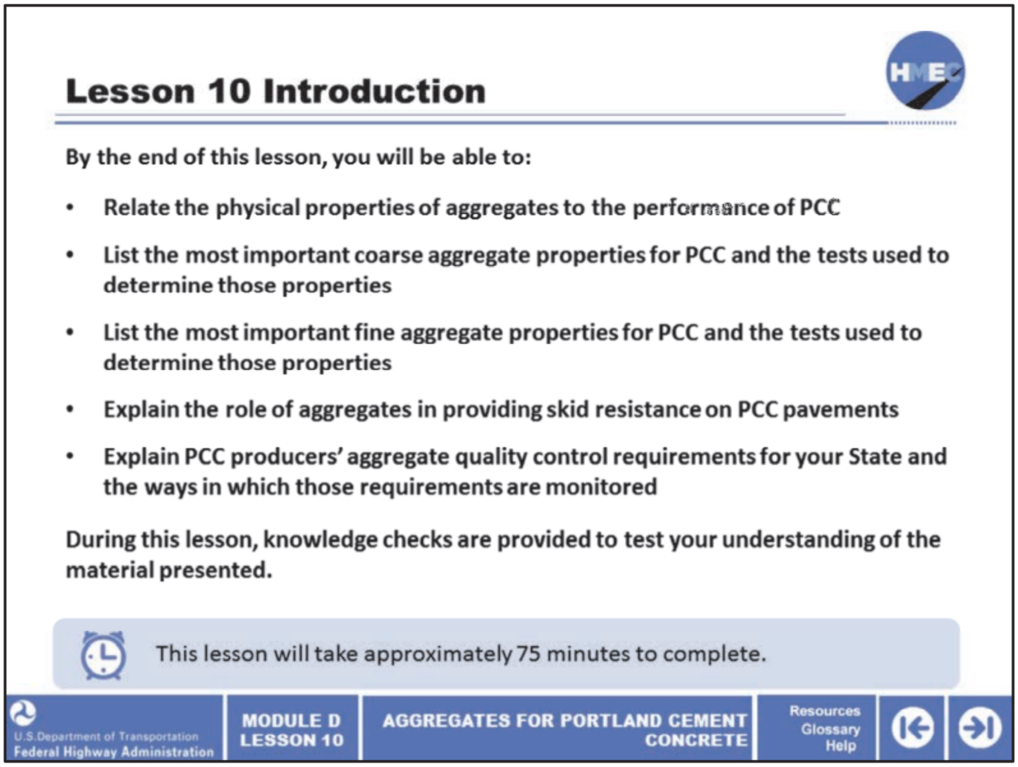
Welcome to the Highway Materials Engineering Course, Lesson 10: Aggregates for Portland Cement Concrete. This lesson explores the aggregate characteristics that are important considerations in Portland cement concrete (PCC).

A printer-friendly version of the lesson materials can be downloaded by selecting the paperclip icon. Only the slides for the this lesson are available.

If you need technical assistance during the training, please select the Help link in the upper right-hand corner of the screen.

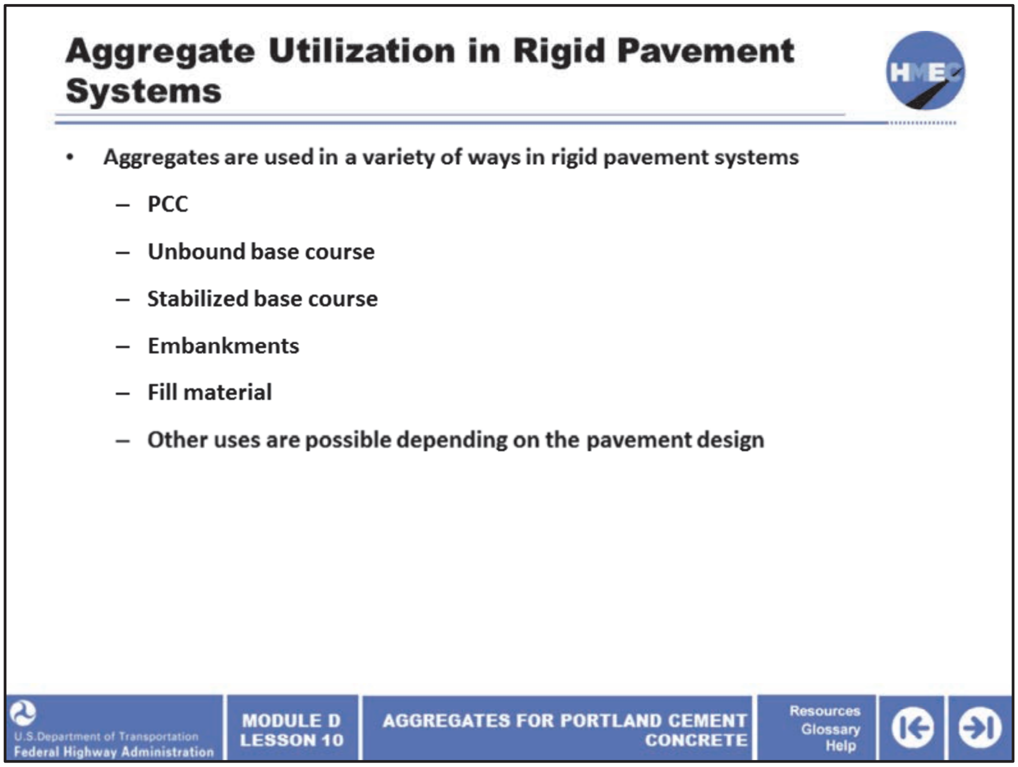


By the end of this lesson, you will be able to:

• Relate the physical properties of aggregates to the performance of PCC;
• List the most important coarse aggregate properties for PCC and the tests used to determine those properties;
• List the most important fine aggregate properties for PCC and the tests used to determine those properties;
• Explain the role of aggregates in providing skid resistance on PCC pavements; and
• Explain PCC producers' aggregate quality control requirements for your State and the ways in which those requirements are monitored.

During this lesson, knowledge checks are provided to test your understanding of the material presented.

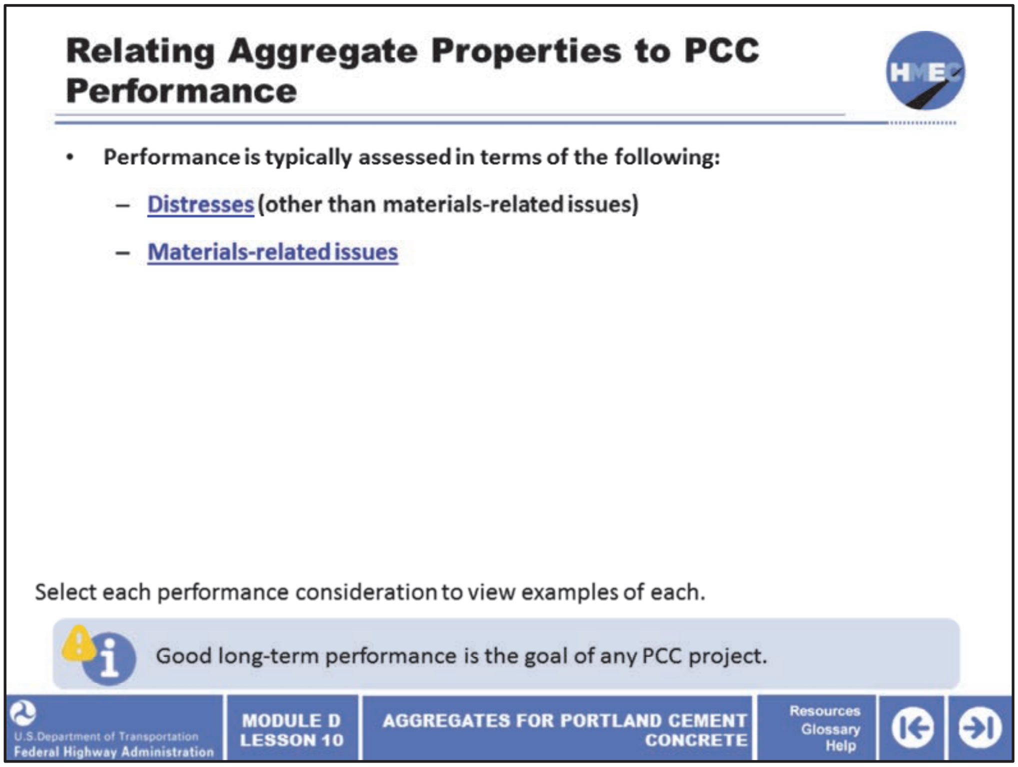
This lesson will take approximately 75 minutes to complete.



Aggregates are used in a variety of ways in rigid pavement systems for support layers, asphalt concrete (AC), and PCC. Specifically, these uses include:

• PCC;
• Unbound base course;
• Stabilized base course;
• Embankments; and
• Fill material.

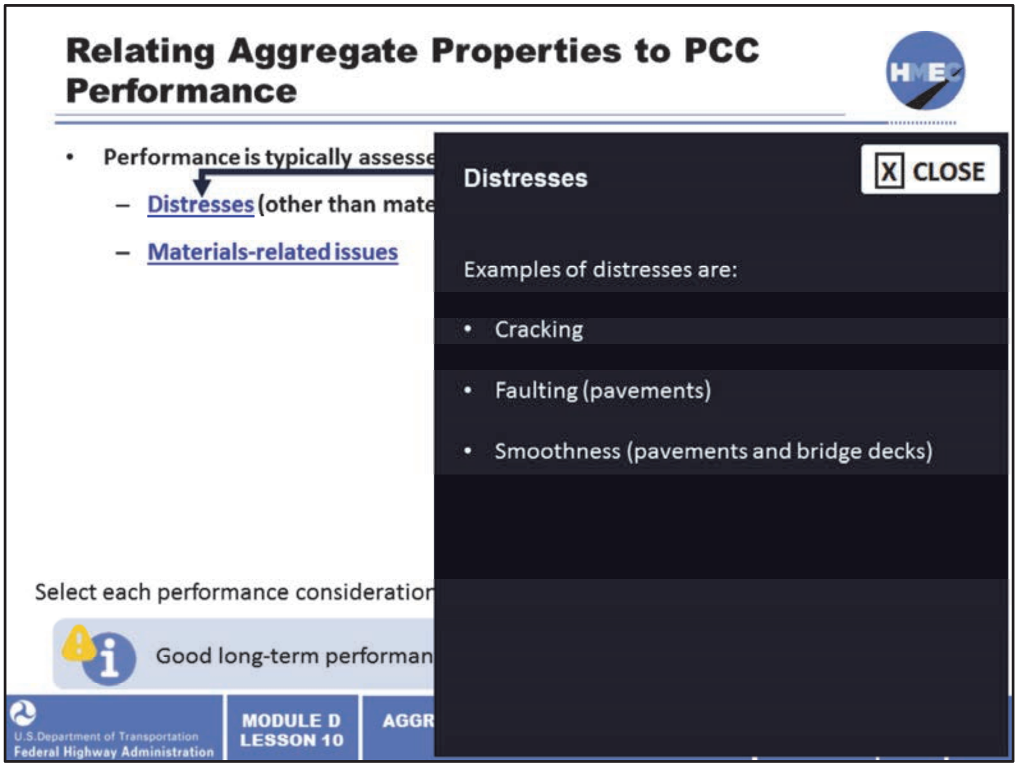
Aggregates are a key component in PCC and have a significant effect on both the fresh and hardened properties. In this lesson, we will focus on the properties of aggregates that have the most influence and how they are measured.



Aggregates play a major role in the behavior of the PCC both during and after construction. As we discuss each of the key aggregate properties, think about the impact it may have on the overall PCC performance in its final use.

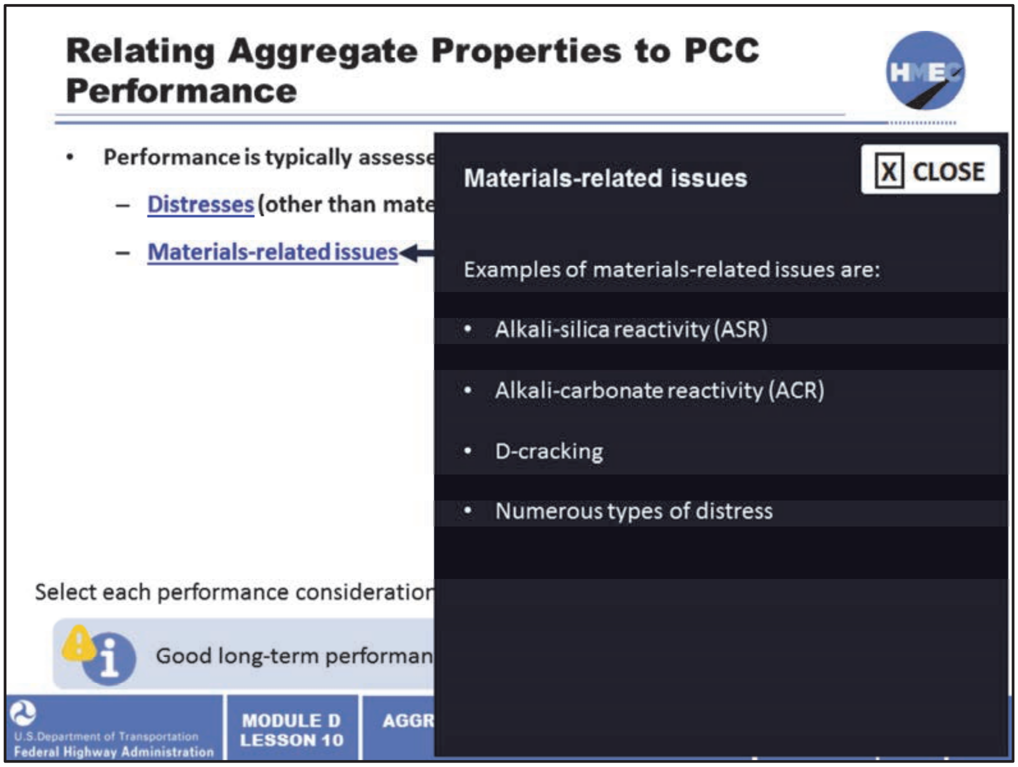
Pavement performance data are collected for virtually all pavements whether it is highly detailed information, such as is found in the Long Term Pavement Performance (LTPP) database or the agency's comprehensive pavement management system. Similar performance data are kept for bridges and, to varying extents, other types of PCC structures.

Select each performance consideration to view examples of each.



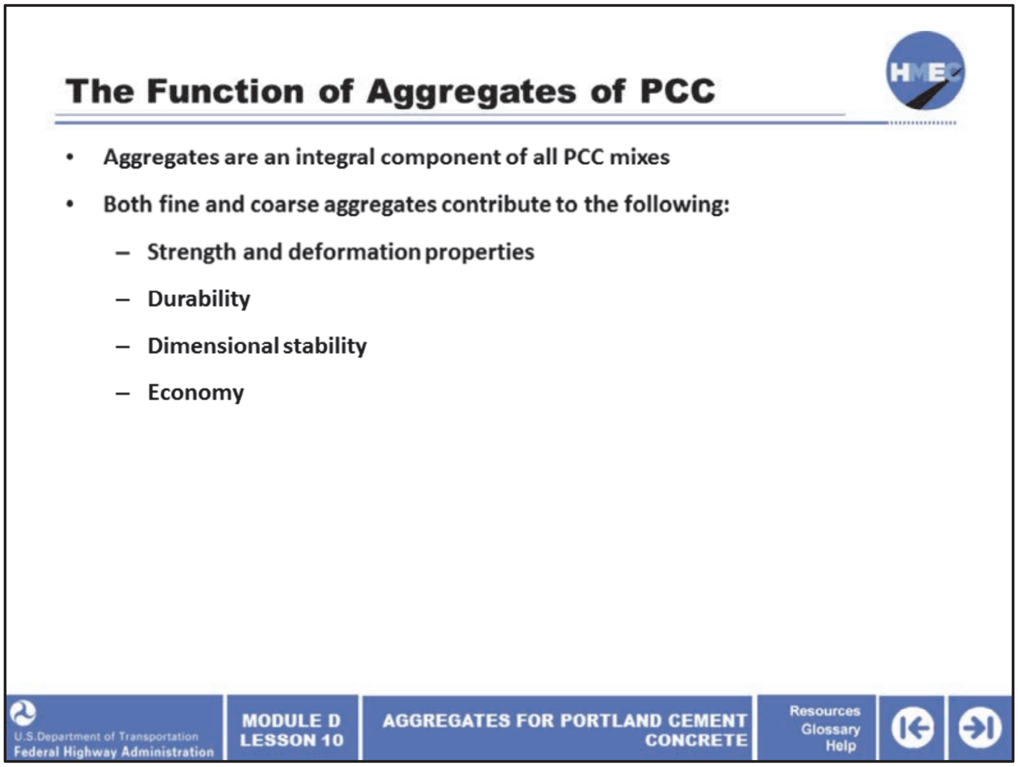
Examples of distresses are:

- Cracking;
- Faulting (pavements); and
- Smoothness (pavements and bridge decks).



Examples of materials-related issues are:

- Alkali-silica reactivity (ASR);
- Alkali-carbonate reactivity (ACR);
- D-cracking; and
- Numerous types of distress.



Aggregates are an integral component of all PCC mixes as they occupy the largest volume of any PCC component. Aggregates influence the following properties to a great extent:

- Strength and deformation;
- Durability
- Dimensional stability; and
- Economy.

The PCC mixture design and proportioning process optimizes the use of aggregates to promote the desired properties in fresh and hardened PCC.

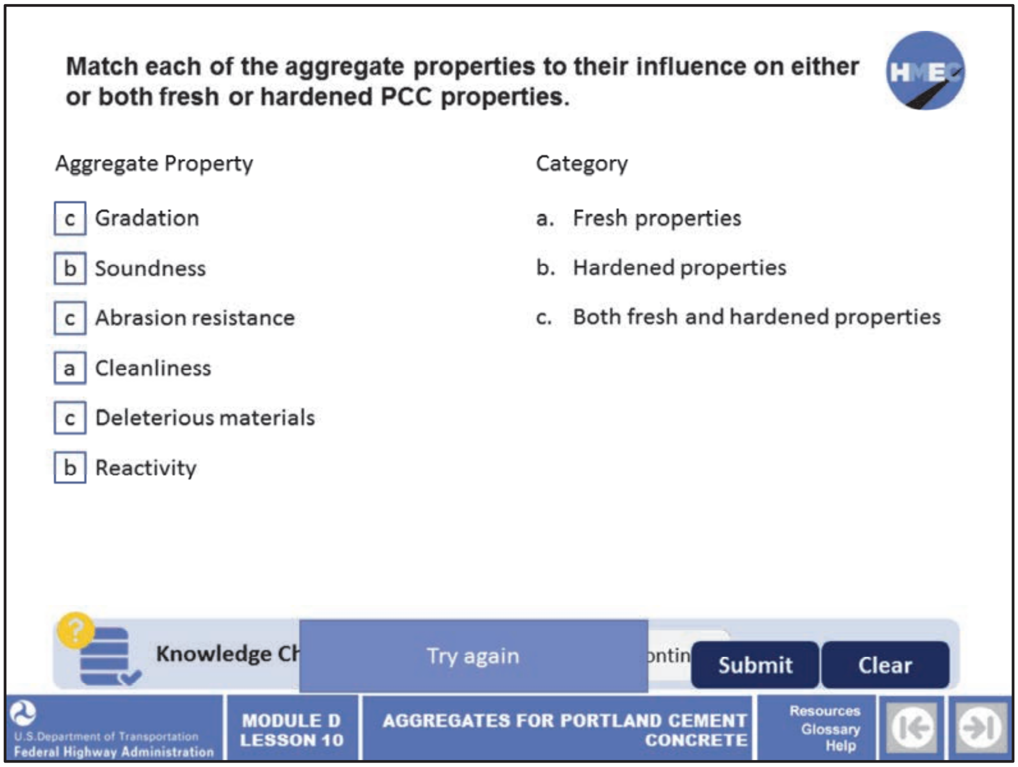
Aggregate Properties and Their Effect on PCC Performance

Aggregate Property	Effect on Fresh PCC	Effect on Hardened PCC
Gradation	Significant	Significant
Unit Weight	Significant	Significant
Absorption and Specific Gravity	Significant	Minimal
Particle Shape	Significant	Minimal
Minus No. 200 (Cleanliness)	Significant	Minimal
Abrasion Resistance	Significant	Significant
Soundness	Minimal	Significant
Deleterious Materials	Significant	Significant
Potential Reactivity	Minimal	Significant
Coefficient of Thermal Expansion	Minimal	Significant

This table shows the primary aggregate properties that affect PCC performance.

Note that certain aggregate properties such as gradation have an effect on both the fresh and hardened PCC, while others such as potential reactivity are only important for hardened PCC.

As we look at each of these properties individually, keep in mind that they may affect the PCC in different ways pertaining to strength, workability, durability, and so on.



