TECHNICAL BULLETIN

Basic Asphalt Materials
Mixture Design and Testing

Technician Training Manual

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Preface

This training manual was developed as part of an effort to provide a step-by-step procedure for understanding basic asphalt mixture composition, creating mix designs and recycling processes.

Mix Design Fundamentals

HMA consists of two basic ingredients: aggregate and asphalt binder. HMA mix design is the process of determining what aggregate to use, what asphalt binder to use and what the optimum combination of these two ingredients ought to be. There are several different methods used to go about this process, of which the Marshall and Superpave methods are the most common.

By manipulating the variables of aggregate, asphalt binder and the ratio between the two, mix design seeks to achieve the following qualities in the final HMA product (Roberts et al., 1996):

- **Deformation resistance:** HMA should not distort (rut) or deform (shove) under traffic loading. HMA deformation is related to aggregate surface and abrasion characteristics, aggregate gradation, asphalt binder content and asphalt binder viscosity at high temperatures.

- **Fatigue resistance:** HMA should not crack when subjected to repeated loads over time. HMA fatigue cracking is related to asphalt binder content and stiffness.

- **Low temperature cracking resistance:** HMA should not crack when subjected to low ambient temperatures. Low temperature cracking is primarily a function of the asphalt binder low temperature stiffness.

- **Durability:** HMA should not age excessively during production and service life. HMA durability is related to air voids as well as the asphalt binder film thickness around each aggregate particle.

- **Moisture damage resistance:** HMA should not degrade substantially from moisture penetration into the mix. Moisture damage resistance is related to air voids as well as aggregate mineral and chemical properties.

- **Skid resistance:** HMA placed as a surface course should provide sufficient friction when in contact with a vehicle's tire. Low skid resistance is generally related to aggregate characteristics or high asphalt binder content.

- **Workability:** HMA must be capable of being placed and compacted with reasonable effort. Workability is generally related to aggregate texture/shape/size/gradation, asphalt binder content and asphalt binder viscosity at mixing and placement temperatures.

Materials Physical Properties

Aggregate

Aggregates can be classified by their mineral, chemical and physical properties. The pavement industry typically relies on physical properties for performance characterization. An aggregate's physical properties are a direct result of its mineral and chemical properties.

Maximum Size

Maximum aggregate size can affect HMA and base/Subbase courses in several ways. In HMA, instability may result from excessively small maximum sizes; and poor workability and/or segregation may result from excessively large maximum sizes (Roberts et al., 1996). ASTM C 125 defines the maximum aggregate size in one of two ways:

Maximum size: The smallest sieve through which 100 percent of the aggregate sample particles pass. Superpave defines the maximum aggregate size as "one sieve larger than the nominal maximum size" (Roberts et al., 1996).

Nominal maximum size: The largest sieve that retains some of the aggregate particles but generally not more than 10 percent by weight. Superpave defines nominal maximum aggregate size as "one sieve size larger than the first sieve to retain more than 10 percent of the material" (Roberts et al., 1996).

It is important to specify whether "maximum size" or "nominal maximum size" is being referenced.

Gradation

An aggregate's particle size distribution, or gradation, is one of its most influential characteristics. In HMA, gradation helps determine almost every important property including stiffness, stability, durability, permeability, workability, fatigue resistance, frictional resistance and resistance to moisture damage (Roberts et al., 1996). Because of this, gradation is a primary concern in HMA mix design and thus most agencies specify allowable aggregate gradations.

Measurement

Gradation is usually measured by a sieve analysis. In a sieve analysis, a sample of dry aggregate of known weight is separated through a series of sieves with progressively smaller openings. Once separated, the weight of particles retained on each sieve is measured and compared to the total sample weight. Particle size distribution is then expressed as a percent passing by weight on each sieve size.

Typical HMA Gradations Blend

Dense or well-graded: Refers to a gradation that is near maximum density. The most common HMA mix designs tend to use dense graded aggregate.

Gap graded: Refers to a gradation that contains only a small percentage of aggregate particles in the mid-size range. The curve is near-horizontal in the mid-size range. These mixes can be prone to segregation during placement.

Open graded: Refers to a gradation that contains only a small percentage of aggregate particles in the small range. This results in more air voids because there are not enough small particles to fill in the voids between the larger particles. The curve is near-horizontal and near-zero in the small-size range.

Uniformly graded: Refers to a gradation that contains most of the particles in a very narrow size range In essence, all the particles are the same size, The curve is steep and only occupies the narrow size range specified.

Aggregate Gradation Terms

Fine aggregate: (sometimes just referred to as "fines"). Defined by AASHTO M 147 as natural or crushed sand passing the 4.75mm and mineral particles passing the 75um sieve.

Coarse aggregate: Defined by AASHTO M 147 as hard, durable particles or fragments of stone, gravel or slag retained on the 4.75mm sieve. Usually coarse aggregate has a toughness and abrasion resistance requirement.

Fine gradation: A gradation that, when plotted on the 0.45 power gradation graph, falls mostly above the 0.45 power maximum density line. The term generally applies to dense graded aggregate.

Coarse gradation: A gradation that, when plotted on the 0.45 power gradation graph, falls mostly below the 0.45 power maximum density line. The term generally applies to dense graded aggregate.

Mineral filler: Defined by the Asphalt Institute as a finely divided mineral product at least 65 percent of which will pass through 75um sieve. Pulverized limestone is the most commonly manufactured mineral filler, although other stone dust, silica, hydrated lime, Portland cement and certain natural deposits of finely divided mineral matter are also used (Asphalt Institute, 1962).

Other Properties

Other important aggregate physical properties are:

Toughness and abrasion resistance: Aggregates should be hard and tough enough to resist crushing, degradation and disintegration from activities such as manufacturing, stockpiling, placing and compaction.

Durability and soundness: Aggregates must be resistant to breakdown and disintegration from weathering (wetting/drying) or else they may break apart and cause premature pavement distress.

Particle shape and surface texture: Particle shape and surface texture are important for proper compaction, load resistance and workability. Generally, cubic angular-shaped particles with a rough surface texture are best.

Specific gravity: Aggregate specific gravity is useful in making weight-volume conversions and in calculating the void content in compacted HMA (Roberts et al., 1996).

Cleanliness and deleterious materials: Aggregates must be relatively clean when used in HMA. Vegetation, soft particles, clay lumps, excess dust and vegetable matter may affect performance by quickly degrading, which causes a loss of structural support and/or prevents binder-aggregate bonding.

Asphalt Cement

Asphalt cement refers to asphalt that has been prepared for use in HMA and other paving applications. In HMA a generic term, "asphalt binder", to represent the principal binding agent in HMA because "asphalt binder" includes asphalt cement as well as any material added to modify the original asphalt cement properties.

Asphalt Physical Properties

Asphalt can be classified by its chemical composition and physical properties. The pavement industry typically relies on physical properties for performance characterization although asphalt's physical properties are a direct result of its chemical composition. Typically, the most important physical properties are:

Durability: Durability is a measure of how asphalt binder physical properties change with age (sometimes called age hardening). In general, as an asphalt binder ages, its viscosity increases and it becomes more stiff and brittle.

Rheology: Rheology is the study of deformation and flow of matter. Deformation and flow of the asphalt binder in HMA is important in HMA pavement performance. HMA pavements that deform and flow too much may be susceptible to rutting and bleeding, while those that are too stiff may be susceptible to fatigue cracking.

Safety: Asphalt cement like most other materials, volatilizes (gives off vapor) when heated. At extremely high temperatures (well above those experienced in the manufacture and construction of HMA) asphalt cement can release enough vapor to increase the volatile concentration immediately above the asphalt cement to a point where it will ignite (flash) when exposed to a spark or open flame. This is called the flash point. For safety reasons, the flash point of asphalt cement is tested and controlled.

