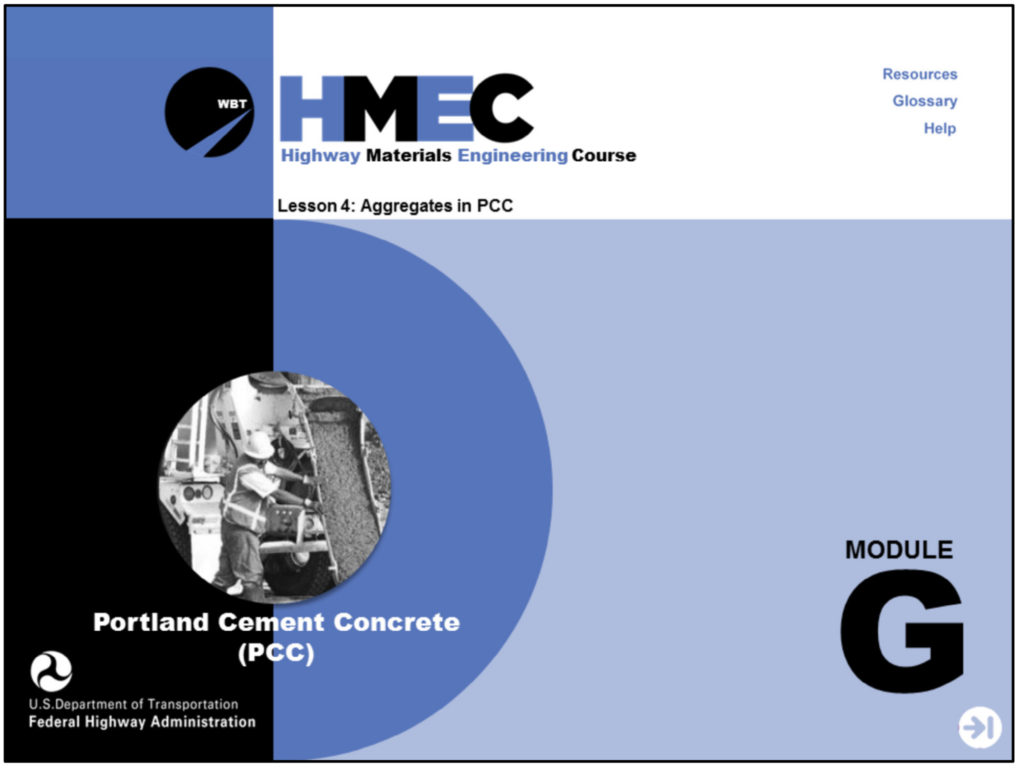
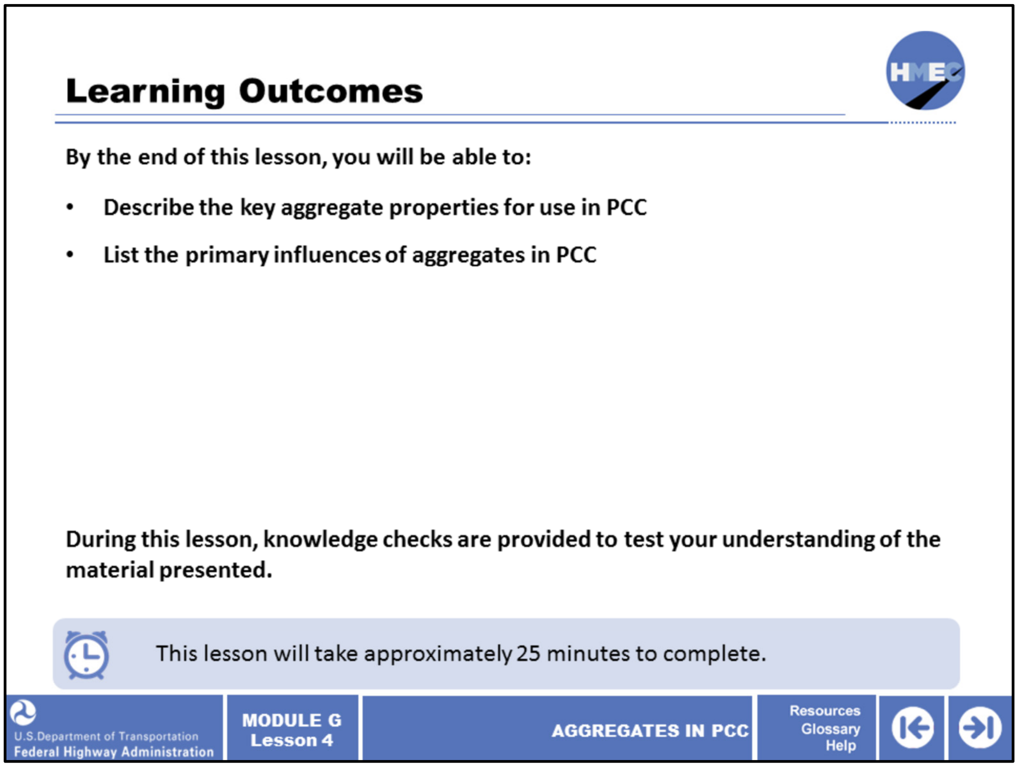