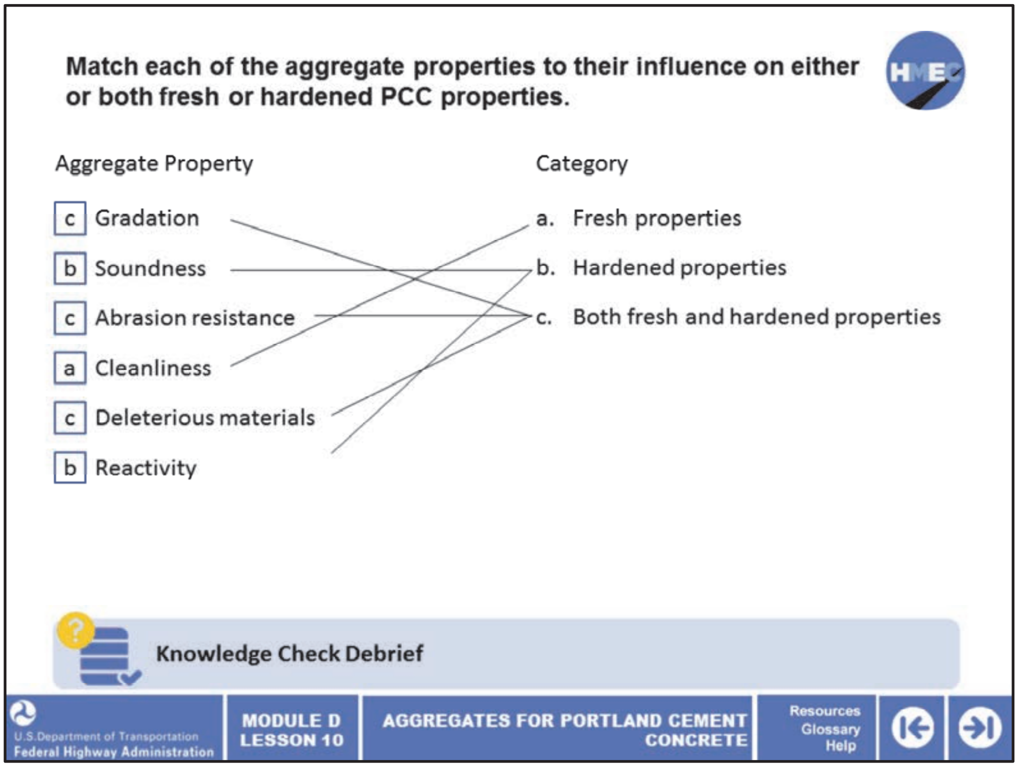
Match each of the aggregate properties to their influence on either or both fresh or hardened PCC properties.

The aggregate properties are:

- Gradation;
- Soundness;
- Abrasion resistance;
- Cleanliness;
- Deleterious materials; and
- Reactivity.

The categories are:

a) Fresh properties;
b) Hardened properties; and
c) Both fresh and hardened properties.



The correct answers are as follows.

- Gradation is c) Both fresh and hardened properties;
- Soundness is b) Hardened properties;
- Abrasion resistance is c) Both fresh and hardened properties;
- Cleanliness is a) Fresh properties;
- Deleterious materials are c) Both fresh and hardened properties; and
- Reactivity is b) Hardened properties.

We are going to begin the detailed discussion of the effects of aggregate properties on PCC performance by looking at course aggregates.

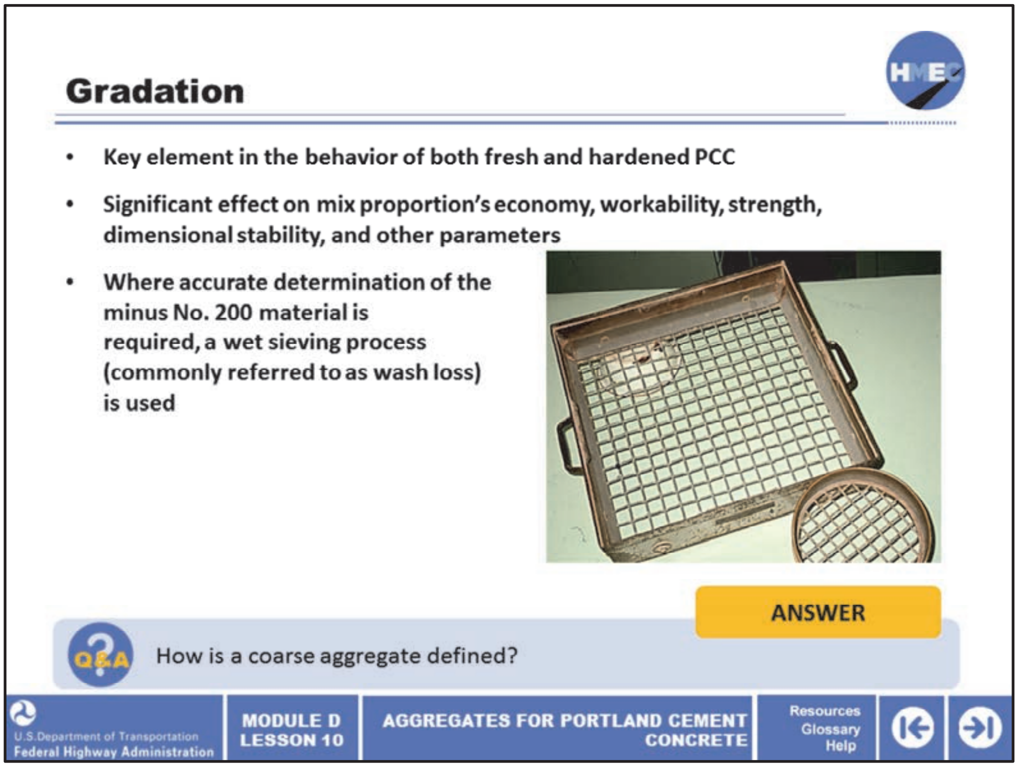
Coarse aggregates, by virtue of their relative volume in a PCC mix, have substantial impact on both the fresh and hardened PCC properties.

The following are important coarse aggregate properties that will be discussed in this lesson:

- Gradation;
- Unit weight;
- Absorption and specific gravity;
- Particle shape;
- Cleanliness;
- Abrasion resistance;
- Soundness;
- Deleterious materials
- Potential reactivity;
- D-cracking potential; and
- Coefficient of thermal expansion.

These aggregate properties do not all impact the PCC to the same extent. For instance, aggregate gradation has a very significant effect on numerous fresh and hardened PCC properties, while particle shape has a relatively minor role impacting only the fresh PCC.

Image description: Photo of coarse aggregate.



Gradation, as determined by a sieve analysis (AASHTO T 27), is one of the most important aggregate parameters for both fresh and hardened PCC. The gradation establishes the maximum and nominal maximum aggregate sizes as well as the size distribution of particles. The PCC mix design and proportioning procedure is dependent on these parameters.

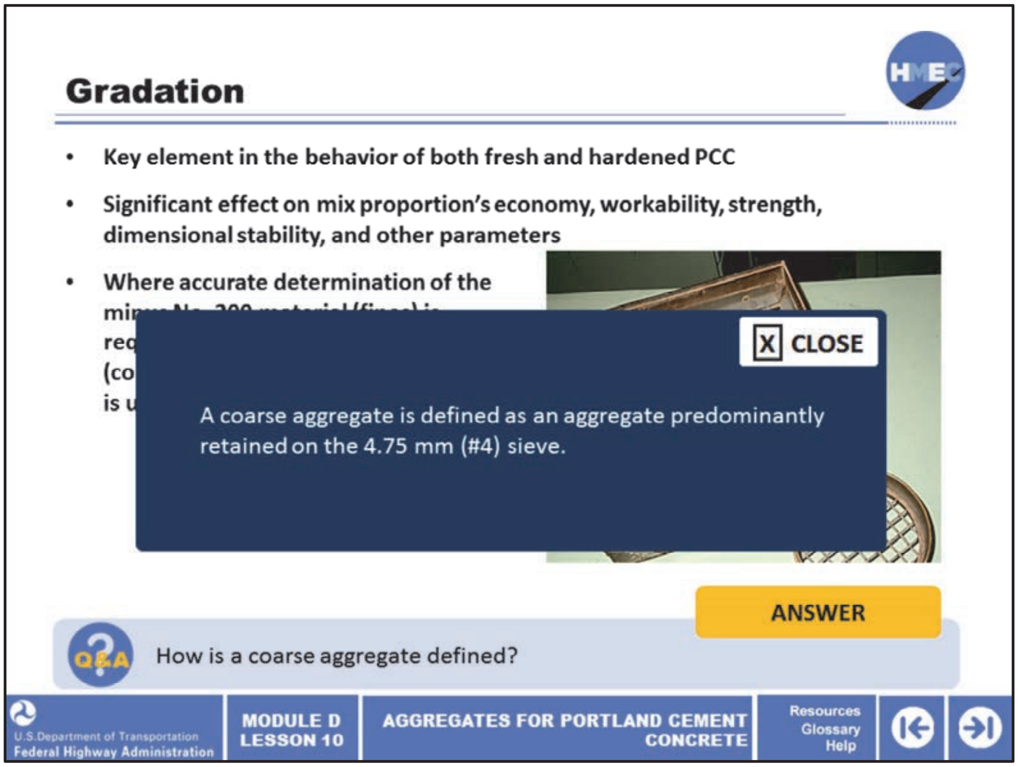
Gradation directly influences a number of properties including:

- Economy;
- Strength and deformation properties;
- Workability;
- Water demand;
- Dimensional stability;
- Coefficient of thermal expansion;
- Drying shrinkage;
- Durability; and
- The potential for others.

Where accurate determination of the #200 material is required, a wet sieving process, commonly referred to as wash loss, is used. The “wash loss” procedure is designated as AASHTO T 111.

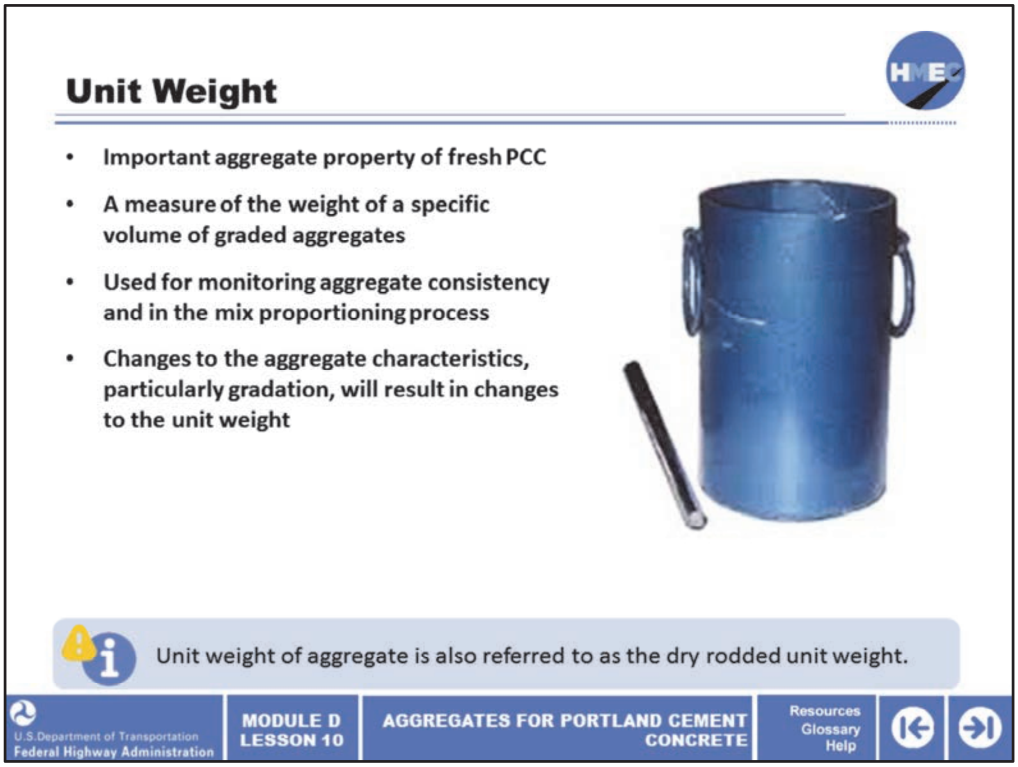
Select the box to reveal the answer to the question: How is coarse aggregate defined?

Image description: Phot of a square sieve and a round sieve.



A coarse aggregate is defined as an aggregate predominantly retained on the 4.75 mm (#4) sieve.

Image description: Phot of a square sieve and a round sieve.



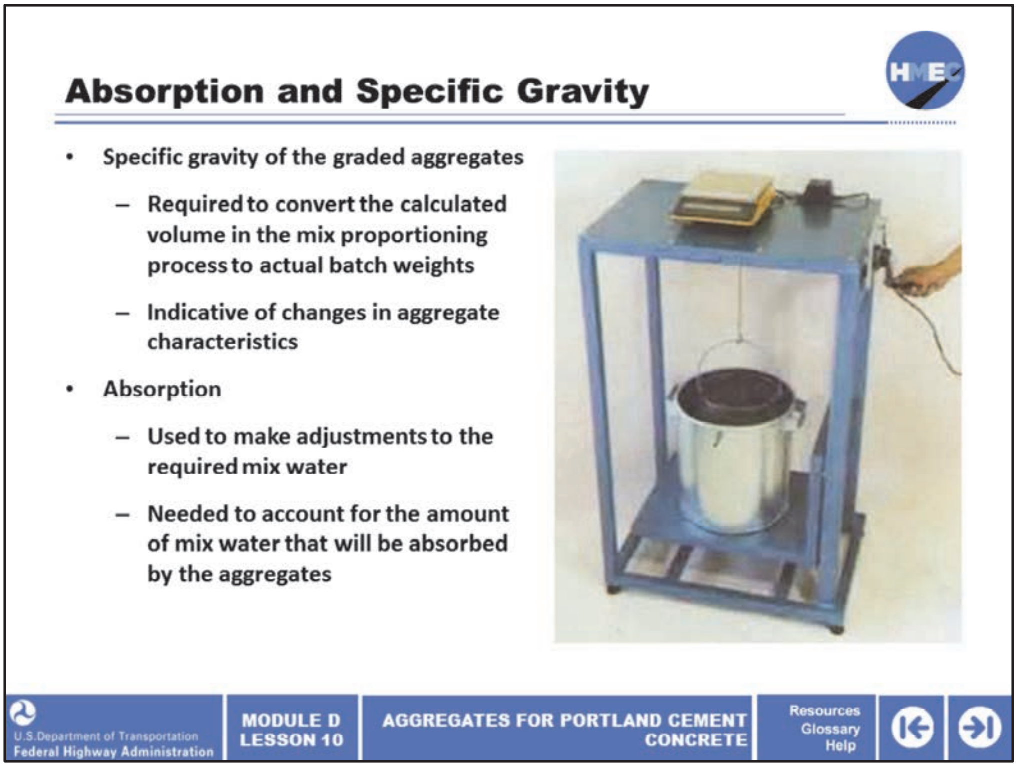
The unit weight of aggregates, as determined by AASHTO T 19, is an important aggregate property for fresh PCC. The unit weight (or dry rodded unit weight) is a measure of the weight of a specific volume of graded aggregates and is used for monitoring aggregate consistency and in the mix proportioning process.

Consistent unit weights are a good indicator of uniformity in the aggregate gradation and characteristics (from a single source).

Widely varying unit weights have a significant impact on the mix proportions. This will typically show up as a change in workability and water demand.

Changes to the aggregate characteristics, particularly gradation, will result in changes to the unit weight.

Image description: Photo of a cylindrical metal measure.



The absorption and specific gravity of coarse aggregates, as determined by AASHTO T 85, are important aggregate properties for fresh PCC.

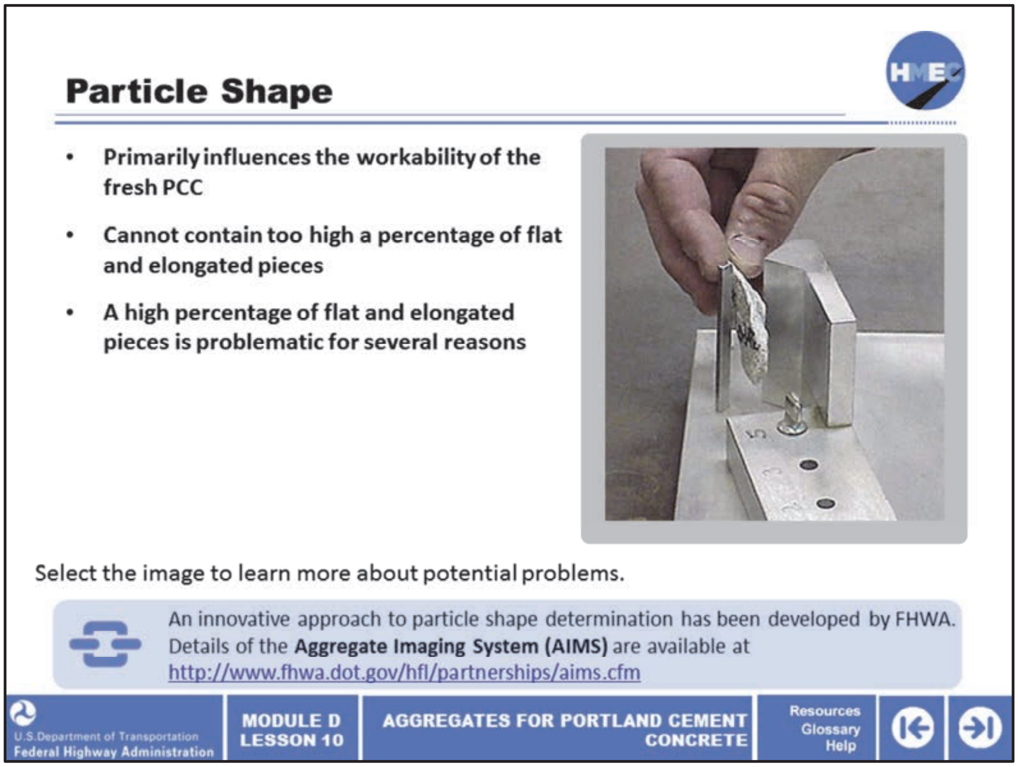
The specific gravity of the aggregates is used in the mix proportioning procedure to calculate the weights of the aggregates required for batching based on their volume in the mix.

Changes in specific gravity are indicative of changes in aggregate characteristics.

The absorption is used to make adjustments to the required mix water based on the moisture state of the aggregates during batching and the capacity of the aggregate to “soak up” mix water, thereby lessening the workability of the PCC.

The absorption is also needed to account for the amount of mix water that will be absorbed by the aggregates in a PCC mix when they are drier than the saturated surface dry (SSD) moisture state.

Image description: Photo of a specific gravity and absorption of coarse aggregate test set.



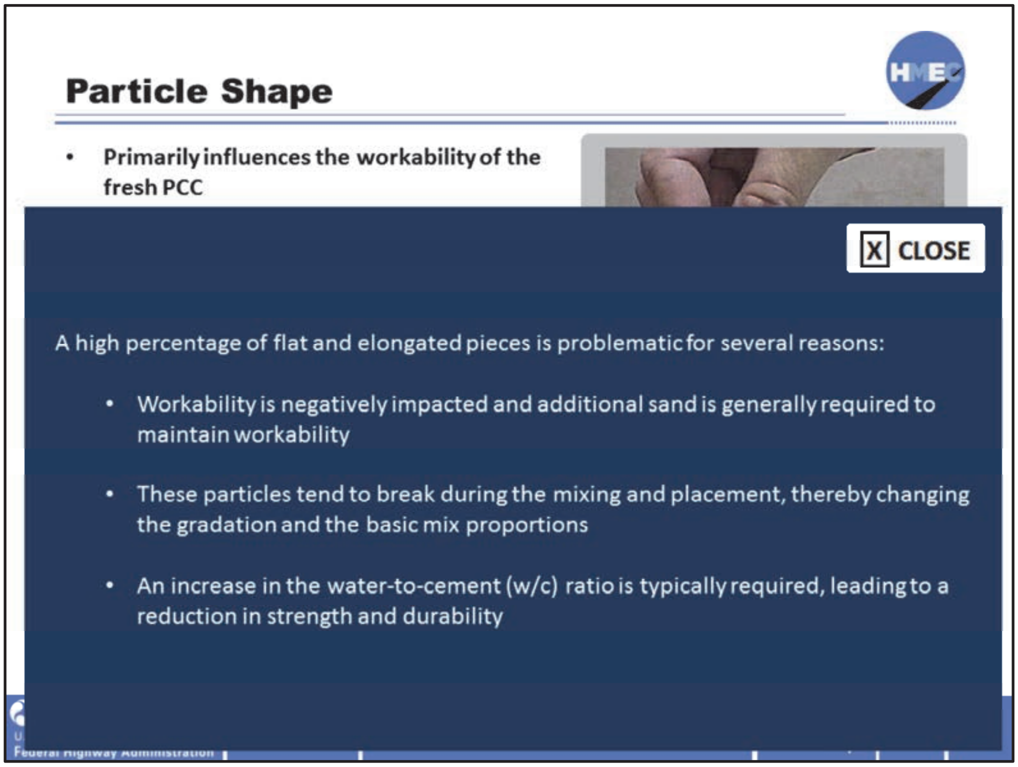
The particle shape of the coarse aggregate, as determined by ASTM D4791, primarily influences the workability of the fresh PCC, as flat and elongated particles do not readily reorient during placement and consolidation. Workability is a function of numerous variables, including the particle shape, which relates to the orientation and interaction between the aggregate particles during placement.

Agencies all have limitations on the amount of flat and elongated particles that are allowed in order to minimize or eliminate the potential problems that they cause.

An innovative approach to particle shape determination has been developed by FHWA. Details of the Aggregate Imaging System (AIMS) are available on the FHWA Web site at http://www.fhwa.dot.gov/hfl/partnerships/aims.cfm.

Select the image to learn more about potential problems.