Purity: Asphalt cement, as used in HMA paving, should consist of almost pure bitumen. Impurities are not active cementing constituents and may be detrimental to asphalt performance.

Grading Systems

Asphalt binders are typically categorized by one or more shorthand grading systems according to their physical characteristics. These systems range from simple to complex and represent an evolution in the ability to characterize asphalt binder. In Ontario the Superpave performance grading (PG) system is specified.

Superpave Performance Grading (PG) System

The Superpave PG system was developed as part of the Superpave research effort to more accurately and fully characterize asphalt binders for use in HMA pavements. The PG system is based on the idea that an HMA asphalt binder's properties should be related to the conditions under which it is used. For asphalt binders, this involves expected climatic conditions as well as aging considerations. Therefore, the PG system uses a common battery of tests (as the older penetration and viscosity grading systems do) but specifies that a particular asphalt binder must pass these tests at specific temperatures that are dependent upon the specific climatic conditions in the area of intended use.

Superpave performance grading is reported using two numbers – the first being the average seven-day maximum pavement temperature (in °C) and the second being the minimum pavement design temperature likely to be experienced (in °C). Thus, a PG 58-28 is intended for use where the average seven-day maximum pavement temperature is 58°C and the expected minimum pavement temperature is -28°C. Notice that these numbers are pavement temperatures and not air temperatures. For example, the typical PG grade used in Central Ontario is a PG 58-28. Realistically, pavement temperatures in Central Ontario will never drop down to -28°C, but the typical asphalt binder used will meet this standard so it is graded as such, grades are bumped up to account for effect of increase traffic loading or down to account for variables such as increased recycle content.

Penetration Grading

Based on the depth a standard needle will penetrate an asphalt binder sample when placed under a 100 g load for 5 seconds. The test is simple and easy to perform but it does not measure any fundamental parameter and can only characterize asphalt binder at one temperature (25°C). Penetration grades are listed as a range of penetration units (one penetration unit = 0.1 mm of penetration by the standard needle). Typical asphalt binders previously used in the U.S. are 65-70 pen and 85-100 pen. This grading system is no longer used in Ontario.

Viscosity Grading

Measures penetration (as in penetration grading) but also measures an asphalt binder's viscosity at 60°C and 135°C. Testing can be done on virgin (AC) or aged (AR) asphalt binder. Grades are listed in poises (cm-g-s = dyne-second/cm^2) or poises divided by 10. Typical asphalt binders used in the U.S. are AC-10, AC-20, AC-30, AR-4000 and AR-8000. Viscosity grading is a better grading system but it does not test low temperature asphalt binder Rheology. This grading system is no longer used in Ontario as well.

Asphalt Binder Modifiers

Some asphalt cements require modification in order to meet specifications. Asphalt cement modification has been practiced for over 50 years but has received added attention in the past decade or so. There are numerous binder additives available on the market today. The benefits of modified asphalt cement can only be realized by a judicious selection of the modifier(s); not all modifiers are appropriate for all applications. In general, asphalt cement should be modified to achieve the following types of improvements (Roberts et al., 1996):

Lower stiffness (or viscosity) at the high temperatures associated with construction. This facilitates pumping of the liquid asphalt binder as well as mixing and compaction of HMA.

Higher stiffness at high service temperatures. This will reduce rutting and shoving.

Lower stiffness and faster relaxation properties at low service temperatures. This will reduce thermal cracking.

Increased adhesion between the asphalt binder and the aggregate in the presence of moisture. This will reduce the likelihood of stripping. Asphalt binder used with the right percent (by weight of asphalt binder) of an anti-stripping modifier if required, will results in good aggregate-asphalt binder adhesion.

Other Forms of Asphalt Used in Paving

Besides asphalt cement, three other forms of asphalt are used prominently in the paving industry:

- Emulsified asphalt. Emulsified asphalt is a suspension of small asphalt cement globules in water, which is assisted by an emulsifying agent (such as soap). Emulsions have lower viscosities than neat (plain) asphalt and can thus be used in low temperature applications. After an emulsion is applied the water evaporates away (breaks) and only the asphalt cement is left. Emulsions are often used as prime coats and tack coats.

- Cutback asphalt. Cutback asphalt is a combination of asphalt cement and petroleum solvent. Like emulsions, cutbacks are used because their viscosity is lower than that of neat asphalt and can thus be used in low temperature applications. After a cutback is applied the solvent evaporates away and only the asphalt cement is left. Cutbacks are much less common today because the petroleum solvent is more expensive than water and can be an environmental concern. Cutbacks are typically used as prime coats and tack coats.

- Foamed asphalt. Foamed asphalt is formed by combining hot asphalt binder with small amounts of cold water. When the cold water comes in contact with the hot asphalt binder it turns to steam, which becomes trapped in tiny asphalt binder bubbles (World Highways, 2001). The result is a thin-film, high volume asphalt foam. This high volume foam state only lasts for a few minutes, after which the asphalt binder resumes its original properties. Foamed asphalt can be used as a binder in soil or base course stabilization, and is often used as the stabilizing agent in cold in-place recycling (CIPR).

Marshall Mix Design Method

The basic concepts of the Marshall Mix design method were originally developed by Bruce Marshall of the Mississippi Highway Department around 1939 and then refined by the U.S. Army.

Typically, the Marshall Mix design method consists of three basic steps:

1. **Aggregate selection:** Different agencies/owners specify different methods of aggregate acceptance. Private labs may or may not run periodic aggregate physical tests on a particular aggregate source. For each mix design, gradation and size requirements are checked. Often, aggregate from more than one source is required to meet gradation requirements.

2. **Asphalt binder selection:** Review the contract document to determine the specified binder grade.