Welcome to the Highway Materials Engineering Course (HMEC) Module G, Lesson 4: Aggregates in PCC. This lesson will focus on aggregates in Portland cement concrete (PCC).

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.

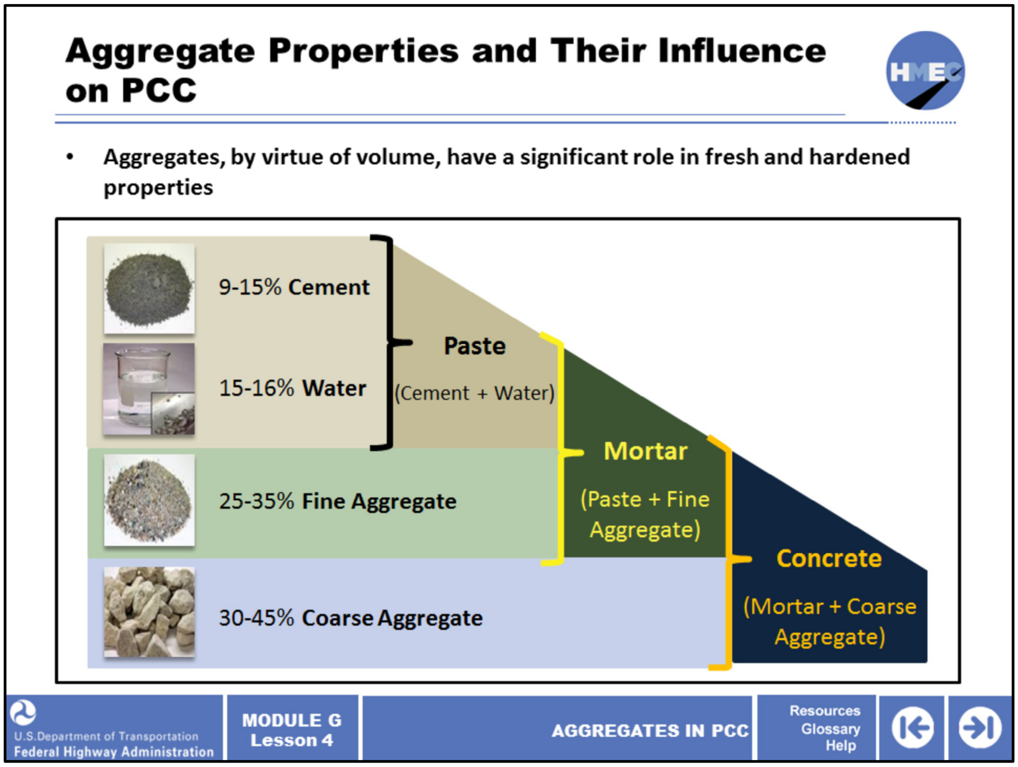



By the end of this lesson, you will be able to:

• Describe the key aggregate properties for use in PCC; and
• List the primary influences of aggregates in PCC.

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

This lesson will take approximately 25 minutes to complete.