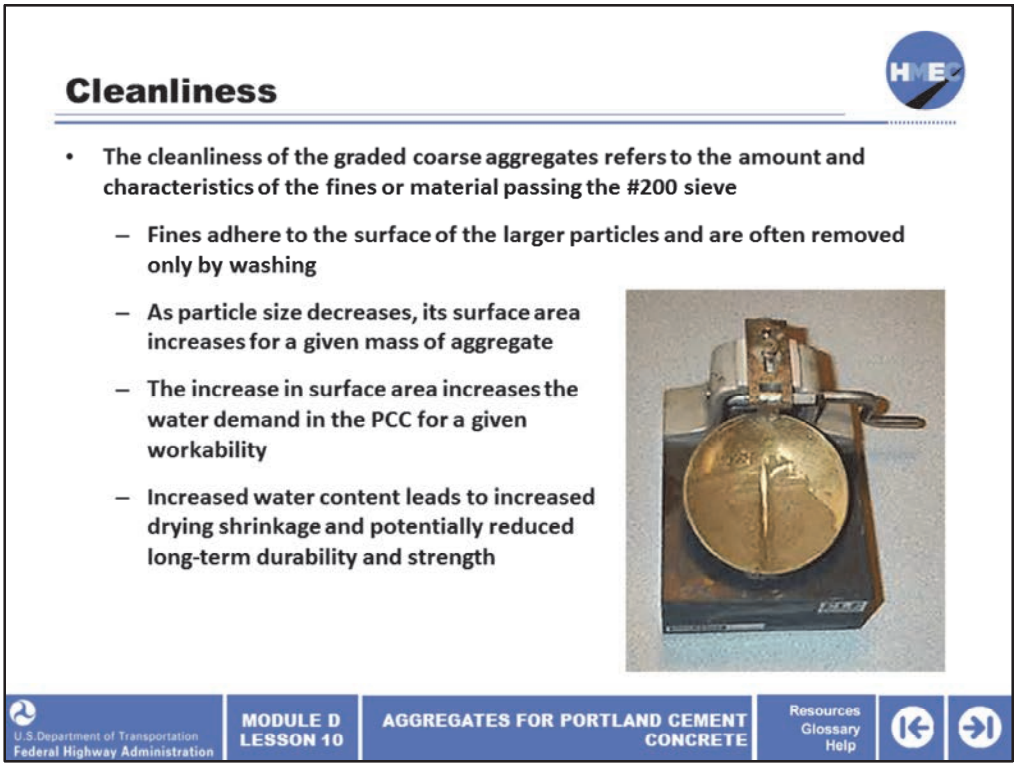
Image description: Photo of a proportional caliper device.



A high percentage of flat and elongated pieces is problematic for several reasons:

• Workability is negatively impacted and additional sand is generally required to maintain workability;
• These particles tend to break during the mixing and placement, thereby changing the gradation and the basic mix proportions; and
• An increase in the water-to-cement (w/c) ratio is typically required, leading to a reduction in strength and durability.

Image description: Photo of a proportional caliper device.



Cleanliness can have significant effect on the properties of fresh PCC.

Cleanliness refers to the amount of fines or minus #200 material present in the graded coarse aggregate (as well as the fine aggregate). The fines adhere to the surface of the larger particles and are often removed only by washing. As particle size decreases, its surface area increases for a given mass of aggregate. This increase in surface area increases the water demand in the PCC for a given workability. The increased water content leads to increased drying shrinkage and potentially reduced long-term durability and strength.

The fines have a very large surface area relative to their weight and can substantially increase the water demand in the mix for a target workability.

The immediate impact to the fresh PCC is the loss of workability. If water is added to the mix to compensate, the durability and strength of the hardened PCC are reduced as is the entrained air content.

The nature of the fines and their plasticity is determined by the plasticity index (PI). PI is determined by AASHTO T 90.

Image description: Photo of a liquid limit test device.

Abrasion Resistance

- Important in fresh and hardened PCC
- Aggregates with low abrasion resistance can abrade against one another (wear) during mixing, generating fines
- When used in pavements and bridge decks, aggregates should not wear (polish) in order to maintain good surface texture and adequate friction
- LA abrasion values are typically in the range of 35-50%

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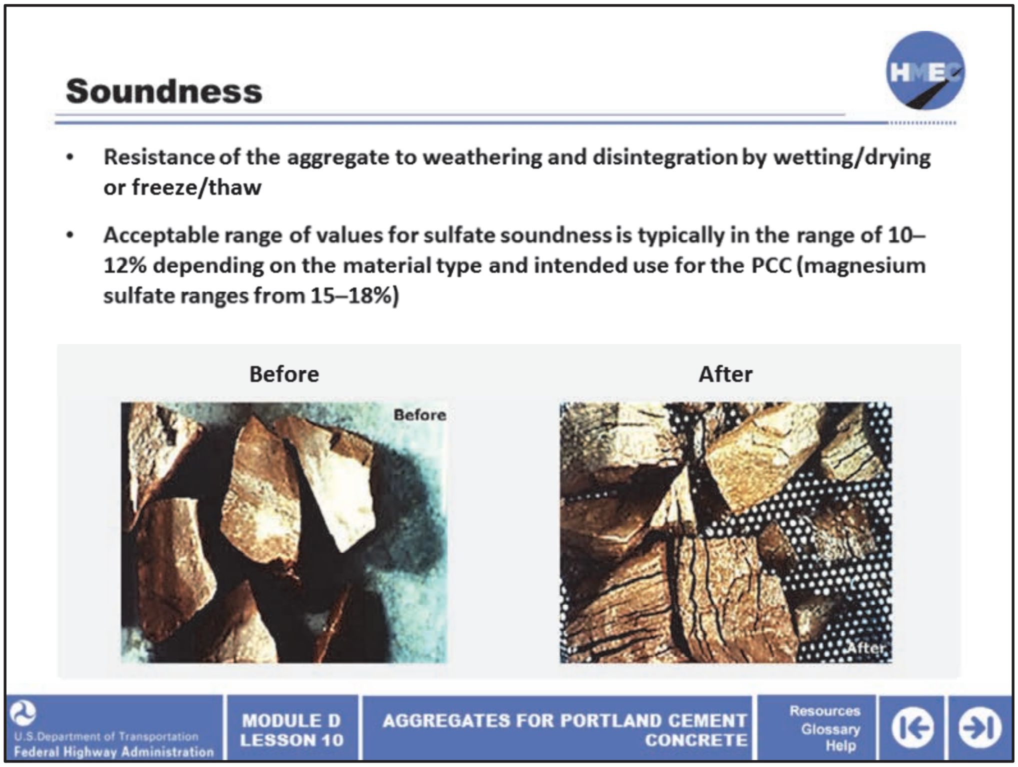
The abrasion resistance of the coarse aggregates, as determined according to AASHTO T 96 or T 327, is important in both fresh and hardened PCC. Abrasion resistance is important during the mixing process and also for the in-place PCC used in pavements and bridge decks.

If the coarse aggregates are prone to abrasion, fines are generated during aggregate handling and mixing of the PCC. The effects of increased fines was previously discussed.

When abrasion prone aggregates are used for pavements and bridge decks, traffic can wear or polish the surface resulting in a loss in skid resistance.

Gravels that have already been exposed to weathering are generally acceptable with an LA abrasion loss of approximately 35% while un-weathered, crushed stone is typically 50%.

Image description: Photo of an LA abrasion test machine.



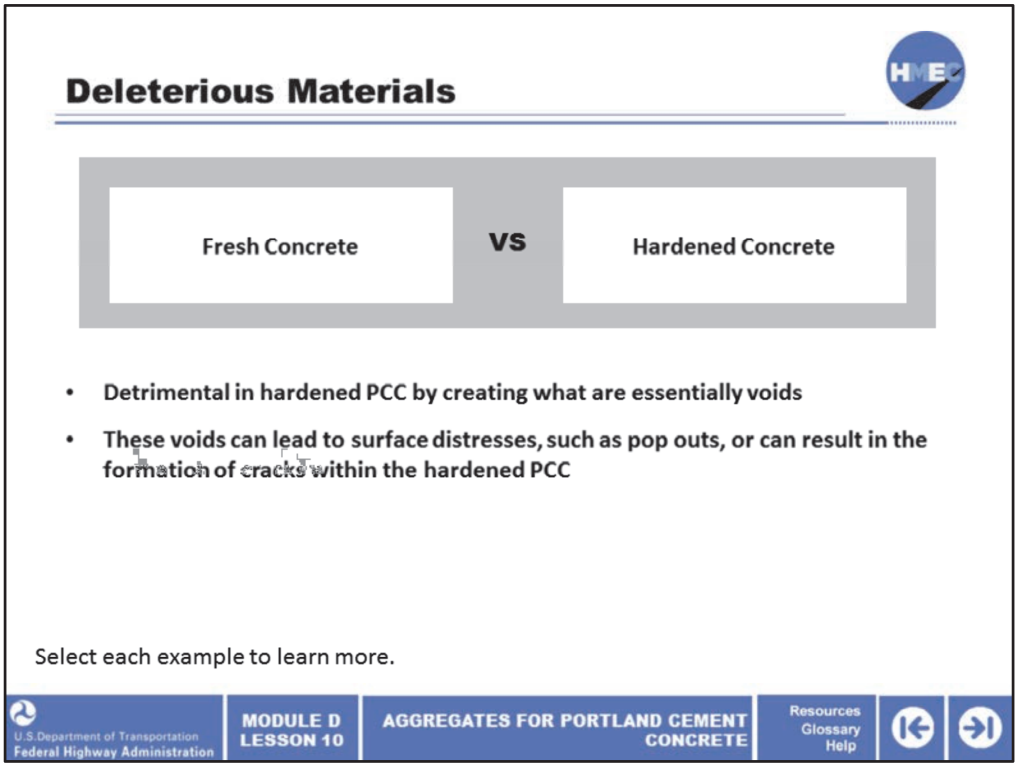
The soundness of coarse aggregates, as determined by the sodium or magnesium sulfate soundness test described in AASHTO T 104, is important for hardened PCC and is directly related to freeze/thaw durability (as is entrained air in the paste).

Aggregates must be dimensionally stable and resistant to weathering, particularly freeze/thaw cycling. If the soundness is substandard, the aggregates can degrade and swell within the hardened PCC matrix, thereby resulting in high stress buildup and resultant cracking.

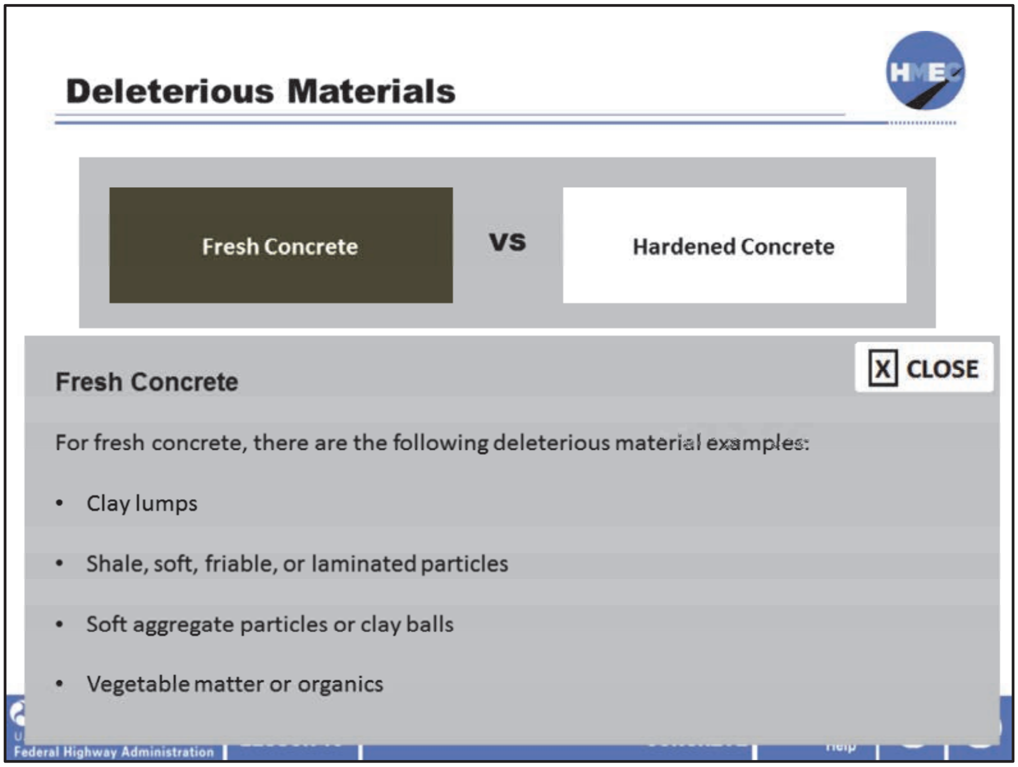
Acceptable range of values for sulfate soundness is typically in the range of 10–12% depending on the material type and intended use for the PCC (magnesium sulfate ranges from 15–18%).

Image description: Photo of aggregates before soundness test.

Image description: Photo of aggregates after soundness test.



Deleterious materials effect both fresh and hardened PCC properties and can encompass many types of contamination, ranging from soft and friable aggregate particles to vegetable matter that may have been introduced during hauling or storage.



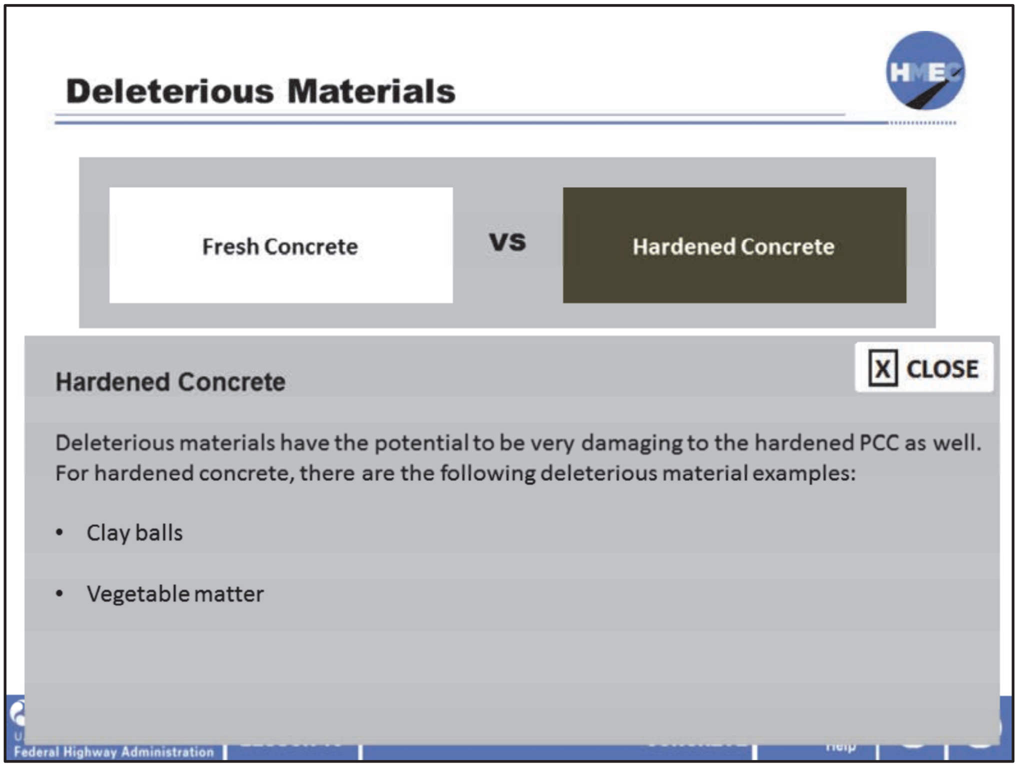
For fresh concrete, there are the following deleterious materials examples.

Clay lumps may break down during the mixing process and generate plastic (high PI) fines. This results in a loss of workability or increased water demand.

Shale, soft, friable or laminated particles all behave in similar fashion in terms of generating fines or altering the aggregate gradation.

If soft aggregate particles or clay balls are introduced into the PCC mix, they typically break down during mixing, thereby generating fines and altering the mix proportions and workability.

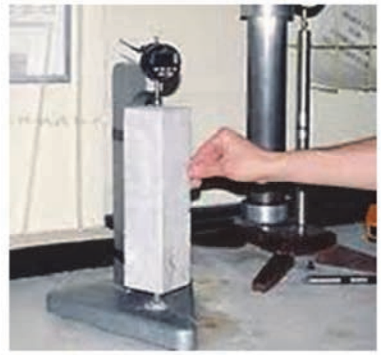
Vegetable matter or organics can act as a retarder or negatively impact the entrained air content in fresh PCC.



Deleterious materials have the potential to be very damaging to the hardened PCC as well. In the case of clay balls, these particles will disintegrate in service and result in surface distresses (pop outs) or the creation of voids in the PCC. Vegetable matter will similarly deteriorate over time and result in a void in the PCC, which reduces strength and durability.

Potential Reactivity

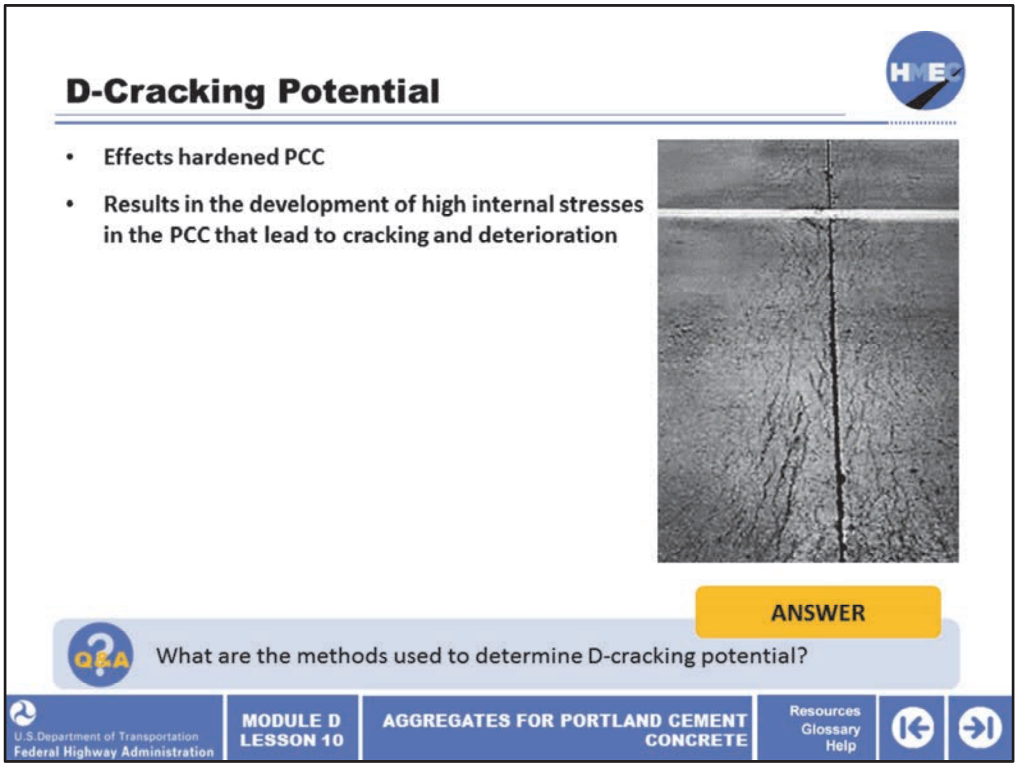
- Must be assessed in order to eliminate or minimize the occurrence of ASR and ACR
- Reactions can occur in the hardened PCC between the alkalis in the Portland cement and certain aggregates
- Result in the formation of an expansive gel surrounding the aggregate particles that can cause PCC cracking and deterioration



Reactivity is determined by numerous ASTM specifications that range in duration from several weeks to over a year. In this case, reactivity refers to the potential for an adverse reaction to occur between alkalis in the Portland cement and certain compounds within the aggregates.

In order for ASR and ACR to occur, sufficient alkalis must be present in the cement and sufficient quantities of reactive components in the aggregates. The end result is the formation of an expansive gel surrounding the aggregate particles. As the gel forms, high internal stresses are developed, resulting in PCC cracking and deterioration of the PCC.

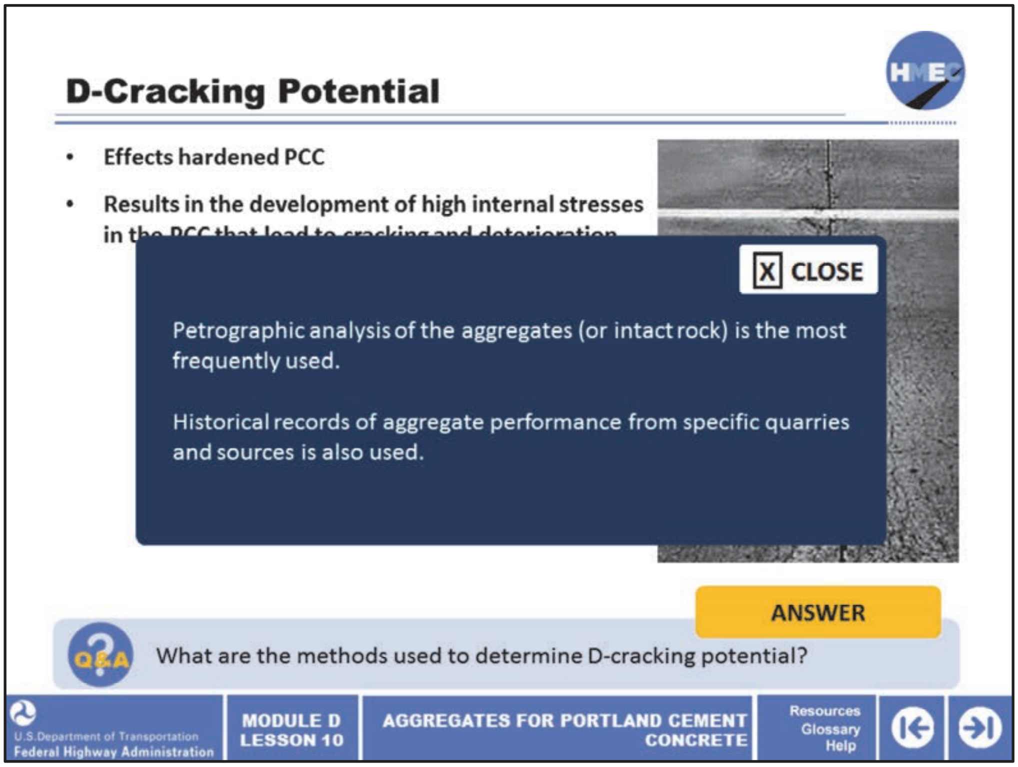
Image description: Photo of concrete prism test.