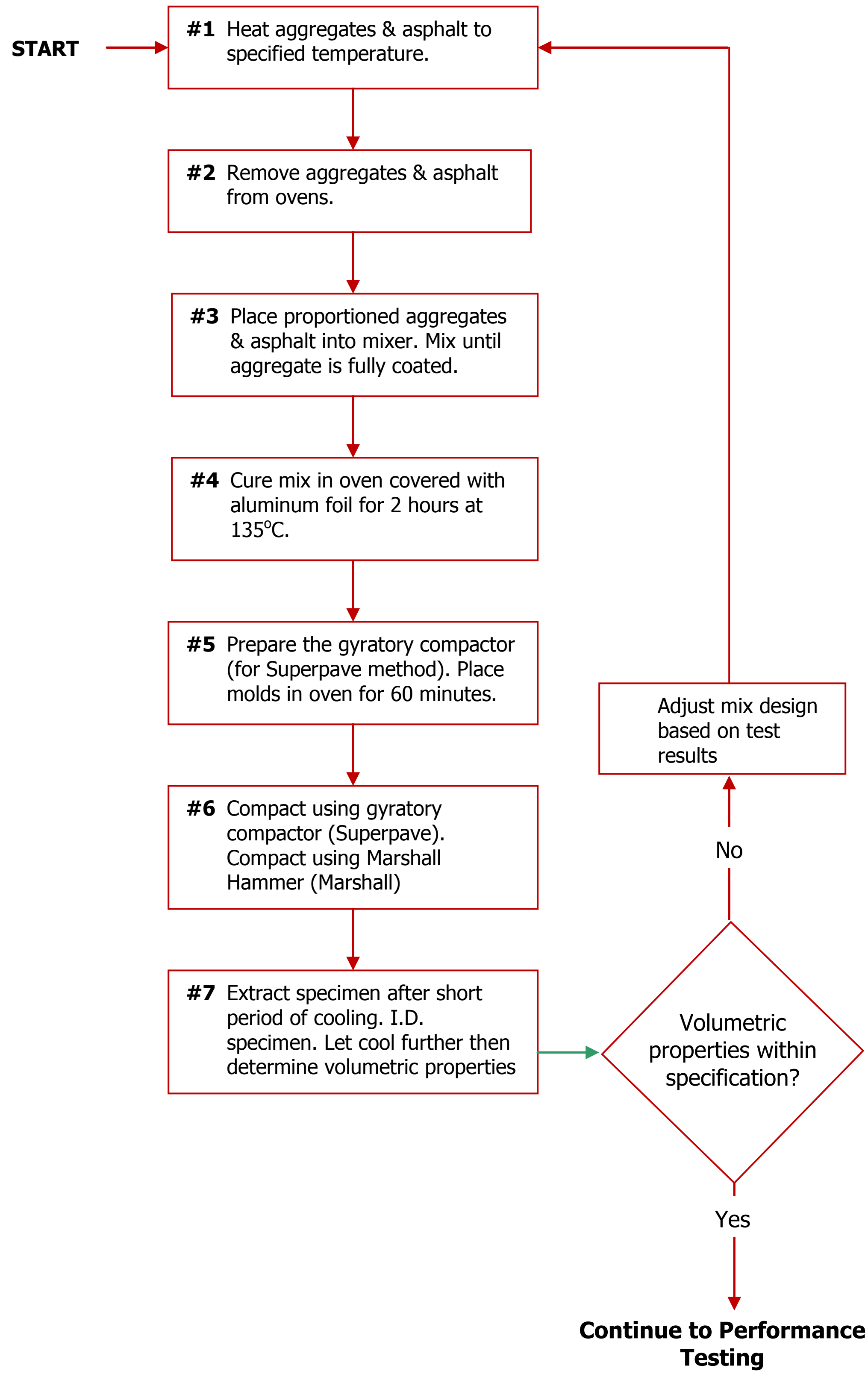
3. **Optimum asphalt binder content determination:** In the Marshall method, this step can be broken up into 5 sub steps:
    I. Prepare a series of initial samples, each at different asphalt binder content. For instance, two to three samples each might be made at 4.5, 5.0, 5.5, 6.0 and 6.5 percent asphalt by dry weight for a total of 10 to 15 samples. There should be at least two samples above and two below the estimated optimum asphalt content.
    II. Compact these trial mixes using the Marshall drop hammer. This hammer is specific to the Marshall Mix design method.
    III. Test the samples in the Marshall testing machine for stability and flow. This testing machine is specific to the Marshall Mix design method. Passing values of stability and flow depend upon the mix class being evaluated.
    IV. Determine the density and other volumetric properties of the samples. Select the optimum asphalt binder content. The asphalt binder content corresponding to 4 percent air voids is selected as long as this binder content passes stability and flow requirements.
    V. A quicker way is to run trials based on aggregate blending, test properties, varying asphalt cement content – the trial blend that gives 4 percent air voids and meet specifications is selected.
    VI.

Types of Mixes Used in Ontario

Table 1: Summary of types of Marshall Mixes used in Ontario

Hot Mix Type	Abbreviation	Summary of Hot Mix Use and Properties
Dense Friction Course	DFC	A dense-graded surface course mix with high frictional resistance for high volume roads
Hot Laid 1	HL 1	A dense-graded surface course mix with a premium quality coarse aggregate
Hot Laid 2	HL 2	A sand mix used primarily as a leveling course on existing pavements or surface course on low speed traffic areas requiring thin overlay
Hot Laid 3	HL 3	A dense-graded surface course mix for intermediate volume roads
Hot Laid 3 High Stability	HL 3HS	A dense-graded padding and leveling mix of high stability
Hot Laid 3 Fine	HL 3F	A fine-graded used as a surface course where hand work is necessary for placement
Hot Laid 4	HL 4	A dense-graded mix used as a surface or binder course on low volume roads
Hot Laid 4 Fine	HL 4F	A fine-graded mix used a s surface course where hand work is necessary for placement
Hot Laid 8	HL 8	A coarse-graded binder course mix
Medium Duty Binder Course	MDBC	A binder course mix intended for use in locations where rutting and deformation is likely
Heavy Duty Binder Course	HDBC	A high stability binder mix designed to provide superior resistance to rutting

Basic Procedure



Superpave Mix Design Method

This section of the manual will cover the essentials to the Superpave Mix Design process. An example is included which places emphasis on developing the trial batch weights and percentages, which should be summarized on a mix design worksheet that the QC Lab personnel will use for making the hot mix asphalt (HMA) specimen.

Traffic Load Estimation

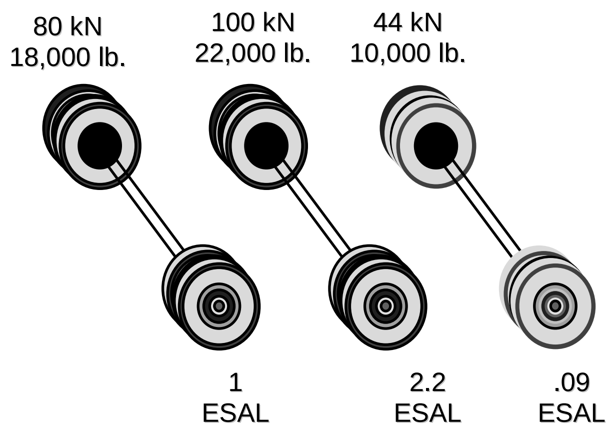


Figure 1: ESAL comparison

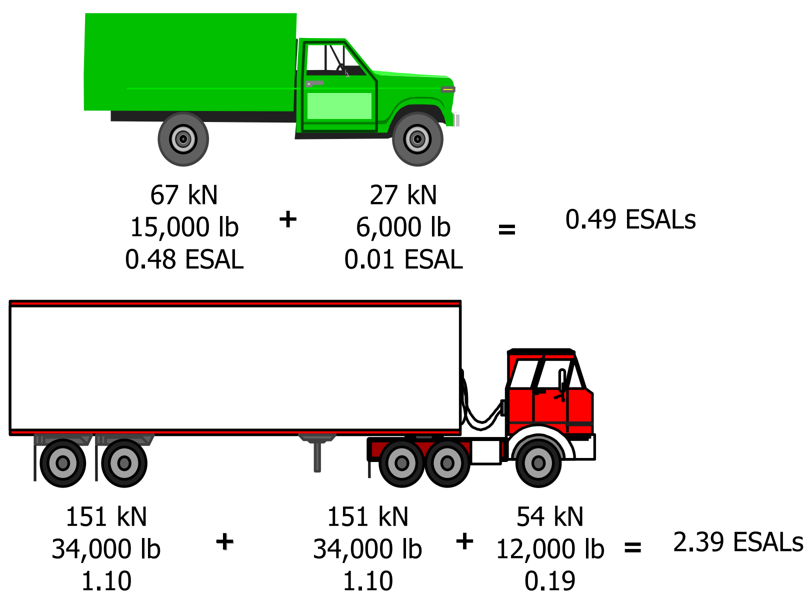


Figure 2: Example ESALs calculation

PGAC Binder Selection

The PGAC grading system is a function of environment and traffic level. **Figure 3** below shows PGAC grading recommendation for various zones (environments).