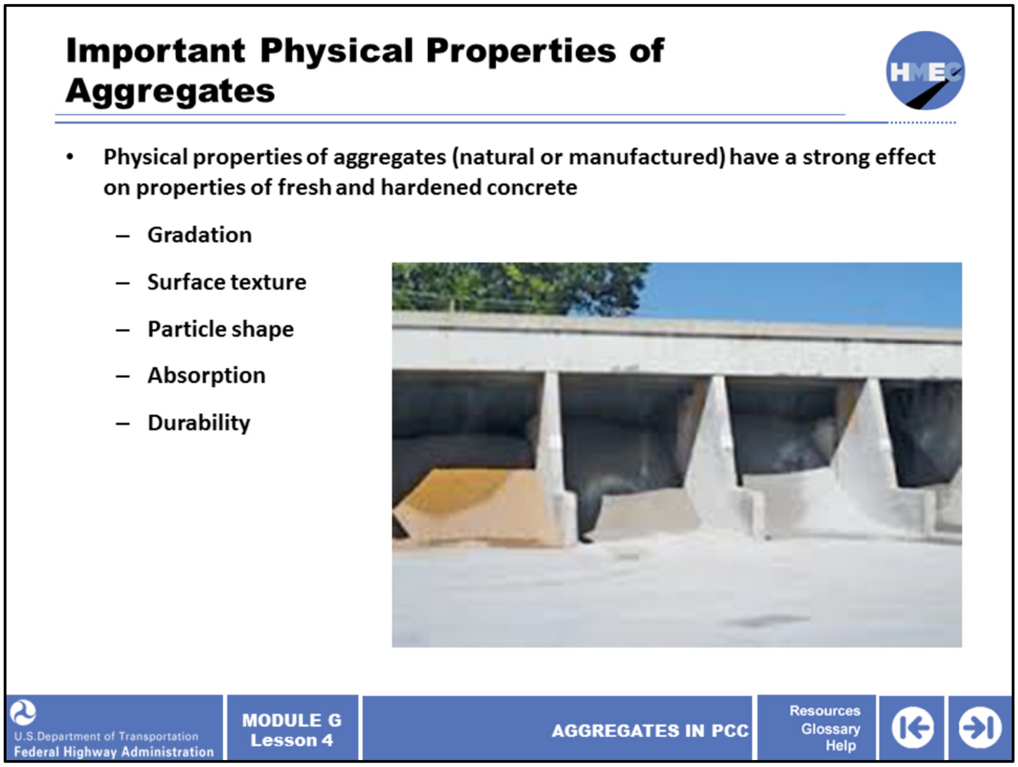



Aggregates, by virtue of their volume, have a significant role in both fresh and hardened properties of a PCC mix.

Aggregates occupy approximately 60 to 70% of the total volume in a typical PCC mix. This translates into roughly 75% by weight for normal weight aggregates.

Depending on the criteria used in the PCC mix design, the proportion of aggregates can change; however, they generally fall into the range shown on the slide.

Image description: Graphic displaying cement, water, fine aggregate, coarse aggregate, paste, mortar and concrete.