D-cracking is basically the expansion of susceptible coarse aggregate particles due to water freezing in the aggregate voids. The expansion results in the development of high internal stresses, which leads to cracking of the PCC.

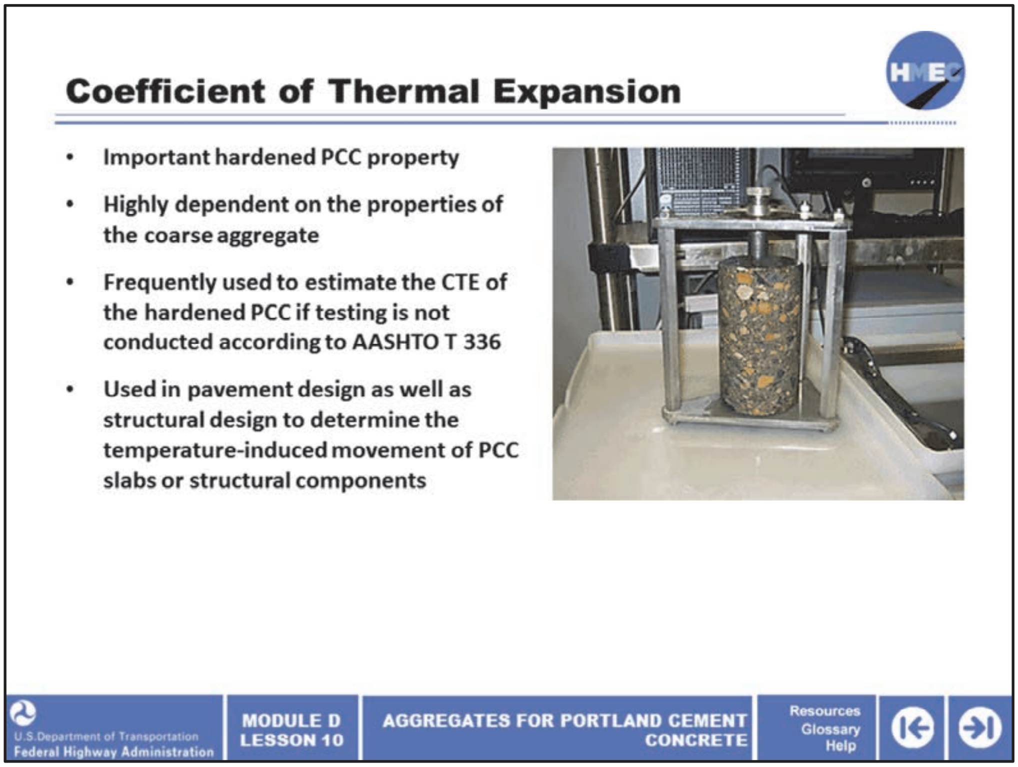
Select the box to reveal the answer to the question: What are the methods used to determine D-cracking potential?

Image description: Photo of D-cracking in roadway.



Petrographic analysis of the aggregates (or intact rock) is the most frequently used method to determine D-cracking potential. Historical records detailing aggregate performance from specific quarries and sources is also used.

Image description: Photo of D-cracking in roadway.

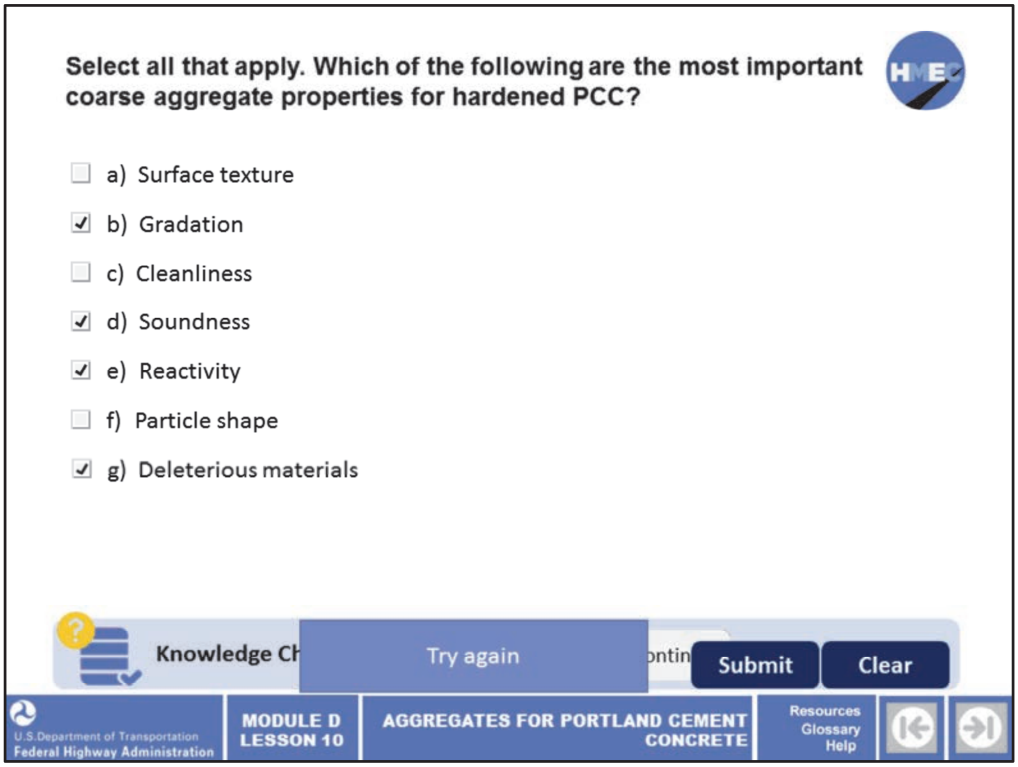


The coefficient of thermal expansion (CTE) is a very important hardened PCC property that is highly dependent on the properties of the coarse aggregate. The CTE of the aggregates is frequently used to estimate the CTE of the hardened PCC if testing is not conducted according to AASHTO T 336.

The CTE has significant implications to pavement design (Mechanistic Empirical Pavement Design Guide, MEPDG) as well as joint design and construction. The CTE is also used in structural design to determine the temperature-induced movement of PCC slabs or structural components.

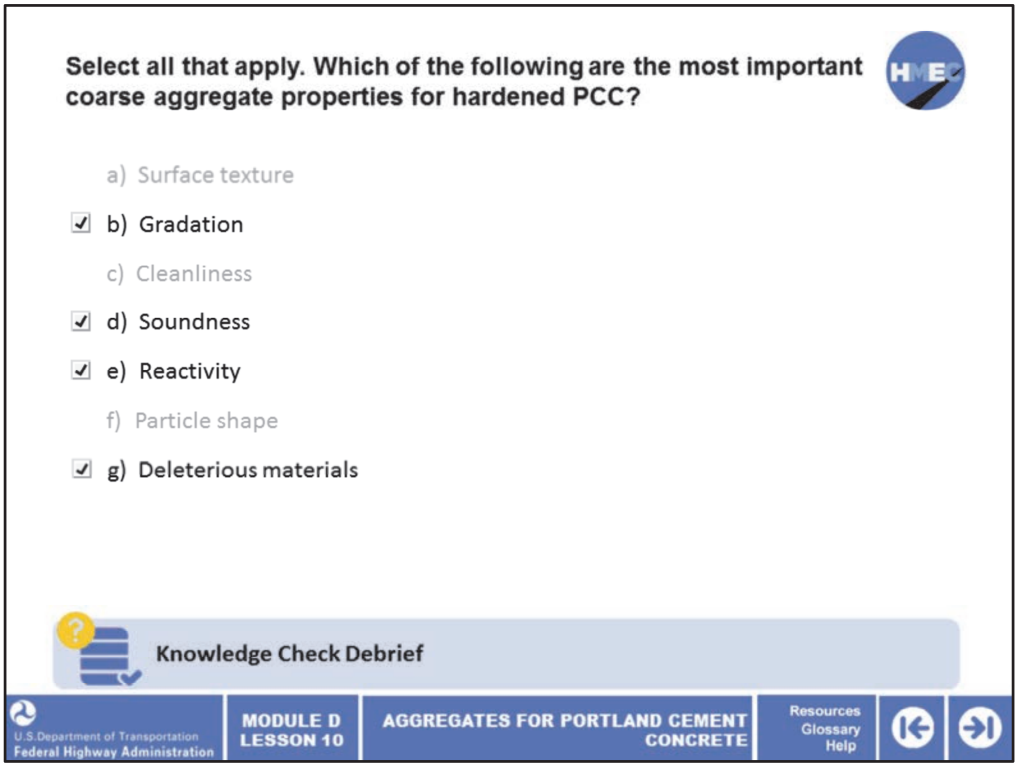
In general, siliceous aggregates have a relatively high CTE while carbonate aggregates are typically much lower.

Image description: Photo of the Coefficient Thermal Expansion test.

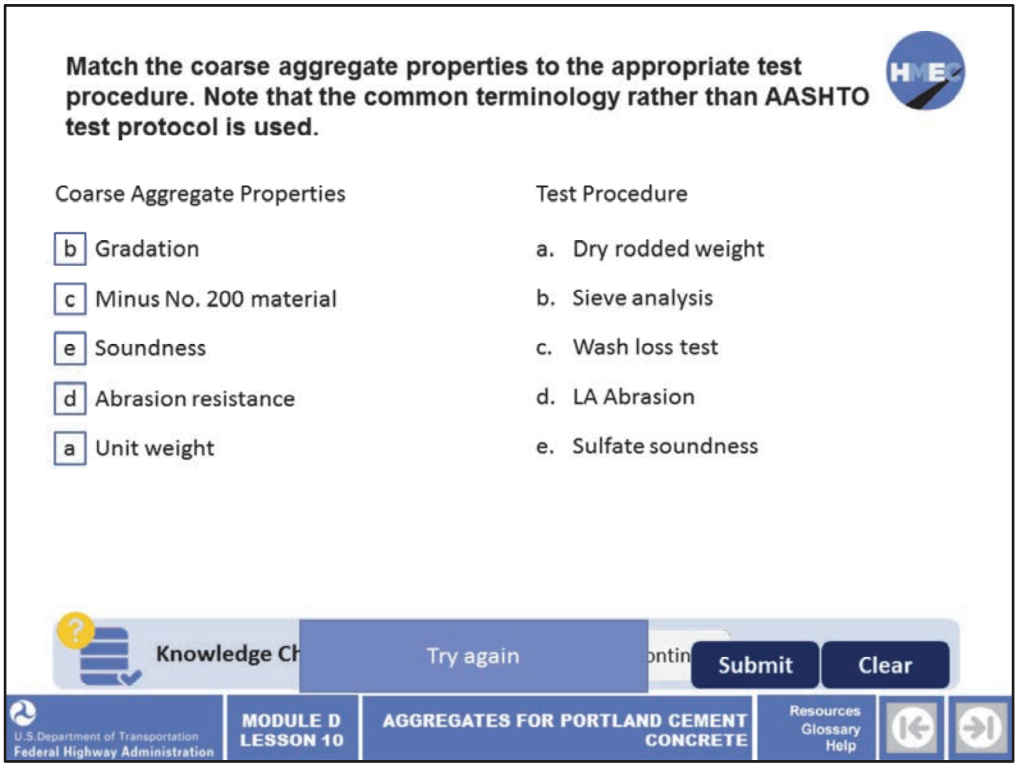


Select all that apply. Which of the following are the most important coarse aggregate properties for hardened PCC?

a) Surface texture;
b) Gradation;
c) Cleanliness;
d) Soundness;
e) Reactivity
f) Particle shape; or
g) Deleterious materials.



The correct answers are b) Gradation, d) Soundness, e) Reactivity, and g) Deleterious materials.



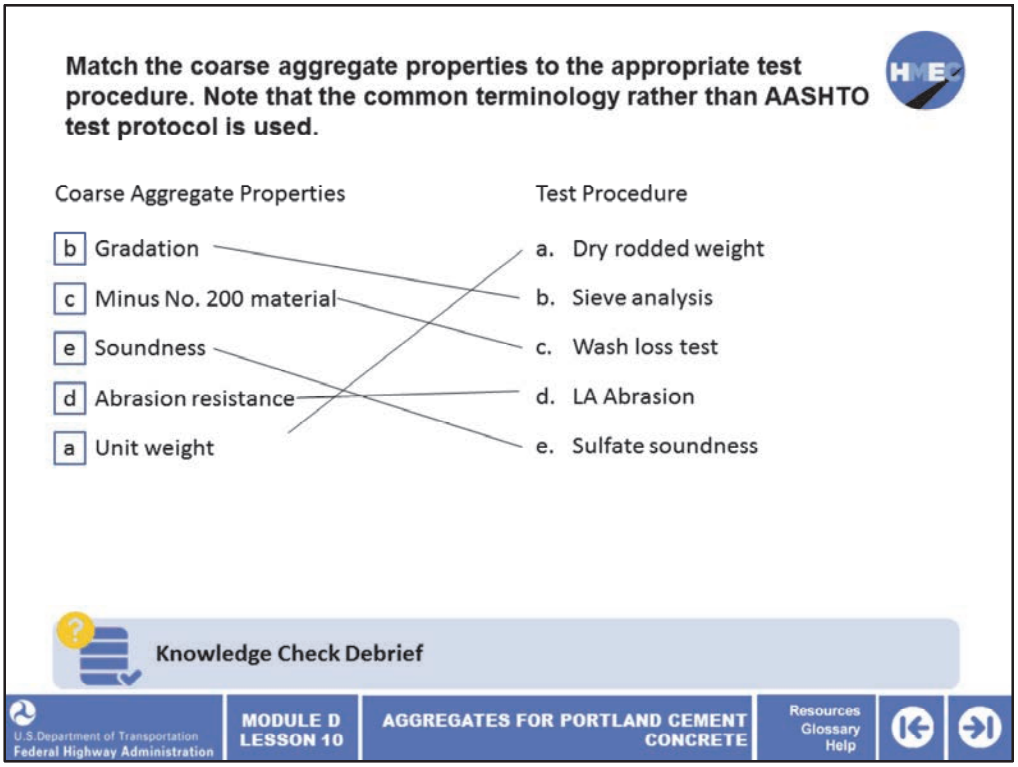
Match the coarse aggregate properties to the appropriate test procedure. Note that the common terminology rather than AASHTO test protocol is used.

The coarse aggregate properties are:

- Gradation;
- Minus #200 material
- Soundness;
- Abrasion resistance; and
- Unit weight.

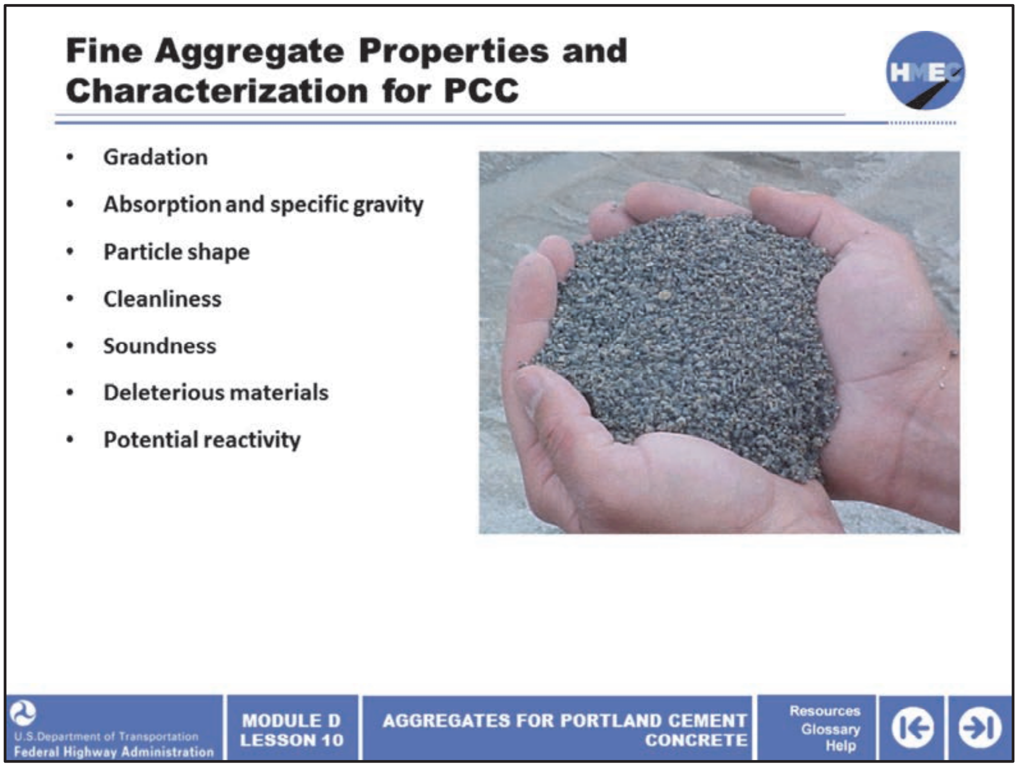
The test procedures are:

a) Dry rodded weight;
b) Sieve analysis;
c) Wash loss;
d) LA abrasion; and
e) Sulfate soundness.



The correct answers are as follows:

- Gradation is b) Sieve analysis;
- Minus #200 material is c) Wash loss;
- Soundness is e) Sulfate soundness;
- Abrasion resistance is d) LA abrasion; and
- Unit weight is a) Dry rodded weight.

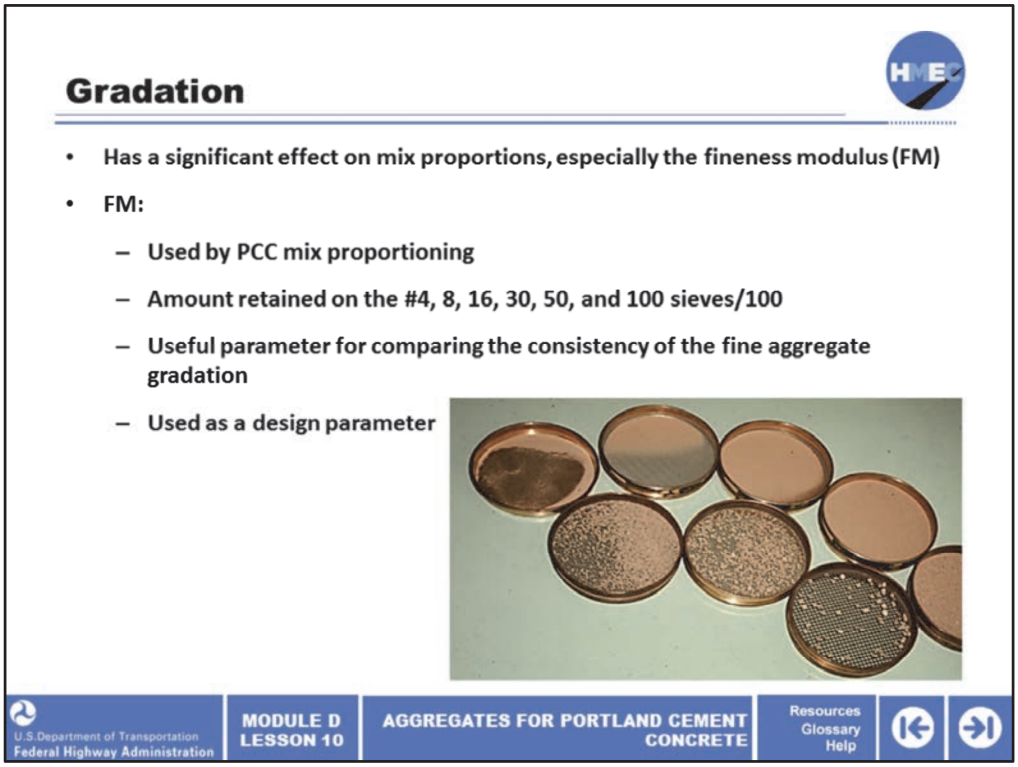


Fine aggregates, similar to coarse aggregates, have substantial impact on both the fresh and hardened PCC properties.

The following are important fine aggregate properties that will be discussed in this lesson:

- Gradation;
- Absorption and specific gravity;
- Particle shape;
- Cleanliness;
- Soundness;
- Deleterious materials; and
- Potential reactivity.

Image description: Photo of coarse aggregates being held in hands.



