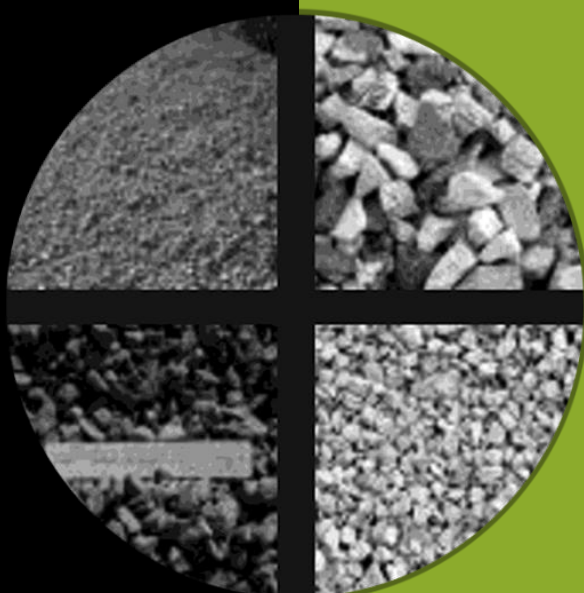
HMEC

Highway Materials Engineering Course

INDEPENDENT STUDY



Aggregates Background

MODULE

D

U.S.Department of Transportation
Federal Highway Administration

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Important Note

You must complete Module D Lesson 1 and Lesson 2 before visiting your state or district laboratory in Module D Lesson 3.

Using This Independent Study Workbook

This self-guided workbook contains the information you need to complete this lesson. Throughout the workbook, instructions are provided that explain how to complete each section. Following the instructions provided ensures that you will successfully complete the independent study (IS) lesson. Make sure that you read all required information, complete exercises, document observations, and answer knowledge check questions as instructed.

Be sure to have your completed workbook available when you attend the Web-conference training (WCT) portion of this module, as the information and your answers, observations, and findings will be reviewed and discussed.

Lesson 2 Introduction

Welcome to Module D: Aggregates for Transportation Construction Projects, Lesson 2: Aggregates Background. By the end of this lesson, you will be able to:

- List common uses of aggregates in transportation projects;
- Define common aggregate-related terms;
- Describe the most important aggregate properties for general transportation-related applications;
- Explain the most important aggregate quality characteristics for Portland cement concrete (PCC), asphalt concrete (AC), and pavement support layers; and
- Identify standard test methods for evaluating aggregates.

This lesson will take approximately 1 hour to complete.

Lesson Resources

To complete this lesson, you will need the following resources:

- Your agency's standard specifications for highway and bridge construction (or the equivalent)
- American Association of State Highway and Transportation Officials (AASHTO) Standard Specifications for Transportation Materials and Methods of Sampling and Testing, 33rd (or most current) Edition and AASHTO Provisional Standards, 2013 (or most current) Edition
- American Society for Testing and Materials (ASTM) Annual Book of Standards, Volume 04.02 (most current), Concrete and Aggregates

The following references are not required reading but may be something you wish to consult for additional information regarding the specific study topic.

- ASTM Volume 04.03 (most current), Road and Paving Materials; Vehicle-Pavement Systems
- National Cooperative Highway Research Program (NCHRP) Report 557: Aggregate Tests for Hot-Mix Asphalt Mixtures Used in Pavements
- NCHRP Report 453: Performance-Related Tests of Aggregates for Use in Unbound Pavement Layers
- NCHRP Report 539: Aggregate Properties and the Performance of Superpave-Designed Hot Mix Asphalt
- NCHRP Report 555: Test Methods for Characterizing Aggregate Shape, Texture, and Angularity
- NCHRP Report 405: Aggregate Tests Related to Asphalt Concrete Performance in Pavements

You will likely have these materials, but if not, they are available in your agency library or materials laboratory.

Instructions

Read the Common Uses of Aggregates in Transportation Projects section and answer the knowledge check questions that follow. Knowledge check questions will be reviewed and discussed during the Web-conference portion of this module.

Common Uses of Aggregates in Transportation Projects

Aggregates are used for many varied purposes in transportation projects, ranging from providing pavement support to serving as a key component in both Portland cement concrete and asphalt mixtures.

The specifications governing aggregate selection and properties differ substantially based on the end use. The majority of these aggregates are naturally occurring (igneous, metamorphic, and sedimentary) and undergo various processing steps to comply with specific end-use requirements. Synthetic or manufactured aggregates are also used in some cases to either supplement or replace natural aggregates to meet a specific project goal.

The most common uses of aggregates in transportation systems are:

- PCC mixtures
- Asphalt mixtures (hot mix asphalt (HMA), warm mix asphalt (WMA), cold patch, etc.)
- Pavement base coarse (stabilized and unbound)
- Pavement subbase coarse
- Select borrow for fill sections
- Riprap for erosion control
- Surface for gravel roads
- Chip seal

Aggregates are used in the production of PCC. The type and size of the production facility is dictated by capacity, location, access to the project, and numerous other factors.

The dry batch facility shown in this photo is relatively high capacity and will require large aggregate stockpiles to meet production goals.

A common use of aggregates in transportation systems is for hot mix, cold mix, and warm mix asphalt production.

This photo shows a typical stationary asphalt production facility. The aggregate stockpiles are visible behind the plant.

