 12 months, as per manufacturer specifications (600 ± 18 kPa)
4. Frequency of gyration shall be standardized every 12 months (30.0 ± 0.5 gyrations per minute)
5. Height shall be verified daily, as used (± 0.1 mm of plug height)
6. The above standardizations/verifications for each calendar year shall be printed (if applicable) and kept in a folder/binder that shall be labeled “Gyratory Compactor Verifications”.
7. The above standardizations/verifications shall be performed within 10 calendar days of moving the compactor from one laboratory to another. A compactor that has been moved cannot be used for mix testing until the required recalibration has been performed. The compactor must also be recalibrated after any repairs or replacement of parts.
8. Gyratory Molds shall be uniquely identified* and the diameter verified every 12 months by the manufacturer or a certified representative, using a three-point internal bore gauge in accordance AASHTO T 312, Annex A. The inside diameter of new molds shall be 149.90 mm to 150.00 mm (measured at room temperature). If any in-service mold exceeds 150.20 mm, it shall be taken out of service and replaced.
9. Gyratory ram face and mold base plates shall be checked for critical dimensions every 12 months.
10. Mold, ram head, and base plate measurement information shall be stored in a binder or folder.

* Uniquely identified molds refer to individual molds that are permanently etched and can be matched with calibration paperwork and tracked over time.

B. Balances and Water Tanks

1. Balances - general purpose balances shall be standardized every 12 months using NIST Class F traceable weights by a registered scale technician through the North Carolina Department of Agriculture and Consumer Services Standards Division. These balances shall be verified weekly by QC/QA lab personnel following the procedures in *Test Method MT-3V* and recorded on *Form 3V* or equivalent.
2. Balances must meet requirements of AASHTO M 231. When standardized every 12 months, each balance shall have a certification/sticker that provides:
    a. Date of standardization.
    b. Scale technician who performed standardization.

3. If the balances are being used for bulk specific gravity or maximum gravity methods and utilize a suspended cable, the steel cable or wire shall be of the smallest practical size to minimize any possible effects of variable immersed length. Also, the opening in the table or stand shall allow the cable free movement with no restrictions. Linked chain of any kind shall not be allowed.
4. The water tanks shall be made of a non-corroding material and have provisions for automatic control of the water temperature as well as a circulation pump.
5. Each tank shall be equipped with a recording thermometer with its bulb located in the water. (Recording charts shall be replaced monthly (or at the appropriate recording interval).
6. The tanks shall be deep enough to completely submerse the specimen and cradle and be equipped with an overflow outlet for maintaining a constant water level. The water tanks shall be visually inspected weekly, and water replaced at least once per month (or more often as needed).

C. Ovens and Water Baths

1. Asphalt mix ovens - shall be a forced draft oven, thermostatically controlled, capable of maintaining any desired temperature setting from room temperature to at least 350°F (176°C).
2. Ovens shall be in proper working order with doors that seal properly with no broken hinges.
3. Ovens shall be standardized every 12 months using a NIST traceable thermocouple thermometer and following the procedures *of Test Method MT-2V* and recorded on *Form 2V* or equivalent. If the temperature readout does not match the NIST thermocouple, it shall be adjusted so the temperature readout is correct.
4. A record shall be kept of all annual standardizations as well as any repairs made to the ovens and shall include the following:
    a. Date of last standardization
    b. Temperature at which oven was standardized
    c. Personnel who performed standardization
5. Water baths shall be thermostatically controlled and shall be standardized every 12 months using an NIST traceable thermocouple thermometer and following the procedures *of Test Method MT-2V* and recorded on *Form 2V* or equivalent. If the temperature readout does not match the NIST thermocouple, it shall be adjusted so the temperature readout is correct.

D. Ignition Furnace

1. Forced air ignition furnaces shall be capable of maintaining the temperature at 1072°F (578°C). The furnace shall have an internal balance capable of weighing a 3500-gram sample in addition to the basket assembly. Ovens shall be in good working condition. All safeguards shall be in place and shall function properly.
2. The internal oven balance shall be standardized every 12 months by a registered scale technician through the North Carolina Department of Agriculture and Consumer Services Standards Division using NIST Class F weights following *Test Method MT-35V* and the results recorded on *Form 35V* or equivalent. (8000-gram weight required)
3. Each ignition furnace shall have a lift test performed monthly when the furnace is at room temperature, following the procedures of *Test Method 35V(A).* These results shall be recorded on *Form 35V(A)* or equivalent.

E. Vacuum Pump(s) and Rice Gravity System

1. Vacuum pumps used for maximum gravity testing shall conform to the standards of AASHTO T 209, Section 6.
2. The vacuum system shall include a vacuum gauge, a water vapor trap, hoses, a vacuum pump, and a manometer (absolute pressure gauge).
3. The vacuum within the pycnometer shall be verified every 3 months with an absolute vacuum gauge and the manometer should be adjusted accordingly. The system shall be verified following the procedures of *Test Method 28V* and documented on *Form 28V* or equivalent. Additionally, this verification shall be conducted anytime maintenance or adjustments are performed.
4. Vacuum settings for Automatic Sealing and/or Rapid Drying equipment shall be verified every 3 months, any time after repairs are performed, and anytime the unit is relocated.
5. The calibrated vacuum gauge used for the above checks shall be capable of being placed inside the device's vacuum chamber to verify vacuum performance and seal integrity. The gauge shall have a minimum range of 10 to 0 mmHg (10 to 0 torr) and readable to 1 mmHg (1 torr) increments as a minimum. This vacuum gauge shall be standardized once every 12 months.
6. Verify the dry weight and under water weight of the Rice pycnometer monthly, using water at 77 ± 2 °F (25 ± 1 °C).

F. Shakers and Sieves

1. Shakers shall be visually inspected weekly and maintained.
2. Sieves shall be visually inspected weekly following *Test Method MT-11V* and documented on *Form 11V* or equivalent.
3. Any sieve that is damaged or broken shall be immediately replaced with a new sieve.

G. Compression Testing Machines

1. The test press shall be capable of loading at a speed of 2 inches/minute (50 mm/min).
2. The test press shall be standardized using the manufacturer's recommended method which usually involves using a proving spring or a proving load ring. The test press shall be standardized every 12 months and the data shall be stored and be available for review.

H. Thermometers

1. Thermometers shall be standardized every 12 months.
2. Thermometers shall be visually inspected daily for damage or defects. Any thermometers that are found to be defective shall be removed from service immediately.

I. Scale Weights

1. Scale Weights used for checking balances and scales shall be calibrated every 12 months.
2. Certificates of calibration shall be available upon request.

Items listed above shall adhere to the requirements of this Manual and Department policies. Failure to comply with these requirements may result in lab certification being suspended until all testing equipment meets calibration requirements.

In the event of an equipment malfunction that cannot be corrected within 24 hours, the laboratory must provide documentation from the service company detailing the repairs and/or parts needed. Also, provide documentation from the service company outlining the timeframe for when the service/repair can be completed. Send documentation to the Asphalt Mix Design Engineer.

QMS Lab Equipment Calibration Requirements

Equipment	Requirement	Minimum Interval
Gyratory Compactor	Standardize: Internal Angle of Gyration, Ram Pressure, Frequency of Gyration, Ram Head dimension	*12 months*
	Verify: Height	*Daily*
Gyratory Mold	Verify: Inside Diameter, Base Plate diameter	*12 months*
Balance/Scale	Standardize: Weight measurement	*12 months*
Water Tank	Visually Inspect	*Daily*
	Replace Water	*Monthly (or as needed)*
Oven	Standardize: Temperature setting	*12 months*
Water Bath	Standardize: Temperature setting	*12 months*
Ignition Furnace	Standardize: Internal Balance	*12 months*
	Perform Lift Test	*Monthly*
Vacuum Pump and System	Verify: Pressure inside pycnometer	*3 months*
	Verify: Dry & Underwater weights of pycnometer	*Monthly*
Automatic Sealing equipment & Rapid Drying equipment	Verify: Pressure inside chamber	*3 months*
Shakers and Sieves	Visually Inspect & Maintain	*Weekly*
Compression Testing Machines	Standardize: Load & Loading Speed	*12 months*
Thermometers	Standardize: Temperature reading	*12 months*
	Visually Inspect	*Daily*
Scale Weights	Calibrate: mass	*12 months*

NORTH CAROLINA DEPARTMENT of TRANSPORTATION

HMA/QMS

CERTIFIED SUPERPAVE
LABORATORY

This is to certify that
the Asphalt Testing Laboratory located at

Quality Paving Co., Inc

Everywhere, NC

meets all requirements of the
North Carolina Department of Transportation's
Superpave and Quality Management System specifications

AS-205-11-19

Certification No.

Charles R. Colgate

Charles R. Colgate
Asphalt Materials Supervisor

OPEN GRADED ASPHALT FRICTION COURSE, PERMEABLE ASPHALT DRAINAGE COURSE, AND ULTRA-THIN BONDED WEARING COURSE:

(4-17-12)✓ 609 SP6 R62

When producing and constructing open graded asphalt friction course, permeable asphalt drainage course, and ultra-thin bonded wearing course revise the *2012 Standard Specifications* as follows:

Page 6-10, Subarticle 609-6(B) Required Sampling and Testing Frequencies, delete the third paragraph and replace with the following:

Sample and test the completed mixture from each mix design per plant per year at the following minimum frequency during mix production:

Accumulative Production Increment	Number of Samples per Increment
500 tons	1

Page 6-10, Subarticle 609-6(C) Control Charts, delete the fourth paragraph and replace with the following:

Record the following data on the standardized control charts and in accordance with the requirements of Section 7.4 of the *HMA/QMS Manual*:

(a) Aggregate Gradation Test Results:

1. 12.5 mm (Types P57 & FC-2 Mod. Only)
2. 9.5 mm (Excluding Type P57)
3. 4.75 mm
4. 2.36 mm
5. 0.075 mm Sieves

(b) Binder Content, %, P_b

Page 6-11, Subarticle 609-6(D) Control Limits, Table 609-1 CONTROL LIMITS, replace with the following:

TABLE 609-1 CONTROL LIMITS			
Mix Control Criteria	**Target Source**	**Moving Average Limit**	**Individual Limit**
12.5 mm Sieve (Types P57 & FC-2 Mod)	JMF	± 4.0	± 8.0
9.5 mm Sieve (Excluding Type P57)	JMF	± 4.0	± 8.0
4.75 mm Sieve	JMF	± 4.0	± 8.0
2.36 mm Sieve	JMF	± 4.0	± 8.0
0.075 mm Sieve	JMF	± 1.5	± 2.5
Binder Content	JMF	± 0.3	± 0.7
TSR (Ultra-thin Only)	Min. Spec. Limit	-	- 15%

Page 6-12, Subarticle 609-6(F) Allowable Retesting for Mix Deficiencies, Table 609-2 RETEST LIMITS FOR MIX DEFICIENCIES, replace with the following:

TABLE 609-2 RETEST LIMITS FOR MIX DEFICIENCIES	
Property	**Limit**
% Binder Content	by more than ± 1.0%
12.5 mm Sieve (Types P 57 & FC-2 Mod)	by more than ± 9.0%
9.5 mm Sieve (Excluding Type P 57)	by more than ± 9.0%
4.75 mm sieve	by more than ± 9.0%
2.36 mm sieve	by more than ± 9.0%
0.075 mm sieve	by more than ± 3.0%
TSR (Ultra-thin only)	by more than -15% from Specification limit

Page 6-17, Subarticle 609-9(C) Limits of Precision, Table 609-3 LIMITS OF PRECISION FOR TEST RESULTS, replace with the following:

TABLE 609-3 LIMITS OF PRECISION FOR TEST RESULTS	
Mix Property	**Limits of Precision**
12.5 mm Sieve (Types P 57 & FC-2 Mod. Only)	± 6.0%
9.5 mm Sieve (Excluding Type P 57)	± 5.0%
4.75 mm Sieve	± 5.0%
2.36 mm Sieve	± 5.0%
0.075 mm Sieve	± 2.0%
Asphalt Binder Content	± 0.5%
TSR (Ultra-thin HMA Only)	± 15.0%

NORTH CAROLINA TEST METHOD
For
MEASUREMENT OF WATER PERMEABILITY OF COMPACTED ASPHALT PAVING MIXTURES

Designation: North Carolina Test Method A-100

1. SCOPE

1.1 This test method covers the laboratory determination of the water conductivity of a compacted mixture sample. The measurement provides an indication of water permeability of that sample as compared to those of other asphalt samples tested in the same manner.

1.2 The procedure uses field core samples obtained from existing pavements.

1.3 The values stated in metric (SI) units are to be regarded as standard. Values given in parenthesis are for information and reference purposes only.

1.4 *This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, and health practices and determine the applicability of regulatory limitations prior to use*

2. APPLICABLE DOCUMENTS

2.1 AASHTO Standards:

M 231 Weights and Balances Used in the Testing of Highway Materials

T 166 Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface Dried Specimens

2.2 ASTM Standards:

D2041 Standard Method for Theoretical Maximum Gravity and Density of Bituminous Paving Mixtures

PS129 Standard Provisional Test Method for Measurement of Permeability of Bituminous Paving Mixtures Using a Flexible Wall Permeameter

D6752, Standard Test Method for Bulk Specific Gravity and Density of

3. SUMMARY OF TEST METHOD

3.1 A falling head permeability test apparatus, as shown in Figure 1, is used to determine the rate of flow of water through the specimen. Water in a graduated cylinder is allowed to flow through a saturated asphalt sample and the interval of time taken to reach a known change in head is recorded. The coefficient of permeability of the asphalt sample is then determined based on Darcy's law.