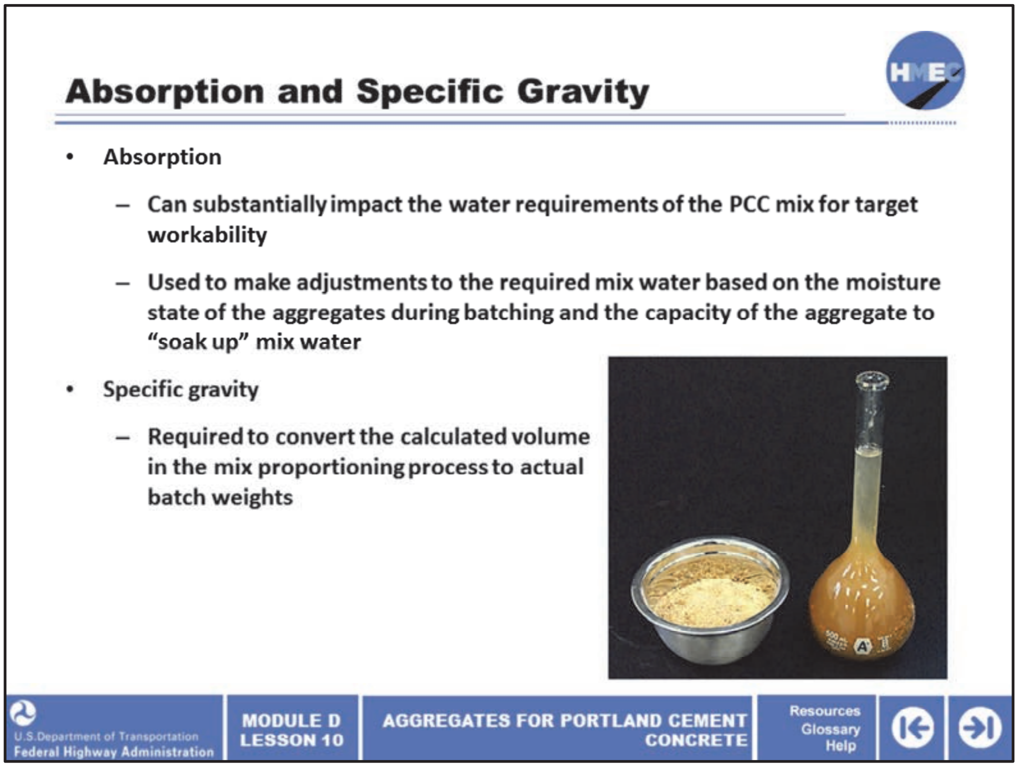
Fine aggregates impact the behavior of both fresh and hardened PCC properties. The gradation of fine aggregates, which is determined by a sieve analysis (AASHTO T 27), has a significant effect on mix proportions, particularly the fineness modulus (FM).

The PCC mix proportioning uses the FM of the fine aggregate or sand. As a reminder, the FM for this use is the amount retained on the #4, 8, 16, 30 50 and 100 sieves/100.

In addition to the FM being a design parameter, it is a useful parameter for comparing the consistency of the fine aggregate gradation.

Where accurate determination of the minus #200 material (fines) is required, a wet sieving process (commonly referred to as wash loss) is used. The wash loss procedure is designated as AASHTO T 111.

Image description: Photo of sieves of different sizes.



The absorption and specific gravity of fine aggregates, as determined by AASHTO T 84, are important aggregate properties for fresh PCC.

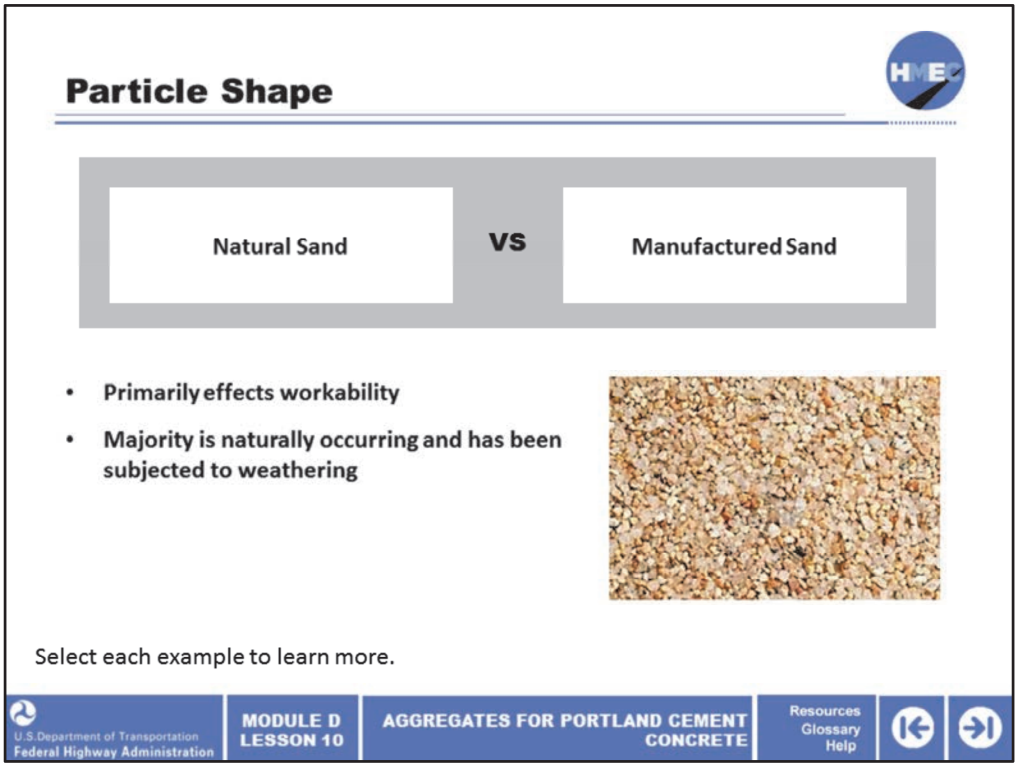
It should be noted that the surface area of the fine aggregates is much larger than the coarse aggregates. The absorption of the fine aggregates and the correspondingly large surface area of the fine aggregates can substantially impact the water requirements of the PCC mix for a target workability. The absorption is used to make adjustments to the required mix water based on the moisture state of the aggregates during batching and the capacity of the aggregate to "soak up" mix water, thereby lessening the workability of the PCC.

Since the surface area of the aggregates is much greater than the coarse aggregates, the amount of mix water required to "wet" the surface of the aggregates is higher.

It is also important to note that when the fine aggregate stockpile is wet, the amount of surface moisture and therefore the amount of free water added to the mix can be substantial.

The specific gravity of the fine aggregate is required to convert the calculated volume in the mix proportioning process to actual batch weights.

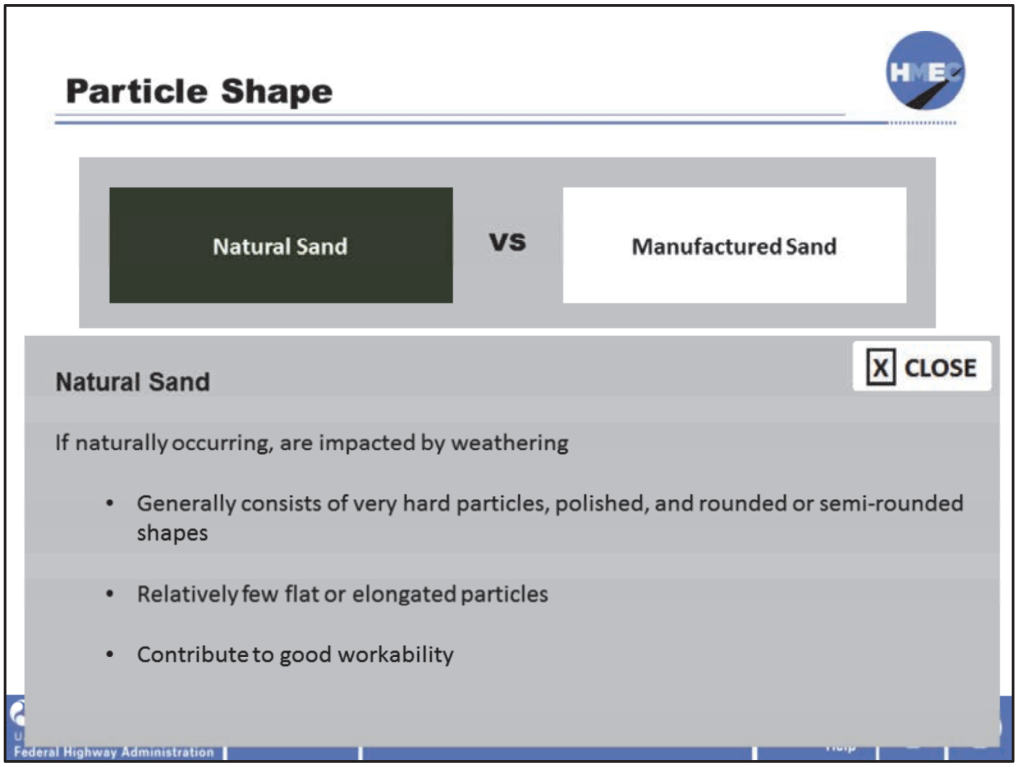
Image description: Photo of specific gravity sample and pycnometer.



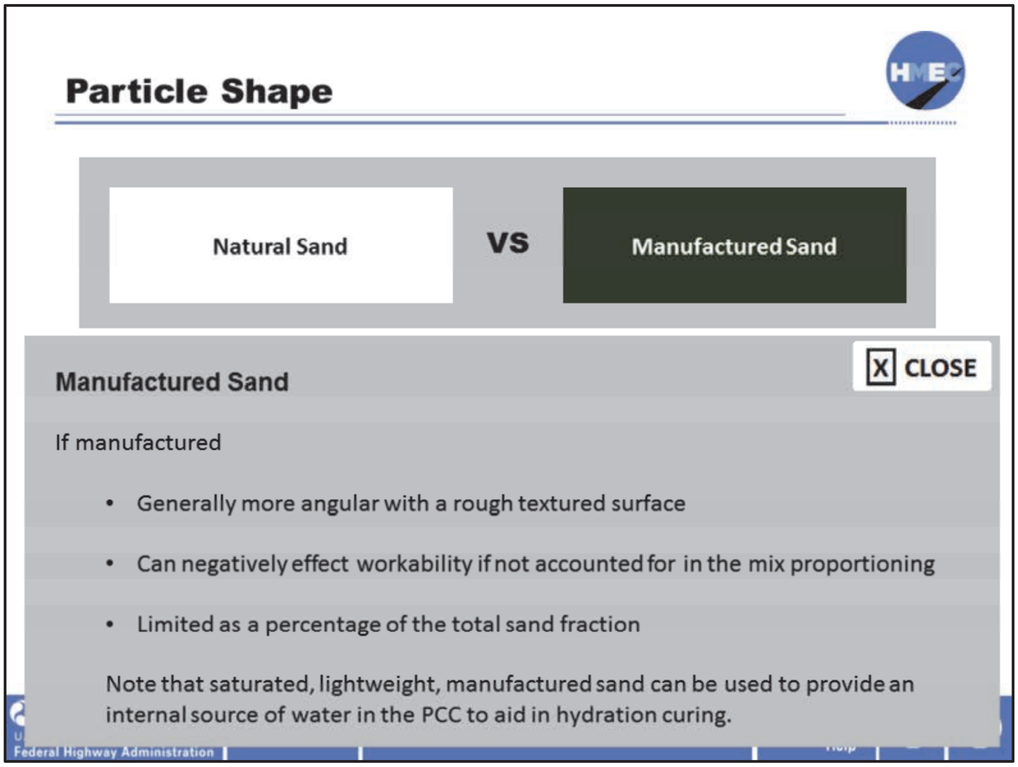
The particle shape of the fine aggregate primarily influences the properties of fresh PCC. Generally, the most effected property is workability as it is a function of gradation, particle shape, and surface texture of the aggregates.

The majority of fine aggregates (or sand) used for PCC are naturally occurring and have been subjected to weathering.

Image description: Photo of sand grains.

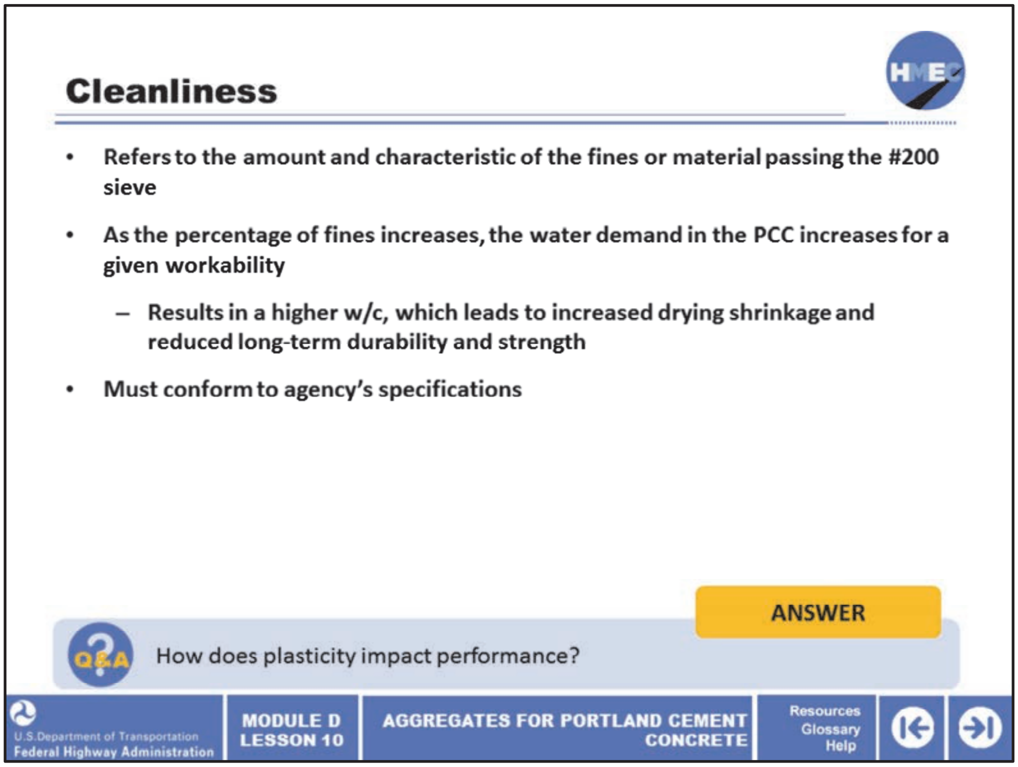


Natural sand that has been exposed to weathering generally consists of very hard particles, polished, and rounded or semi-rounded shapes. As a rule, there are relatively few flat or elongated particles. These shapes and smooth surface texture contribute to good workability and finishability in a correctly proportioned mix.



Manufactured sand is generally more angular with a rough textured surface that can negatively effect workability if not accounted for in the mix proportioning. Due to the nature of these particles, manufactured sand is generally limited as a percentage of the total sand fraction.

Note that saturated, lightweight, manufactured sand can be used to provide an internal source of water in the PCC to aid in hydration curing. Specifics of this practice can be found in Module G.

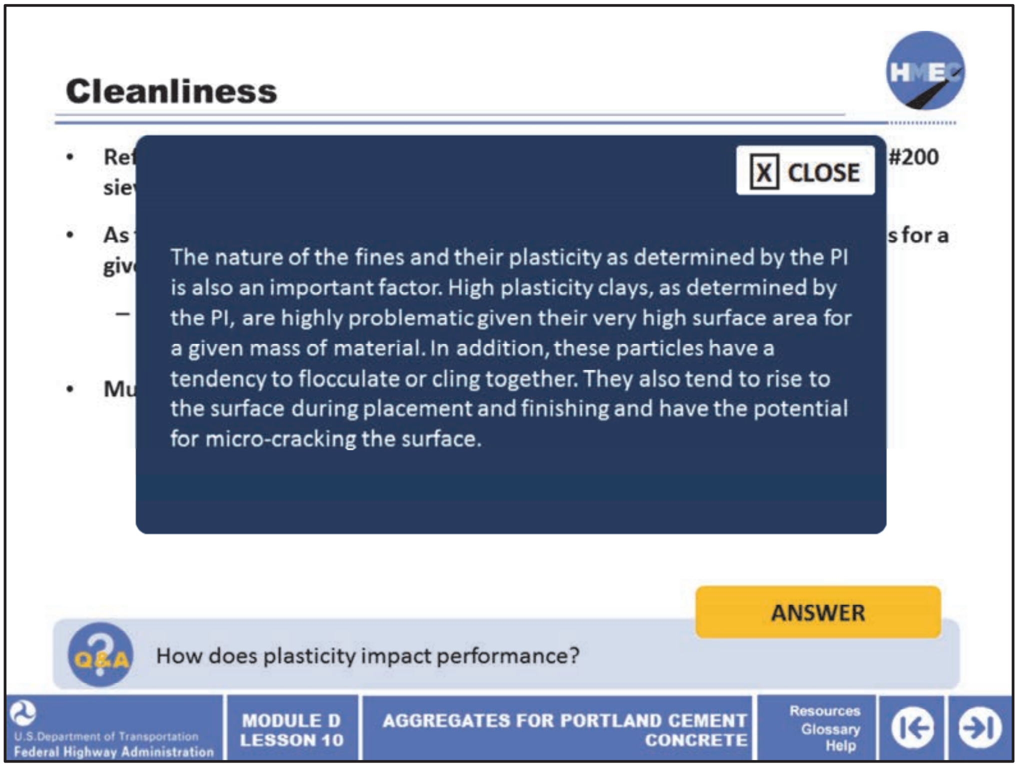


The cleanliness of the fine aggregates is an important property in fresh PCC, as it was for coarse particles. Although the immediate effects are in the fresh PCC, there are long-term effects on the hardened PCC.

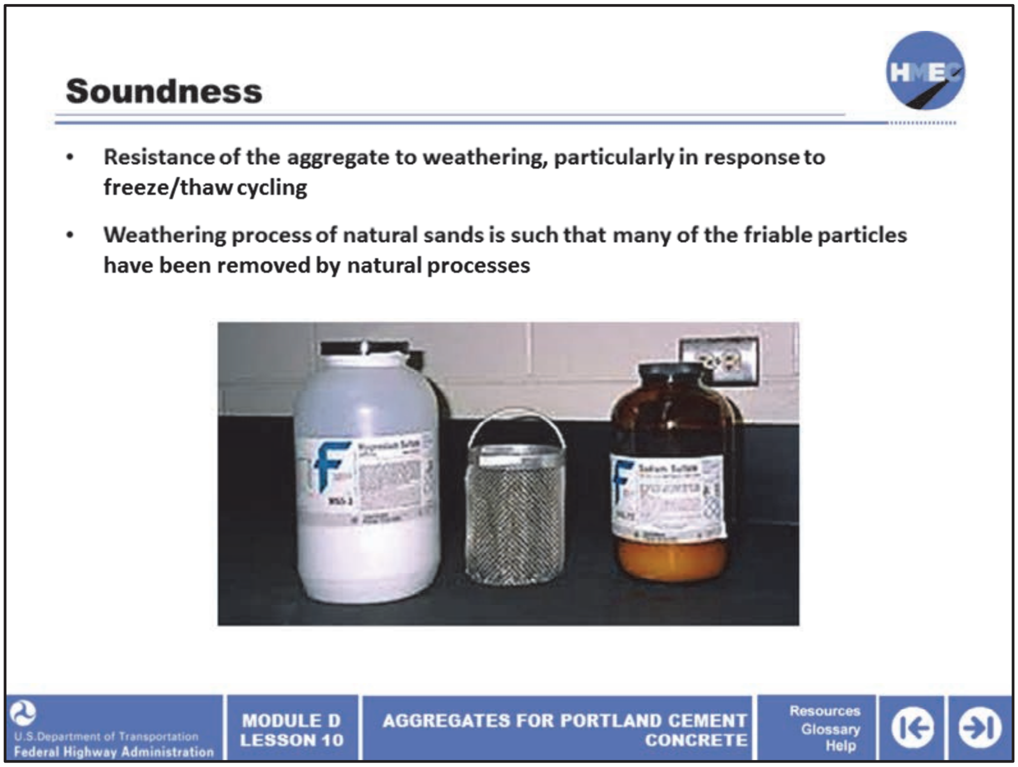
The cleanliness of the fine aggregates refers to the amount and characteristic of the fines or material passing the #200 sieve. As the percentage of fines increases, the water demand in the PCC increases for a given workability. The increased water content results in a higher w/c, which leads to increased drying shrinkage and reduced long-term durability and strength.

The fines content in the sand fraction is controlled by processing and must conform to the agency's specifications. Most agencies limit the amount of combined minus #200 material for the fine and coarse aggregate to 3–5%.

Select the box to reveal the answer to the question: How does plasticity impact performance?



The nature of the fines and their plasticity as determined by the PI is also an important factor. High plasticity clays, as determined by the PI, are highly problematic given their very high surface area for a given mass of material. In addition, these particles have a tendency to flocculate or cling together. They also tend to rise to the surface during placement and finishing and have the potential for micro-cracking the surface.