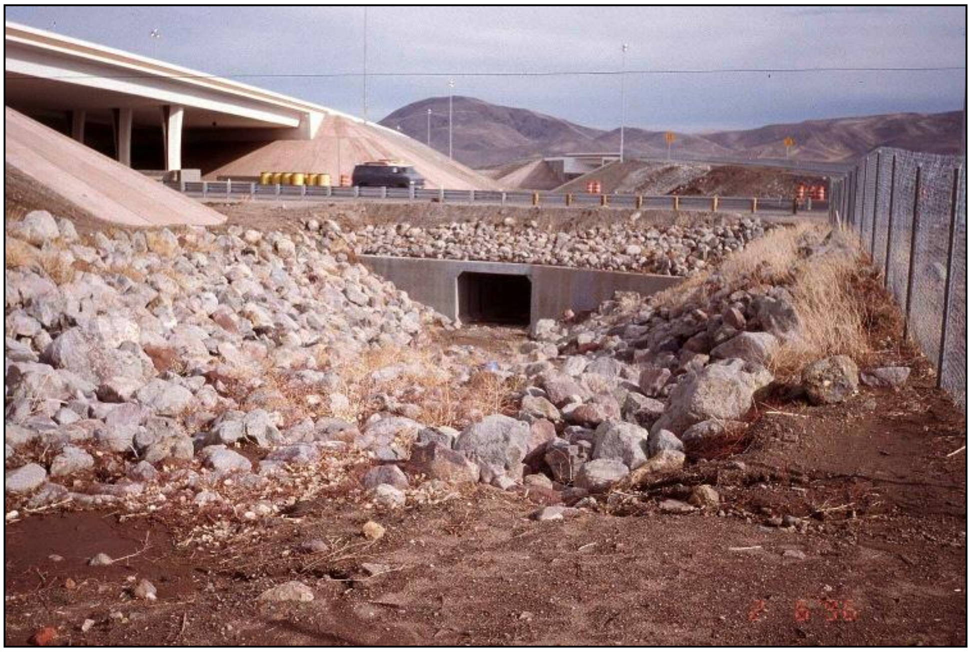
	The performance of the jointed plain concrete pavement (JPCP) shown in the photo is highly dependent on the concrete mixture characteristics. Aggregates play a significant role in determining the durability, economy, volumetric stability, and other key performance characteristics of the PCC.
	

	Aggregates are also a key component in determining the long-term performance of flexible pavements. Important properties include particle shape, surface texture, combined gradation, and numerous others. The photo shows the construction of a hot mix asphalt pavement.
	

	Unbound aggregate bases are the most common type of support under both flexible and rigid bases. These materials can be open graded to promote drainage or dense graded for additional stability. The dense-graded aggregate base pictured in this photo is the most common type of base for both rigid and flexible pavements.
	

	Stabilized aggregate bases are frequently used under both flexible and rigid pavements and may be either open graded or dense graded to meet specific project requirements. The most common stabilized bases include cement stabilized bases (CTB), asphalt stabilized bases (ASB), or lean concrete bases. The photo shows an asphalt treated base (ATB) with dowel basket assemblies in place for the placement of concrete pavement.
	

	Gravel surfaced roads are common in rural areas and generally consist of multiple layers (or lifts) of dense-graded gravel or crushed stone. This photo shows a recently placed unbound aggregate surface.
	

	Large boulders, cobbles, and occasionally recycled concrete are sometimes used for erosion control. The specific aggregate characteristics are relatively unimportant other than the size. The photo shows the various-sized, large boulders used to control erosion in this drainage ditch.
	

Knowledge Check

Circle the correct answer.

Which of the following are considered primary uses of aggregates in transportation systems?

a) PCC pavements

b) HMA pavements

c) Base coarse materials

d) All of the above

e) None of the above

Knowledge Check

Circle the correct answer.

Which of the following represents the most widely used base coarse material for rigid (PCC) pavements?

a) Cement treated base

b) Lean concrete base

c) Unbound aggregate base

d) Open graded, unbound permeable base

e) Asphalt treated base

	Instructions Read the Aggregate Terminology section. This terminology will be used throughout the HMEC.

Aggregate Terminology

There are many terms used to classify and differentiate aggregates. The most common classification schemes are based on aggregate gradation (AASHTO and ASTM). Virtually all classification schemes are related to one or more of the following physical properties:

- Gradation
- Particle shape
- Aggregate type
  - Source or mineralogy
  - Natural or synthetic (manufactured)
  - Virgin or recycled

In this section, we are going to cover common terminology used to describe aggregates. Note that the terms used in Module D are in common use, although some regional differences may exist.

Aggregate Terminology Related to Gradation

Based on common gradation parameters, the following terms are used:

- Coarse aggregate: Aggregate predominantly retained on the 4.75 mm (#4) sieve. The maximum aggregate size used for transportation projects (other than riprap) is generally less than 3 inches.
- Fine aggregate: Aggregate predominantly passing the 4.75 mm (#4) sieve and retained on the 0.075 mm (#200) sieve.
- Fines: Sometimes used to designate fine aggregate or the very fine material that passes the 0.075 mm (#200) sieve**.**
- Maximum size and nominal maximum size: The following table illustrates and compares the definitions for nominal maximum aggregate size and maximum aggregate size.

	Nominal Max. Size	Maximum Size
ASTM C 125 *Concrete*	In a Spec – 100% ***Permitted*** to Pass	In a Spec – 100% ***Required*** to Pass
AASHTO M 323 *HMA*	One Size Larger Than Size That Retains More Than 10%	Next Size Larger Than Nominal Max.