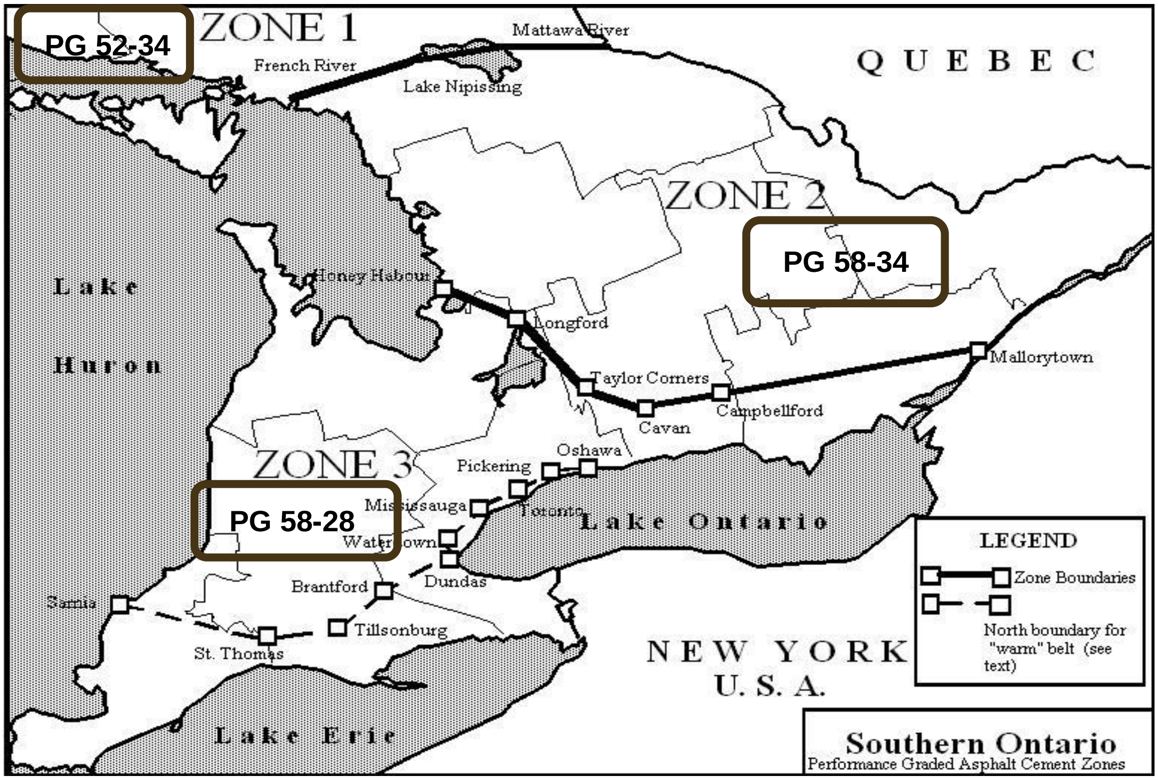


Figure 3: PGAC grades for different zones

Another factor that affects binder selection is effect of loading rate.

Example:

For toll road with speed of **90 km/h**

Recommended: **PGAC 64-22**

For toll booth with **slow moving traffic**

Recommended: **PGAC 70-22**

For weigh stations that involve a lot of **stopping**

Recommended: **PGAC 76-22**

Aggregate Size Definitions

Table 2: Primary Control Sieve designations

Primary Control Sieve (PCS) Control Point for Mixture Nominal Maximum Aggregate Size (% Passing)					
Nominal Maximum Aggregate Size **(mm)**	37.5	25.0	19.0	12.5	9.5
Primary Control Sieve **(mm)**	9.5	4.75	4.75	2.36	2.36
PCS Control Point **(% Passing)**	47	40	47	37	47

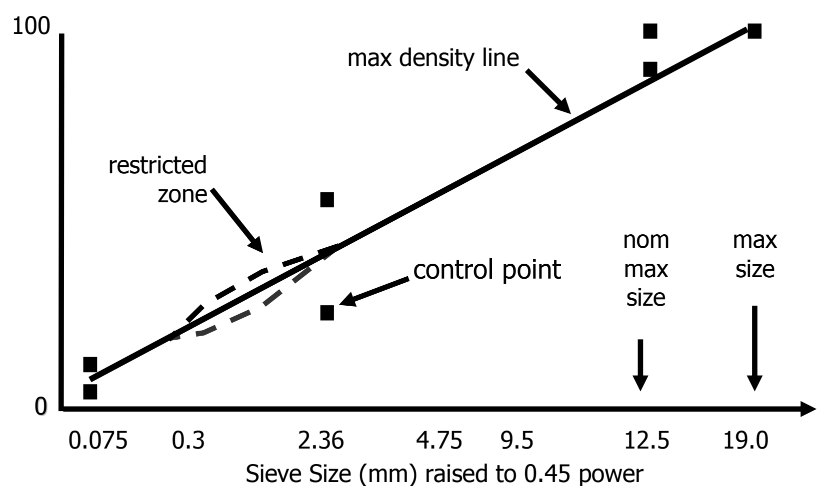


Figure 4: Aggregate blend gradation chart with Superpave gradation limits

Aggregate Consensus Properties

Flat, Elongated or Flat and Elongated (F&E)

Definition:
-Flat, or Elongated particles of aggregate are those particles of aggregate having a ratio of width or length to width greater than a specified value.

-Flat and Elongated particles of aggregate are those particles having a ratio of length to thickness greater than a specified value.

* Length – maximum dimension of the particle
* Width – maximum dimension in the plane perpendicular to the length
* Thickness – maximum dimension perpendicular to the length and width

Summary of Test Method:
Individual particles of aggregate of specified sieve sizes are measured to determine the ratio of width to thickness; length to width, or length to thickness.

Significance and Use
Flat or Elongated particles of aggregates, for some construction uses, may interfere with consolidation and result in harsh, difficult to place materials.
This test provides a means for checking compliance with specifications that limits such particles or to determine the relative shape characteristics of coarse aggregates.

Procedure:
Use materials retained on sieve size 4.75mm (No.4), reduce each size fraction present to 100 particles for each size fraction required.

Test Procedure
Set the larger opening equal to the length of the particle. The particle is flat and elongated if when oriented to measure its thickness, can pass completely through the smaller opening of the caliper. On the caliper, set the minimum dimension of the caliper device such that the particle, when oriented to measure its thickness, passes smugly between the post and swing arm. The particle is flat and elongated if the particle, when oriented to measure its length, fails to pass the desired large opening of the caliper device.

After the particles have been classified into group, determine the proportion of the sample in each group by count or mass as required.

Calculation:
Calculate the percentage of flat and elongated particles to the nearest 1% for each sieve size greater than 9.5mm or 4.75mm.

Sand Equivalent Test (SE)

Scope:
This test is intended to serve as a rapid field test to show the relative proportion of fine dust or claylike material in the soil or graded aggregate.

Sample Preparation:

(a) The sand equivalent test shall be performed on aggregate materials passing the 4.75mm sieve size, and all fines shall be cleaned from particles retained on the 4.75mm sieve and included with the materials passing 4.75mm sieve.

(a) Split the sample to fill the 85mL (3oz) tin measure so it is slightly rounded above the brim, while filling tap the bottom edge to cause consolidation of the material and allow maximum amount to be placed in the tin. Strike off the top of the tin with a spatula.
(b) Add solution about 101.6+/-2.5 (4.0 +/-0.1in) of working calcium chloride solution into cylinder. Allow to stand, sample and solution for about 10min +/- 1min. At the end of the time, stopper the cylinder, the loose the materials from the bottom by partially inverting the cylinder and shaking it simultaneously. After loosing the materials shake the cylinder and content manually, hand holding in a horizontal position, shake it vigorously in a horizontal linear motion from end to end. Shake the cylinder 90 cycles in approximately 30secounds using a throw 229 +/- 25 (9+/-1in). A cycle is defined as a complete back and forth motion.
(c) After shaking, set the cylinder upright on the work table and remove stopper. Irrigate by inserting irrigator tube and working the sample down and rinsing materials from the body of the cylinder, release solution up to 381mm, raise irrigator and top up solution to 381mm mark on cylinder.