4. SIGNIFICANCE AND USE

4.1 This test method provides a means for determining water conductivity of water-saturated asphalt samples. It applies to one-dimensional laminar flow of water. It is assumed that Darcy's law is valid.

5. APPARATUS

5.1 *Permeameter* – See Figure 1. The device shall meet the following requirements:

a) A calibrated cylinder of 31.75 ± 0.5-mm (1.25 ± 0.02 in.) inner diameter graduated in millimeters capable of dispensing 500 ml of water.

b) A sealing tube using a flexible latex membrane 0.635 mm (0.025 in) thick and capable of confining asphalt concrete specimens up to 152.4 mm (6.0 in) in diameter and 80 mm (3.15 in) in height.

c) An upper cap assembly for supporting the graduated cylinder and expanding an o-ring against the sealing tube. The opening in the upper cap shall have the same diameter as the inner diameter of the calibrated cylinder mentioned previously in 5.1 a. The underside of the upper cap assembly should be tapered at an angle of 10 ± 1° (see Figure 1).

d) A lower pedestal plate for supporting the asphalt concrete specimen and expanding an o-ring against the sealing tube. The opening in the plate should have a minimum diameter of 18 mm (0.71 in). The topside of the lower cap should be tapered at an angle of 10 ± 1° (see Figure 1).

e) O-rings of sufficient diameter and thickness for maintaining a seal against the sealing tube.

f) A frame and clamp assembly for supplying a compressive force to the upper cap assembly and lower pedestal necessary to expand the o-rings.

g) An air pump capable of applying 103.42 kPa (15 psi) pressure and capable of applying vacuum to evacuate the air from the sealing tube / membrane cavity.

h) A pressure gauge with range 0 to 103.42 kPa (0 to 15 psi) with ± 2% accuracy.

i) Quick connects and pressure line for inflating and evacuating the sealing tube / membrane cavity.

j) An outlet pipe with a minimum inside diameter of 18 mm (0.71 in) with shutoff valve for draining water.

5.2 *Water*- A continuous supply of clean, non-aerated water, preferably supplied by flexible hose from water source of top graduated cylinder.

5.3 *Thermometer*- A mercury or thermocouple device capable of measuring the temperature of water to the nearest 0.1°C (0.2°F).

5.4 *Beaker*- A 600 ml beaker or equivalent container to be used while measuring the temperature of a water sample.

5.5 *Timer*- A stop watch or other timing device graduated in divisions of 0.1s or less and accurate to within 0.05% when tested over intervals of not less than 15 min.

5.6 *Measuring Device*- A device used to measure the dimensions of the specimen, capable of measuring to the nearest 0.5 mm or better.

5.7 *Saw*- Equipment for wet cutting the specimen to the desired thickness. Dry cut type saws are not to be used.

5.8 *Fan*- An electric fan for drying the wet asphalt specimen.

5.9 *Vacuum Pump*- Capable of evacuating air from the vacuum container to a residual pressure of 4.0 kPa (30 mm of Hg) or less.

5.10 *Vacuum Container*-Either a metal or plastic bowl with a diameter of approximately 180 to 260 mm (7 to 10.25 in.) and a bowl height of at least 160 mm (6.3 in.) shall be equipped with a transparent cover fitted with a rubber gasket and a connection for the vacuum line. Both the bowl and cover should be sufficiently stiff to withstand the applied vacuum pressure without visibly deforming.

6. PREPARATION OF TEST SAMPLES

6.1 *Laboratory Samples*

6.1.1 Specimens shall be compacted in accordance with AASHTO T 312.

6.1.2 After compaction, specimens shall be allowed to cool to room temperature.

6.1.3 Laboratory specimens shall be compacted to four times the nominal maximum aggregate size (NMAS) of the mixture type using the gyratory compactor in height mode. Specimens shall be compacted to target 7± 0.5% air voids.

6.2 *Roadway Cores*

6.2.1 Saw cut the field core to the desired test sample thickness. The thickness shall be as close to the actual or desired in-place thickness as possible.

6.2.2 Wash the test sample thoroughly with water to remove any loose, fine material resulting from saw cutting.

6.3 Determine the bulk specific gravity of the specimen, if necessary, using either ASTM 6752 or AASHTO T166, as required.

6.4 Measure and record, to the nearest 0.5 mm (0.02 in.) or better, the height and diameter of the sample at three different locations. The three height measurements shall not vary by more than 5 mm (0.2 in.). The diameter of the specimen shall not be less than 144 mm (5.67 in.). (Use M&T Form 651)

6.5 Place the specimen in the vacuum container supported above the bottom by a spacer. Fill the container with distilled water at room temperature so that the specimen has at least one-inch of water above the surface. Apply a vacuum of 13 – 67 kPa absolute pressure (10- 26 in. Hg partial pressure) for a 5 minutes. Remove the vacuum and leave the specimen submerged for a 5 minutes.

7. TEST PROCEDURE

7.1 Evacuate the air from the sealing tube / membrane cavity.

NOTE 1: Complete evacuation of the air is aided by pinching the membrane and slightly pulling it away from the hose barb fitting as the pump is stroked.

7.2 For laboratory compacted specimens, it is necessary to apply a thin layer of petroleum jelly to the sides of the specimen to achieve a satisfactory seal between the membrane and the specimen. This shall be accomplished using a spatula or similar instrument. Sealant shall be applied only to the sides of the specimen. Remove the specimen from the vacuum container filled with water, dry to SSD, apply the petroleum jelly sealant to the sides, and then quickly place the specimen on the pedestal of the permeameter.

7.3 Center the specimen on top of the lower pedestal plate.

7.4 Place the sealing tube over the specimen and lower pedestal plate making sure that the sealing tube is oriented so that the hose barb fitting will be located between the o-rings on the upper cap and lower pedestal.

7.5 Insert the upper cap assembly into the sealing tube and let it rest on top of the asphalt concrete specimen.

NOTE 2: Insertion of the upper cap assembly is aided if the graduated cylinder is already inserted into the upper cap assembly. The graduated cylinder can then be used as a handle.

7.5 Install the two cap assemblies onto the permeameter frame and evenly tighten each one, applying a moderate pressure to the upper cap assembly. This action seals the o-rings against the membrane and sealing tube.

7.6 Inflate the membrane to 96.5 ± 7.0 kPa (14 ± 1 psi). Maintain this pressure throughout the test.

7.7 Fill the graduated cylinder with water approximately halfway and rock the permeameter back, forth, and sideways enough to dislodge any trapped air from the upper cavity.

7.8 Fill the graduated cylinder to a level above the upper timing mark, see Figure 1. Start the timing device when the bottom of the meniscus of the water reaches the upper timing mark. Stop the device when the bottom of the meniscus reaches the lower timing mark. Record the time to the nearest second. Perform this test three times and check for saturation. While checking for saturation, do not allow the remaining water in the graduated cylinder to run out, as this will allow air to re-enter the specimen.

Saturation in defined as the repeatability of the time to run 500 ml of water through the specimen. A specimen will be considered saturated when the % difference between the first and third test is ≤ 4.0%. Therefore, a <u>minimum</u> of three tests will be required for each asphalt concrete specimen except as stated in Note 4. Saturation of the specimen may require many test runs prior to achieving the ≤ 4.0% requirement. One technique that aids in achieving saturation is to nearly fill the graduated cylinder with water and adjust the water inflow so that it equals the outflow. Allow the water to run in this manner for five or ten minutes and then begin the timed testing. If more than three test runs are required, which is typically the case, then the ≤ 4.0% requirement shall apply to the last three testing times measured.

NOTE 3: If after the third run, the test run time is greater than ten minutes, then the tester can use judgement and consider ending the test, using the lowest time recorded in the permeability evaluation.

NOTE 4: If the test time is approaching thirty minutes during the first test run without the water level reaching the lower timing mark, then the tester may mark the water level at thirty minutes and record this mark and time. Run the test one more time and record the mark and time. Use the mark and time that will result in the highest permeability value.

7.9 Obtain a sample of water in a beaker or other suitable container and determine the temperature to the nearest 0.1°C (0.2°F).

7.10 After the saturation has been achieved and the final time and mark recorded, then release the pressure from the container and evacuate the sealing tube / membrane cavity. Remove the clamp assemblies, upper cap, and specimen.

8. CALCULATIONS

8.1 The coefficient of permeability, k, is determined using the following equation:

$$k = \frac{aL}{At} \ln(h_1/h_2) \times t_c$$

Where: k = coefficient of permeability, cm/s;

a = inside cross-sectional area of the buret, cm^2

L= average thickness of the test specimen, cm;

A= average cross-sectional area of the test specimen, cm^2

t = elapsed time between h_1 and h_2, s;

h_1= initial head across the test specimen, cm;

h_2= final head across the test specimen, cm;

t_c = temperature correction for viscosity of water; see Table 1.

A temperature of 20°C (68°F) is used as the standard.

8.2 h_1 and h_2 are the dimensions shown in Figure 1.

NOTE 5: It is beneficial to determine a set of constant dimensional values for a particular permeameter. The dimensions from the underside of the top cap assembly to the lower timing mark and from the underside of the top cap assembly to the upper timing mark are constants. Add the average specimen thickness to these two dimensions and h_1 and h_2 are determined. If the test is stopped at a mark other than the 0-ml lower mark, then add the difference to the h_2 value to arrive at the new h_2 value for this sample. It is helpful to create a spreadsheet that will calculate these values and permeability values automatically.

8.3 For each sample, the coefficient of permeability is computed based on the time and lower mark recorded in 7.8. The result is reported in whole units x 10^{-5} cm/s.

Table 1 – Temperature Correction Factors for Viscosity of Water

°C	°F	*Factor*
10	50	1.30
11	51.8	1.26
12	53.6	1.23
13	55.4	1.20
14	57.2	1.16
15	59	1.13
16	60.8	1.10
17	62.6	1.08
18	64.4	1.05
19	66.2	1.02
20	68	1.00
21	69.8	0.98
22	71.6	0.95
23	73.4	0.93
24	75.2	0.91
25	77	0.89
26	78.8	0.87
27	80.6	0.85
28	82.4	0.83
29	84.2	0.82
30	86	0.80
31	87.8	0.78
32	89.6	0.77
33	91.4	0.75
34	93.2	0.74
35	95	0.72

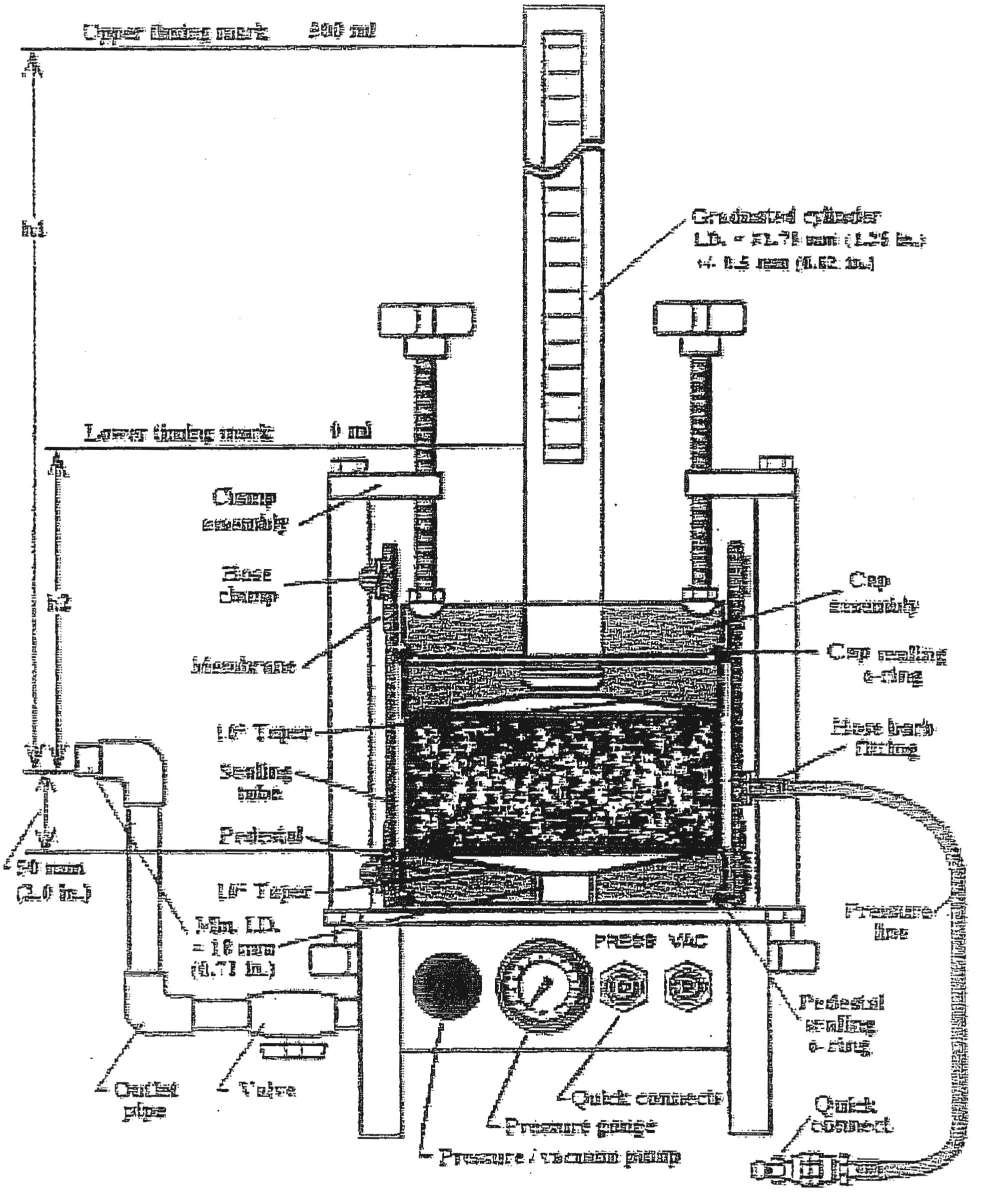

FIG. 1 Water Permeability Testing Apparatus (not to scale)

of the graduated cylinder mentioned previously in 6.1.1. The underside of the cap assembly should be tapered at an angle of 10 ± 1° (see Fig. 1).