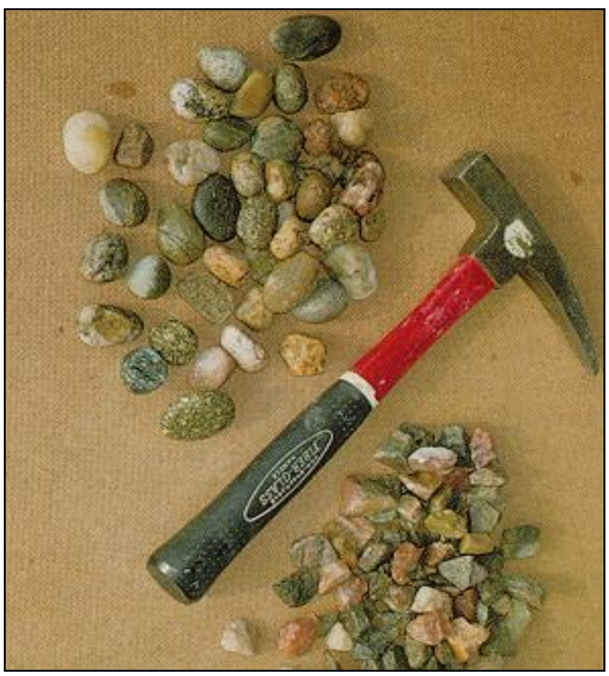
Note the subtle differences in the definition of maximum and nominal maximum aggregate size. This distinction is very important as these terms are sometimes incorrectly used. For example, in the American Concrete Institute (ACI) 211.1 mix design procedure, the calculations are based on the nominal maximum aggregate size.

The ASTM definition is based on the specification limits for the aggregate product. The AASHTO definition in M 323 for Superpave HMA is based on the actual grading of the aggregate material.

Aggregate Terminology Related to Particle Shape

Aggregates may also be differentiated by particle shape as well as gradation:

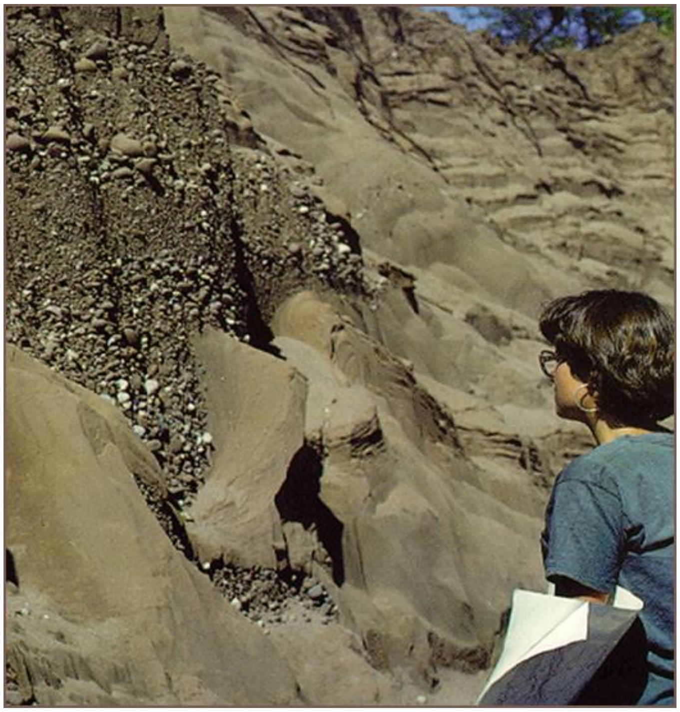
- Gravel: Natural aggregate particles generally ranging from the plus #4 sieve to 3 inches. These particles are typically smooth and rounded due to weathering.
- Sand: Natural aggregate particles generally ranging from the minus #4 sieve to plus #200 sieve.
- Sand and gravel: Aggregate resulting from natural disintegration of rock.
- Bank-run: Sand and gravel mined and used in construction with little or no processing.
- Crushed gravel: Mechanically crushed gravel, boulders, or large cobbles for the purpose of creating more angular particles. Specifications typically require at least one, often more, fractured faces.
- Crushed stone: Product resulting from mechanical crushing of blasted ledge rock, substantially all faces of which have resulted from the crushing operation.
- Crusher-run: The total product of a rock crusher that passes a designated screen.



Aggregate Terminology Related to Type: Natural Aggregates

The following terms are in common use to describe natural aggregates:

- Aggregates: Defined by *Webster's Dictionary*, aggregates are composed of mineral crystals of one or more kinds or of mineral rock fragments.
- Natural aggregates: Defined by the US Geological Survey (USGS) as meeting the following criteria:
  - Composed of rock fragments including sand, gravel, and crushed stone
  - Used in their natural state or after processing by crushing, washing, sizing, etc.



Aggregate Terminology Related to Type: Manufactured or Synthetic Aggregates

The following terms are in common use to describe synthetic aggregates:

- Synthetic or manufactured aggregates: Those typically produced as a byproduct of industrial processes, e.g. blast furnace slag, steel slag, lightweight aggregate, and so on.
- Manufactured fine aggregate: A crushed, sand-sized material originating from stone or gravel and used as a fine aggregate.
- Slag: The nonmetallic product developed in a molten condition simultaneously during the manufacture of iron, steel, or other products. Slag aggregate includes blast furnace slag from the reduction of iron ore and steel slag from the steel furnace operations.
- Lightweight aggregates: Expanded cellular materials obtained by controlled processes from molten slag, clay, or shale.