(d) Allow cylinder and content to stand for 20mm +/-15secounds. Start a timer immediately after withdrawing the irrigator tube.
(e) At the end of 20min. sedimentation period, read and record the level of the top of clay suspension. This is referred to as “clay reading”. After clay reading, take the “sand reading” by the weighted foot assembly having the sand indicator on the rod of the assembly, place the gently on the sand and make contact with the cylinder body. Subtract 254mm(10in.) from the level indicator by extreme top edge of the indicator and record this value as the “sand reading”
(f) If the sand reading or clay reading falls between 2.5mm (0.1in.) graduation, record the level of the higher graduation reading.

Calculation:
Calculate the sand equivalent (SE) to the nearest 0.1 using the formulae:

SE = Sand Reading x100/Clay reading.

Fine Aggregate Angularity (FAA)

Scope:
This method describes the determination of the loose un-compacted void content of a sample of fine aggregate. When void content is measured on an as-received fine aggregate, it can be an indicator of the effect of fine aggregate on the workability of a mixture it may be used.

Three procedures are included for the measurement of void contents. Two uses standard grading or as-received grading, while the third uses several individual size fractions for void content measurement. Method C measures the un-compacted void content of the minus 4.75mm portion of the as-received material. This void content depends on grading as well as particle shape and texture.

Procedure:
A nominal 100mL calibrated cylindrical measure is filled with fine aggregate of prescribed grading allowing the sample to flow through a funnel from a fixed height into the measure. The fine aggregate is struck off, and its mass is determined by weighing. Un-compacted void content is calculated as the difference between the volume of the cylinder measure and the absolute volume of fine aggregate collected in the measure. Un-compacted void content is calculated using the bulk dry specific gravity of the fine aggregate. Two runs are made on each sample and the results are averaged.

Testing sample in the as-received grading may be useful in selecting proportion of components used in a variety of mixtures. In general, high void content suggest that the materials could be improved by providing additional fines in the fine aggregate or more cementatious material may be needed to fill voids between particles.

Calculation:
Calculate the un-compacted voids for each determination as follows:

U=V-(F/G)/V * 100 where V= volume of cylindrical measure, F= net mass of fine aggregate in the measure, G= dry bulk specific gravity of fine aggregate, U= un-compacted voids, percent

Traffic Categories

Table 3: Traffic categories with design ESALs

Category	Design ESALs (millions)
A	< 0.3
B	0.3 to 3
C	3 to 10
D	10 to 30
E	> 30

Compaction Effort

Table 4: Traffic categories and compaction parameters

Traffic	Compaction Parameters		
Category	$N_{initial}$	N_{design}	N_{max}
A	6	50	75
B, C	7	75	100
D	8	100	160
E	9	125	205

Note:

$N_{initial}$ – Density for stability under rollers

N_{design} – Density for short term performance

N_{max} – Density for long term performance

How to Choose

Table 5: Design ESALs with relative Gyratory compaction parameters

Design ESALs (Million)	Gyratory Compaction Parameters			Typical Roadway Description
	$N_{initial}$	N_{design}	N_{max}	
< 0.3	6	50	75	• Light traffic • Local roads • Recreational roadways • Where traffic is at a very minimal level
0.3 to 3	7	75	100	• Medium trafficked city streets • Majority of country roadways
3 to 30	8	100	125	• Medium to highly trafficked city streets • Some rural interstates
> 30	9	125	205	• US interstate system • Truck weighing stations • Truck climbing lanes

Mix Design Example

Materials:

The following materials will be used in the trail batch and the HMA specimen fabrication. The aggregate designations are based on the Ministry of Transportation Ontario (MTO) Specifications:

- Performance Graded Asphalt Cement Binder: **PGAC 58-28**
- Course Aggregate: **CA #1**
- Fine Aggregate: **FA #1**
- Fine Aggregate**: FA #2**
- Plant Dust – Mineral Filler

Design Criteria:

The following specifications outline in **Table 6** are presented to highlight the primary design target values necessary for approval of the mix under MTO's criteria for the **12.5mm SP** mix designation only. For other mixes, refer to appropriate sources of the target values.

Table 6: Mix design specification

Mix Specification	MTO 12.5mm SP
Mix Category	A
Equivalent Single Axle Loads (ESALs)	< 0.3 million
Number of Gyrations (N_{design})	50
Voids in Mineral Aggregate (VMA)	14.0%
Percent (%) Air Voids (V_a)	4.0%
Voids Filled with Aggregate (VFA)	70 – 80%
Dust Proportion (DP)	0.6 – 1.2

Table 7: Gradation requirements for 12.5mm SP mix

Gradation Requirements: Mix Composition		
Percent Passing	**Control Points**	
Sieve Size	Minimum	Maximum
12.5 mm	90	100
9.5 mm		90
4.75 mm		
2.36 mm	28	58
75 µm	2	10

Note: Superpave uses the 0.45 power chart for plotting the mix gradation. The following example illustrates how this is accomplished for the 12.5mm SP mix. The final mix gradation must be between the control points. To increase or decrease VMA, change the gradation such that the mix line moves above or below the maximum density line as indicated (See **Figure 4**).

Procedures

Step 1

Choose percentages of aggregate and asphalt cement for the trail batch. Guidelines are provided below for use in the 12.5 mm SP mix.

Table 8: Material composition guidelines for 12.5mm SP mix

Material	Percentage Range (%)
CA #1	55 – 60
FA #1	18 – 23
FA #2	20 – 25
Dust (MF)	1 – 2
AC 58-28	4.5 – 6.0

Step 2

Compute the total batch percentages from the individual material gradations. The example that follows is for the 2.36mm sieve.

Sieve Size	CA #1	FA #1	FA #2	Dust	AC 58-28
Trial Batch %	57.5	19.0	22.0	1.5	5.0
% Passing 2.36mm sieve	4	92	77	100	

Total Batch Percentage (for the aggregate materials) is calculated by summing the trial percentages of each aggregate by its gradational percent passing value.

Example:

$$\begin{aligned}\text{Batch Percentage} &= (0.575\times 4)+(0.19\times 92)+(0.22\times 77)+(0.015\times 100)\\ &= 38.2\%\ (2.36\text{mm Sieve})\end{aligned}$$

Note:

Using this example, every sieve size that is included in the trial batch must be calculated in the same manner so a batch percentage passing (for the aggregates) can be obtained. It should be noted that the asphalt cement binder is simply added to the mix based on its percent weight, due to the fact it is a liquid component of the batch.

Step 3

Plot the total batch percentages for each sieve size computed in Step 2 on the 0.45 power chart.

Step 4

Verify that the batch gradation stays in between the control points. If it doesn't, then choose different material percentages, recalculate the batch percentages, and plot the new batch.

Note:

The trial batch must be within the parameters of the 0.45 power chart in order to proceed.

Step 5:

Having successfully obtained the trial batch gradation percentages, make a batch of asphalt mix.

Step 6

Determine if the trial batch meets the MTO specification. Computer Air Voids (Va), Voids in Mineral Aggregates (VMA), Voids Filled with Asphalt (VFA) and Dust of Binder Proportion (DP). Having met these criteria, you will have successfully completed a proper Superpave mix design.

Mix Design Volumetric

In order to determine if the trial batch meets the Design Criteria, the mix needs to be tested to ascertain whether the target values have been met for the particular gradation chosen. The following procedures highlight the final process of the mix design and the results will determine whether the mix is adequate based on the criteria.