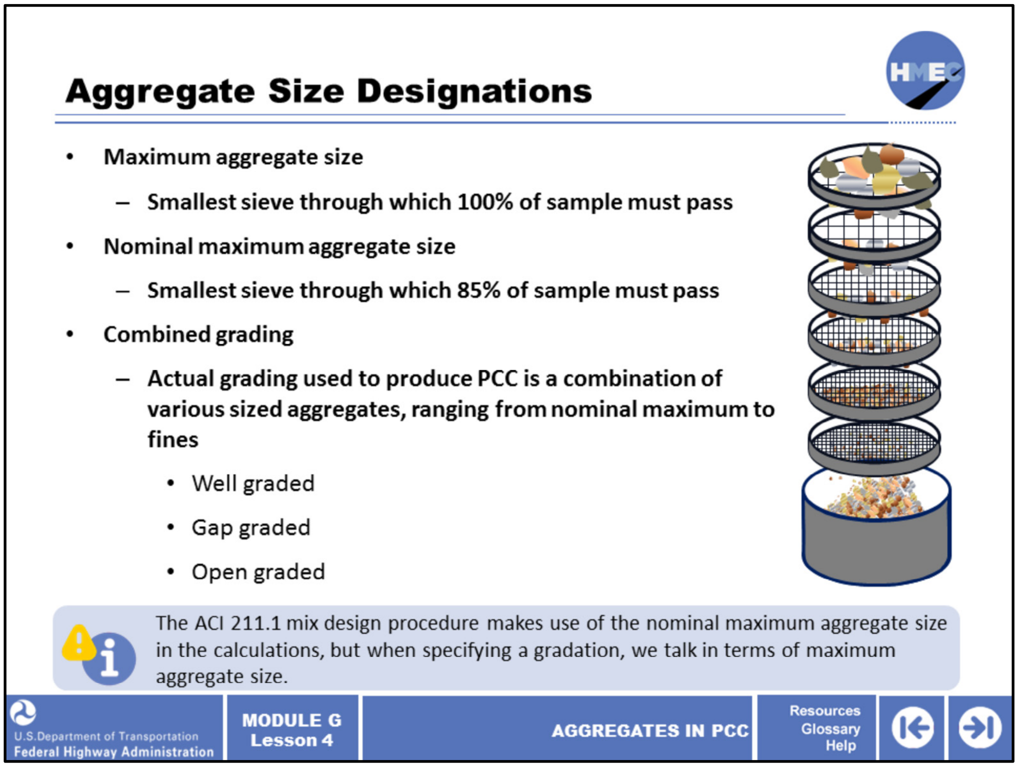



The physical properties of aggregates (natural or manufactured) can have a strong effect on the properties of fresh and hardened concrete. The physical characteristics of aggregates that have the most influence on PCC properties are listed here. They are:

- Gradation;
- Surface texture;
- Particle shape;
- Absorption; and
- Durability.

Depending on the environment and type of application (highway or structure), the relative importance of these may change somewhat. We covered the physical properties of aggregates in Module D and will revisit a few of the key points relative to PCC.

Image description: Photo of an aggregate storage facility.