Aggregate Terminology Related to Type: Recycled Aggregates

The following terms are in common use to describe synthetic aggregates:

- Recycled aggregates: Aggregates produced from crushing and screening of broken or fragmented concrete, asphaltic pavements, or other previously cemented mixtures, usually including much of the cementing medium reclaimed in the process.
- Recycled concrete aggregate (RCA): Granular material manufactured by removing, crushing, and processing hydraulic-cement concrete (typically PCC). This material may be used for a variety of purposes including pavement support layers, coarse aggregate for PCC, and others.
- Reclaimed asphalt pavement (RAP): Granular material resulting from the removal and processing of existing asphalt pavements. When properly crushed and screened, RAP consists of high-quality, well-graded aggregates coated by asphalt cement. RAP may be used for a variety of purposes ranging from base and subbase materials to incorporation in new AC mixes.

Additional Aggregate Terminology

- Soil-aggregate: Natural or prepared mixtures consisting predominantly of stone, gravel, or sand and which contain a significant amount of minus #200 (0.075 mm) material.
- Base coarse: A layer of specified material constructed on the subgrade or subbase for the purpose of distributing load, providing drainage, minimizing frost action, etc.
- Subbase coarse: The subbase coarse is typically thought of as the layer between the base and the subgrade in flexible pavements. The term subbase is also frequently used to describe the layer between the concrete slab and the subgrade in rigid pavements. The specifications for subbases are generally less stringent than for a base coarse material.
- California bearing ratio (CBR): The California bearing ratio (CBR) is a penetration test for evaluation of the mechanical strength of road subgrades and base coarses. It was developed by the California Department of Transportation. The CBR rating was developed for measuring the load-bearing capacity of soils used for building roads. The standard material for this test is crushed California limestone, which has a value of 100.
- Soundness: The soundness test determines an aggregate's resistance to disintegration by weathering and, in particular, freeze-thaw cycles.
- Plasticity: Plasticity is based on the Atterberg limits and is a basic measure of the critical water contents of a fine-grained soil, such as its shrinkage limit, plastic limit, and liquid limit. As a dry, clayey soil takes on increasing amounts of water, it undergoes dramatic and distinct changes in behavior and consistency. Depending on the water content of the soil, it may appear in four states: solid, semi-solid, plastic, and liquid. In each state, the consistency and behavior of a soil is different and consequently so are its engineering properties. High plasticity soils tend to be moisture sensitive while non-plastic or low plasticity materials are much less so. It should be noted that the behavior of granular materials may be significantly impacted by both the amount of fines and the plasticity of the fines.

Knowledge Check

Circle the correct answer.

Coarse aggregates are generally differentiated from fine aggregates based on what standard sieve size?

a) #200

b) #16

c) #4

d) ¾ inch

Knowledge Check

Circle the correct answer.

Which of the following terms are used to describe the total production of a rock-crushing operation (generally passing a specific screen size)?

a) Bank-run
b) Crushed stone
c) Crushed gravel
d) Crusher-run
e) River gravel

Knowledge Check

Circle the correct answer.

The support layer immediately under the surface coarse in an asphalt pavement is typically referred to as which of the following?

a) Base coarse
b) Subbase coarse
c) Subgrade

Knowledge Check

Circle the correct answer.

Which of the following is not considered a manufactured or synthetic aggregate?

a) Expanded shale
b) Blast furnace slag
c) Pumice
d) Steel slag

Knowledge Check

Circle the correct answer.

Aggregates are often classified based on which of the following?

a) Gradation
b) Particle shape
c) Mineralogy
d) All of the above
e) None of the above

Instructions

Read the Important Aggregate Properties section and answer the knowledge check questions that follow. This section lists the most commonly specified aggregate properties and their relative importance for different end uses.

Important Aggregate Properties

The desirable properties of aggregates vary somewhat by the intended use. In other words, aggregates suitable for PCC may not necessarily be the best choice for AC or base coarse materials.

The most frequently specified aggregate properties include the following:

- Gradation
- Strength
- Particle shape
- Surface texture
- Durability (abrasion resistance, hardness)
- Reactivity
- Volumetric stability (coefficient of thermal expansion)

These general categories encompass the majority of aggregate specifications and test protocols.

The following three tables show the relative importance of physical, chemical, and mechanical properties of aggregates based on their intended use.

Relative Importance of Physical Aggregate Properties

The following table shows the relative importance of common physical properties of aggregates based on their end use.

Property	PCC	AC	Base Coarse
Particle shape – angularity	M	V	V
Particle shape – flakiness, elongation	M	V	M
Particle size – maximum	M	M	M
Particle size – distribution	M	M	M
Particle surface texture	M	V	V
Pore structure, porosity	V	M	U
Specific gravity, absorption	V	M	M
Soundness – weatherability	V	M	M
Unit wt, voids – loose, compacted	V	M	M
Volumetric stability -- thermal	M	U	U
Volumetric stability -- wet/dry	M	U	M
Volumetric stability -- freeze/thaw	V	M	M
Integrity during heating	U	M	M
Deleterious constituents	V	M	M

V = Very important
M = Moderately important
U = Unimportant or importance unknown

Relative Importance of Chemical Aggregate Properties

The following table shows the relative importance of common chemical properties of aggregates based on their end use.