6.1.4 A pedestal plate for supporting the asphalt concrete specimen and expanding an o-ring against the sealing tube. The opening in the pedestal plate should have a minimum diameter of 18 mm (0.71 in.). The top side of the lower cap should be tapered at an angle of 10 ± 1° (see Fig. 1).

6.1.5 O-rings of sufficient diameter and thickness for maintaining a seal against the sealing tube.

6.1.6 A frame and clamp assembly for supplying a compressive force to the cap assembly and pedestal plate necessary to expand the o-rings.

6.1.7 An air pump capable of applying 103 kPa (15 psi) pressure to the specimen as well as vacuum to evacuate the air from the sealing tube/membrane cavity.

6.1.8 A pressure gage with range 0 to 103 kPa (15 psi) with ± 2 % accuracy.

6.1.9 Quick connects for both vacuum and pressure lines.

6.1.10 An outlet pipe, 50.8 mm (2.0 in.) long with an inside diameter of 18 mm (0.71 in.).

6.1.11 Valve positioned upstream of the outlet pipe.

Note 1—A device manufactured by the Karol-Warner Company has been found to meet the above specifications.

6.2 *Vacuum Container, Type E*, described in Test Method D 2041.

6.3 *Vacuum Pump*, specified in Test Method D 2041.

6.4 *Manometer or Pressure Regulator*, specified in Test Method D 4867/D 4867M.

6.5 *Spacer*, described in AASHTO T 283.

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NORTH CAROLINA TEST METHOD

For

DETERMINING OPTIMUM ASPHALT CONTENT FOR OPEN-GRADED BITUMINOUS PAVING MIXTURES

Designation: North Carolina Test Method A-101

The purpose of this test is to determine the optimum asphalt content for an open-graded bituminous mix using the most current test methods.

TEST METHOD A

1. SCOPE:

This method of design for open-graded bituminous mixtures (FC-1, FC-1 Modified, and FC-2 Modified) consists of four steps (some of which may be optional) including: mix design, draindown, permeability/porosity, and Cantabro loss test. These steps are used to determine the best gradation and optimum asphalt content for the open-graded friction coarse mixture. All materials used shall meet the requirements of Section 650 in the NCDOT Standard Specifications.

2. REFERENCED DOCUMENTS

2.1 AASHTO Standards

M231, Weighing Devices used in the Testing of Materials

T96, Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine

T209, Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures

T312, Preparing and Determining the Density of Hot-Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor

T305, Determination of Draindown Characteristics in Uncompacted Asphalt Mixtures

2.1 ASTM Standards

D6752, Standard Test Method for Bulk Specific Gravity and Density of Bituminous Mixtures using Automatic Vacuum Sealing Method

2.2 North Carolina Department of Transportation Standards Specifications for Roads and Structures, 2012, Section 650

2.3 North Carolina Test Method For Measurement Of Water Permeability Of Compacted Asphalt Paving Mixtures, Designation A-100

2.4 NCHRP Report 673 – A Manual for Design of Hot Mix Asphalt with Commentary

3. APPARATUS:

The apparatus required shall consist of the following:

3.1 Oven – Thermostatically controlled to ± 3°C for heating aggregates, binder, HMA and equipment as required.

3.2 Balance – A balance meeting the requirements of AASHTO M231, Class G 5 for determining mass of aggregates, binders, and HMA.

3.3 Superpave Gyratory Compactor – An approved Superpave gyratory compactor meeting the requirements of AASHTO T312.

3.4 Standard 2.36 mm wire mesh basket (2) – meeting the dimensions shown in AASHTO T305 and NCHRP 673 p. 204

3.5 Los Angeles Machine – meeting the requirements of ASTM C131, Section 6.1

3.6 Vacuum Sealing device – meeting the requirements of ASTM D 6752, Section 4.4 and 4.5. (The Corelok device is suitable for this test)

3.7 Falling head permeameter – meeting the requirements of NCDOT Test Method A-100.

4. OGAFC MIX DESIGN CRITERIA

4.1 Design the open-graded asphalt friction course utilizing a mixture of coarse and fine aggregates, recycled materials, asphalt binder, mineral filler, mineral fiber, fiber stabilizing additive and other additives as required to produce a mix meeting the requirements of Table 650-1 of the Standard Specifications.

5. STEP 1- GYRATORY DESIGN METHOD

5.1 The following procedure is suggested for the design:

5.1.1 Combine aggregate at the proper percentages to meet the gradation requirements of table 650-1. Weigh the appropriate aggregate fractions into a separate pan and combine them to the desired batch weight. Weight should be adjusted to obtain specimens 115 ± 5 mm in height.

5.1.2 For neat asphalts, the mixing and compaction temperatures are determined by the viscosity of the asphalt. For polymer modified binders, refer to the asphalt binder supplier's guidelines for mixing and compaction temperatures. Heat aggregate batches and binder to no more than 28° C higher than the mixing temperature. Heat molds to the compaction temperature.

5.1.3 Mix aggregate with asphalt at three asphalt contents in 0.5 % intervals. Three specimens should be compacted at the nearest 0.5% interval to optimum and three specimens each at both 0.5% above and below the mid- interval. Estimated optimum should be between 6.0% and 7.0% AC (based on past experience).

5.1.4 Use a mechanical mixer to mix the batches. Mix the batch longer than the time required for conventional mixes so that the stabilizing fibers are well mixed and coated with liquid. Condition the mix at compaction temperature for 2 hours when using aggregates with water absorption less than 2%, or for 4 hours when aggregates have more than 2% water absorption. After conditioning, compact the specimens using 50 gyrations in the Superpave Gyratory compactor.

5.1.5 The specimens should be cooled for a period of 5 to 10 minutes in front of a fan before extruding them from the mold.

5.2 Density Procedure

5.2.1 Determine the maximum specific gravity (G_{mm}) of the loose mix in accordance with AASHTO T209 using a companion sample mixed with the middle increment AC content. Remember to condition this sample the same as the bulk gravity samples.

5.2.2 Determine the bulk specific gravity (G_{mb}) using the vacuum sealing procedure in accordance with ASTM 6752. Also determine the percent porosity using the procedure and spreadsheet provided with the device.

OR

5.2.3 Determine the density of a regular shaped specimen of compacted mixture from its dry mass (in grams) and its volume in cubic centimeters obtained from its dimensions for height and radius.

For 150 mm gyratory specimens:

Density = W ÷ V = W ÷ (A x h) = W ÷ (176.71 x h)

Gmb = Density ÷ 0.99707, the density of water @ 77 °F or 25 °C

W = Weight of specimen in grams

h = height in centimeters

5.2.4 Calculate the percent voids, VMA, and VFA.

5.2.5 Plot VMA curve versus A.C. content.

6. DRAINDOWN DETERMINTATION

6.1 Perform the draindown tests in accordance with the QMS Manual. (Ref.: AASHTO T305, Section 7).

6.2 For convenience, one extra specimen (approximately 4800 - 5000 grams) should be mixed at each increment for use in the draindown tests. (See Section 5.1.1). The actual test size of the sample placed into the basket should be 1200 ± 200 grams.

6.3 The design criteria given for draindown is for a test temperature that is 15°C higher than the anticipated production temperature.

7. LABORATORY PERMEABILITY (Optional)

7.1 Perform lab permeability test on each compacted specimen using the falling head permeameter meeting the requirements of NCDOT Test Method A-100.

7.2 For each increment, follow the test procedures outlined in North Carolina DOT Test Method A-100.

7.3 The average of the three specimens shall meet the requirements of Table 1 below.

8. RESISTANCE TO ABRASION – CANTABRO TEST ON UNAGED SPECIMENS (Optional)

8.1 The gyratory compacted specimens compacted in Step 5.1.3 shall be tested individually and the percent loss will be averaged for each increment. The procedure below should be followed for un-aged specimens:

8.1.1 The mass of the specimens shall be determined to the nearest 0.1 gram and recorded as P_1.

8.1.2 The specimen is then placed in the Los Angeles Machine without the charge of steel balls.

8.1.3 The operating temperature is usually 77 °F (25°C).

8.1.4 The machine is set for 300 revolutions at a speed of 30 to 33 rpm.

8.1.5 After the test is complete, the specimen will be removed and the mass, P_2, shall be recorded to the nearest 0.1 gram. The percent loss (P) is calculated according the to the formula:

$$P = [(P_1 - P_2) \div P_1] \times 100$$

8.1.6 The percent loss shall meet the requirements listed in Table 1 below.

9. DETERMINING OPTIMUM AC CONTENT

9.1 After completion of the mix design, draindown, permeability/porosity and Cantabro tests, the optimum AC content can be determined based on the minimums and maximums listed in the table below.

Table 1

Criteria	Minimum	Maximum
% VTM, vacuum	16%	-
% VTM, dimensional	18%	-
% Draindown	-	0.3
Permeability, m/d % Porosity	100 *15%	-
Cantabro, % loss (unaged specimens)	-	15 - 20

*proposed (for information only at this time)

9.2 Choose a reasonable design AC content based on the above criteria.

9.3 TSR tests are not required by NCDOT specifications.

Consensus Aggregate Test Procedures Training

Section 1 - Test Procedures for Fine Aggregate Angularity, Sand Equivalency, and Flat and Elongated Aggregate Tests.

A. Fine Aggregate Angularity
B. Specific Gravity of Fine Aggregate
C. Flat and Elongated
D. Sand Equivalent

Section 2 - Checklist for QA Supervisors - used to check technicians interested in taking the DOT Superpave Mix Design Certification Class.

1A. Sampling procedure

1. Fine Aggregate Angularity Procedure Checklist
2. Fine Aggregate Specific Gravity Checklist
3. Flat and Elongated Checklist
4. Sand Equivalent Procedure Checklist

Section 1 - Test Procedures

- TEST PROCEDURES FOR FINE AGGREGATE ANGULARITY, SPECIFIC GRAVITY OF FINE AGGREGATE, SAND EQUIVALENCY, AND FLAT AND ELONGATED AGGREGATE TESTS.

*Equipment and procedures for these tests are detailed in the AASHTO or ASTM standards and the following procedures should be used as guidelines only. If there are any discrepancies, refer to the proper specification in the Standards manual. The step numbers (*italics)* are taken from the actual standards manual.

A. Fine Aggregate Angularity (AASHTO TP-33, ASTM C1252-93)

Description - Analysis of void content to provide an indication of an aggregate's angularity, sphericity, and surface texture compared with other fine aggregates tested in the same grading.

1.2.1. Standard Graded Sample (Method A) - This method uses a standard fine aggregate grading that is obtained by combining individual sieve fractions from a typical fine aggregate sieve analysis. The grading is as follows:
(*9.1*)

Individual Size Fraction	Mass, g
2.36 mm (No.8) to 1.18 mm (No. 16)	44
1.18 mm (No. 16) to 0.600 mm (No.30)	57
0.600 mm (No.30) to 0.300 µm (No.50)	72
0.300 mm (No.50) to 0.150 mm (No. 100)	17
	190

The tolerance on each of these amounts is ± 0.2 g.

9.4 The bulk specific gravity of this material is needed in order to calculate the results. Test Method C128 (Specific Gravity of Fine Aggregate) will have to be performed on the -4.75 mm (-No. 4) material. This test method will be covered in the next section.

Note: The cylindrical measure should be calibrated and the volume printed on the cup itself. If this cup is not calibrated, please follow the procedure (*8.1*) in the test method specification (ASTM C1252-93).

Procedure

10.1 Mix each test sample with a spatula until it appears to be well mixed. Use a finger to block the opening in the funnel. Pour the test sample into the funnel. Level off with a spatula. Remove the finger and allow the sample to fall freely into the cylindrical measure.

10.2 After the funnel empties, strike off excess fine aggregate from the cylindrical measure with a single pass of the spatula. Until the strike off is complete, avoid vibration or any disturbance that could cause compaction of the fine aggregate. Brush adhering grains from the outside of the container and determine the mass of the cylindrical measure and its contents to the nearest 0.1 g. Retain all fine aggregate particles for a second test run.

10.3 Recombine the sample from the pan and the cylindrical measure and repeat procedure 2 more times. Record all necessary information on the worksheet provided. Follow calculations on worksheet to obtain results.

B. Fine Aggregate Specific Gravity (AASHTO T 84, ASTM C 128)

Description – This method covers the determination of bulk and apparent specific gravity and absorption of fine aggregate, -4.75 mm (- No. 4 material), for use in the Fine Aggregate Angularity test.

Procedure

6.1 Obtain approximately 1000 grams of the oven dried fine aggregate, following sampling procedures from Section 2 below.

6.1.1 Soak material in water for 15 – 19 hours.

6.2 After soak time, decant excess water, spread in a pan and expose to a gentle moving current of air from a fan and allow to dry to saturated surface dry (SSD) condition.

6.2.1 The **SSD condition is reached** when the material slumps when the inverted cone is removed after light compaction. The compaction procedure is as follows:

- Fill inverted cone with fine aggregate until it overflows
- Tamp specimen 10 times.
- Refill, then tamp 10 more times, refill, tamp 3 times, refill, and tamp 2 more times.
- Level off top of cone, remove loose material from the base, and lift mold vertically. Repeat until SSD is reached.