- HMA Maximum Theoretical Density, G_{mm}
  Refer to ASTM D 2041-95
- HMA Bulk Specific Gravity, G_{mb}
  Refer to ASTM D 2726-96a
- Combined Bulk Specific Gravity of Aggregate Blend, G_{sb}
  When the total aggregate trial blend consists of aggregates with different specific gravities, which is usually the case, then the Bulk Specific Gravity for the blend must be calculated using:

$$G_{sb} = \frac{P_1 + P_2 + \ldots\ldots + P_n}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + \ldots\ldots + \frac{P_n}{G_n}}$$

Where G_{sb} = bulk specific gravity of total aggregate blend

P_1, P_2, P_n = individual percentages by mass of aggregate

G_1, G_2, G_n = individual specific gravities of aggregate

- Aggregate Percentage by Volume, P_s
  Total percentage by mass of the batch that the aggregate makes up

Computation

Using the above values, substitute into the following equations to determine VMA, Va, and VFA

Property	Target Value
$VMA = 100 - \frac{(G_{mb} \times P_s)}{G_{sb}}$	15%
$Va = 100 \times \frac{(G_{mm} - G_{mb})}{G_{mm}}$	4.0%
$VFA = 100 \times \frac{(VMA - Va)}{VMA}$	65% - 78%

Conclusion

Creating an HMA design that meets the Superpave criteria is a time consuming and detailed task but one that must be completed by the instructor if the asphalt lab is to run efficiently. There is more to mix design that just mixing aggregate with hot asphalt to form an HMA specimen. Careful attention to the details of aggregate gradation and meeting target values will ensure that the asphalt mix batched in the lab and the test results found y the students is valid. By creating a sound mix design, the students will gain more advanced knowledge of the mix design process and necessity for properly designed pavements.

Mix Production Process Control

Once we complete the mix design, we hand it over to the plant for production. There can sometimes be a difference between what we tell the plant to make and what actually is produced; you must remember the mix design is made in a lab in ideal conditions.

- There are a number of variables that occur in the field, including a number of plant variables and fluctuating aggregate stockpiles which affect mix properties.
- That is why we do process control of mix produced at the plant, as the plant produces, we continue to test for those required properties, and as soon as they deviate, we adjust the plant or our Job-Mix-Formula to return back to specification.

Obtaining Field Samples

As the paving process starts, field samples are collected and brought back to us in the Lab for checks on quality by testing for its properties.

- MTV available – use a truck mounted sample hopper to obtain sizable amount of test sample, remix and split through a Gilson Quarter Master. Transfer to individual sample boxes for QC, QA, and Referee testing laboratories. Ensure each sample boxes are adequately and legibly identified.
- Direct delivery from haul truck to paving machine hopper – take couple of plate samples, remix and split through a large capacity splitter then transfer to sample boxes for QC, QA, and Referee.

Laboratory Testing

Asphalt Concrete Mixes either designed by Marshall or Superpave Method play important role in road pavement construction. The objective in each case is to provide a smooth-riding road surface that is durable and stable. The success of all these depends on the aggregates, asphalt cement and any other value products used.

Aggregate for hot mix must include coarse and fine particles to help fill the voids between the larger particles. The shape of the aggregate particles is also important, irregular, crushed face of particles helps them interlock together for greater stability. If aggregate particles are smooth and rounded or they are all same size they will not interlock together and support each other.

Sometimes mineral admixture such as lime, etc. is added to Hot Mix to improve resistance to stripping.

In asphalt paving mixes, the asphalt is added to the aggregate and thoroughly mixed in to bind the aggregate particles together. Remember, it must be just the right amount of asphalt cement. If there's not enough AC, it can't do its job of holding the aggregate particles together, and if there's too much AC, it tends to lubricate the particles so that they slide past each other.
Remember that design and testing of Superpave hot mix is carried out in accordance with OPSS 1151 and AASHTO T 312 standards.

Test Sample Preparation

To maintain consistency between your test results (QC), QA and Referee laboratories, all field samples tested for acceptance should be cooled, split and reheated before testing. Follow LS procedure for Marshall testing with respect to this process.

- If field sample arrive hot at the Laboratory, such sample may be split to the required size for testing immediately, and the test portions subsequently allowed cooling to room temperature before reheating and testing.
- Field samples shall be heated to a temperature of 85^{o}C to 100^{o}C to allow workability of samples for initial splitting into required test fractions.
- Be aware of the AC grade in the sample being reheated, a higher PG grade say PG 70-28 may require a temperature at the higher end of recommended range while softer AC say PG 58-28 may require temperature closer to the bottom end of the range.
- Microwave Oven is acceptable for initial reheating of samples; ensure that the box of samples being reheated is constantly repositioned to prevent localized sample overheating or the box catching a fire.
- Convection or forced air ovens used for initial reheating of samples shall be set at 110+/-5^{o}C. The oven shall be capable of heating the sample to a workable temperature range as quickly as possible. Ensure samples reheated are not held in the oven for more than 1 hour. This will ensure that the AC in the sample is not oxidized before you start your test.
- Split down your samples with a riffle box splitter, this method from our experience reduces the sample segregation; ensure that a representative portion of the test sample is obtained for each test fraction.
- Sample fractions for AC/Gradation, MRD and BRD shall be prepared by progressively splitting the sample until the required mass of test fraction is obtained for each required test.
- Then proceed to test for AC/Gradation, MRD and Moisture Content by relevant LS procedures and record all your test parameters on your laboratory approved worksheet.

- When we receive the sample at the Lab, we split it down to a workable size depending on the test. For example, a test for percent asphalt cement, and gradation usually require a sample size of about 2000grams for binder mixes.
- There are two methods to determine the percent asphalt cement in the mix.

  - ✓ The first method uses a solvent called trichloroethylene to dissolve the asphalt cement from the rest of the sample. We let the sample soak in the chemical for a few cycles and then spin it out.
  - ✓ The second method is the ignition furnace, instead of dissolving the asphalt cement, this method burns it off. The ignition furnace operates at about 500^{o}C and is a faster method of determining the percent asphalt cement.

- With both these methods, we weigh the sample before and after the asphalt is eliminated; we can then calculate the percent asphalt cement and compare it to the mix design.
- Once the asphalt cement is removed from the sample we are left with the aggregate matrix composed of stone and sand. The sample is washed, dried and thrown into a nest of sieves which separates the aggregates by their size and we then we compute the gradation of the sample. We compare this gradation with the gradation on the mix design which is referred to as the JMF.
- Samples obtained in the field are also tested for their Marshall properties, similar to the tests carried out at the mix design stage. If the percent air voids in the briquette are out of range, then we usually make adjustments to the virgin aggregates going into the plant so that the voids become acceptable.

Superpave Test Sample

The BRD samples are to be formed by a Gyratory Compactor, totally different from Marshall Method for obtaining BRD. Follow these guidelines to remain on top of Laboratories offering this service.

- Remember that the sample height target at N_{des} shall be 115 +/- 3mm. BRD samples split for Gyratory Compaction should be sufficient to yield a briquette as close as possible to 115mm.
- Use the mix design weight for the mixture as a starting point to obtaining this height. If the weight given in the mix design does not produce the correct height, adjust the mass of the mix to produce a sample meeting the height requirements.
- Generally, for normal density mixes, a variance of approximately 40 grams from the mix design recommended weight will produce a 1 mm change in sample height. Note that some coarse or fine graded Superpave mixes my not follow this general rule.