Property	PCC	AC	Base Coarse
Solubility	M	U	U
Surface charge	U	V	U
Asphalt affinity	U	V	M
Reactivity to chemicals	V	U	U
Volume stability – chemical	V	M	M

V = Very important
M = Moderately important
U = Unimportant or importance unknown

Relative Importance of Mechanical Aggregate Properties

The following table shows the relative importance of common mechanical properties of aggregates based on their end use.

Property	PCC	AC	Base Coarse
Compressive strength	M	U	U
Toughness – impact resistant	M	M	U
Abrasion resistance	M	M	M
Character of products of abrasion	M	M	U
Mass stability – stiffness, resilience	U	V	V
Polishability	M	M	U

V = Very important
M = Moderately important
U = Unimportant or importance unknown

Knowledge Check

Circle the correct answer.

We have discussed many physical properties of aggregates. Which of the following is the most important property for use in an unbound aggregate base coarse?

a) Particle shape
b) Coefficient of thermal expansion
c) Porosity
d) All of the above
e) None of the above

Knowledge Check

Circle the correct answer.

Elongated aggregate particles (particle shape) are considered very important for which of the following?

a) PCC
b) AC
c) Base coarse material
d) Subbase material
e) All of the above

Knowledge Check

Circle the correct answer.

The compressive strength of aggregates is considered important for which of the following?

a) PCC
b) AC
c) Base coarse material
d) Subbase material
e) All of the above

Overview of AASHTO and ASTM Test Procedures

In this section, we are going to look at a number of different test procedures specified by AASHTO and ASTM that are used to characterize the physical properties of aggregates.

In the laboratory session (Lesson 3), you are going to perform or observe a number of the more frequently performed tests.

The AASHTO and ASTM test method numbers are provided for many of the tests listed. As you read through this section, you should prepare a list of these test standards and read through the actual test protocols in the standards books to familiarize yourself with the procedures.

Standard Test Methods for Evaluating Aggregates

Aggregate characterization generally involves performing a number of physical, mechanical, or chemical tests conducted on representative material samples.

The end use of the aggregates and the relative importance of the project may dictate which tests are performed.

In Lesson 3, you will actually be performing or observing many of the tests highlighted in this section. Complete details regarding these and other test procedures will be provided at that time.

The most frequently performed tests are physical characterization. The majority of central and field laboratories perform these on a routine basis. Chemical and mechanical testing is much more specialized and these tests are not as frequently performed.

In this section, we will look at some of the basic aggregate characterization tests.

- Physical properties
  - Grading, shape, angularity, texture
  - Density, pore properties
  - Others depending on intended use
- Chemical properties
  - Affinity for asphalt, bond with PC paste
  - Reactivity
- Mechanical properties
  - Resistance to applied loads (strength and deformation)

Particle Versus Bulk Aggregate Properties

Although many of the typical aggregate tests are performed on bulk or combined aggregates, there are circumstances where individual particles are tested.

- Individual particles (rock, minerals)
  - Specific gravity (particle density)
  - Absorption, pore properties
  - Strength, hardness, toughness (dry, wet)
  - Volume stability (thermal, moisture)
- Bulk aggregate (collection of particles)
  - Grading, size, minus #200, cleanliness
  - Unit weight (bulk density), void content
  - Moisture content

Obtaining Representative Samples

Determining realistic aggregate properties requires tests to be performed on representative samples of either individual or combined aggregates.

Obtaining representative samples consists of using appropriate sampling techniques for the specific application (i.e. stockpiles, conveyor belts, silos, etc.) and splitting the samples to aid in uniformity.

- Sampling of Aggregates, AASHTO T 2 (ASTM D 75)
- Reducing Samples of Aggregates to Testing Size, AASHTO T 248 (ASTM C 702)

It should be noted that in order to obtain representative test results, proper sampling and sample splitting are key.

Grading Aggregates

Aggregate grading is performed on either individual or combined aggregate samples.

- Sieve Analysis, AASHTO T 27 (ASTM C 136)
  - Individual size fractions
  - Cumulative percent passing (basis for typical specification)
  - Cumulative percent retained (for fineness modulus (FM) determination)
- Maximum aggregate size*
- Nominal maximum aggregate size*
- Minus #200 fraction (75 µm)
  - Dry sieve
  - Wash loss, AASHTO T 11

*The maximum and nominal maximum aggregate sizes differ by the intended aggregate use and are defined in the following slides. Gradation is one of the most important parameters regardless of intended use. These procedures will be demonstrated in the laboratory portion of Lesson 3.

Coarse Aggregate Grading

The sieve sizes and type are selected based on the aggregate, primarily the maximum aggregate size and the appropriate specification.

For coarse aggregate sieve analysis, larger sieves are used to accommodate the larger sample test portions required to get accurate results.

It should be noted that the sieve configuration and overall size is dependent on the equipment used. The photo shows a small round sieve that can be used in either a mechanical shaker or for hand sieving. The larger sieve is only applicable for a large mechanical shaker. Although the sieve size is the same, the sample size would be substantially reduced for the smaller sieve.

Coarse Aggregate Sieves

Fine Aggregate Grading

For fine aggregate sieve analysis, smaller sieves are used due to the smaller sample size required for accurate results.

In some cases, there may be overlap with the coarse aggregate sieve sizes depending on the sample being tested and the governing specification.

Note that the AASHTO T 88 standard (and ASTM equivalent) for soils and soil aggregate may have application for base/subbase materials as well as borrow and fill materials.

Fine Aggregate Sieves

Gradation: Determining Minus #200 (75 µm) Size Fraction

These tests will be demonstrated in the laboratory portion of Lesson 3.