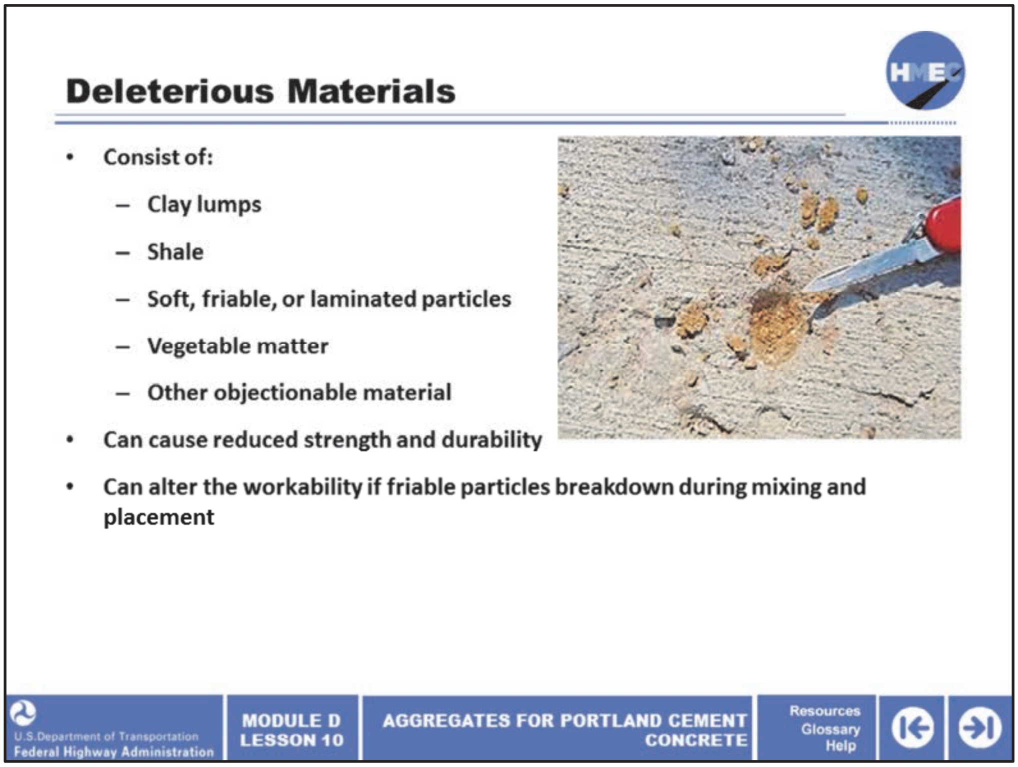
The soundness of aggregates is an important fine aggregate characteristic in hardened PCC, and is equally important in fine and coarse aggregates.

Soundness is essentially the resistance of the aggregate to weathering, particularly in response to freeze/thaw cycling.

The resistance of aggregates to disintegration by wetting/drying or freeze/thaw is determined by the sodium or magnesium sulfate soundness test described in AASHTO T 104.

The weathering process of natural sands is such that many of the friable particles (those that would be potentially unsound) have been removed by natural processes. Nonetheless, new sand sources or changes in the existing deposit should be evaluated according to the AASHTO T 104 procedure or its equivalent agency standard.

Image description: Photo of chemicals and basket.



Deleterious materials can affect both the fresh and hardened properties of PCC depending on their type and relative amount.

Deleterious materials are essentially the same as those found in coarse aggregates consisting of clay lumps, shale, soft, friable, or laminated particles, vegetable matter, or other objectionable material.

The same problems that were listed for coarse aggregates apply to fine aggregates as well, reduced strength and durability being the most noteworthy. Friable particles that break down during mixing and placement can alter the workability of the PCC. Intact particles that are present after placement can deteriorate over time, resulting in durability and strength issues in the hardened PCC.

Due to the processing (grading) of the fine aggregate, the sizes discussed here would be materials passing the #4 sieve.

Image description: Photo of near surface aggregate particles.

Potential Reactivity

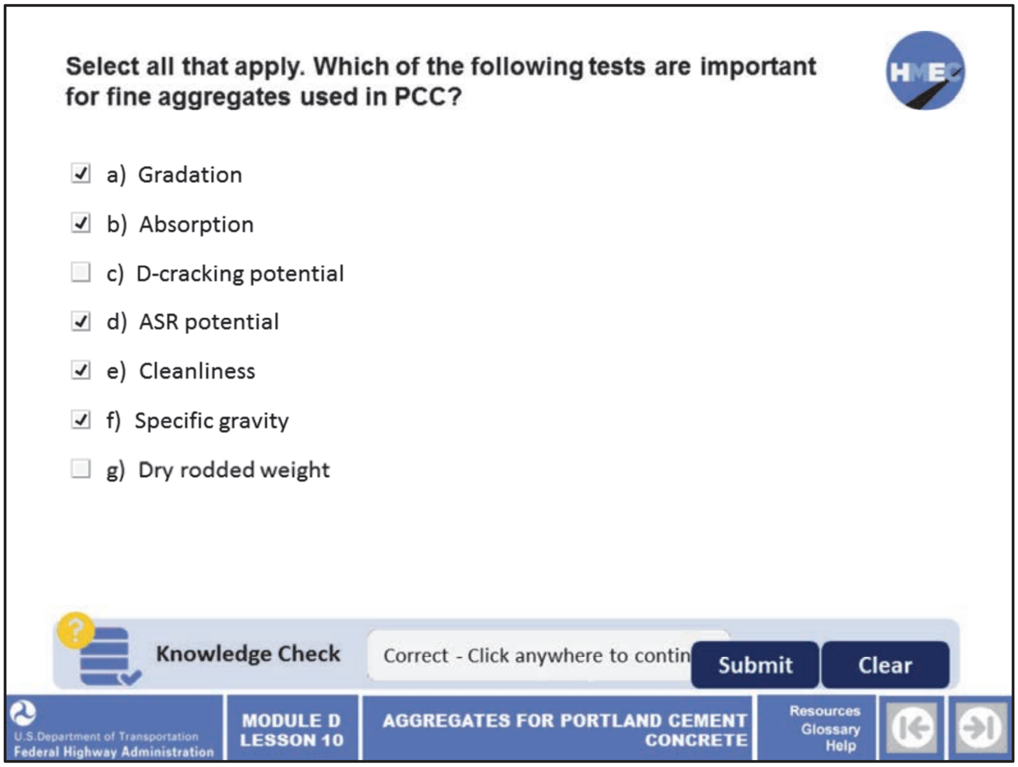
- Must be assessed to eliminate or minimize the occurrence of ASR
- Reactivity can occur in fine aggregates because of their high surface area, if they contain appreciable amounts of amorphous silica

The potential reactivity of aggregates must be assessed in order to eliminate or minimize the occurrence of ASR. These reactions can occur in the hardened PCC between the alkalis in the Portland cement and certain aggregates containing amorphous or reactive silica.

Fine aggregates, by virtue of their high surface area, can be very reactive if they contain appreciable amounts of amorphous silica.

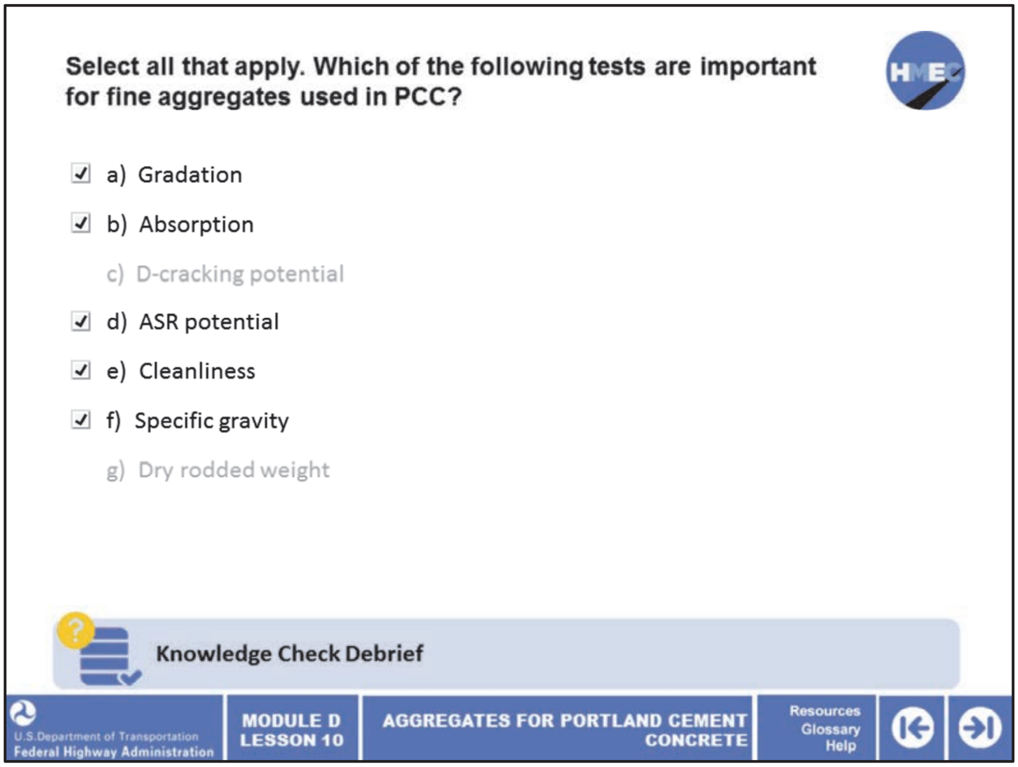
The tests to determine potential reactivity are governed by numerous ASTM specifications and range in duration from several weeks to over a year. The mortar bar test shown in the photo is according to ASTM C1260 and is commonly used to assess the reactivity.

Image description: Photo of mortar-bar test.

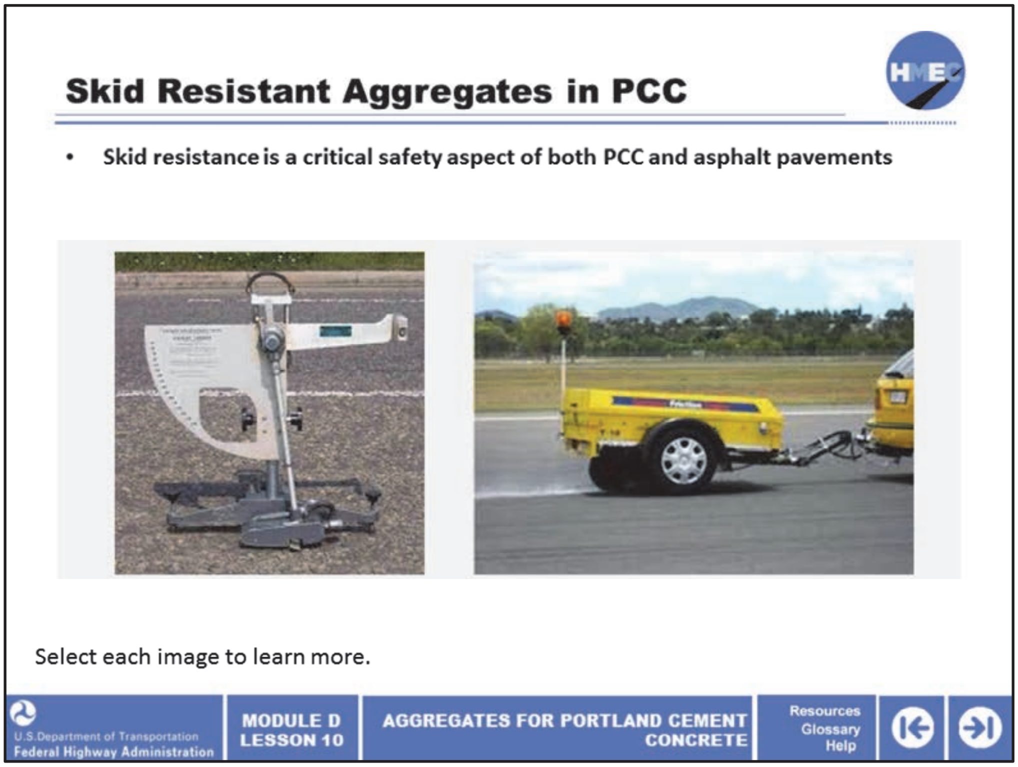


Select all that apply. Which of the following tests are important for fine aggregates used in PCC?

a) Gradation;
b) Absorption;
c) D-cracking potential;
d) ASR potential;
e) Cleanliness;
f) Specific gravity; and/or
g) Dry rodded weight.



The correct answers are a) Gradation, b) Absorption, d) ASR potential, e) Cleanliness, and f) Specific gravity.

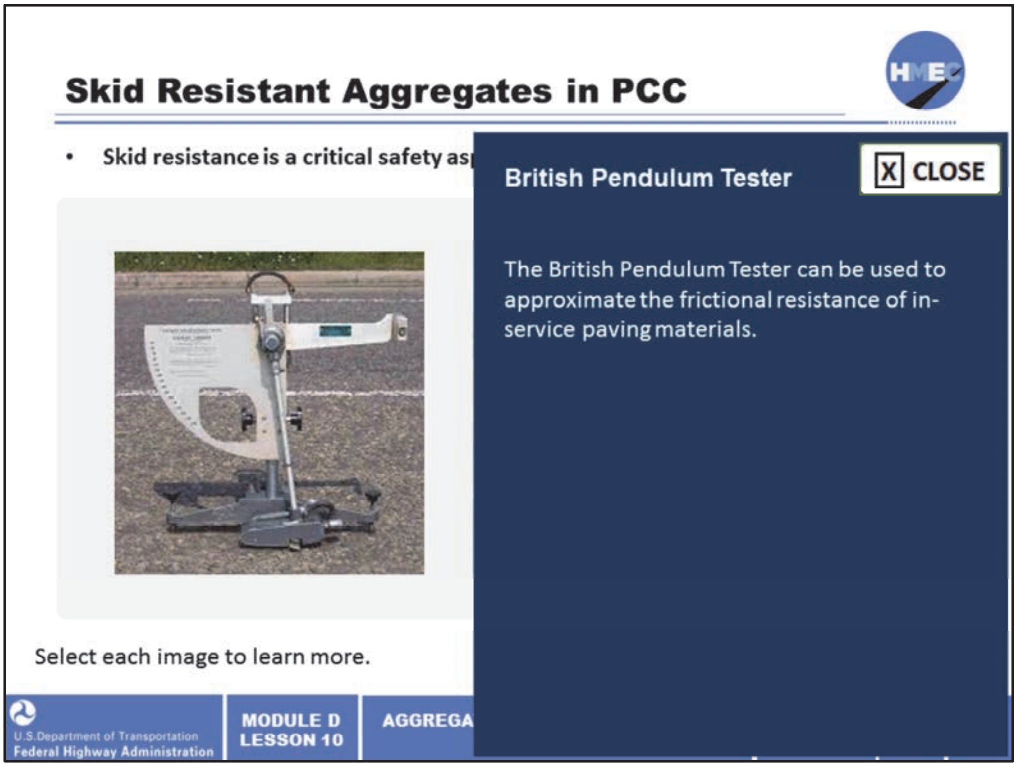


Skid resistance is a critical safety aspect of both PCC and asphalt pavements. Skid resistance is based on the friction that is developed between the pavement surface and tires. The skid resistance of the roadway is well correlated to accident rates, particularly on curves, at intersections and during wet weather.

Select each image to learn more.

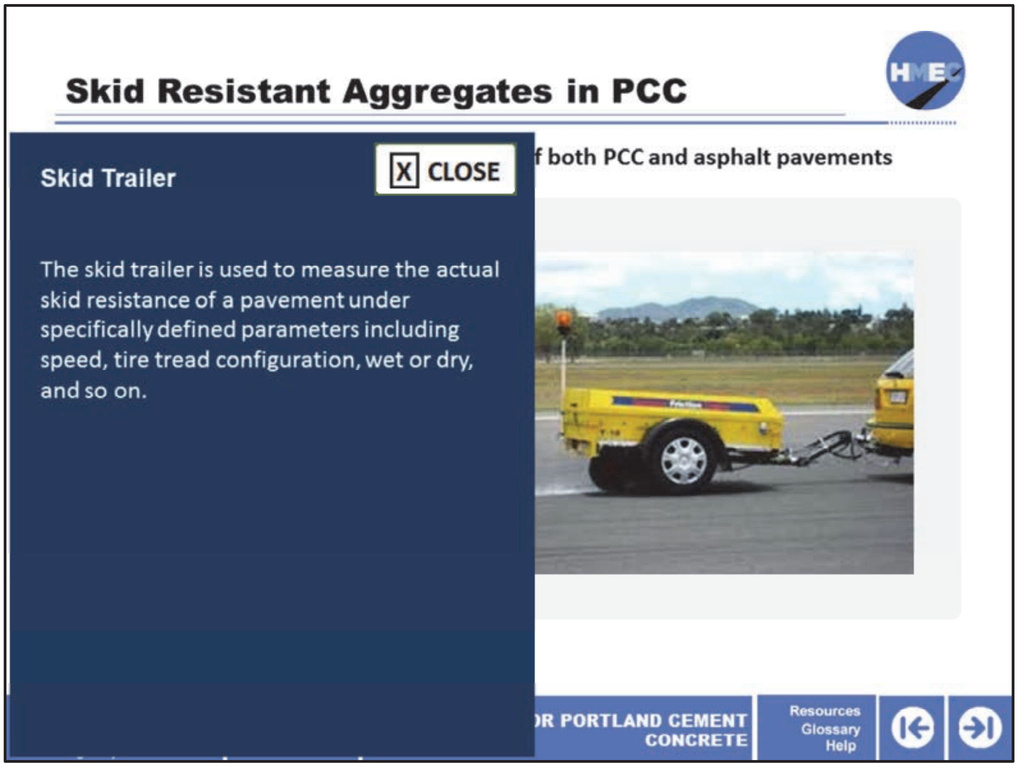
Image description: Photo of a British Pendulum Tester.

Image description: Photo of a Surface Friction Tester.



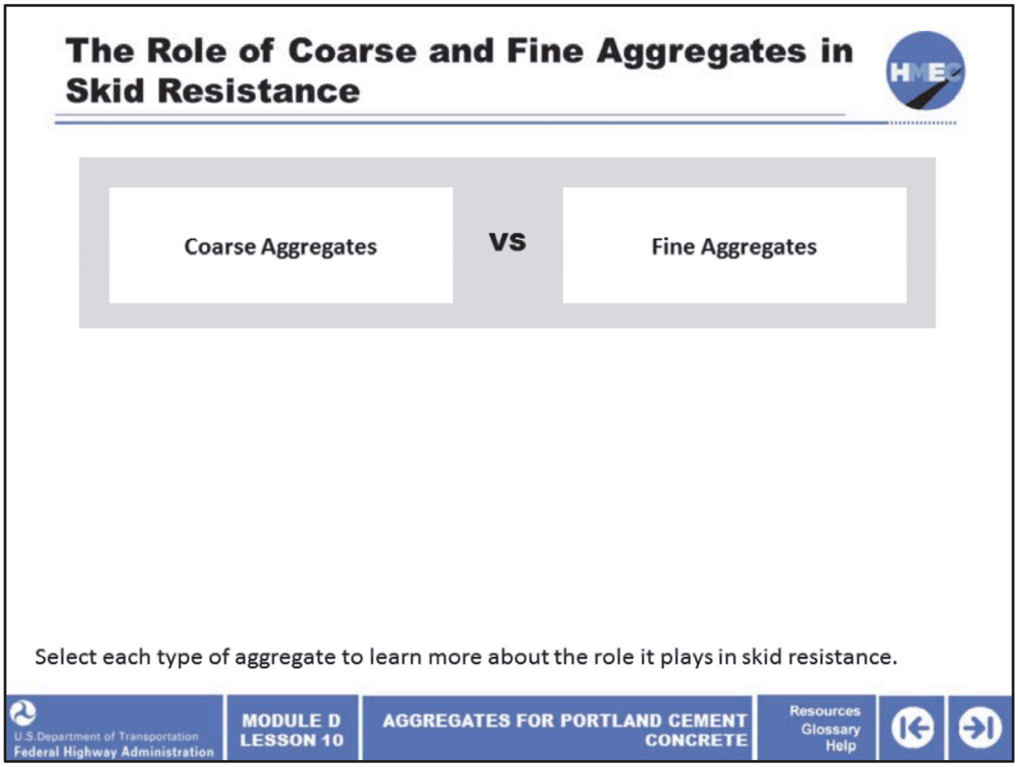
The British Pendulum Tester can be used to approximate the frictional resistance of in-service paving materials.

Image description: Photo of a British Pendulum Tester.

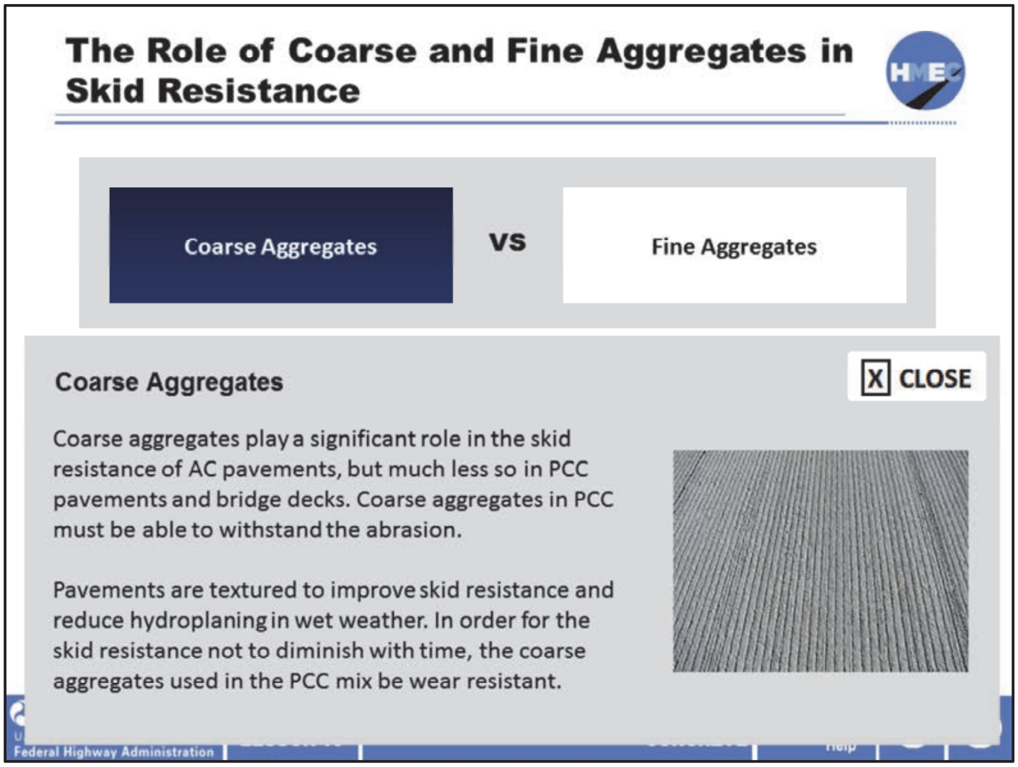


The skid trailer is used to measure the actual skid resistance of a pavement under specifically defined parameters including speed, tire tread configuration, wet or dry, and so on.