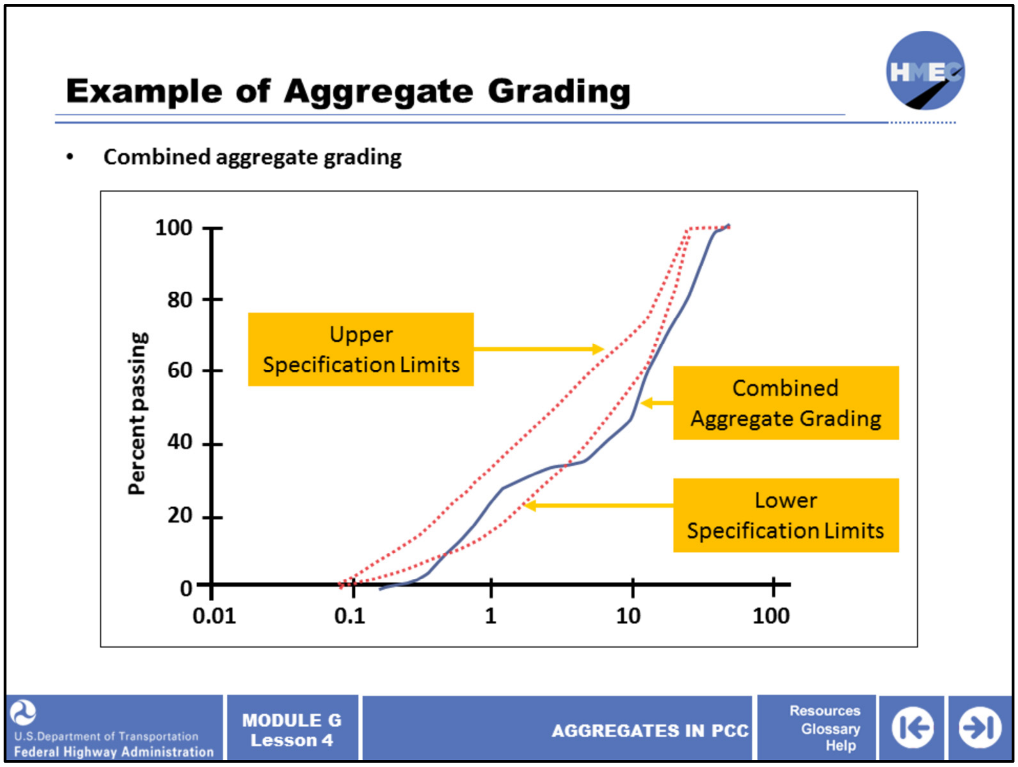



The maximum aggregate size and nominal maximum size are important from a mix design standpoint as well as in the performance of the fresh and hardened PCC.

The maximum aggregate size is the smallest sieve through which 100% of the sample must pass. The nominal maximum aggregate size is the smallest sieve size through which the majority of the sample passes (up to 15% can be retained). The actual grading used to produce PCC is a combination of various sized aggregates, ranging from the nominal maximum aggregate size to fines—this is referred to as combined grading.

The American Concrete Institute (ACI) 211.1 mix design procedure makes use of the nominal maximum aggregate size in the calculations. However, when specifying a gradation, we typically talk in terms of maximum aggregate size. Combined grading may be designated as well graded, gap graded, or open graded, depending on what sizes of aggregates are combined and in what proportion.

Image description: Image of six sieves of different sizes with aggregate falling through.

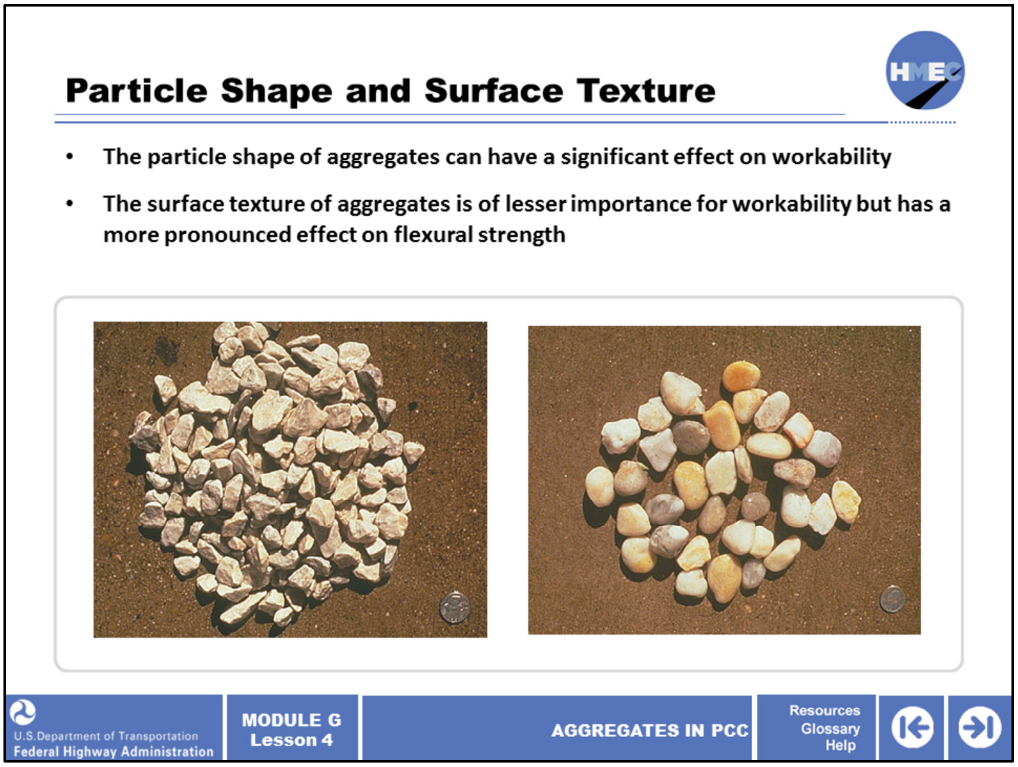



This example shows a combined aggregate grading, which is represented by the blue line. The upper and lower specification limits for this aggregate are shown by the two red dashed lines. Note that the gradation shown falls outside of the specifications on the lower bound.