- **When SSD condition is met, proceed to next section (*7)***

7.2 Partially fill the pycnometer with water. Introduce into the pycnometer 500 ± 10 grams of SSD fine aggregate. Then fill with additional water, about 90% of capacity, not to white line. Roll, and agitate the pycnometer to release all the air bubbles. Next fill to white line. Determine total mass of the pycnometer, sample and water and record on M&T 622 SP. Complete calculations for the bulk dry specific gravity, bulk SSD specific gravity, apparent specific gravity, and percent absorption.

C. Flat and Elongated Particle Test (ASTM 4791)

To be performed on +4.75 mm (+No. 4) material.
The test should be run on approximately 100 pieces of each size fraction to retain at least 10% after gradation, at a caliper ratio of 5:1.

Procedure

8.4 Flat and Elongated Particle test - Test each of the particles in each size fraction and place in one of two groups: (1) flat and elongated or (2) not flat and elongated.

8.4.2 Set the larger opening equal to the particle length (maximum dimension). The particle is flat and elongated if the thickness (minimum dimension) can be placed in the smaller opening.

- Using form M&T 621-SP, weigh the flat and elongated particles and record the weight in the proper column for each size fraction tested. Perform the calculations according to the instructions on M&T 621-SP.

Instructions for M&T 621SP:

- Presently, test is always run at 5:1.
- Column 1, Percent Retained, is taken from blend gradation which is on M&T Form 601(SP).
- Column 2, Ratio, is calculated using the simple formula at the bottom of the page.
- The weight, column 3, is the weight of approximately 100 pieces of each particular size fraction of aggregate.
- Weight Flat and Elongated, column 4, is the weight of the failing particles, to the nearest 0.1 g.
- Column 5, % Flat or Elongated, is calculated using the formula at the bottom of the page. For a sieve size not tested (less than 10% retained), assume that it has the same percentage of flat and elongated particles as the next smaller or next larger size. An example has been included at the end.
- For the final column, use simple multiplication and add your results to obtain the Total Percent Flat or Elongated.

D. Sand Equivalent Test (AASHTO T 176)

Description – Used to show relative proportions of fine dust or claylike materials in graded aggregates. It is to be performed on materials passing the 4.75 mm sieve (- No. 4). Follow the sampling procedures in Section 2 to obtain the proper amount of aggregate for this test.

Procedure

5.1 Siphon 4.0 ± 0.1 in. of the calcium chloride solution into the graduated cylinder. Pour the prepared sample from the tin cup into the cylinder using a funnel. Tap the cylinder sharply on the heel of the hand to release air bubbles and to help promote thorough wetting of the sample.

5.2 Allow wetted sample to stand undisturbed for 10 ± 1 minutes. After 10 minutes, stopper the cylinder, then loosen the material from the bottom by partially inverting the cylinder and shaking simultaneous.

5.3 After loosening the material from the bottom of the cylinder, shake the cylinder and contents in the mechanical shaker for 45 ± 1 seconds.

5.4 After the shaking operation, remove the stopper.

5.5 Insert the irrigator tube into the cylinder and rinse the material from the walls as it is lowered. Force the irrigator through the material to the bottom of the cylinder by applying a stabbing and twisting action while the solution flows from the irrigator tip. Continue this motion until the cylinder is filled to the 15 in. line. Remove the irrigator tube.

5.6 Allow the cylinder and contents to sit for 20 minutes ± 15 seconds. Start the timing immediately after withdrawing the irrigator tube.

5.7 After the 20 minute soak period, read and record the level of the top of the clay suspension. This is the clay reading. If no clear line has formed, let the sample sit until one can be obtained. Do not exceed 30 minutes.

5.8.1 After the clay reading has been taken, lower the weighted foot assembly into the cylinder, being careful not to touch the side. When the foot comes to a rest, take the reading at the indicator, then subtract 10 in., this is the sand reading.

- If the reading falls between the small graduations on the cylinder, record the level of the higher graduation.

6.1 Record the clay and sand reading in the appropriate section on form M&T 620SP, and perform calculations.

Section 2 - Checklist for QA Supervisors

Description - This checklist will be used by the QA Supervisors to insure the Contractors technicians are competent in the Aggregate Consensus tests before they can be approved to take the NCDOT Mix Design Certification Class. In order for consistency in reporting results, use forms M&T 620-SP and M&T 621-SP to record all results.

1A. Sampling Procedure

In order for each test to be performed properly, a minimum sample of 5000 grams shall be used. The sample shall be taken from either a mix design sample with no asphalt added, or a sample which has been run through the ignition furnace. For each test the proper amount and size fraction are as follows:

Test	Size Fraction	Amount
Fine Aggregate Angularity*	- 4.75 mm (No. 4)	1000 g
Sand Equivalent	- 4.75 mm (No. 4)	3 oz. cup full
Flat and Elongated	+ 4.75 mm (No. 4)	All
Fine Aggregate Specific Gravity	- 4.75 mm (No. 4)	1000 g

* For Fine Aggregate Angularity, sample must be washed, then re-sieved over Nos. 8, 16, 30, 50, and 100 sieves, with the No. 8 material discarded. The specific weights from the Nos. 16, 30, 50 and 100 are as follows:

Sieve	Weight	Accumulated Weight
1.18 mm (No. 16)	44	44
0.600 mm (No. 30)	57	101
0.300 mm (No. 50)	72	173
0.150 mm (No. 100)	17	190

Consensus Aggregate Properties Test Procedures Checklist

DATE: ____________________

NAME: ______________________________

S.S. NO.: ______________ QMS CERTIFICATION NO.: __________

AGENCY/COMPANY: ____________________ DOT DIVISION: _____

QA SUPERVISOR: ____________________

1. Fine Aggregate Angularity Procedure Checklist

Things to check for while observing test:

- Has sample been weighed correctly, into proper size fractions?
- Is blend well mixed?
- Has cylindrical measure been calibrated?
- Does sample flow freely?
- Has cup been brushed off completely?
- Weighed properly?
- Are results acceptable (i.e. all three runs relatively close)?

Test has been performed satisfactorily: ______ QA Supervisor (initial) ______

2. Fine Aggregate Specific Gravity

Things to check for while observing test:

- Is sample at SSD condition? Does is pass provisional cone test?
- Has at least 500 grams of material been put into flask?
- Are all air bubbles gone?
- Have proper weights been recorded on work sheet?
- Has sample been saved for dry-back?
- Are calculations correct? Do results look reasonable?

Test has been performed satisfactorily: ______ QA Supervisor (initial) ______

3. Flat and Elongated Particle Procedure Checklist

Things to check for while observing test:

- Are % retained calculations correct?
- Is caliper set at proper ratio (5:1) ?
- Are the particles being measured properly?
- Do results look okay? (i.e. within acceptable range?)

Test has been performed satisfactorily: ______ QA Supervisor (initial) ______

4. Sand Equivalent Procedure Checklist

Things to check for while observing test:

- Is solution mixed properly and is it homogeneous?
- Has aggregate been sampled properly? (i.e. in a 3 oz. cup?)
- Is plastic cylinder filled to 4 in. line?
- Has technician tapped bottom of cylinder to release air?
- Let sit 10 minutes.
- Shaken in mechanical shaker for 45 seconds?
- Filled to 15 in. line and allowed to sit for 20 minutes?
- Are calculations correct?

Test has been performed satisfactorily: ______ QA Supervisor (initial) ______

Comments: ____

____

____

____

____

Technician has successfully performed all required tests and is approved for enrollment in the NCDOT Mix Design Class Certification.

QA Supervisor Date

M&T 621-SP *EXAMPLE* 8/4/98

NORTH CAROLINA DEPARTMENT OF TRANSPORTATION
MATERIALS & TEST UNIT

STANDARD TEST FOR FLAT OR ELONGATED PARTICLES (+ 4.75 mm)

DATE: ____________

SAMPLE NO. ____________________

MATERIAL ____________________

COUNTY ____________________

SOURCE ____________________

CALIPER RATIO (CIRCLE) : [✓ 5:1] 4:1 3:1 2:1

SIEVE	% RETAINED [A]	RATIO [C] = [A]/[B]	WEIGHT [D]	WT. FLAT & ELONG. [E]	% FLAT OR ELONG. [F] = [E]/[D] x 100	[F] x [C]
37.5 mm (1 1/2")						
25.0 mm (1")	8	0.143	-	-	6.9***	0.99
19.0 mm (3/4")	13	0.23	175*	12**	6.9	1.59
12.5 mm (1/2")	24	0.43	225*	15**	6.7	2.88
9.5 mm (3/8")	7	0.13	-	-	6.7***	0.87
4.75 mm (No. 4)	4	0.07	-	-	6.7***	0.47

56 ← TOTAL PERCENT RETAINED [B]

TOTAL % FLAT OR ELONGATED = 6.8%

[A] – OBTAINED FROM GRADATION SHEET

RATIO [C] = % RETAINED /TOTAL PERCENT RETAINED = [A]/[B]

[D] – *NUMBERS ARE OBTAINED BY WEIGHING APPROXIMATELY 100 PIECES OF AGGREGATE

[E] – **NUMBERS ARE OBTAINED BY WEIGHING AGGREGATE THAT FAILS

% FLAT AND ELONGATED [F] = WT. FLAT & ELONG [E] / WEIGHT [D] = [E]/[D] x 100

***NUMBERS ARE OBTAINED BY USING THE PERCENTAGE FROM THE NEXT SIEVE SIZE, ABOVE OR BELOW, WHEN A SIEVE DOES NOT HAVE AT LEAST 10% RETAINED.

TOTAL % FLAT OR ELONGATED = SUM OF { % FLAT OR ELONGATED [F] x RATIO [C] = [F] x [C]}

M&T 621-SP **8/4/98**

NORTH CAROLINA DEPARTMENT OF TRANSPORTATION
MATERIALS & TEST UNIT

STANDARD TEST FOR FLAT OR ELONGATED PARTICLES (+ 4.75 mm)

DATE: ____________

SAMPLE NO. ____________________

MATERIAL ____________________

COUNTY ____________________

SOURCE ____________________

CALIPER RATIO (CIRCLE) : 5:1 4:1 3:1 2:1

SIEVE	% RETAINED [A]	RATIO [C] = [A]/[B]	WEIGHT [D]	WT. FLAT & ELONG. [E]	% FLAT OR ELONG. [F] = [E]/[D] x 100	[F] x [C]
37.5 mm (1 1/2")						
25.0 mm (1")						
19.0 mm (3/4")						
12.5 mm (1/2")						
9.5 mm (3/8")						
4.75 mm (No. 4)						

____________ ← **TOTAL PERCENT RETAINED [B]**

TOTAL % FLAT OR ELONGATED = __________

[A] – OBTAINED FROM GRADATION SHEET

RATIO [C] = % RETAINED /TOTAL PERCENT RETAINED = [A]/[B]

[D] – NUMBERS ARE OBTAINED BY WEIGHING APPROXIMATELY 100 PIECES OF AGGREGATE

[E] – NUMBERS ARE OBTAINED BY WEIGHING AGGREGATE THAT FAILS

% FLAT AND ELONGATED [F] = WT. FLAT & ELONG [E] / WEIGHT [D] = [E]/[D] x 100 ***

> ***NUMBERS ARE OBTAINED BY USING THE PERCENTAGE FROM THE NEXT SIEVE SIZE, ABOVE OR BELOW, WHEN A SIEVE DOES NOT HAVE AT LEAST 10% RETAINED.

TOTAL % FLAT OR ELONGATED = SUM OF {% FLAT OR ELONGATED [F] x RATIO [C] = [F] x [C]}

M&T 620-SP **3/31/98**

NORTH CAROLINA DEPARTMENT OF TRANSPORTATION

MATERIALS & TESTS UNIT

TEST FOR UNCOMPACTED VOID CONTENT (FAA)

*** TEST METHOD A *** DATE: ________________

SAMPLE NO. ____________________
COUNTY ____________________
PROJECT NO. ___ . ________________
CUP VOLUME [V] ______.______ ml

MATERIAL ________________________
SOURCE ________________________
BULK DRY S.G. [G] ____. ____________
CUP WEIGHT [B] ________.________ g

RUN	WEIGHT OF CUP+SAMPLE [A]	WEIGHT OF SAMPLE [W]=(A-B)	W/G	% VOIDS {[V-(W/G)]/V} x 100

UNCOMPACTED VOID CONTENT = AVERAGE (1, 2, 3) → ____________________%

SAMPLE PREPARATION:

INDIVIDUAL SIEVE WEIGHTS		**ACCUMULATED WEIGHTS**
NO. 16	44 GRAMS	44 GRAMS
NO. 30	57 GRAMS	101 GRAMS
NO. 50	72 GRAMS	173 GRAMS
NO. 100	17 GRAMS	190 GRAMS

SAND EQUIVALENT TEST (- 4.75 mm, -No.4)

SAMPLE NO. ____________________

MATERIAL ________________________
SOURCE ________________________

SAND EQUIVALENT = (SAND READING X 100) / CLAY READING

CLAY READING [C] = ____________________
SAND READING [S] = ____________________

SE = {[S] X 100}/ [C] = ____________________

S.E. = ________________

FLAT OR ELONGATED PARTICLE TEST (+4.75 mm, +No. 4)

SAMPLE NO. ____________________
CALIPER RATIO (CIRCLE): 5:1 4:1 3:1 2:1

MATERIAL ________________________
SOURCE ________________________

TOTAL % FLAT OR ELONGATED* = ____________________ (*FROM M&T 621-SP)

FINE AGGREGATE SPECIFIC GRAVITY

LAB NO.: ____________________ DATE: ________________________

PROJECT NO.: ____________________ SOURCE: ______________________

MATERIAL: ____________________ TESTED BY: ___________________

			INITIAL ANALYSIS	CHECK ANALYSIS
FLASK NUMBER:				
FLASK WEIGHT:		(2)		
FLASK & SSD WEIGHT:		(1)		
SSD WEIGHT:	(1) – (2)	[B]		
FLASK, SSD, & WATER WT.:		(3)		
FLASK & WATER WEIGHT:		(4)		
WET WEIGHT:	(3) – (4)	[C]		
AGGREGATE & PAN WEIGHT:		(5)		
PAN TARED WEIGHT:		(6)		
OVEN DRIED WEIGHT:	(5) – (6)	[A]		
B – C				
A – C				
B – A				

BULK DRY SPECIFIC GRAVITY

$$\frac{A}{B - C}$$ ____________ ____________

BULK SSD SPECIFIC GRAVITY

$$\frac{B}{B - C}$$ ____________ ____________

APPARENT SPECIFIC GRAVITY

$$\frac{A}{A - C}$$ ____________ ____________

PERCENT ABSORPTION

$$\frac{B - A}{A} \times 100$$ ____________ ____________

Standard Method of Test for

Specific Gravity of Soils

AASHTO Designation: T 100-06 (2010)[1]
ASTM Designation: D 854-00

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444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

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Standard Method of Test for

Specific Gravity of Soils

AASHTO Designation: T 100-06 (2010)[1]
ASTM Designation: D 854-00

1. SCOPE

1.1. This method covers determination of the specific gravity of soils by means of a pycnometer. When the soil is composed of particles larger than the 4.75-mm (No. 4) sieve, the method outlined in T 85 shall be followed. When the soil is composed of particles both larger and smaller than the 4.75-mm sieve, the sample shall be separated on the 4.75-mm sieve and the appropriate test method used on each portion. The specific gravity value for the soil shall be the weighted average of the two values (Note 1). When the specific gravity value is to be used in calculations in connection with the hydrometer portion of AASHTO T 88, Particle Size Analysis of Soils, it is intended that the specific gravity test be made on that portion of the soil that passes the 2.00-mm (No. 10) sieve.