Image description: Photo of a Surface Friction Tester.



Select each type of aggregate to learn more about the role it plays in skid resistance.



Coarse aggregates play a significant role in the skid resistance of AC pavements, but much less so in PCC pavements and bridge decks.

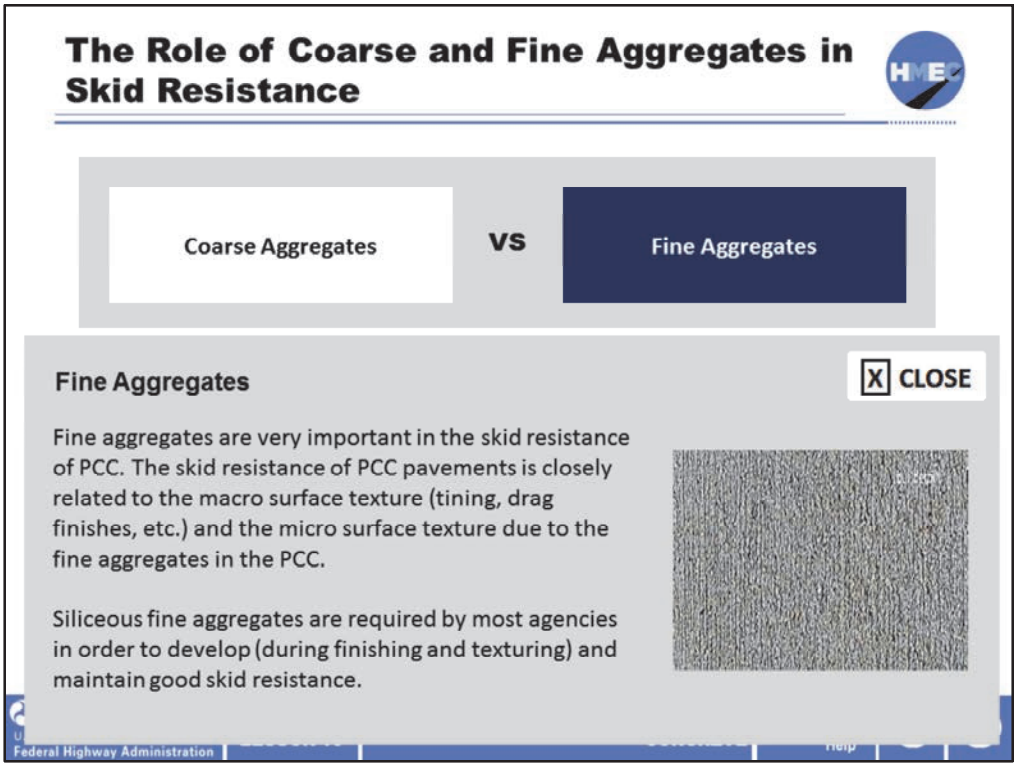
Coarse aggregates in PCC must be able to withstand the abrasion induced by tire wear (and snow plows where appropriate) and are important primarily to maintain the built-in texturing (tining, drag finish, diamond grinding and grooving).

Pavements are textured to improve skid resistance and reduce hydroplaning in wet weather. The macro textures used for PCC pavements including drag finishes, tining, diamond grinding and grooving are all intended to promote good skid resistance. Polishing prone aggregates are to be avoided as this can lead to a loss of skid resistance.

In order for the skid resistance not to diminish with time, the coarse aggregates used in the PCC mix must be wear resistant. The primary role of the coarse aggregates in this case is to maintain the built-in texture.

In general, siliceous aggregates are wear resistant while carbonate aggregates are less so and may need to be evaluated prior to use.

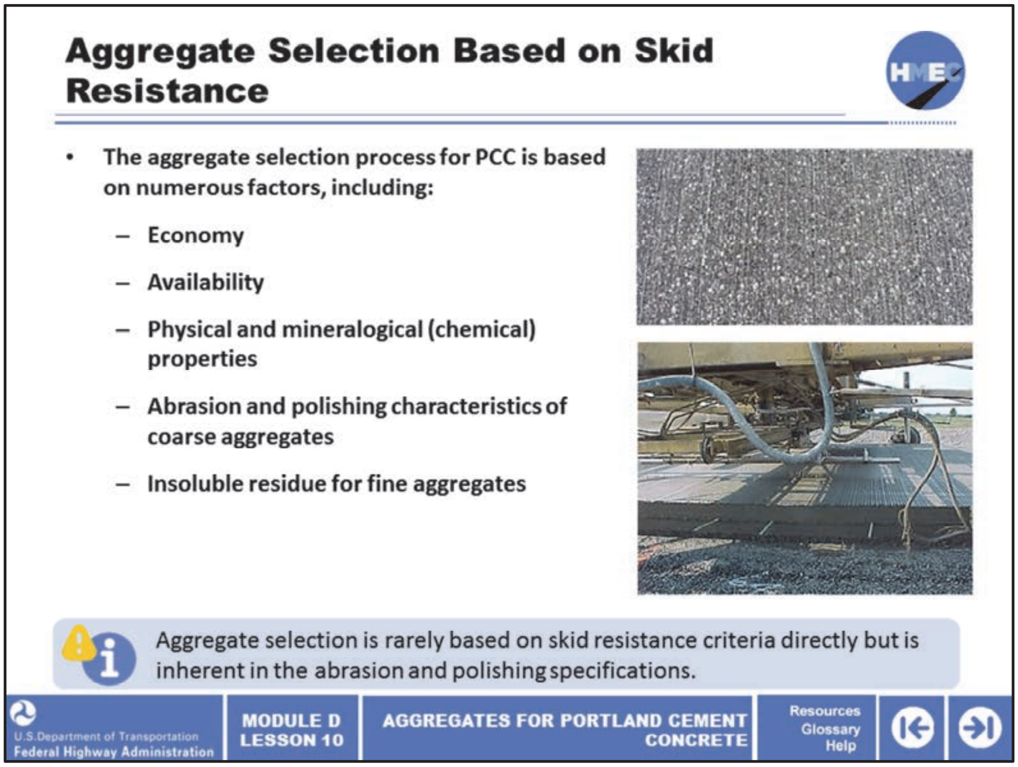
Image description: Photo of grooving texture in roadway surface.



Fine aggregates are very important in the skid resistance of PCC. The skid resistance of PCC pavements is closely related to the macro surface texture (tining, drag finishes, etc.) and the micro surface texture due to the fine aggregates in the PCC.

Siliceous fine aggregates are required by most agencies in order to develop (during finishing and texturing) and maintain good skid resistance.

Image description: Photo of grooving texture in roadway surface.



Aggregate selection is based on a number of factors including the economy, availability, physical and mineralogical (chemical) properties, abrasion and polishing characteristics of coarse aggregates, and insoluble residue for fine aggregates.

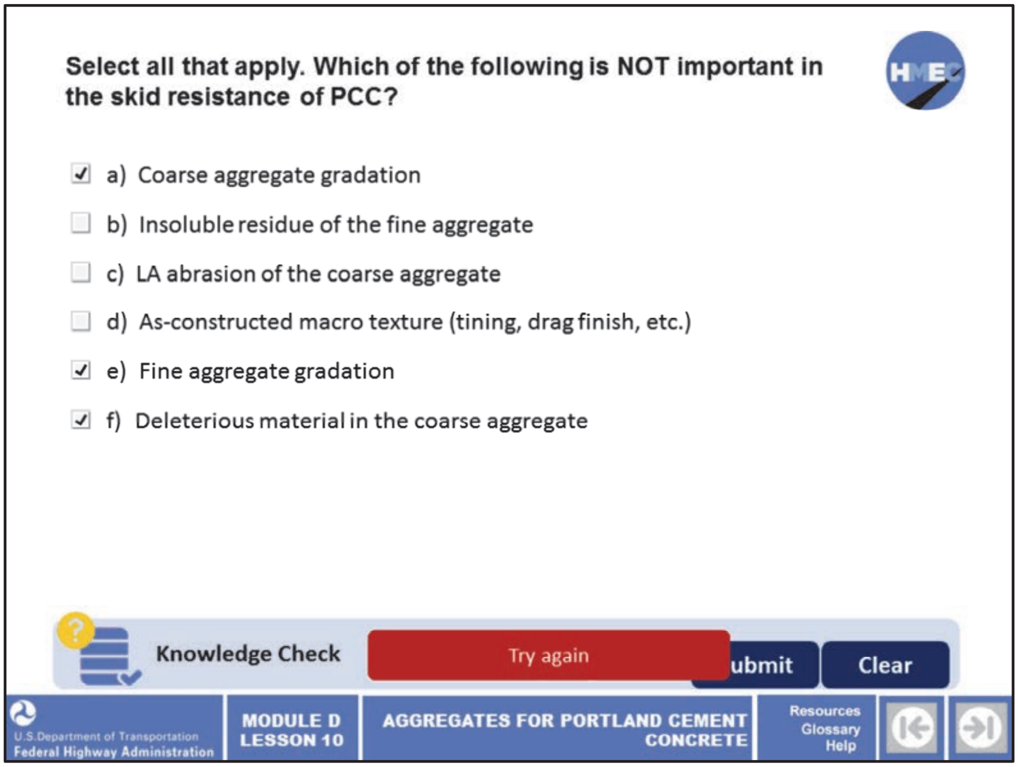
Aggregate selection is rarely based on skid resistance criteria directly but is inherent in the abrasion and polishing specifications.

Siliceous aggregates typically provide adequate wear characteristics resulting in good long-term skid resistance. Carbonate aggregates, however, can range from moderately wear resistant to those that are highly prone to wear and polishing.

As previously discussed, the LA abrasion value for the coarse aggregate is generally limited to 50% while the insoluble residue limit for the fine aggregate is approximately 60%, thereby ensuring adequate silica content for good wear resistance.

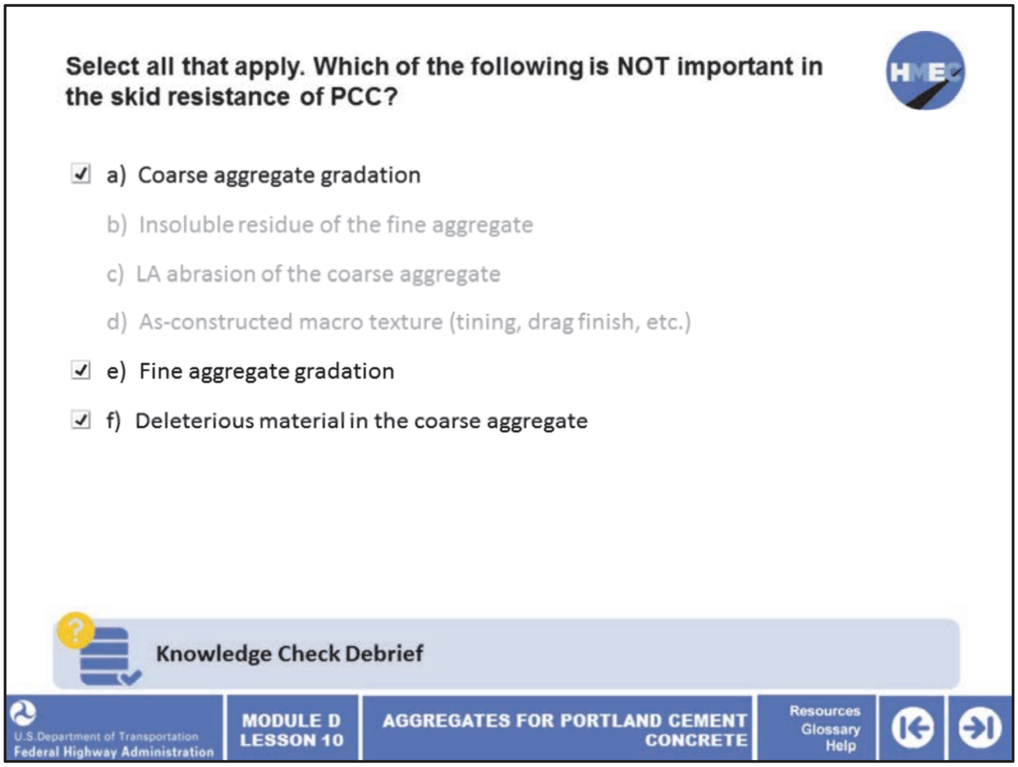
Image description: Photo of grooving texture in roadway surface.

Image description: Photo of grooving by the Cure/Texture machine.

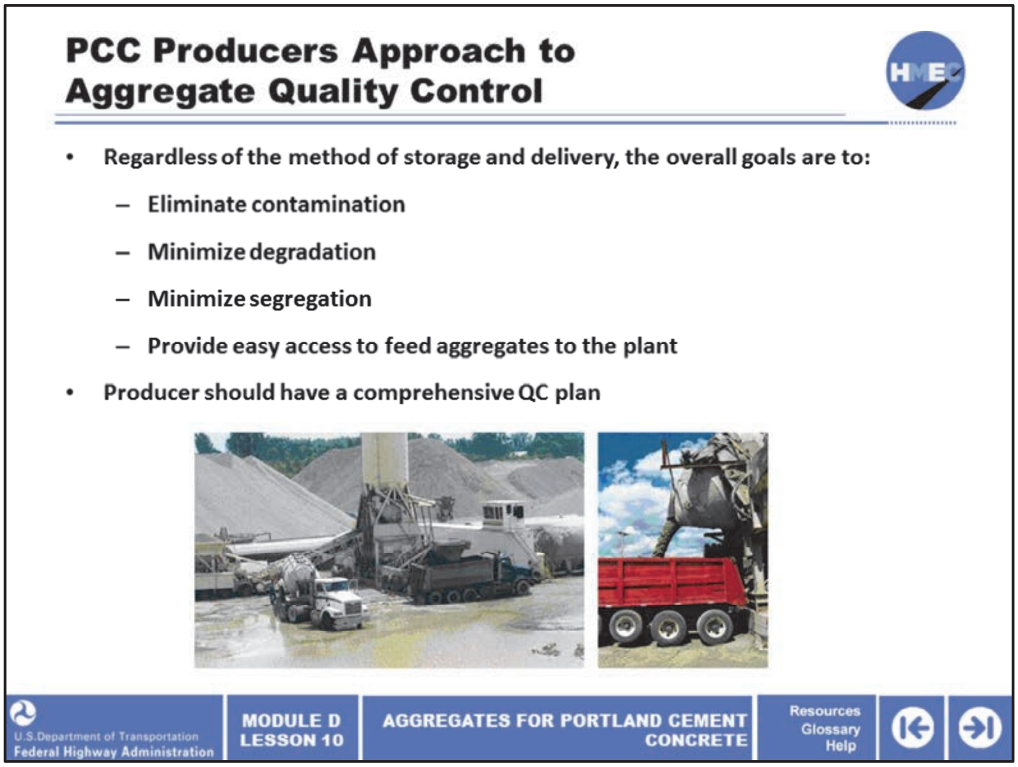


Select all that apply. Which of the following is NOT important in the skid resistance of PCC?

a) Coarse aggregate gradation;
b) Insoluble residue of the fine aggregate
c) LA abrasion of the coarse aggregate
d) As-constructed macro-texture (tining, drag finish, etc.);
e) Fine aggregate gradation; and/or
f) Deleterious material in the coarse aggregate.



The correct answers are a) Coarse aggregate gradation, e) Fine aggregate gradation, and f) Deleterious material in the coarse aggregate.



Aggregate quality control (QC) is based on providing a consistent graded aggregate for producing the PCC. The overall goals listed encompass the majority of the considerations.

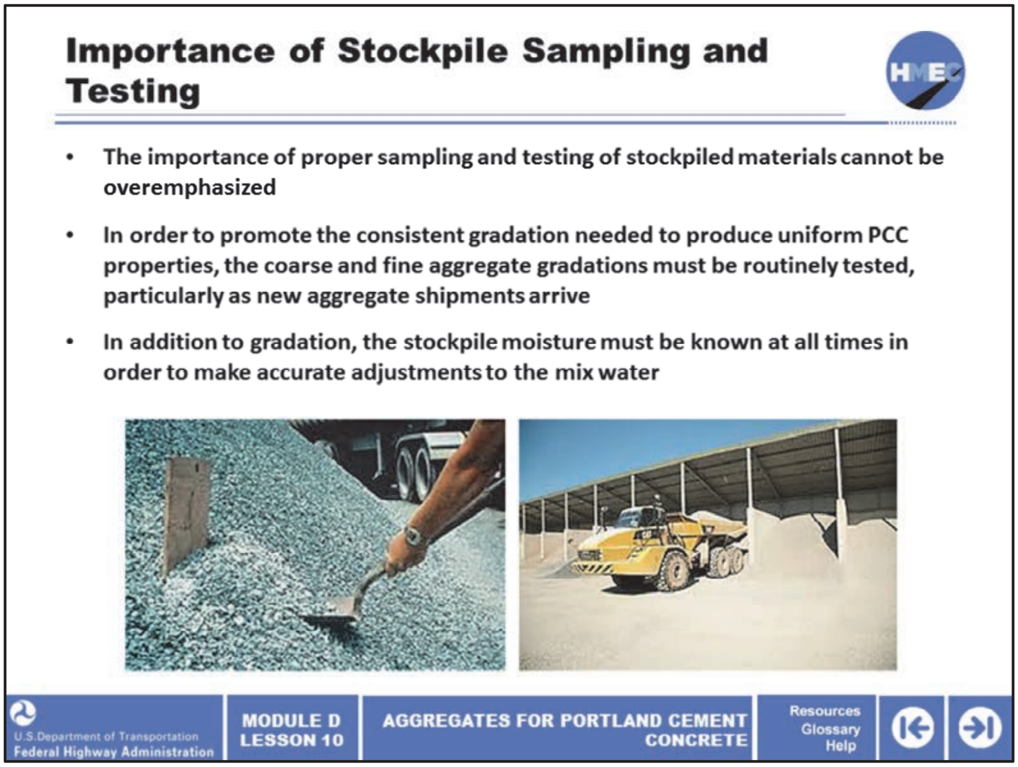
Aggregates at PCC production plants are either stored in stockpiles or bunkers. Delivery may be by truck, rail, or barges depending on the size and location of the facility.

Regardless of the method of storage and delivery, the overall goals are to:

- Eliminate contamination;
- Minimize degradation;
- Minimize segregation; and
- Provide easy access to feed aggregates to the plant.

The majority of plants that produce PCC for State projects have a high rate of turnover for the aggregates. A comprehensive QC plan on the part of the producer is standard operating procedure.

Image description: Photo of a PCC production plant.



The importance of proper sampling and testing of stockpiled materials cannot be overemphasized. Routine testing of the aggregate stockpiles is required to monitor changes in gradation, unit weight, absorption, and other properties that may vary with different shipments or sometimes within the same shipment.

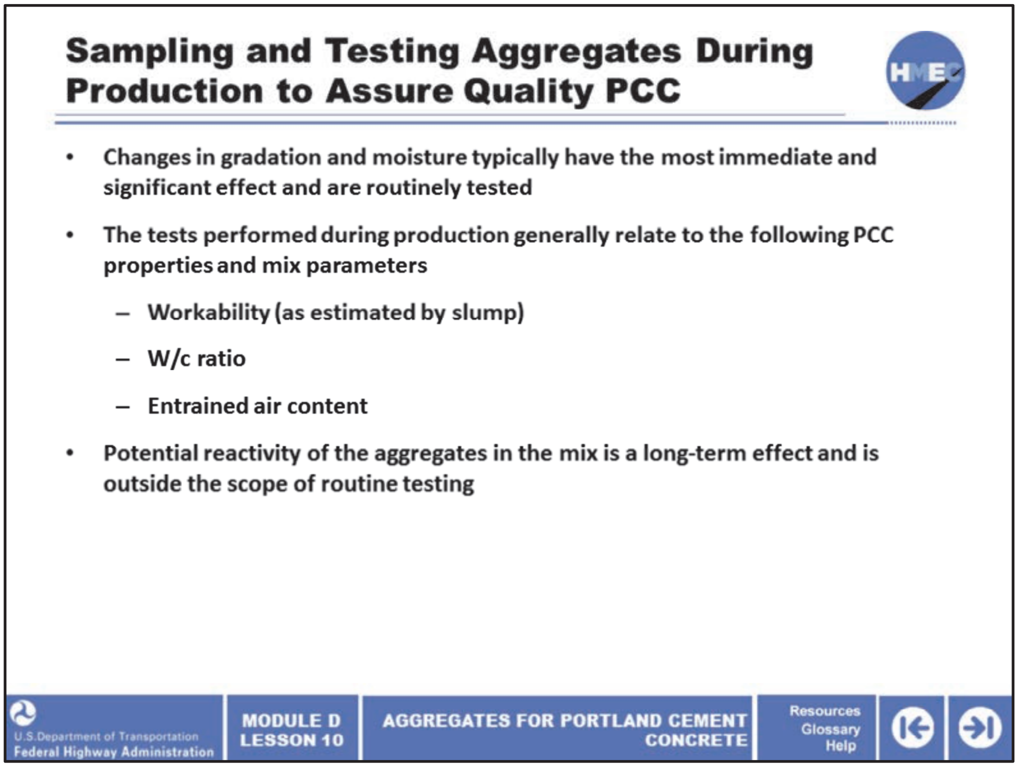
Agencies typically have guidelines that govern when stockpile sampling and testing is required. However, plant operators may sample and test more frequently if changes in the stockpile are evident during batching.