- Dry sieving, including the #200 sieve
- By washing – decanting over the #200 sieve
  - With wetting agent (AASHTO T 11)
  - Without wetting agent (ASTM C 117)
- Minus #200 included in Sieve Analysis = (Minus #200 by washing) + (additional minus #200 by dry sieving of the same sample)
  - This procedure is important because the minus #200 can have a significant effect on the moisture sensitivity and stability of unbound granular materials (particularly plastic fines), the water demand and workability of PCC, and the stability of AC mixtures.

Aggregate Cleanliness

The cleanliness of the aggregates may have a significant influence on the combined aggregate properties as previously mentioned. The tests indicated above will be demonstrated in the laboratory portion of Lesson 3.

Cleanliness of aggregates can also be measured by methods other than minus #200, such as those listed in the slide for fine and coarse aggregates.

For graded aggregates, the initial sample is often dry sieved on coarse aggregate sieves first, and then a split of the minus #4 material is tested as a fine aggregate.

Fine aggregate methods include sand equivalent, plasticity index, and the methylene blue value test to detect the presence of active clays in the fines.

For coarse aggregate material, minus #200 can be determined by washing. Other cleanliness tests include adherent fines and the California cleanliness value (CV).

- Fine aggregate fraction
  - Minus #200 sieve (as previously described)
  - Sand equivalent, AASHTO T 176 (ASTM D 2419)
  - Plasticity index, AASHTO T 90 (ASTM C 4318)
  - Methylene blue value, AASHTO T 330
- Coarse aggregate fraction
  - Minus #200 sieve
  - Adherent fines, ASTM D 5711
  - Cleanliness value (CV), California Test Method 227

Fine Aggregate Shape, Angularity, and Texture

Aggregate shape, angularity, and texture affect the interaction of the aggregate particles as well as the void space that exists in both the loose and compacted states. This photo shows the effect of these characteristics in conjunction with slight variations in gradation. The lowest void ratio of the samples shown is the natural sand sample, which tends to be somewhat smooth and rounded in relation to the very angular and rough manufactured sand. As a general rule, the more rounded and smooth the particles are, the easier it is for them to reorient. For instance, consider the workability differences arising from using manufactured sand as opposed to natural sand in a typical paving PCC mixture.

The coarse aggregate shape, angularity and surface texture can be determined according to the following tests:

Uncompacted Void Content of Fine Aggregate (as Influenced by Particle Shape, Surface Texture, and Grading), AASHTO T 304

	Coarse Aggregate Shape, Angularity, and Texture This is an example of rounded river gravel. Note the smooth surface texture, which in conjunction with the rounded shape, permits these particles to reorient very easily. As would be expected, the stability of these aggregates would not be high due to these characteristics. The coarse aggregate shape, angularity and surface texture can be determined according to the following tests: Determining the Percent of Fracture in Coarse Aggregate, AASHTO T 335, (ASTM D 5821) Standard Test Method for Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate ASTM D 4791 Uncompacted Void Content of Coarse Aggregate (as Influenced by Particle Shape, Surface Texture, and Grading), AASHTO T 326
	

Coarse Aggregate Shape, Angularity, and Texture

This is an example of crushed stone. Note the angular shape and relatively rough surface texture. These particles do not reorient easily and therefore tend to be relatively stable compared to those in the previous slide. Note that the compactive effort required to achieve good density, and therefore stability, may be quite high.

Coarse Aggregate Shape, Angularity, and Texture

This is an example of blast furnace slag. Note the angular or near cubical shape and the rough and porous surface texture.

Strength and Durability

There are various strength parameters used to describe aggregates. It is difficult to measure strength of individual aggregate particles; and, for many common uses, strength itself does not greatly influence performance. Examples of uses where strength is not overly important include aggregate base and subbase, aggregate for moderate strength Portland cement concrete, and aggregate for asphalt base and binder layers.

Example tensile strengths of aggregate materials are shown here. Aggregate particle strength can be important in some applications, such as for high strength concrete, surface coarses on heavily traveled pavements, and aggregate interlock for load transfer in plain-jointed concrete pavement. Generally, the strength of aggregate is evaluated based on the performance of a mixture containing the aggregate, from previous experience using the aggregate in similar applications, or from subjective petrographic evaluation of the competence of minerals and rocks present.

The following list includes some of the more common strength and durability characteristics of aggregates:

- Compressive strength
  - 4,000 to 70,000 psi
- Tensile strength
  - 30 to 380 psi (Shale)
  - 300 to 1,200 psi (Limestone)
  - 500 to 2,300 psi (Quartzite)
- Hardness
- Impact resistance – toughness
- Wear, degradation, abrasion – wet or dry
- Polishing – pavement friction

Aggregate strength of a bulk sample can be determined according to the following test:

Determining the Resilient Modulus of Soils and Aggregate Minerals, AASHTO T 307

Compressive Strength

The compressive strength of the rocks and minerals comprising typical aggregates vary widely. Although the strengths may vary by a substantial amount, most sources of aggregates may be successfully utilized by identifying the end use and service environment. Strength is not generally measured or specified for aggregates used in construction per se. The following values were determined from rock core strength tests.