1.2. The following applies to all specified limits in this standard: For the purposes of determining conformance with these specifications, an observed value or a calculated value shall be rounded off "to the nearest unit" in the last right-hand place of figures used in expressing the limiting value, in accordance with ASTM E 29.

Note 1—The weighted average specific gravity should be calculated using the following equation:

$$G_{avg} = \frac{1}{\frac{R_1}{100G_1} + \frac{P_1}{100G_2}} \qquad (1)$$

where:

G_{avg} = weighted average specific gravity of soils composed of particles larger and smaller than the 4.75-mm (No. 4) sieve,

R_1 = percent of soil particles retained on the 4.75-mm sieve,

P_1 = percent of soil particles passing the 4.75-mm sieve,

G_1 = apparent specific gravity of soil particles retained on the 4.75-mm sieve as determined by AASHTO T 85, and

G_2 = specific gravity of soil particles passing the 4.75-mm sieve as determined by this test method.

1.3. The values stated in SI units are to be regarded as the standard.

1.4. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

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2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- M 145, Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes
- M 146, Terms Relating to Subgrade, Soil-Aggregate, and Fill Materials
- M 231, Weighing Devices Used in the Testing of Materials
- T 85, Specific Gravity and Absorption of Coarse Aggregate
- T 88, Particle Size Analysis of Soils

2.2. *ASTM Standards*:

- C 127, Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate
- D 653, Standard Terminology Relating to Soil, Rock, and Contained Fluids
- D 2487, Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
- D 4753, Standard Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing
- D 6026, Standard Practice for Using Significant Digits in Geotechnical Data
- E 1, Standard Specification for ASTM Liquid-in-Glass Thermometers
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

3. DEFINITION

3.1. *specific gravity*—The ratio of the mass of a unit volume of a material at a stated temperature to the mass of the same volume of gas-free distilled water at a stated temperature (per Definition, E 1547).

4. SIGNIFICANCE AND USE

4.1. The specific gravity of a soil is used in almost every equation expressing the phase relationship of air, water, and solids in a given volume of material.

4.2. The term *solid particles*, as used in geotechnical engineering, is typically assumed to mean naturally occurring mineral particles that are not very soluble in water. Therefore, the specific gravity of materials containing extraneous matter (such as cement, lime, etc.), water-soluble matter (such as sodium chloride), and soils containing matter with a specific gravity of less than one, typically require special treatment or a qualified definition of specific gravity.

5. APPARATUS

5.1. *The apparatus shall consist of the following*:

5.1.1. *Pycnometer*—Either a volumetric flask having a capacity of at least 100 mL or a stoppered bottle having a capacity of at least 50 mL (Note 2). The stopper shall be of the same material as the bottle, and of such size and shape that it can be easily inserted to a fixed depth in the neck

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of the bottle, and shall have a small hole through its center to permit the emission of air and surplus water.

Note 2—The use of either the volumetric flask or the stoppered bottle is a matter of individual preference, but in general, the flask should be used when a larger sample than can be used in the stoppered bottle is needed due to maximum grain size of the sample. A 500-mL flask is required for samples of clayey soils containing their natural moisture content. (See Section 8.2.)

5.1.2. *Balance*—Either an M 231, Class G 1 balance for use with the volumetric flask, or an M 231, Class B balance for use with the stoppered bottle.

5.1.3. *Oven*—A thermostatically controlled drying oven capable of maintaining a temperature of 110° ± 5°C (230 ± 9°F).

5.1.4. *Thermometer*—Capable of measuring the temperature range within which the test is being performed, graduated in a 0.5°C (1.0°F) division scale and meeting the requirements of ASTM E 1 or any other thermometric device of equal accuracy, precision, and sensitivity.

6. GENERAL REQUIREMENTS FOR WEIGHING

6.1. When the volumetric flask is used in the specific gravity determination, all masses shall be determined to the nearest 0.01 g. When the stoppered bottle is used in the specific gravity determination, all masses shall be determined to the nearest 0.001 g.

7. CALIBRATION OF PYCNOMETER

7.1. The pycnometer shall be cleaned, dried, weighed, and the mass recorded. The pycnometer shall be filled with distilled water (Note 3) essentially at room temperature. The mass of the pycnometer and water, W_a, shall be determined and recorded. A thermometer shall be inserted in the water and its temperature, T_i, determined to the nearest whole degree.

Note 3—Kerosene is a better wetting agent than water for most soils and may be used in place of distilled water for oven-dried samples.

7.2. A table of values of mass W_a shall be prepared for a series of temperatures that are likely to prevail when the mass W_b of the pycnometer, sample, and water is determined at the end of testing (Note 4). These values of W_a shall be calculated as follows:

$$W_a\left(\text{at } T_x\right)=\left(\text{density of water at } T_x/\text{density of water at } T_i\right)\times\left(W_a\left(\text{at } T_i\right)-W_f\right)+W_f \qquad (2)$$

where:

W_a = mass of pycnometer and water, in grams;

W_f = mass of pycnometer, in grams;

T_i = observed temperature of water, in degrees Celsius; and

T_x = any other desired temperature, in degrees Celsius.

Note 4—This method provides a procedure that is most convenient for laboratories making many determinations with the same pycnometer. It is equally applicable to a single determination. Bringing the pycnometer and contents to some designated temperature when masses W_a and W_b are taken requires considerable time. It is much more convenient to prepare a table of masses W_a for various temperatures likely to prevail when masses W_b (see Section 9.3) are taken. It is important that masses W_a and W_b be based on water at the same temperature. Values for the relative density of water at temperatures from 18 to 30°C are given in Table 1.

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Table 1—Relative Density of Water and Correction Factor *K* for Various Temperatures

Temperatures, °C	Relative Density of Water	Correction Factor *K*
18	0.9986244	1.0004
19	0.9984347	1.0002
20	0.9982343	1.0000
21	0.9980233	0.9998
22	0.9978019	0.9996
23	0.9975702	0.9993
24	0.9973286	0.9991
25	0.9970770	0.9989
26	0.9968156	0.9986
27	0.9965451	0.9983
28	0.9962652	0.9980
29	0.9959761	0.9977
30	0.9956780	0.9974

8. SAMPLE

8.1. The soil to be used in the specific gravity test may contain its natural moisture or be oven-dried. The mass of the test sample on an oven-dry basis shall be at least 25 g when the volumetric flask is to be used, and at least 10 g when the stoppered bottle is to be used.

8.2. *Samples Containing Natural Moisture*—When the sample contains its natural moisture, the mass of the soil, W_o, on an oven-dry basis shall be determined at the end of the test by evaporating the water in an oven maintained at 110° ± 5°C (230 ± 9°F) (Note 5). Samples of clay soils containing their natural moisture content shall be dispersed in distilled water before placing in a 500-mL flask, using the dispersing equipment specified in T 88 (Note 6).

8.3. *Oven-Dried Samples*—When an oven-dried sample is to be used, the sample shall be dried for at least 12 hours, or to constant mass, in an oven maintained at 110° ± 5°C (230 ± 9°F) (Note 5), cooled to room temperature, then weighed and transferred to the pycnometer or transferred to the pycnometer and then weighed. Distilled water shall be added into the pycnometer in an amount that will provide complete sample coverage. The sample shall then soak for at least 12 hours.

Note 5—Drying of certain soils at 110°C may bring about loss of moisture of composition or hydration, and in such cases drying shall be done, if desired, in reduced air pressure and at a lower temperature.

Note 6—The minimum volume of slurry that can be prepared by the dispersing equipment specified in T 88 is such that a 500-mL flask is needed as the pycnometer.

9. PROCEDURE

9.1. The sample as prepared in Section 8 shall have distilled water added to a level that will cover the soil to a maximum of about three-fourths full in the volumetric flask, or about one-half full in the stoppered bottle (Note 7).

9.2. Remove entrapped air by either of the following methods: (1) subject the contents to a partial vacuum of 13.33 kPa (100 mm Hg) or less absolute pressure or (2) boil gently for at least 10 minutes, while occasionally rolling the pycnometer to assist in the removal of the air. Subjection of the contents to reduced air pressure may be done either by connecting the pycnometer directly to an aspirator or vacuum pump, or by use of a bell jar. Some soils boil violently when subjected

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to reduced air pressure. It will be necessary in those cases to reduce the air pressure at a slower rate or to use a larger flask (Note 8). Samples that are heated shall be cooled to room temperature.

Note 7—If the vacuum method of air removal is used, the required amount of distilled water may be added in layers, with each layer being subjected to the vacuum until the sample ceases to release air.

Note 8—When using a partial vacuum, agitate the flask gently at intervals during the evacuation process. (A) Samples containing natural moisture with high plasticity may require 6 to 8 hours to remove air; samples with low plasticity may require 4 to 6 hours to remove air. (B) Oven-dried samples may require 2 to 4 hours to remove air.

9.3. Fill the pycnometer with distilled water to its calibrated capacity and then clean the outside and dry with a clean, dry cloth. Determine the mass of the pycnometer and contents, W_b, and the temperature in degrees Celsius, T_x, of the contents as described in Section 7.

10. CALCULATION AND REPORT

10.1. Calculate the specific gravity of the soil, based on water at a temperature T_x, as follows:

$$\text{Specific Gravity, } T_x / T_x = W_o / \left[W_o + \left(W_a - W_b \right) \right] \tag{3}$$

where:

T_x = temperature of the contents of the pycnometer when mass W_b was determined, in degrees Celsius;

W_o = mass of sample of oven-dried soil in grams;

W_a = mass of pycnometer filled with water at temperature T_x (Note 9), in grams; and

W_b = mass of pycnometer filled with water and soil at temperature T_x, in grams.

Note 9—This value shall be taken from the table of values of W_a, prepared in accordance with Section 7.2, for the temperature prevailing when mass W_b was taken.

10.2. Unless otherwise required, specific gravity values reported shall be based on water at 20°C. The value based on water at 20°C shall be calculated from the value based on water at the observed temperature T_x, as follows:

$$\text{Specific Gravity, } T_x / 20^\circ\text{C} = K \times \text{ Specific Gravity, } T_x / T_x \tag{4}$$

where:

K = a number found by dividing the relative density of water at temperature T_x by the relative density of water at 20°C. Values for a range of temperatures are given in Table 1.

10.3. When it is desired to report the specific gravity value based on water at 4°C, such a specific gravity value may be calculated by multiplying the specific gravity value at temperature T_x by the relative density of water at temperature T_x.

10.4. When any portion of the original sample of soil is eliminated in the preparation of the test sample, the portion on which the test has been made shall be reported.

10.5. When using the volumetric flask to determine specific gravities, report results to at least the nearest 0.01.

10.6. When using the stoppered bottle to determine specific gravities, report results to at least the nearest 0.001.

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11. PRECISION AND BIAS

11.1. Criteria for judging the acceptability of specific gravity test results obtained by this test method on material passing the 4.75-mm (No. 4) or 2.00-mm (No. 10) sieve are given in Table 2 (see Note 10):

Table 2—Specific Gravity Test Results

Material and Type Index	Standard Deviation[a]		Acceptable Range of Two Results (Percent of Mean)[a]	
	ASTM[b] Passing 4.75 mm (No. 4)	AASHTO[c] Passing 2.00 mm (No. 10)	ASTM[b] Passing 4.75 mm (No. 4)	AASHTO[c] Passing 2.00 mm (No. 10)
Single-Operator precision:				
Cohesive soils	0.021	0.02	0.06	0.05
Noncohesive soils	[d]	[d]	[d]	[d]
Multilaboratory precision:				
Cohesive soils	0.056	0.04	0.16	0.11
Noncohesive soils	[d]	[d]	[d]	[d]

[a] These numbers represent, respectively, the (1s) and (d2s) limits as described in ASTM C 670 for Preparing Precision Statements for Test Methods for Construction Materials.