Note that aggregate gradation influences:

- Mix proportions;
- Water demand;
- Density and strength;
- Workability; and
- Economy.

Image description: Graph showing an example of aggregate grading.

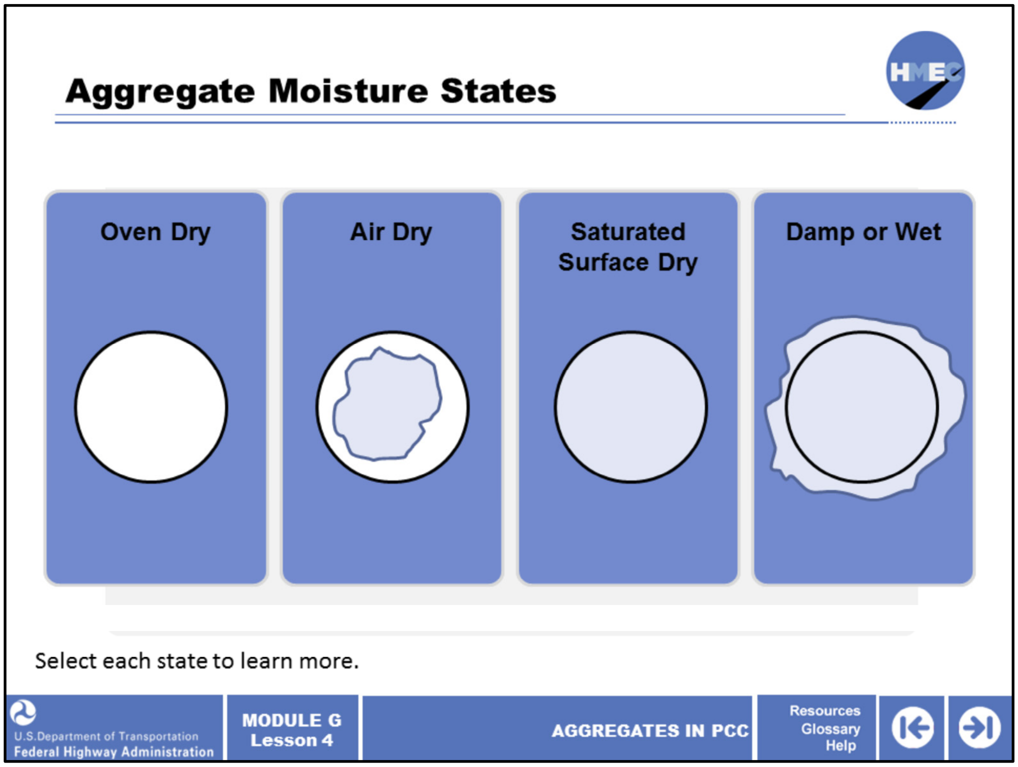



The particle shape of aggregates can have a significant effect on workability. The surface texture of the aggregates is generally not a primary consideration except for very rough surfaces that may negatively impact workability. Through proper mix proportioning and adjustments, almost any surface texture is acceptable.

The photo on the left shows very angular crushed stone particles with a rough surface texture. The photo on the right shows rounded particles (river gravel) with a relatively smooth surface texture. Note that a rough surface texture may lead to a somewhat increased mechanical bond between the cement paste and aggregates, resulting in a higher flexural strength.

Image description: Photo of very angular crushed stone particles with a rough surface texture.

Image description: Photo of rounded particles (river gravel) with a relatively smooth surface texture.