- Quartzite 21,000 to 68,000 psi
- Basalt 8,000 to 44,000 psi
- Traprock (Gabbro) 15,000 to 34,000 psi
- Limestone 7,000 to 39,000 psi
- Granite 4,000 to 40,000 psi
- Sandstone 5,000 to 16,000 psi
- Shale 5,000 to 13,000 psi
- Low Strength – cinders, coral, lightweight aggregate

The compressive strength of rock cores can be determined by the following test:

Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures, ASTM D 7012

Hardness

Hardness can be measured in many ways. Weaker, softer aggregate particles may perform well in some applications or climates. However, if the weakness is due to high porosity or the presence of planes of weakness due to clays or mineral cleavage planes, then they may be subject to freezing and thawing or chemical durability problems. Hard aggregates generally provide better abrasion resistance and better wet-weather friction on pavement surfaces.

A number of methods are used to determine the hardness of aggregates. The most frequently used procedures are shown below:

- Scratch – Mohs scale of hardness
- Polished stone value – British wheel equivalent

Aggregate hardness can be determined according to the following tests:

Moh's Hardness (No AASHTO designation)

Accelerate Polishing of Aggregates Using the British Wheel, AASHTO T 279

Abrasion, Wear, and Degradation

The abrasion, wear, and degradation of both fine and coarse aggregates are important properties for materials when subjected to repeated traffic loadings. Normally, the primary concern is for the degradation of coarse materials. However, fine aggregate, with its much greater surface area, can degrade with a resulting increase in the amount of minus #200 fines. This can happen during aggressive mixing or handling procedures where the particles of fine aggregate abrade one another, for example, during PCC mixing.

Aggregate particles behave differently under wet and dry conditions and therefore are tested under both conditions. The following tests represent the current standards for measuring the abrasion, wear, and degradation characteristics of both coarse and fine aggregates.

- Dry (Los Angeles Abrasion Test)
  - Small coarse aggregate – less than 1½ inches

    AASHTO T 96 (ASTM C 131)
  - Large coarse aggregate – greater than ¾ inch

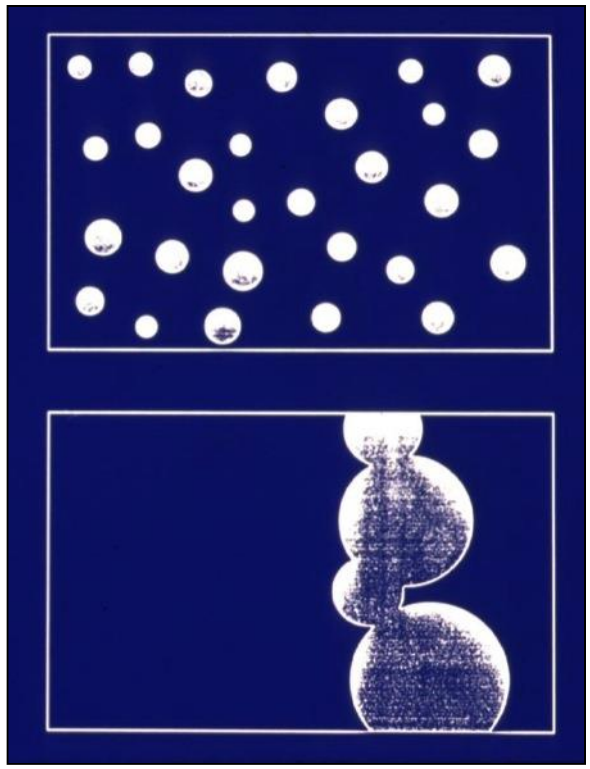
    ASTM C 535
- Wet
  - Micro Deval Test
  - ASTM D 7428 - 08e1, Standard Test Method for Resistance of Fine Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus
  - AASHTO T 327, Standard Method of Test for Resistance of Coarse Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus
  - ASTM D 6928 – 10, Standard Test Method for Resistance of Coarse Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus

Durability

Pores in aggregate particles and in rock are distributed in a size range that is related to mineral composition, the method of creation of the rock, and weathering. Another important characteristic is the interconnection structure of the pores in rock or aggregate particles. Pores that are isolated will not transmit fluids as readily as those that are interconnected and can allow water and ions to penetrate or pass through the rock material. Pores that become saturated are more vulnerable to freezing and thawing damage in concrete and to stripping in hot mix asphalt. The faster transmission of ions in aggregate particles can speed alkali-aggregate reactions in concrete and speed corrosion of reinforcing steel in concrete if chlorides are present.