[b] These numbers represent standard deviation values assigned by ASTM Committee on Materials.

[c] These numbers represent standard deviation values assigned by AASHTO Subcommittee on Materials.

[d] Criteria for assigning standard deviation values for noncohesive soils are not available at the present time.

Note 10—The figures given in Column 2 are the standard deviations that have been found to be appropriate for the materials described in Column 1. The figures given in Column 3 are the limits that should not be exceeded by the difference between the results of two properly conducted tests.

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[1] Except for the requirements given for the thermometer, reporting accuracy, minimum sampling size and weighing, and our deletion of the desiccator, this method is the same as ASTM D 854-00.

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Standard Method of Test for

Specific Gravity and Absorption of Fine Aggregate

AASHTO Designation: T 84-10[1]
ASTM Designation: C 128-07a

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Standard Method of Test for

Specific Gravity and Absorption of Fine Aggregate

AASHTO Designation: T 84-10[1]
ASTM Designation: C 128-07a

1. SCOPE

1.1. This method covers the determination of bulk and apparent specific gravity, 23/23°C (73.4/73.4°F), and absorption of fine aggregate.

1.2. This method determines (after 15 hours in water) the bulk specific gravity and the apparent specific gravity, the bulk specific gravity on the basis of mass of saturated surface-dry aggregate, and the absorption.

1.3. The values stated in SI units are to be regarded as the standard.

1.4. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 6, Fine Aggregate for Hydraulic Cement Concrete
- M 231, Weighing Devices Used in the Testing of Materials
- T 2, Sampling of Aggregates
- T 11, Materials Finer Than 75-μm (No. 200) Sieve in Mineral Aggregates by Washing
- T 19M/T 19, Bulk Density ("Unit Weight") and Voids in Aggregate
- T 85, Specific Gravity and Absorption of Coarse Aggregate
- T 100, Specific Gravity of Soils
- T 133, Density of Hydraulic Cement
- T 248, Reducing Samples of Aggregate to Testing Size
- T 255, Total Evaporable Moisture Content of Aggregate by Drying

2.2. *ASTM Standards*:

- C 128, Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate
- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

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2.3. *IEEE/ASTM Standard:*

- SI 10, American National Standard for Use of the International System of Units (SI): The Modern Metric System

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3. TERMINOLOGY

3.1. *Definitions:*

3.1.1. *absorption*—the increase in the mass of aggregate due to water in the pores of the material, but not including water adhering to the outside surface of the particles, expressed as a percentage of the dry mass. The aggregate is considered "dry" when it has been maintained at a temperature of 110 ± 5°C for sufficient time to remove all uncombined water by reaching a constant mass.

3.1.2. *specific gravity*—the ratio of the mass (or weight in air) of a unit volume of a material to the mass of the same volume of gas-free distilled water at stated temperatures. Values are dimensionless.

3.1.2.1. *apparent specific gravity*—the ratio of the weight in air of a unit volume of the impermeable portion of aggregate at a stated temperature to the weight in air of an equal volume of gas-free distilled water at a stated temperature.

3.1.2.2. *bulk specific gravity*—the ratio of the weight in air of a unit volume of aggregate (including the permeable and impermeable voids in the particles, but not including the voids between particles) at a stated temperature to the weight in air of an equal volume of gas-free distilled water at a stated temperature.

3.1.2.3. *bulk specific gravity (SSD)*—the ratio of the mass in air of a unit volume of aggregate, including the mass of water within the voids filled to the extent achieved by submerging in water for approximately 15 hours (but not including the voids between particles) at a stated temperature, compared to the weight in air of an equal volume of gas-free distilled water at a stated temperature.

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4. SIGNIFICANCE AND USE

4.1. Bulk specific gravity is the characteristic generally used for calculation of the volume occupied by the aggregate in various mixtures containing aggregate including portland cement concrete, bituminous concrete, and other mixtures that are proportioned or analyzed on an absolute volume basis. Bulk specific gravity is also used in the computation of voids in aggregate in T 19M/T 19. Bulk specific gravity determined on the saturated surface-dry basis is used if the aggregate is wet, that is, if its absorption has been satisfied. Conversely, the bulk specific gravity determined on the oven-dry basis is used for computations when the aggregate is dry or assumed to be dry.

4.2. Apparent specific gravity pertains to the relative density of the solid material making up the constituent particles not including the pore space within the particles that is accessible to water. This value is not widely used in construction aggregate technology.

4.3. Absorption values are used to calculate the change in the mass of an aggregate due to water absorbed in the pore spaces within the constituent particles, compared to the dry condition, when it is deemed that the aggregate has been in contact with water long enough to satisfy most of the absorption potential. The laboratory standard for absorption is that obtained after submerging dry aggregate for approximately 15 hours in water. Aggregates mined from below the water table may have a higher absorption when used, if not allowed to dry. Conversely, some aggregates when

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used may contain an amount of absorbed moisture less than the 15 hours soaked condition: For an aggregate that has been in contact with water and that has free moisture on the particle surfaces, the percentage of free moisture can be determined by deducting the absorption from the total moisture content determined by T 255 by drying.

5. APPARATUS

5.1. *Balance*, conforming to the requirements of M 231, Class G 2.

5.2. *Pycnometer*—A flask or other suitable container into which the fine aggregate test sample can be readily introduced and in which the volume content can be reproduced with ±100 mm^3. The volume of the container filled to mark shall be at least 50 percent greater than the space required to accommodate the test sample. A volumetric flask of 500-mL capacity or a fruit jar fitted with a pycnometer top is satisfactory for a 500-g test sample of most fine aggregates. A Le Chatelier flask as described in T 133 is satisfactory for an approximately 55-g test sample.

5.3. *Mold*—A metal mold in the form of a frustum of a cone with dimensions as follows: 40 ± 3 mm inside diameter at the top, 90 ± 3 mm inside diameter at the bottom, and 75 ± 3 mm in height, with the metal having a minimum thickness of 0.8 mm.

5.4. *Tamper*—A metal tamper having a mass of 340 ± 15 g and having a flat circular tamping face 25 ± 3 mm in diameter.

6. SAMPLING

6.1. Sampling shall be accomplished in general accordance with T 2.

7. PREPARATION OF TEST SPECIMEN

7.1. Obtain approximately one kilogram of the fine aggregate from the sample using the applicable procedures described in T 248.

7.1.1. Dry it in a suitable pan or vessel to constant mass at a temperature of 110 ± 5°C (230 ± 9°F). Allow it to cool to comfortable handling temperature, cover with water, either by immersion or by the addition of at least 6 percent moisture to the fine aggregate and permit to stand for 15 to 19 hours.

7.1.2. As an alternative to Section 7.1.1, where the absorption and specific gravity values are to be used in proportioning concrete mixtures with aggregates used in their naturally moist condition, the requirement for initial drying to constant mass may be eliminated and, if the surfaces of the particles have been kept wet, the 15-hour soaking may also be eliminated.

Note 1—Values for absorption and for specific gravity in the saturated surface-dry condition may be significantly higher for aggregate not oven dried before soaking than for the same aggregate treated in accordance with Section 7.1.1.

7.2. Decant excess water with care to avoid loss of fines, spread the sample on a flat, nonabsorbent surface exposed to a gently moving current of warm air, and stir frequently to secure homogeneous drying. If desired, mechanical aids such as tumbling or stirring may be employed to assist in achieving the saturated surface-dry condition. As the material begins to dry sufficiently, it may be necessary to work it with the hands in a rubbing motion to break up any conglomerations, lumps, or balls of material that develop. Continue this operation until the test specimen approaches

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a free-flowing condition. Follow the procedure in Section 7.2.1 to determine whether or not surface moisture is present on the constituent fine aggregate particles. It is intended that the first trial of the cone test will be made with some surface water in the specimen. Continue drying with constant stirring, and if necessary, work the material with a hand-rubbing motion, and test at frequent intervals until the test indicates that the specimen has reached a surface-dry condition. If the first trial of the surface moisture test indicates that moisture is not present on the surface, it has been dried past the saturated surface-dry condition. In this case, thoroughly mix a few milliliters of water with the fine aggregate and permit the specimen to stand in a covered container for 30 minutes. Then resume the process of drying and testing at frequent intervals for the onset of the surface-dry condition.

7.2.1. *Cone Test for Surface Moisture*—Hold the mold firmly on a smooth nonabsorbent surface with the large diameter down. Place a portion of the partially dried fine aggregate loosely in the mold by filling until overflow occurs and heaping additional material above the top of the mold by holding it with the cupped fingers of the hand holding the mold. Lightly tamp the fine aggregate into the mold with 25 light drops of the tamper. Each drop should start about 5 mm (0.2 in.) above the top surface of the fine aggregate. Permit the tamper to fall freely under gravitational attraction on each drop. Adjust the starting height to the new surface elevation after each drop and distribute the drops over the surface. Remove loose sand from the base and lift the mold vertically. If surface moisture is still present, the fine aggregate will retain the molded shape. When the fine aggregate slumps slightly, it indicates that it has reached a surface-dry condition. Some angular fine aggregate or material with a high proportion of fines may not slump in the cone test upon reaching a surface-dry condition. This may be the case if fines become airborne upon dropping a handful of the sand from the cone test 100 to 150 mm onto a surface. For these materials, the saturated surface-dry condition should be considered as the point that one side of the fine aggregate slumps slightly upon removing the mold.

Note 2—The following criteria have also been used on materials that do not readily slump:

1. *Provisional Cone Test*—Fill the cone mold as described in Section 7.2.1 except only use 10 drops of the tamper. Add more fine aggregate and use 10 drops of the tamper again. Then add material two more times using three and two drops of the tamper, respectively. Level off the material even with the top of the mold; remove loose material from the base; and lift the mold vertically.
2. *Provisional Surface Test*—If airborne fines are noted when the fine aggregate is such that it will not slump when it is at a moisture condition, add more moisture to the sand, and at the onset of the surface-dry condition, with the hand lightly pat approximately 100 g of the material on a flat, dry, clean, dark, or dull nonabsorbent surface such as a sheet of rubber, a worn oxidized, galvanized, or steel surface, or a black-painted metal surface. After one to three seconds, remove the fine aggregate. If noticeable moisture shows on the test surface for more than one to two seconds, then surface moisture is considered to be present on the fine aggregate.
3. Colorimetric procedures described by Kandhal and Lee, *Highway Research Record No. 307*, p. 44.
4. For reaching the saturated surface-dry condition on a single-size material that slumps when wet, hard-finish paper towels can be used to surface dry the material until the point is just reached where the paper towel does not appear to be picking up moisture from the surfaces of the fine aggregate particles.

8. PROCEDURE

8.1. Make and record all mass determinations to 0.1 g.

8.2. Partially fill the pycnometer with water. Immediately introduce into the pycnometer 500 ± 10 g of saturated surface-dry fine aggregate prepared as described in Section 7, and fill with additional

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water to approximately 90 percent of capacity. Manually roll, invert, and agitate or use a combination of these actions to eliminate all air bubbles in the pycnometer (Note 3). Accomplish mechanical agitation by external vibration of the pycnometer in a manner that will not degrade the sample. A level of agitation adjusted to just set individual particles in motion is sufficient to promote de-airing without degradation. A mechanical agitator shall be considered acceptable for use if comparison tests for each six-month period of use show variations less than the acceptable range of two results (d2s) indicated in Table 1 from results of manual agitation on the same material. Adjust its temperature to 23.0 ± 1.7°C (73.4 ± 3°F), if necessary by immersion in circulating water, and bring the water level in the pycnometer to its calibrated capacity. Determine total mass of the pycnometer, specimen, and water.

Note 3—It normally takes about 15 to 20 minutes to eliminate air bubbles by manual methods. Dipping the tip of a paper towel into the pycnometer has been found to be useful in dispersing the foam that sometimes builds up when eliminating the air bubbles, or adding a few drops of isopropyl alcohol, after removal of air bubbles and just prior to bringing the water level to its calibrated capacity, has also been found useful in dispersing foam on the water surface. Do not use isopropyl alcohol when using the alternative method described in Section 8.2.1.

Table 1—Precision

	Standard Deviation (1s)[a]	Acceptable Range of Two Results (d2s)[a]
Single-operator precision:		
Bulk specific gravity (dry)	0.011	0.032
Bulk specific gravity (SSD)	0.0095	0.027
Apparent specific gravity	0.0095	0.027
Absorption,[b] percent	0.11	0.31
Multilaboratory precision:		
Bulk specific gravity (dry)	0.023	0.066
Bulk specific gravity (SSD)	0.020	0.056
Apparent specific gravity	0.020	0.056
Absorption,[b] percent	0.23	0.66

[a] These numbers represent, respectively, the (1s) and (d2s) limits as described in ASTM C 670. The precision estimates were obtained from the analysis of combined AASHTO Materials Reference Laboratory reference sample data from laboratories using 15- to 19-hour saturation times and other laboratories using 24 ± 4 hours of saturation time. Testing was performed on aggregates of normal specific gravities, and started with aggregates in the oven-dry condition.

[b] Precision estimates are based on aggregates with absorptions of less than 1 percent and may differ for manufactured fine aggregates having absorption values greater than 1 percent.

8.2.1. *Alternative to Determining the Mass in Section 8.2*—The quantity of added water necessary to fill the pycnometer at the required temperature may be determined volumetrically using a buret accurate to 0.15 mL. Compute the total mass of the pycnometer, specimen, and water as follows:

$$C = 0.9975\,V_a + S + W \qquad (1)$$

where:

C = mass of pycnometer with specimen and water to calibration mark, g;
V_a = volume of water added to pycnometer, mL;
S = mass of saturated surface-dry specimen, g; and
W = mass of the pycnometer empty, g.