- For Mix Design Superpave samples, condition in the oven for two hours before compacting. If testing plant produced Superpave hot mix samples from the job site, do not condition.
- Spread out Mix design gyratory samples to a uniform thickness of 25 to 50 mm in flat bottomed pan, cover sample with a tin foil to prevent additional oxidization during heating to compaction temperature specified for the mix.
- Set oven temperature not more than 5^{o}C above the compaction temperature established for the mix. Monitor temperature continually at frequency that will allow compaction of sample immediately on reaching the designated compaction temperature.
- Samples should be stirred to prevent localized overheating and promote uniform heating of samples at least every 30 minutes, be aware of "hot spots" in the oven used for heating samples to compaction temperature and rotate samples as required to ensure uniform heating of all samples
- Gyratory moulds and Platens shall be preheated in an oven to compaction temperature of the mix for a minimum of 30 minutes before use. At all times have your Moulds cleaned after each usage with a cleaner that will not leave a residue. Try using Varsol; do not use lubricants of any form on the mould interior surface.

Gyratory Compaction Process

- Transfer heated sample from the oven into a trough, preheated to the compaction temperature, mix sample to ensure proper blending. Trough being used should be of sufficient size to allow stirring of sample without materials being lost. Due care should be taken not to overheat test sample.
- Charge the heated Gyratory Mould with the sample in one motion as quickly as possible, rotating the trough around the circumference of the mould to distribute the mix uniformly in the mould. The moulds should be charged as fast as possible to prevent excessive cooling of the mix.
- Check the temperature of the mix now in the mould, making use of a digital thermometer calibrated to accuracy of +/- 1^{o}C. Once sample meets the compaction temperature requirement for the mix AC grade, place immediately in the Gyratory Compactor and compact to the required number of gyrations.
- After compacting to the require effort, let specimen remain in the mould to cool down for about 10 minutes or more, depending on the mix type, before extruding from the mould.

- After extruding, cool down compacted specimen to room temperature and test for Bulk Relative Density (BRD) in accordance with LS 262/ASTM D2726.

- If the BRD of a pair of gyratory samples are found to vary by more than 0.020, the test results shall be considered suspect. In this case fabricate a third sample and use result to replace an individual sample found to show the highest variance from the other two samples.
- MRD samples are to be tested in duplicate. MRD variance of greater than 0.010 should be considered suspect and a third sample should be prepared and tested. The third sample shall replace an individual sample found to show the highest variance from the other two samples.
- Utilize the test results for %AC, MRD, BRD to compute mix volumetric properties – VMA, VFA, % Air Voids and Dust Proportion. Also carry out particle size analysis for % passing all control/pay sieves. Finally, utilize your compaction heights out from the Gyratory Compactor to calculate % G_{mm} @ N_{ini} and % G_{mm} @ N_{des}.

Troubleshooting

How to go about an Incident

1. Verify the problem.
    a. Interview those involved with the project in question
    b. Visit the site to inspect the issue
    c. Observe site operations and construction techniques
    d. Take photos of the situation
2. Collect all relevant information
    a. All test reports - Process Control, Mix Designs, QA/QC, et
    b. Weather records on Paving Days
    c. Asphalt Plant daily reports
    d. Job site Delivery tickets
    e. Test report for Aggregate, Asphalt Binder and any other materials used for production
    f. Field inspection reports
3. Collect all available samples material used and test as required.
    a. Gradations of aggregates
    b. Specific gravity, Absorption, etc.
    c. PGAC properties
4. Analyze the data
    a. Are there observable trends in the test results?
    b. Was the HMA manufactured in accordance with the design?
    c. Are there indications on the test reports that relevant specification was not adhered to?
    d. Do pictures or job site observations reveal inadequate construction practices?
    e. Do the delivery tickets indicate actual HMA delivered to job site?
    f. Do the raw material test results correspond to the appropriate standard?
    g. Do the weather records highlight any potential issues that may have been encountered during placement?
    h. Do interviews indicate unusual incidents on the project?

5. Determine the probable cause(s) and complete a quality incident report with findings
6. Report findings to QC/QA staff and discuss
7. Respond to customer
8. Arrange for any additional testing to be performed (to be performed only when proven necessary and agreed through internal discussion)

Note:

Depending on the issue under investigation, the elapsed time from report of incident to response to the customer may vary from a few hours to days, or in extreme cases months. In any case, the intent should be respond to the customer as quickly as possible.

Asphalt Recycling Techniques

In-Place Recycling

The three different methods used for in-place asphalt recycling include: hot in-place recycling (HIR), cold in-place recycling (CIR) and full-depth reclamation (FDR). Additional methods of asphalt recycling include: hot recycling (HR) and cold central plant recycling (CCPR). When choosing the right method for a project, the type of distress the road is currently exhibiting should be the main consideration. The difference between CIR and FDR is that CIR mills and screens the top 50-100 mm of the existing asphalt layer and places it as a layer for a new base course, while FDR mills and screens the entire asphalt layer and portions of the underlying pavement structure to produce a new base course. HIR is best used when the asphalt is experiencing raveling, flushing, slipperiness, corrugations, shallow rutting or longitudinal (wheel path or joint) cracking. Assessment of the existing pavement conditions, mode of failure, causes of distress and testing of pavement material, base, sub-base, and subgrade should be completed before choosing a method of rehabilitation.

CIR and FDR are both suitable for load and non-load associated cracking but since FDR addresses structural and base problems, it should be used when the road has a weak base or subgrade because the subgrade can also be treated. The subgrade, however, is not always treated. FDR is also better than CIR for treating depressions or high spots on the road, especially if the depressions are caused by soft, wet subgrade conditions, or the high spots are caused by frost heave or swelling of an expansive subgrade soil.

Some signs that a road could benefit from FDR include: frequent transverse and longitudinal cracking, reflective cracking, heavy pothole patching, severe rutting, frost heaves, soil strains on the surface, parabolic shape and insufficient base strength to support current loads. FDR eliminates all distress areas in the flexible pavement.

Other pavement rehabilitation strategies include a thick structural overlay and removal and replacement of the existing base and asphalt surface. Although both provide a new pavement structure they can be very expensive and excessive virgin aggregates are necessary. Because of the uniqueness of each technique, very few roads qualify for more than one recycling technique.

Cold In-Place Recycling

The CIR process consists of milling the existing HMA layer to a specified depth (typically 50-150 mm) and crushing and screening the reclaimed asphalt pavement (RAP) to meet the contract specifications. Additives are blended in and the final mixture is spread and compacted over the same roadway. It is then overlaid with an HMA or a chip seal.

The CIR processing units come in three classes. The Multi-Unit Train cuts to a precise depth. The Two-Unit Train has a variable width cutting head. The Single-Unit Train is an all-in-one system. CIR should be used when the deficiencies are not throughout the entire HMA layer but are still deep enough that they cannot be corrected by HIR or a mill-and-fill. If the pavement has base deficiencies, structural problems or drainage issues CIR should not be used.

Selecting the appropriate pavement section is an important aspect to consider for successful CIR mixtures. Expected traffic volume should also be considered. CIR is typically used for lower volume roads. When CIR is performed on trafficked highways it is usually closed to the traffic until it is overlaid. Fatigue cracking, transverse thermal cracking, reflective cracking and raveling are the types of distress that can be easily corrected by CIR.

CIR provides a base that has good rutting resistance and is cost effective. The resistance to rutting and great amount of flexibility makes it a popular method in warm regions. When the RAP has high asphalt content and/or soft asphalt, rutting becomes more significant. Although CIR is more flexible than HIR, the higher air voids make it more susceptible to moisture damage. Because of this, the pavement must be sealed with an adequate wearing course. CIR is also good for rural roads because few if any truckloads of material need to be moved. CIR is quick and occupies only one lane of traffic so most roads can be kept open throughout the entire process. CIR costs anywhere between 15 and 50% less than conventional methods and produces roads that last 15 years or more.