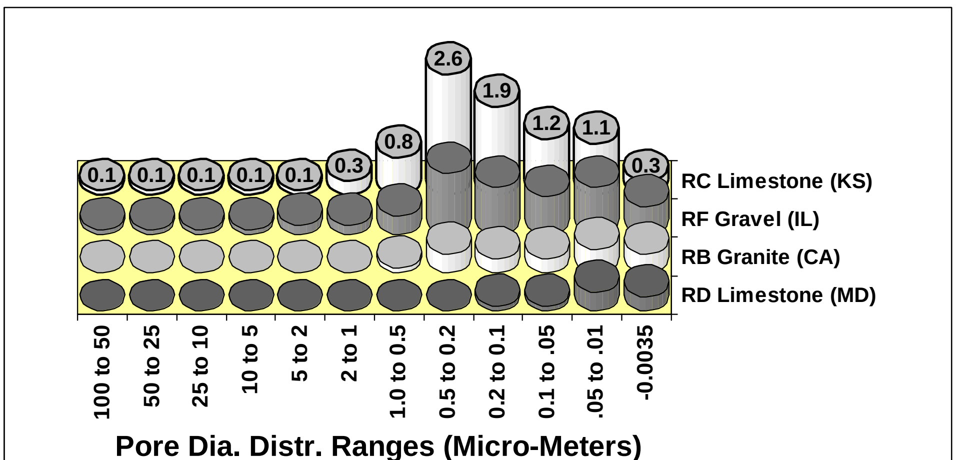
Pore Size Distribution

Interconnectivity of Pores



Porosity of Various Aggregates

Pore structure of aggregate particles can range in size from a few angstroms (which is smaller than a water molecule) up to very large holes of 1 mm or more, which can be easily seen without magnification. Pore size distributions have been determined down to 0.01 micrometers by mercury intrusion methods. As a frame of reference, 1 mm = 1,000 micrometers. An example of pore size distributions for several aggregate sources is shown. The sizes of pores that are generally thought to cause freeze-thaw durability problems are those in the 0.1 to 5 micrometer range. Smaller pores are too small for water to freeze in great quantity, and large pores are somewhat like air entrainment in PCC. The larger voids rarely become fully saturated with water.



Porosity, % (Mercury Intrusion)

Volume Stability of Aggregate Particles, Thermal Movement

Volume stability of aggregate particles is most important in PCC but must be considered in base/subbase materials or AC mixtures if large volume changes may occur. Volume change of aggregates or mixtures can be caused by several factors—thermal, moisture, chemical reactions.

- PCC: The range of values for coefficient of thermal expansion (CTE) of PCC ranges from approximately 0.000004 to 0.000007 inch per inch per °F. This value is influenced primarily by aggregate type and to a lesser extent gradation. Limestone aggregates tend to have a lower CTE (.000002); however, some coarse grained limestone can be as high as .000004. Quartz and aggregates with high silica contents are generally much higher (approximately 0.0000065). The CTE of PCC is determined by AASHTO T 336, "Coefficient of Thermal Expansion of Hydraulic Cement Concrete."
- AC: Aggregate thermal properties are not considered important in AC mixtures. Under most temperature conditions, asphalt is flexible and thermal movements are generally accommodated. However, at very cold temperatures, much of the flexibility is lost and thermal cracking can result in asphalt pavement as it cools and contracts.
- Base: Thermal expansion is not important in unbound base and subbase materials. However, cement stabilized bases may be subject to the same considerations as PCC at higher cement contents and strengths (i.e. lean concrete bases).

Volume Stability of Aggregate Particles, Chemical Reactions

Volume changes may occur due to chemical reactions (i.e. alkali silica reactions in PCC) or physical processes, such as volume increases due to water freezing in the pore structure of the aggregates (i.e. D-cracking in PCC).

Steel slag (different from blast furnace slag) aggregates can experience significant volume changes due to hydration reactions (ASTM D 4792) in which free calcium and magnesium expand in volume when exposed to water.

For this reason, steel slag should not be used in concrete. For use in HMA and in bases/subbases, the slag must be wetted, cured, and aged to make sure the expansion reactions have run their full course before use in construction—particularly construction in a confined space.

Volume Stability of Aggregate Particles, Moisture-Induced Movement

Volume changes may also be the result of moisture fluctuations. Although these changes may be present in AC and bases/subbases, their effects are minimal and are usually disregarded. However, in the case of PCC, these changes may be significant and are assessed by the following methods.

- AASHTO T 160 (ASTM C 157) Length Change of Hardened Hydraulic Cement Mortar and Concrete
- AASHTO T 334-08 (2012) Estimating the Cracking Tendency of Concrete

Activity: State Standards Compared to AASHTO/ASTM Standards

In Lesson 1, you compiled a table of information regarding your agency standards. Now, look up and review the various AASHTO and ASTM standards listed in this lesson. You should take the time now to flag them for easy reference during Lesson 3. Note that when you begin preparation for Lesson 3, there will be additional specifications to review.

In this activity, you will compare your State standards with the AASHTO/ASTM standards. In the majority of cases, they will be the same since most agencies base their specifications on AASHTO or ASTM. Since not all standards will be the same, note any differences regarding test protocols and recommended values. These differences may be in regard to general aggregate properties or they may be specific to intended use, i.e. PCC, AC, bases, and subbases. Document these variations in the following table. There are a few examples included.

The table is not intended to be all inclusive of your agency standards but will provide a framework for what is requested in this exercise.

Material Property	Intended Use	AASHTO or ASTM Requirement	Agency Requirement	Notes
Gradation – Minus #200	**Base coarse**	**AASHTO T11**	**Hydrometer analysis**	**Determine characteristics of minus #200 material**
Cleanliness	**HMA**	**AASHTO 176 (Sand Equivalent) or AASHTO T 330 (Methylene Blue Index)**	**Methylene blue**	**Predicts stripping potential of AC/aggregate**
Volume Stability – CTE	**PCC**	**AASHTO T 336**	**Not performed in laboratory, estimated based on aggregate type**	**Used to estimate CTE of the PCC**

Material Property	Intended Use	AASHTO or ASTM Requirement	Agency Requirement	Notes

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Material Property	Intended Use	AASHTO or ASTM Requirement	Agency Requirement	Notes

Summary

This completes Lesson 2: Background. You are now able to:

- List common uses of aggregates in transportation projects;
- Define common aggregate-related terms;
- Describe the most important aggregate properties for general transportation-related applications;
- Explain the most important aggregate quality characteristics for PCC, AC, and pavement support layers; and
- Identify standard test methods for evaluating aggregates.