8.2.2. *Alternative to the Procedure in Section 8.2*—Use a Le Chatelier flask initially filled with water to a point on the stem between the 0 and the 1-mL mark. Record this initial reading with the flask and contents within the temperature range of 23.0 ± 1.7°C (73.4 ± 3°F). Add 55 ± 5 g of fine

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aggregate in the saturated surface-dry condition (or other mass as necessary to result in raising the water level to some point on the upper series of graduation). After all fine aggregate has been introduced, place the stopper in the flask and roll the flask in an inclined position, or gently whirl it in a horizontal circle so as to dislodge all entrapped air, continuing until no further bubbles rise to the surface (Note 4). Take a final reading with the flask and contents within 1°C (1.8°F) of the original temperature.

Note 4—When using the Le Chatelier flask method, slowly adding a small measured amount (not to exceed 1 mL) of isopropyl alcohol, after removal of air bubbles, has been found useful in dispersing foam appearing on the water surface. The volume of alcohol used must be subtracted from the final reading (R_2).

8.3. Remove the fine aggregate from the pycnometer, dry to constant mass at a temperature of 110 ± 5°C (230 ± 9°F), cool in air at room temperature for 1.0 ± 0.5 hours and determine the mass.

Note 5—In lieu of drying and determining the mass of the sample which has been removed from the pycnometer, a second portion of the saturated surface-dry sample may be used to determine the oven-dry mass. This sample must be obtained at the same time and be within 0.2 grams of the mass of the sample which is introduced into the pycnometer.

8.3.1. If the Le Chatelier flask method is used, a separate sample portion is needed for the determination of absorption. Weigh a separate 500 ± 10 g portion of the saturated surface-dry fine aggregate, dry to constant mass, and reweigh. This sample must be obtained at the same time as the sample that is introduced into the Le Chatelier flask.

8.4. Determine the mass of the pycnometer filled to its calibration capacity with water at 23.0 ± 1.7°C (73.4 ± 3°F).

8.4.1. *Alternative to Determining the Mass in Section 8.4*—The quantity of water necessary to fill the empty pycnometer at the required temperature may be determined volumetrically using a buret accurate to 0.15 mL. Calculate the mass of the pycnometer filled with water as follows:

$$B = 0.9975\,V + W \tag{2}$$

where:

B = mass of flask filled with water, g;
V = volume of flask, mL; and
W = mass of the flask empty, g.

9. BULK SPECIFIC GRAVITY

9.1. Calculate the bulk specific gravity, 23/23°C (73.4/73.4°F) as follows:

$$\text{Bulk sp gr} = A/(B + S - C) \tag{3}$$

where:

A = mass of oven-dry specimen in air, g;
B = mass of pycnometer filled with water, g;
S = mass of saturated surface-dry specimen, g; and
C = mass of pycnometer with specimen and water to calibration mark, g.

9.1.1. If the Le Chatelier flask method was used, calculate the bulk specific gravity, 23/23°C, as follows:

$$\text{Bulk sp gr} = \frac{S_1(A/S)}{0.9975(R_2 - R_1)} \tag{4}$$

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where:

S_1 = mass of saturated surface-dry specimen used in Le Chatelier flask, g;
R_2 = final reading of water level in Le Chatelier flask; and
R_1 = initial reading of water level in Le Chatelier flask.

10. BULK SPECIFIC GRAVITY (SATURATED SURFACE-DRY BASIS)

10.1. Calculate the bulk specific gravity, 23/23°C (73.4/73.4°F), on the basis of mass of saturated surface-dry aggregate as follows:

$$\text{Bulk sp gr}\left(\text{saturated surface-dry basis}\right) = S/(B+S-C) \quad (5)$$

10.1.1. If the Le Chatelier flask method was used, calculate the bulk specific gravity, 23/23°C, on the basis of saturated surface-dry aggregate as follows:

$$\text{Bulk sp gr}\left(\text{saturated surface-dry basis}\right) = \frac{S_1}{0.9975\left(R_2 - R_1\right)} \quad (6)$$

11. APPARENT SPECIFIC GRAVITY

11.1. Calculate the apparent specific gravity, 23/23°C (73.4/73.4°F) as follows:

$$\text{Apparent sp gr} = A/\left(B+A-C\right) \quad (7)$$

12. ABSORPTION

12.1. Calculate the percentage of absorption as follows:

$$\text{Absorption, percent} = \left[\left(S-A\right)/A\right] \times 100 \quad (8)$$

13. REPORT

13.1. Report specific gravity results to the nearest 0.001 (Fine Aggregate meeting M 6 requirements may be reported to the nearest 0.01) and absorption to the nearest 0.1 percent. The Appendix gives mathematical interrelationships among the three types of specific gravities and absorption. These may be useful in checking the consistency of reported data or calculating a value that was not reported by using other reported data.

13.2. If the fine aggregate was tested in a naturally moist condition other than the oven dried and 15-hour soaked condition, report the source of the sample and the procedures used to prevent drying prior to testing.

14. PRECISION AND BIAS

14.1. The estimates of precision of this test method (listed in Table 1) are based on results from the AASHTO Materials Reference Laboratory Reference Sample Program, with testing conducted by this test method and ASTM C 128. The significant difference between the methods is that ASTM C 128 requires a saturation period of 24 ± 4 hours, and T 84 requires a saturation period of 15 to 19 hours. This difference has been found to have an insignificant effect on the precision indices. The data are based on the analyses of more than 100 paired test results from 40 to 100 laboratories.

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14.2. Since there is no accepted reference material suitable for determining the bias for the procedure in T 84 for measuring specific gravity and absorption of fine aggregate, no statement on bias is being made.

APPENDIX

(Nonmandatory Information)

X1. POTENTIAL DIFFERENCES IN BULK SPECIFIC GRAVITY AND ABSORPTION DUE TO PRESENCE OF MATERIAL FINER THAN 75 μM (NO. 200)

X1.1. It has been found that there may be significant differences in bulk specific gravity and absorption between fine aggregate samples tested with the material finer than 75 μm (No. 200) present and not present in the samples. Samples from which the material finer than 75 μm is not removed usually give a higher absorption and a lower bulk specific gravity compared with testing the same fine aggregate from which the material finer than 75 μm is removed following the procedures of Test Method T 11. Samples with material finer than 75 μm may build up a coating around the coarser fine aggregate particles during the surface-drying process. The resultant specific gravity and absorption that is subsequently measured is that of the agglomerated and coated particles and not that of the parent material. The difference in absorption and specific gravity determined between samples from which the material finer than 75 μm have not been removed and samples from which the material finer than 75 μm have been removed depends on both the amount of the material finer than 75 μm present and the nature of the material. When the material finer than 75 μm is less than about 4 percent by mass, the difference in specific gravity between washed and unwashed samples is less than 0.03. When the material finer than 75 μm is greater than about 8 percent by mass, the difference in specific gravity obtained between washed and unwashed samples may be as great as 0.13.

X1.2. The material finer than 75 μm, which is removed, can be assumed to have the same specific gravity as the fine aggregate. Alternatively, the specific gravity of the material finer than 75 μm may be further evaluated using T 100; however, this test determines the apparent specific gravity and not the bulk specific gravity.

X2. INTERRELATIONSHIPS BETWEEN SPECIFIC GRAVITIES AND ABSORPTION AS DEFINED IN T 84 AND T 85

X2.1. Let:

S_d = bulk specific gravity (dry-basis),
S_s = bulk specific gravity (SSD-basis),
S_a = apparent specific gravity, and
A = absorption in percent.

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Then:

$$S_s = (1 + A/100)S_d \tag{X1.1}$$

$$S_a = \frac{1}{\frac{1}{S_d} - \frac{A}{100}} = \frac{S_d}{1 - \frac{AS_d}{100}} \tag{X1.2}$$

Or:

$$S_a = \frac{1}{\frac{1 + A/100}{S_s} - \frac{A}{100}} = \frac{S_s}{1 - \frac{A}{100}(S_s - 1)} \tag{X1.3}$$

$$A = \left(\frac{S_s}{S_d} - 1\right)100 \tag{X1.4}$$

$$A = \left(\frac{S_a - S_s}{S_a(S_s - 1)}\right)100 \tag{X1.5}$$

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[1] This method is technically equivalent to ASTM C 128-07a.

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Standard Method of Test for

Specific Gravity and Absorption of Coarse Aggregate

AASHTO Designation: T 85-10[1]
ASTM Designation: C 127-04

1. SCOPE

1.1. This method covers the determination of specific gravity and absorption of coarse aggregate. The specific gravity may be expressed as bulk specific gravity, bulk specific gravity (saturated-surface-dry (SSD)), or apparent specific gravity. The bulk specific gravity (SSD) and absorption are based on aggregate after 15 hours soaking in water. This method is not intended to be used with lightweight aggregates.

1.2. The values stated in SI units are to be regarded as the standard.

1.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:
- M 43, Sizes of Aggregate for Road and Bridge Construction
- M 80, Coarse Aggregate for Hydraulic Cement Concrete
- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- T 2, Sampling of Aggregates
- T 19M/T 19, Bulk Density ("Unit Weight") and Voids in Aggregate
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 84, Specific Gravity and Absorption of Fine Aggregate
- T 248, Reducing Samples of Aggregate to Testing Size
- T 255, Total Evaporable Moisture Content of Aggregate by Drying

2.2. *ASTM Standard*:
- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

2.3. *IEEE/ASTM Standard*:
- SI 10, American National Standard for Use of the International System of Units (SI): The Modern Metric System

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3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. *absorption*—the increase in the mass of aggregate due to water in the pores of the material, but not including water adhering to the outside surface of the particles, expressed as a percentage of the dry mass. The aggregate is considered "dry" when it has been maintained at a temperature of 110 ± 5°C for sufficient time to remove all uncombined water by reaching a constant mass.

3.1.2. *specific gravity*—the ratio of the mass (or weight in air) of a unit volume of a material to the mass of the same volume of gas-free distilled water at stated temperatures. Values are dimensionless.

3.1.2.1. *apparent specific gravity*—the ratio of the weight in air of a unit volume of the impermeable portion of aggregate at a stated temperature to the weight in air of an equal volume of gas-free distilled water at a stated temperature.

3.1.2.2. *bulk specific gravity*—the ratio of the weight in air of a unit volume of aggregate (including the permeable and impermeable voids in the particles, but not including the voids between particles) at a stated temperature to the weight in air of an equal volume of gas-free distilled water at a stated temperature.

3.1.2.3. *bulk specific gravity (SSD)*—the ratio of the mass in air of a unit volume of aggregate, including the mass of water within the voids filled to the extent achieved by submerging in water for approximately 15 hours (but not including the voids between particles) at a stated temperature, compared to the weight in air of an equal volume of gas-free distilled water at a stated temperature.

4. SUMMARY OF METHOD

4.1. A sample of aggregate is immersed in water for approximately 15 hours to essentially fill the pores. It is then removed from the water, the water dried from the surface of the particles, and weighed. Subsequently the sample is weighed while submerged in water. Finally the sample is oven-dried and weighed a third time. Using the mass and weight measurements thus obtained and formulas in the method, it is possible to calculate three types of specific gravity and absorption.

5. SIGNIFICANCE AND USE

5.1. Bulk specific gravity is the characteristic generally used for calculation of the volume occupied by the aggregate in various mixtures containing aggregate, including portland cement concrete, bituminous concrete, and other mixtures that are proportioned or analyzed on an absolute volume basis. Bulk specific gravity is also used in the computation of voids in aggregate in T 19M/T 19. Bulk specific gravity (SSD) is used if the aggregate is wet, that is, if its absorption has been satisfied. Conversely, the bulk specific gravity (oven-dry) is used for computations when the aggregate is dry or assumed to be dry.

5.2. Apparent specific gravity pertains to the relative density of the solid material making up the constituent particles not including the pore space within the particles which is accessible to water.

5.3. Absorption values are used to calculate the change in the mass of an aggregate due to water absorbed in the pore spaces within the constituent particles, compared to the dry condition, when it is deemed that the aggregate has been in contact with water long enough to satisfy most of the

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absorption potential. The laboratory standard for absorption is that obtained after submerging dry aggregate for approximately 15 hours in water. Aggregates mined from below the water table may have a higher absorption, when used, if not allowed to dry. Conversely, some aggregates when used may contain an amount of absorbed moisture less than the 15-hour soaked condition. For an aggregate that has been in contact with water and that has free moisture on the particle surfaces, the percentage of free moisture can be determined by deducting the absorption from the total moisture content determined by T 255.

5.4. The general procedures described in this method are suitable for determining the absorption of aggregates that have had conditioning other than the 15-hour soak, such as boiling water or vacuum saturation. The values obtained for absorption by other methods will be different than the values obtained by the prescribed 15-hour soak, as will the bulk specific gravity (SSD).

5.5. The pores in lightweight aggregates may or may not become essentially filled with water after immersion for 15 hours. In fact, many such aggregates can remain immersed in water for several days without satisfying most of the aggregates' absorption potential. Therefore, this method is not intended for use with lightweight aggregate.

6. APPARATUS

6.1. *Balance*—Conforming to the requirements of M 231, Class G 5. The balance shall be equipped with suitable apparatus for suspending the sample container in water from the center of the weighing platform or pan of the balance.

6.2. *Sample Container*—A wire basket of 3.35 mm (No. 6) or finer mesh, or a bucket of approximately equal breadth and height, with a capacity of 4 to 7 L for 37.5-mm ($1^1/_2$-in.) nominal maximum size aggregate or smaller, and a larger container as needed for testing larger maximum size aggregate. The container shall be constructed so as to prevent trapping air when the container is submerged.

6.3. *Water Tank*—A watertight tank into which the sample and container are placed for complete immersion while suspended below the balance, equipped with an overflow outlet for maintaining a constant water level.