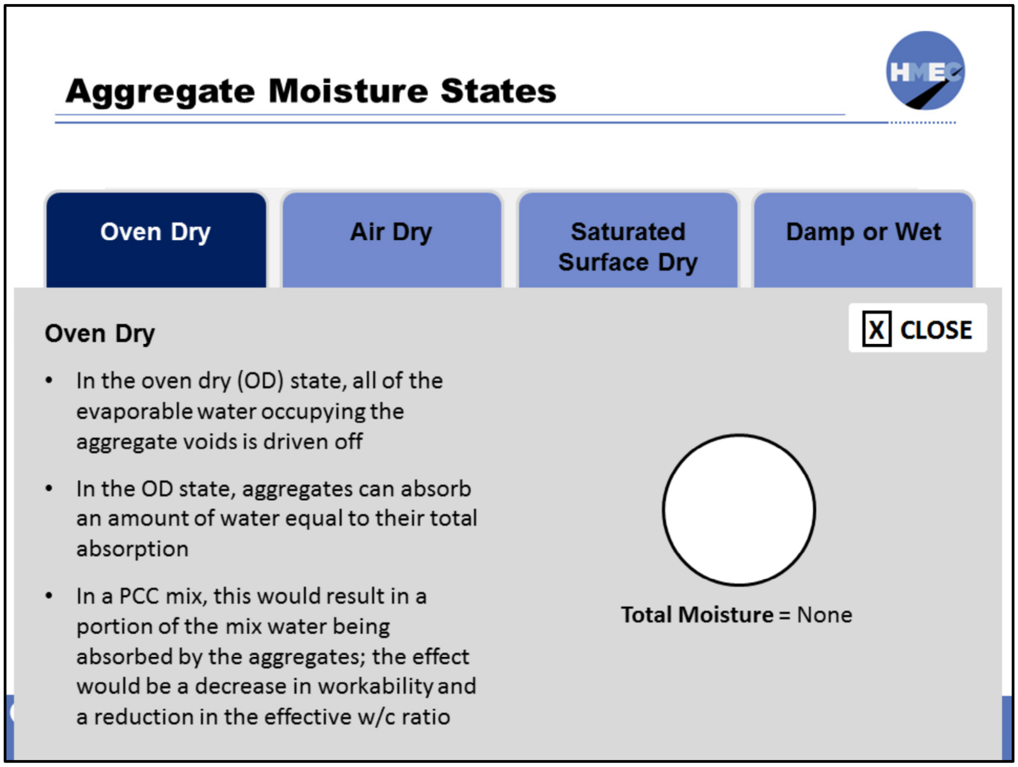

There are four moisture states of aggregates: oven dry, air dry, saturated surface dry, and damp or wet. Select each state to learn more.

Image description: Illustration of oven dry aggregate.

Image description: Illustration of air dry aggregate.

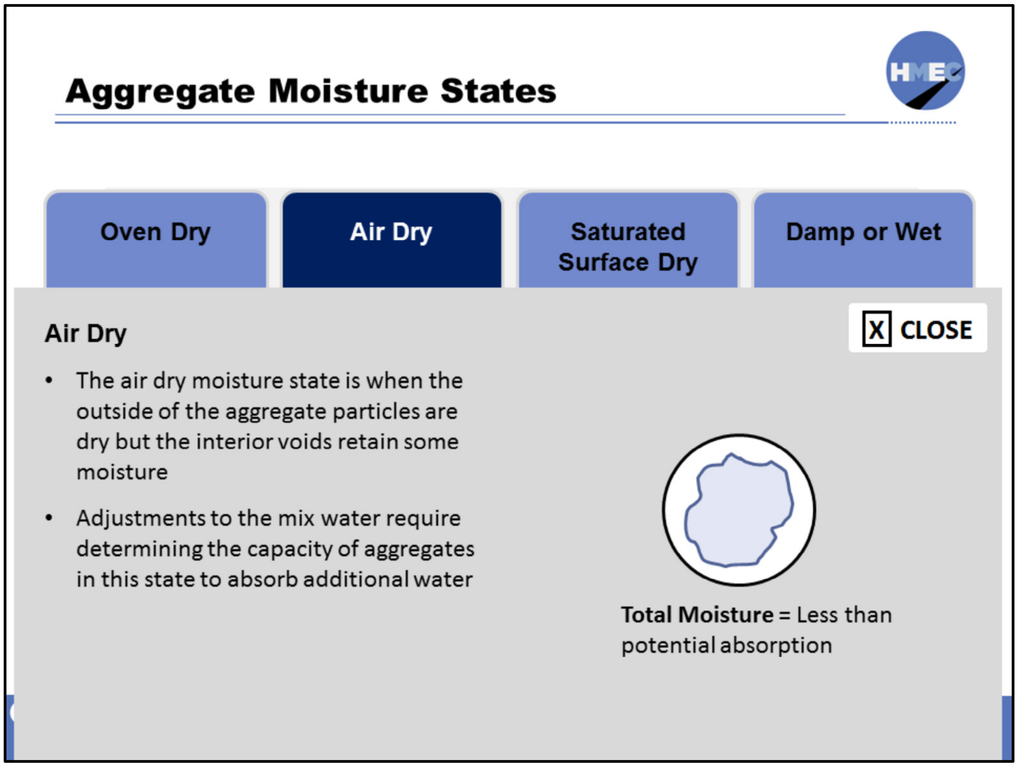
Image description: Illustration of saturated surface dry aggregate.