Full Depth Reclamation

FDR is a recycling technique for asphalt pavement in which the entire HMA layer and a predetermined amount of the underlying base, sub-base, or subgrade material are recycled to produce a new base course, which can be overlaid with a new HMA layer. Other surface treatments such as; single and double chip seals, slurry seals or micro-surfacing can be used during low traffic conditions. The process starts with uniformly crushing, pulverizing and mixing the existing HMA with a predetermined portion of the underlying roadway materials and any other required materials, such as virgin aggregate. The depth of pulverization is usually 150 to 250 mm with a maximum depth of 400 mm. More than one pass of the equipment may be necessary to achieve the proper gradation. The pulverized material is then combined with mechanical, chemical, or bituminous stabilizers to form a high quality stabilized base. With a strengthened base the depth of the asphalt layer may be reduced.

The FDR process can be done using two approaches. In the first approach the existing pavement and base can be salvaged and hauled to a plant for crushing, screening, and mixing. This is a form of central plant recycling and is not common for most FDR applications. In the second approach, the material is crushed, screened, and mixed in-place by a recycling machine. This practice is much more common.

Figure 1 shows a schematic of the in-place recycling process. The reclamation can either be done in a Single Pass or a Multiple Passes process. The Single Pass process is typically used when additives are not used and if the required material gradation is already obtained. The Multiple Passes process is used when the road is widened or there is a change in grade. It should also be used when the depth is greater than 150 mm or additives are being used.

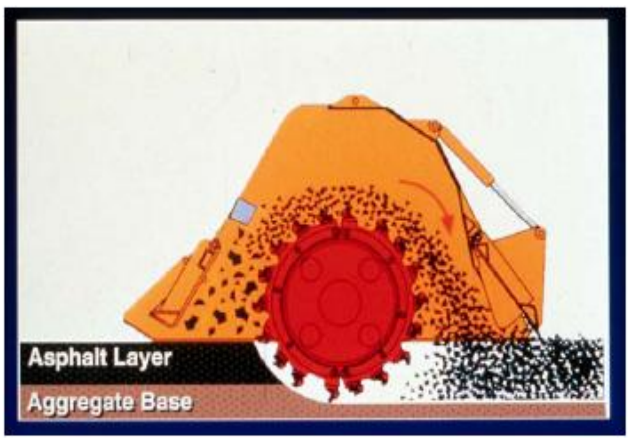


Figure 1. Graphic of the In-Place Recycling Process. (Graphic courtesy of ARRA)

Figure 2. Example of pavement with base problems. (Photo courtesy of the Portland Cement Association (PCA)).

The advantages of in-place recycling include: reduced material hauling, no plant setup, lower costs, and it can be used with weak subgrade soils where residual base materials provide support for construction operations. The advantages of plant recycling include: better mix of aggregates and additives and more control over the process and product.

The FDR process can be generalized by a six-step process:

1. Perform a site evaluation which includes determining types, levels and sources of pavement damage.
2. Sample the existing roadway to determine the available materials to be recycled. Determine the degree and type of stabilization required.
3. Decide if in-place recycling is appropriate. Pulverized materials from the site should be mixed so that it has a similar consistency of that expected in the field. Laboratory tests such as maximum dry density, plasticity index, sand equivalence, gradation by washing and optimum moisture content should be performed on the mixture to determine if in-place recycling will be suitable.
4. Conduct in-place recycling and verify initial product for specification compliance and suitability.
5. Grade and compact new FDR base material.
6. Construct the new overlay on top of the recycled base. This surface could be hot-mix asphalt, chip seal or concrete.

The main advantage of FDR is the reduction in cost because the use of in-situ materials reduces the amount of materials that must be hauled to or away from the site. Also, with the rising costs of aggregate, virgin material usage is reduced. FDR is also an excellent method for dust and erosion control on existing aggregate roadways reducing complaints from the public and environmental effects on water. Due to a minimal change in elevation, problems with curb, gutter and overhead clearances are eliminated. The construction cycle is fast and there is usually no need for detours.

When rehabilitating a pavement, the road is often built up due to an increase in pavement thickness and requires an extension of the shoulders. This also requires more right-of-way which can be costly. The use of FDR alone does not build the road up like this because the thickness of the recycled asphalt and base is removed and then included within the new base. For sections having a thicker HMA surfacing, widening of the embankment may be required unless some of the existing pavement is removed to maintain the original elevation after surfacing.

The process (FDR) has been proven on a wide range of flexible pavement structures to produce quality results at substantially lower costs and considerably shorter construction periods than conventional reconstruction practices."

Unlike CIR, FDR reconstructs the base layer with different types of recycling methods. FDR is therefore most suitable for treating problems related to the base. During construction, the pulverized material can easily be used to change the elevation of the roadway to obtain the desired cross-section and grade. FDR is also the best rehabilitation alternative for deep rutting and load and non-load associated cracking. FDR does not result in the typical reflective cracking associated with asphalt overlays while improving the pavement base condition. The FDR procedure allows for pavement and shoulder restoration and replacement, structural resurfacing and shoulder widening. Highly deteriorated roads requiring structural improvements due to pavement failure, design deficiencies, inadequate sub-base materials or surface rutting and cracking are best rehabilitated using FDR.

There are currently no standard design/mix specifications for FDR. Although several agencies have used a number of different mix designs, few of these mix design methods have been reported in the literature. Water is normally added to bring the mixture up to the desired moisture content and the mixture is typically compacted to a density of at least 96% of the standard Proctor density (ASTM International (ASTM) D 558) or 97% of the modified Proctor density (ASTM D 1557). The plasticity index, sieve analysis, dry unit weight, optimum moisture content and specific gravity tests should be conducted on all types of FDR bases.

After FDR has been chosen for the recycling method, it is necessary to determine if the presumed base material that can be generated will have enough strength or if it will need to be stabilized. When the material is stabilized, a bonding agent is mixed with the RAP and base aggregate to create a cohesive material. Types of material stabilization include chemical and bituminous. Chemical stabilization changes the chemical properties of the base to increase the strength. Chemical stabilizers include Portland cement, calcium chloride, hydrated lime and coal fly ash. Calcium chloride absorbs moisture, which helps in compaction and maintaining cohesion.

Calcium chloride is the least expensive of the stabilizers and works best in well graded non-plastic soils. Other chemical stabilizers such as Portland cement, lime and coal fly ash convey cohesive strength to the base through the hydraulic nature of the stabilizer and its ability to develop substantial compressive strength. These stabilizers are also susceptible to cracking if the strength developed is too great.

Bituminous stabilization adds asphalt to the newly formed base. Bituminous stabilizers include foamed asphalt and slow or medium set asphalt emulsions. An emulsion-stabilized base is flexible, fatigue resistant and not prone to cracking. It is however, more expensive than chemical stabilizers or foamed asphalt.

The RAP can also be mixed with other materials to provide mechanical stabilization without a bonding agent while still increasing its strength. The increase in strength can come from the addition of virgin aggregate, crushed glass, and geosynthetic fibers. These materials assure the lowest initial cost but may not be the most cost effective because the increase in strength may not be sufficient or long lasting.

In-place Recycle Mix Design

This standard practice for the mix design evaluation uses properties of the reclaimed asphalt pavement (RAP) material, base course material, and stabilizing agent to produce job-mix formula for the recycled layer in asphalt pavements. The mix design is based on the optimum density, strength property, and moisture damage resistance of the recycle materials.

For mix design and specifications, follow Ministry of Transportation Ontario (MTO):

- ✓ OPSS 330 – Construction Specification for In-Place Full Depth Reclamation of Bituminous Pavement with Underlying Granular
- ✓ OPSS 331 - Construction Specification For Full Depth Reclamation With Expanded Asphalt Stabilization
- ✓ OPSS 333 - Construction Specification For Cold In-Place Recycling
- ✓ OPSS 335 - Construction Specification For Cold In-Place Recycling With Expanded Asphalt