6.4. *Suspended Apparatus*—Wire suspending the container shall be of the smallest practical size to minimize any possible effects of a variable immersed length.

6.5. *Sieves*—A 4.75-mm (No. 4) sieve or other sizes as needed (Sections 7.2, 7.3, and 7.4), conforming to M 92.

7. SAMPLING

7.1. Sample the aggregate in accordance with T 2.

7.2. Thoroughly mix the sample of aggregate and reduce it to the approximate quantity needed using the applicable procedures in T 248. Reject all material passing a 4.75-mm (No. 4) sieve by dry sieving and thoroughly washing to remove dust or other coatings from the surface. If the coarse aggregate contains a substantial quantity of material finer than the 4.75-mm (No. 4) sieve (such as for Size No. 8 and 9 aggregates in M 43), use the 2.36-mm (No. 8) sieve in place of the 4.75-mm (No. 4) sieve. Alternatively, separate the material finer than the 4.75-mm (No. 4) sieve and test the finer material according to T 84.

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7.3. The minimum mass of test sample to be used is given below. In many instances it may be desirable to test a coarse aggregate in several separate size fractions; and if the sample contains more than 15 percent retained on the 37.5-mm ($1^1/_2$-in.) sieve, test the material larger than 37.5 mm in one or more size fractions separately from the smaller size fractions. When an aggregate is tested in separate size fractions, the minimum mass of test sample for each fraction shall be the difference between the masses prescribed for the maximum and minimum sizes of the fraction.

Nominal Maximum Size, mm (in.)	Minimum Mass of Test Sample, kg (lb)
12.5 ($^1/_2$) or less	2 (4.4)
19.0 ($^3/_4$)	3 (6.6)
25.0 (1)	4 (8.8)
37.5 ($1^1/_2$)	5 (11)
50 (2)	8 (18)
63 ($2^1/_2$)	12 (26)
75 (3)	18 (40)
90 ($3^1/_2$)	25 (55)
100 (4)	40 (88)
112 ($4^1/_2$)	50 (110)
125 (5)	75 (165)
150 (6)	125 (276)

7.4. If the sample is tested in two or more size fractions, determine the grading of the sample in accordance with T 27, including the sieves used for separating the size fractions for the determinations in this method. In calculating the percentage of material in each size fraction, ignore the quantity of material finer than the 4.75-mm (No. 4) sieve or 2.36-mm (No. 8) sieve when that sieve is used in accordance with Section 7.2.

8. PROCEDURE

8.1. Dry the test sample to constant mass at a temperature of 110 ± 5°C (230 ± 9°F), cool in air at room temperature for 1 to 3 hours for test samples of 37.5 mm ($1^1/_2$-in.) nominal maximum size, or longer for larger sizes until the aggregate has cooled to a temperature that is comfortable to handle (approximately 50°C). Subsequently immerse the aggregate in water at room temperature for a period of 15 to 19 hours.

Note 1—When testing coarse aggregate of large nominal maximum size requiring large test samples, it may be more convenient to perform the test on two or more subsamples, and the values obtained combined for the computation described in Section 9.

8.2. Where the absorption and specific gravity values are to be used in proportioning concrete mixtures in which the aggregates will be in their naturally moist condition, the requirement for initial drying to constant mass may be eliminated, and, if the surfaces of the particles in the sample have been kept continuously wet until test, the 15-hour soaking may also be eliminated.

Note 2—Values for absorption and bulk specific gravity (SSD) may be significantly higher for aggregate not oven dried before soaking than for the same aggregate treated in accordance with Section 8.1. This is especially true of particles larger than 75 mm (3 in.) since the water may not be able to penetrate the pores to the center of the particle in the prescribed soaking period.

8.3. Remove the test sample from the water and roll it in a large absorbent cloth until all visible films of water are removed. Wipe the larger particles individually. A moving stream of air may be used to assist in the drying operation. Take care to avoid evaporation of water from aggregate pores

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during the operation of surface-drying. Determine the mass of the test sample in the saturated surface-dry condition. Record this and all subsequent masses to the nearest 1.0 g or 0.1 percent of the sample mass, whichever is greater.

8.4. After determining the mass, immediately place the saturated-surface-dry test sample in the sample container and determine its mass in water at 23.0 ± 1.7°C (73.4 ± 3°F), having a density of 997 ± 2 kg/m^3. Take care to remove all entrapped air before determining the mass by shaking the container while immersed.

Note 3—The container should be immersed to a depth sufficient to cover it and the test sample during mass determination. Wire suspending the container should be of the smallest practical size to minimize any possible effects of a variable immersed length.

8.5. Dry the test sample to constant mass at a temperature of 110 ± 5°C (230 ± 9°F), cool in air at room temperature 1 to 3 hours, or until the aggregate has cooled to a temperature that is comfortable to handle (approximately 50°C), and determine the mass. Use this weight for A in the calculations in Section 9.

9. CALCULATIONS

9.1. *Specific Gravity*:

9.1.1. *Bulk Specific Gravity*—Calculate the bulk specific gravity, 23/23°C (73.4/73.4°F), as follows:

$$\text{Bulk sp gr} = A/(B-C) \tag{1}$$

where:

A = mass of oven-dry test sample in air, g;
B = mass of saturated-surface-dry test sample in air, g; and
C = mass of saturated test sample in water, g.

9.1.2. *Bulk Specific Gravity (Saturated-Surface-Dry)*—Calculate the bulk specific gravity, 23/23°C (73.4/73.4°F), on the basis of mass of saturated-surface-dry aggregate as follows:

$$\text{Bulk sp gr (saturated - surface - dry)} = B/(B-C) \tag{2}$$

9.1.3. *Apparent Specific Gravity*—Calculate the apparent specific gravity, 23/23°C (73.4/73.4°F), as follows:

$$\text{Apparent sp gr} = A/(A-C) \tag{3}$$

9.2. *Average Specific Gravity Values*—When the sample is tested in separate size fractions, the average value for bulk specific gravity, bulk specific gravity (SSD), or apparent specific gravity can be computed as the weighted average of the values as computed in accordance with Section 9.1 using the following equation:

$$G = \frac{1}{\dfrac{P_1}{100\,G_1} + \dfrac{P_2}{100\,G_2} + \cdots \dfrac{P_n}{100\,G_n}} \tag{4}$$

where:

G = average specific gravity (All forms of expression of specific gravity can be averaged in this manner.);
$P_1, P_2 \ldots P_n$ = mass percentages of each size fraction present in the original sample; and

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$G_1, G_2 \ldots G_n$ = appropriate specific gravity values for each size fraction depending on the type of specific gravity being averaged.

Note 4—Some users of this method may wish to express the results in terms of density. Density may be determined by multiplying the bulk specific gravity, bulk specific gravity (SSD), or apparent specific gravity by the density of water (997.5 kg/m^3 or 0.9975 Mg/m^3 or 62.27 lb/ft^3 at 23°C). Some authorities recommend using the density of water at 4°C (1000 kg/m^3 or 1.000 Mg/m^3 or 62.43 lb/ft^3) as being sufficiently accurate. The density terminology corresponding to bulk specific gravity, bulk specific gravity (SSD), and apparent specific gravity has not been standardized.

9.3. *Absorption*—Calculate the percentage of absorption, as follows:

$$\text{Absorption, percent} = [(B - A)/A] \times 100 \qquad (5)$$

9.4. *Average Absorption Value*—When the sample is tested in separate size fractions, the average absorption value is the average of the values as computed in Section 9.3, weighted in proportion to the mass percentages of the size fractions in the original sample as follows:

$$A = (P_1 A_1/100) + (P_2 A_2/100) + \cdots (P_n A_n/100) \qquad (6)$$

where:

A = average absorption, percent;

$P_1, P_2 \ldots P_n$ = mass percentages of each size fraction present in the original sample; and

$A_1, A_2 \ldots A_n$ = absorption percentages for each size fraction.

10. REPORT

10.1. Report specific gravity results to the nearest 0.001(Coarse Aggregate meeting M 80 requirements may be reported to the nearest 0.01), and indicate the type of specific gravity, whether bulk, bulk (saturated-surface-dry), or apparent.

10.2. Report the absorption result to the nearest 0.1 percent.

10.3. If the specific gravity and absorption values were determined without first drying the aggregate, as permitted in Section 8.2, it shall be noted in the report.

11. PRECISION AND BIAS

11.1. The estimates of precision of this test method listed in Table 1 are based on results from the AASHTO Materials Reference Laboratory Reference Sample Program, with testing conducted by this test method and ASTM C 127. The significant difference between the methods is that ASTM C 127 requires a saturation period of 24 ± 4 hours, while T 85 requires a saturation period of 15 hours minimum. This difference has been found to have insignificant effect on the precision indices. The data are based on the analyses of more than 100 paired test results from 40 to 100 laboratories.

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Table 1—Precision

	Standard Deviation $(1s)^a$	Acceptable Range of Two Results $(d2s)^a$
Single-operator precision:		
Bulk specific gravity (dry)	0.009	0.025
Bulk specific gravity (SSD)	0.007	0.020
Apparent specific gravity	0.007	0.020
Absorption,[b] percent	0.088	0.25
Multilaboratory precision:		
Bulk specific gravity (dry)	0.013	0.038
Bulk specific gravity (SSD)	0.011	0.032
Apparent specific gravity	0.011	0.032
Absorption,[b] percent	0.145	0.41

[a] These numbers represent, respectively, the (1s) and (d2s) limits as described in ASTM C 670. The precision estimates were obtained from the analysis of combined AASHTO Materials Reference Laboratory reference sample data from laboratories using 15-hour minimum saturation times and other laboratories using 24 ± 4-hour saturation time. Testing was performed on aggregates of normal specific gravities and started with aggregates in the oven-dry condition.

[b] Precision estimates are based on aggregates with absorptions of less than 2 percent.

11.2. *Bias*—Since there is no accepted reference material for determining the bias for the procedure in this test method, no statement on bias is being made.

APPENDIXES

(Nonmandatory Information)

X1. DEVELOPMENT OF EQUATIONS

X1.1. The derivation of the equation is apparent from the following simplified cases using two solids. Solid 1 has a mass W_1 in grams and a volume V_1 in milliliters; its specific gravity (G_1) is therefore W_1/V_1. Solid 2 has a mass W_2 and volume V_2, and $G_2 = W_2/V_2$. If the two solids are considered together, the specific gravity of the combination is the total mass in grams divided by the total volume in milliliters:

$$G = (W_1 + W_2)/(V_1 + V_2) \tag{X1.1}$$

Manipulation of this equation yields the following:

$$G = \frac{1}{\dfrac{V_1 + V_2}{W_1 + W_2}} = \frac{1}{\dfrac{V_1}{W_1 + W_2} + \dfrac{V_2}{W_1 + W_2}} \tag{X1.2}$$

$$G = \frac{1}{\dfrac{W_1}{W_1 + W_2}\left(\dfrac{V_1}{W_1}\right) + \dfrac{W_2}{W_1 + W_2}\left(\dfrac{V_2}{W_2}\right)} \tag{X1.3}$$

However, the mass fractions of the two solids are:

$$W_1/\left(W_1 + W_2\right) = P_1/100 \tag{X1.4}$$

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and:

$$W_2/(W_1+W_2)=P_2/100 \tag{X1.5}$$

and:

$$1/G_1=V_1/W_1 \text{ and } 1/G_2=V_2/W_2 \tag{X1.6}$$

therefore:

$$G=1/[(P_1/100)(1/G_1)+(P_2/100)(1/G_2)] \tag{X1.7}$$

An example of the computation is given in Table X1.1.

Table X1.1—Example Calculation of Average Values of Specific Gravity and Absorption for a Coarse Aggregate Tested in Separate Sizes

Size Fraction, mm (in.)	Percent in Original Sample	Bulk Specific Gravity (SSD)[a]	Sample Mass Used in Test, g	Absorption, percent
4.75 to 12.5 (No. 4 to $^1/_2$)	44	2.72	2213.0	0.4
12.5 to 37.5 ($^1/_2$ to $1^1/_2$)	35	2.56	5462.5	2.5
37.5 to 63 ($1^1/_2$ to $2^1/_2$)	21	2.54	12593.0	3.0

[a] Average Specific Gravity (SSD)

$$G_{SSD}=\frac{1}{\frac{0.44}{2.72}+\frac{0.35}{2.56}+\frac{0.21}{2.54}}=2.62 \tag{X1.8}$$

Average Absorption:

$$A=(0.44)\ (0.4)+(0.35)\ (2.5)+(0.21)\ (3.0)=1.7\% \tag{X1.9}$$

X2. INTERRELATIONSHIPS BETWEEN SPECIFIC GRAVITIES AND ABSORPTION AS DEFINED IN METHODS T 85 AND T 84

X2.1. Let:

S_d = bulk specific gravity (dry basis),
S_s = bulk specific gravity (SSD basis),
S_a = apparent specific gravity, and
A = absorption in percent.

Then:

$$S_s=(1+A/100)\,S_d \tag{X2.1}$$

$$S_a=\frac{1}{\frac{1}{S_d}-\frac{A}{100}}=\frac{S_d}{1-\frac{AS_d}{100}} \tag{X2.2}$$

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$$Sa\ \cancel{S_d} = \frac{1}{\frac{1+A/100}{S_s} - \frac{A}{100}} \qquad (X2.3)$$

$$= \frac{S_s}{1-\left(\frac{A}{100}(S_s - 1)\right)}$$

$$A = \left(\frac{S_s}{S_d} - 1\right)100 \qquad (X2.4)$$

$$A = \left(\frac{S_a - S_s}{S_a(S_s - 1)}\right)100 \qquad (X2.5)$$

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[1] This method is technically equivalent to ASTM C 127-04.

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