It should be noted that the loader operator plays a key role in providing uniform material to the plant as even the best constructed stockpiles have some measure of non-uniformity.

Of equal importance to gradation control is moisture control. Stockpile moisture is rarely uniform and should be tested when changes in the PCC are noted. Again, the loader operator can generally see these changes and blend to a more uniform moisture content.

Image description: Photo of shoveling a stockpile of aggregate.

Image description: Photo of dump truck near aggregate stockpiles.



PCC production facilities routinely test the variables over which they have control. In other words, the aggregate gradation and moisture content have significant and immediate implications to the properties of the fresh PCC and must be monitored.

Changes in gradation and moisture typically have the most immediate and significant effect and are routinely tested. The tests performed during production generally relate to the following PCC properties and mix parameters, including:

- Workability (as estimated by slump);
- W/c ratio; and;
- Entrained air content.

Some properties are not routinely tested. The potential reactivity of the aggregates in the mix is a long-term effect and is consequently well outside of the scope of routine testing.

By controlling the properties of the fresh PCC, the long-term strength and durability become less variable and will more closely correspond to the assumptions used in the mix design and proportioning. If stockpile sampling is done correctly, the tests will provide accurate gradation and moisture content for that stockpile. By combining the overall results of the various stockpiles, coarse, intermediate, and fine aggregate (or some variation), appropriate adjustments to the batch weights can be made.

Proper stockpile construction and management practices are necessary to produce uniform PCC with consistent properties. Proper management begins at the time of construction by providing a firm and stable platform on which to construct the stockpiles. The site drainage plan should allow water to drain away from the stockpiles. The stockpiles should be sufficiently separated so that cross contamination doesn't occur. The drop height of the aggregates during construction should be minimized to prevent segregation and degradation. The use of an end loader to blend the individual stockpiles is also beneficial as shown in the video.

The most effective stockpile management routine will likely not eliminate segregation, degradation, and contamination but will minimize them to reasonable levels. Stockpile segregation, degradation, and contamination should be considered in the initial plant layout.

When sampling and testing indicate that routine problems exist in aggregate management, the source must be identified and corrected. Oftentimes theses issues are due to improper stockpiling of the aggregates rather than changes in the aggregates properties, assuming a consistent aggregate source is used.

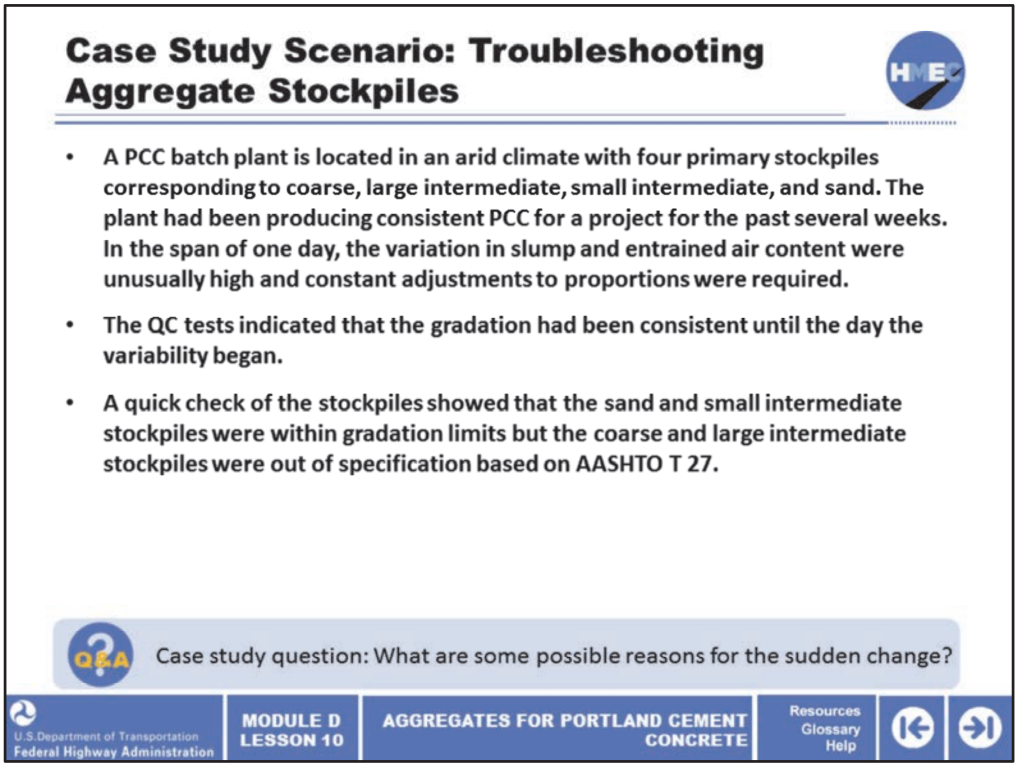
Image description: Photo of a stockpile of PCC.

Aggregate QC records must be maintained by the plant in order to determine if significant variability is present. By routinely monitoring the gradation, unit weight (dry rodded weight), FM of the sand, and variations in stockpile moisture, decisions in regards to stockpile management are simplified.

For instance, if the gradation of a particular stockpile has been consistent for the past several weeks and now is fluctuating significantly on a daily basis, an immediate investigation as to the cause is warranted.

If adequate records are not kept, the plant operator may be forced to react to the changes in the aggregates by altering the mix proportions to meet the criteria for slump and air.

Image description: Photo of front-end loader depositing material in dump truck.



Let’s take a few minutes to think about a case study. Review the case study and answer the question in your participant workbook. When you have finished answering the question, advance to the next screen for a debrief.

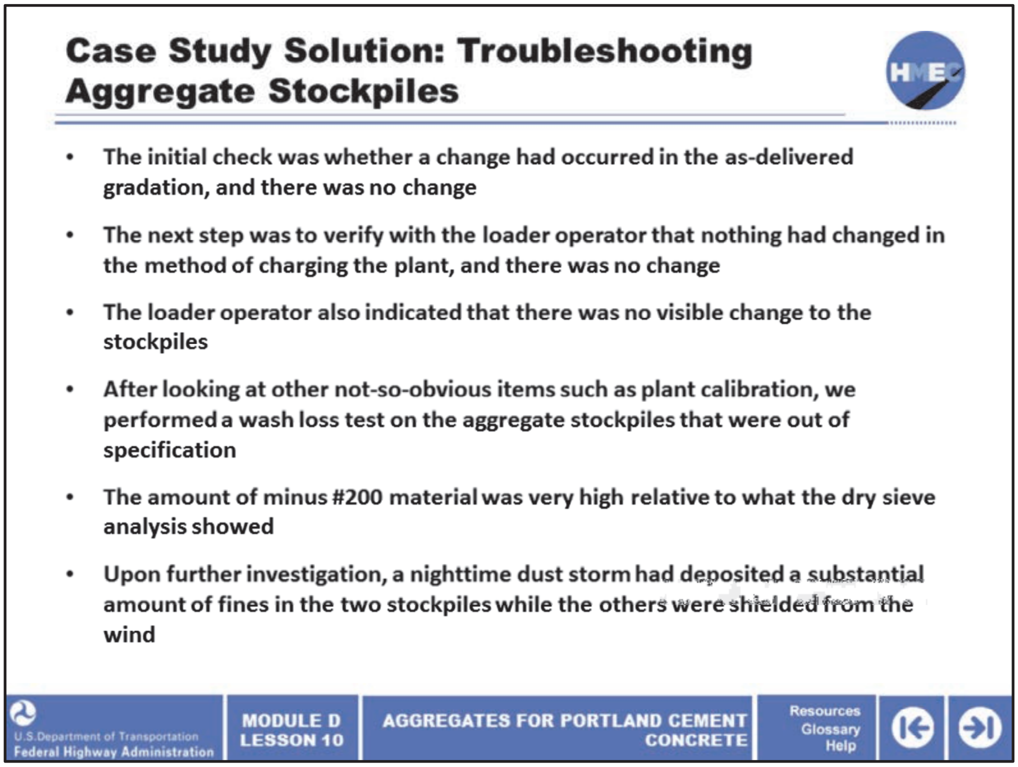
Scenario: A PCC batch plant is located in an arid climate with four primary stockpiles corresponding to coarse, large intermediate, small intermediate, and sand. The plant had been producing consistent PCC for a project for the past several weeks. In the span of one day, the variation in slump and entrained air content were unusually high and constant adjustments to proportions were required.

The QC tests indicated that the gradation had been consistent until the day the variability began.

A quick check of the stockpiles showed that the sand and small intermediate stockpiles were within gradation limits but the coarse and large intermediate stockpiles were out of specification based on AASHTO T 27.

Case study question: What are some possible reasons for the sudden change?

Pause the training to document your answer. When you are ready, advance to the next screen.



Let’s debrief the scenario. The initial check was whether a change had occurred in the as delivered gradation. There was no change.

The next step was to verify with the loader operator that nothing had changed in the method of charging the plant. Again, no change.

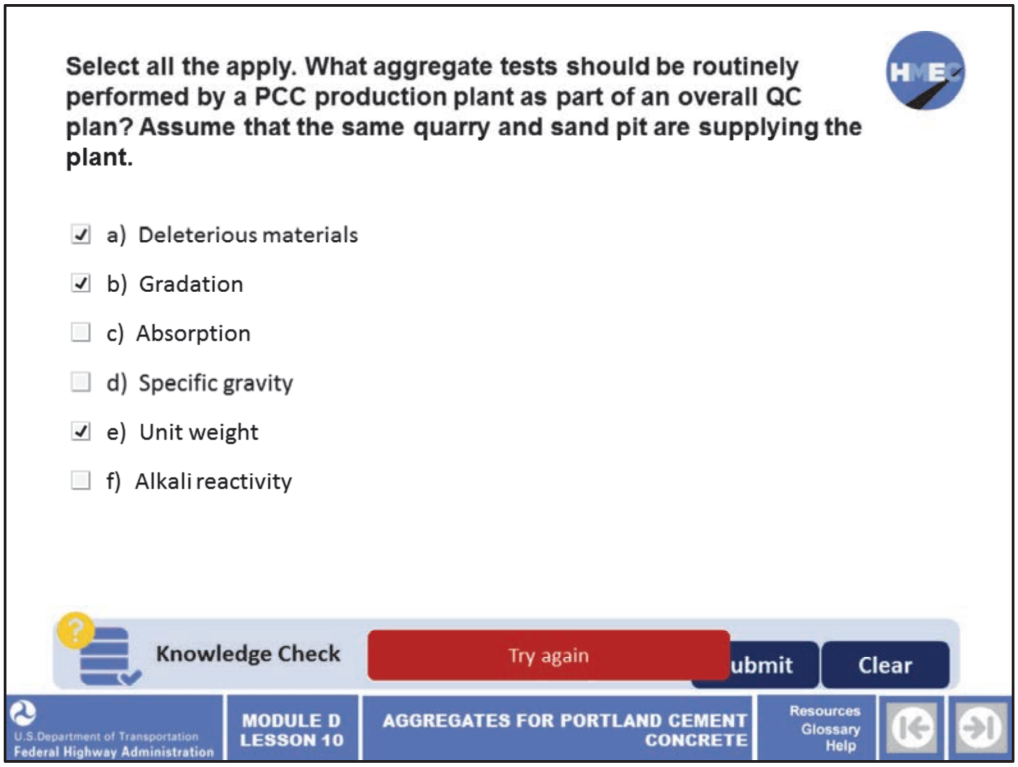
The loader operator also indicated that there was no visible change to the stockpiles.

After looking at other not-so-obvious items such as plant calibration, we performed a wash loss test on the aggregate stockpiles that were out of specification.

The amount of minus #200 material was very high relative to what the dry sieve analysis showed.

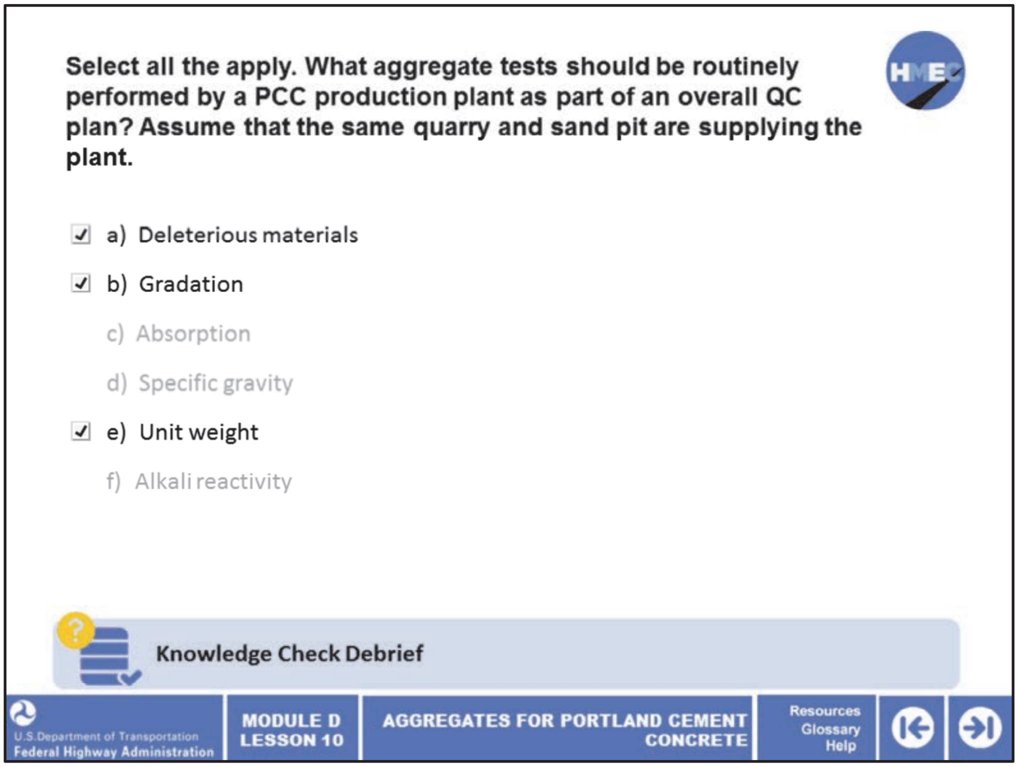
Upon further investigation, a nighttime dust storm had deposited a substantial amount of fines in the two stockpiles while the others were shielded from the wind.

This scenario illustrates that it is best to start with the easiest answer first and then delve into more involved analysis. The solution involved removal of the excess fines by washing the stockpiles prior to use.



Select all that apply. What aggregate tests should be routinely performed by a PCC production plant as part of an overall QC plan? Assume that the same quarry and sand pit are supplying the plant.

a) Deleterious materials;
b) Gradation;
c) Absorption;
d) Specific gravity;
e) Unit weight; or
f) Alkali reactivity.



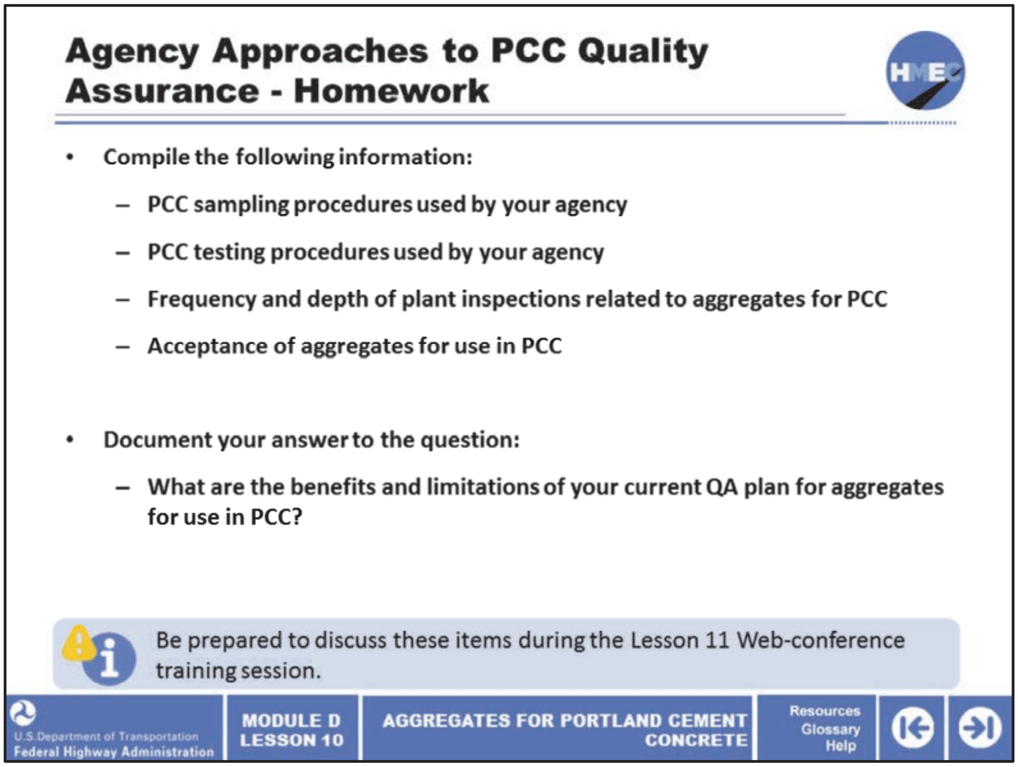
The correct answers are a) Deleterious materials, b) Gradation, and e) Unit weight.

Quality assurance (QA) is important to verify compliance with the specifications. Agency approaches to aggregate QA differ substantially depending on location, aggregate types, sources, and myriad other factors, and may include:

- Required testing;
- Plant inspection and certification;
- Record keeping; and
- Acceptance.

The frequency of testing varies considerably based on the test type. For instance, gradation tests are routine and frequently conducted; however, ASR testing is very important but not frequently performed.

Image description: Photo of conveyors stockpiling material.

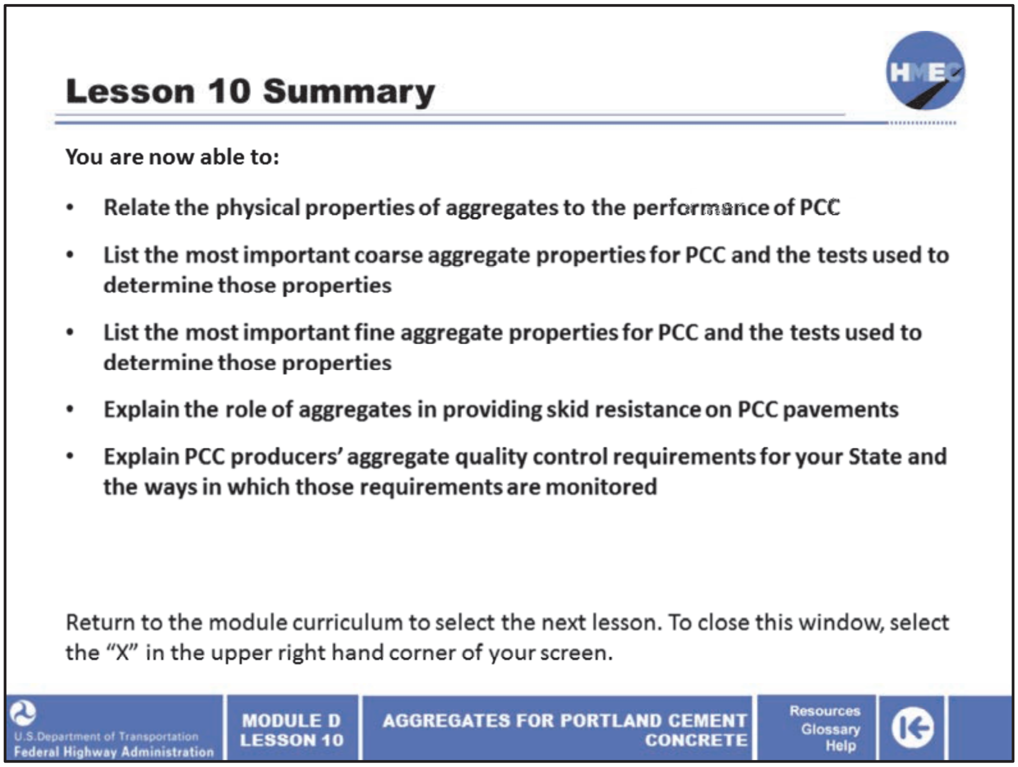


Most agencies have their own protocols that are followed in terms of QA plans. In preparation for the next Web-conference training (WCT) session, you are requested to compile information on the following:

- PCC sampling procedures used by your agency;
- PCC testing procedures used by your agency;
- Frequency and depth of plant inspections related to aggregates for PCC; and
- Acceptance of aggregates for use in PCC.

In addition, what are the benefits and limitations of your current QA plan for aggregates for use in PCC?

Document this information in your participant workbook or compile as appropriate from your agency's documentation. Be prepared to discuss these items during the Lesson 11 WCT session.



You have completed Module D, Lesson 10: Aggregates for Portland Cement Concrete. You are now able to:

• Relate the physical properties of aggregates to the performance of PCC;
• List the most important coarse aggregate properties for PCC and the tests used to determine those properties;
• List the most important fine aggregate properties for PCC and the tests used to determine those properties;
• Explain the role of aggregates in providing skid resistance on PCC pavements; and
• Explain PCC producers' aggregate quality control requirements for your State and the ways in which those requirements are monitored.

Close this lesson, and return to the module curriculum to select the next lesson. To close this window, select the "X" in the upper right-hand corner of your screen.