Image description: Illustration of damp or wet aggregate.



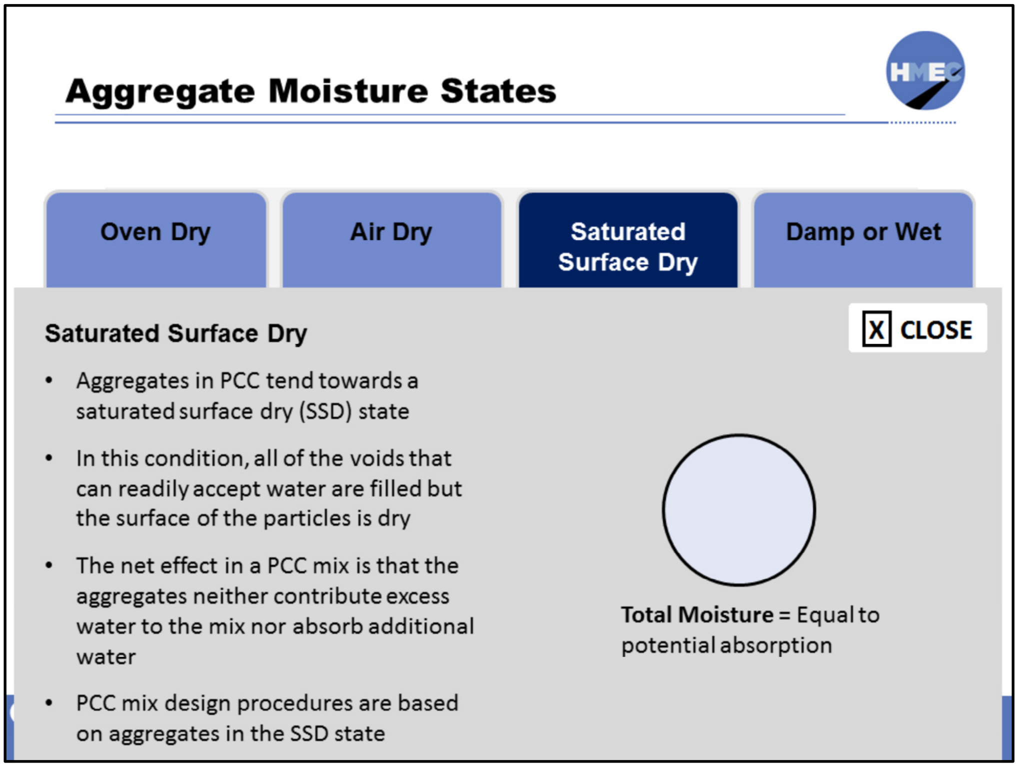

In the oven dry (OD) state, all of the evaporable water occupying the aggregate voids is driven off. The AASHTO and ASTM specifications require a drying temperature of 230 °F, although rapid test methods using a hot plate or microwave don't require this temperature to be reached. In the OD state, aggregates can absorb an amount of water equal to their total absorption. In a PCC mix, this would result in a portion of the mix water being absorbed by the aggregates. The effect would be a decrease in workability and a reduction in the effective water-to-cement (w/c) ratio.

Image description: Illustration of oven dry aggregate.



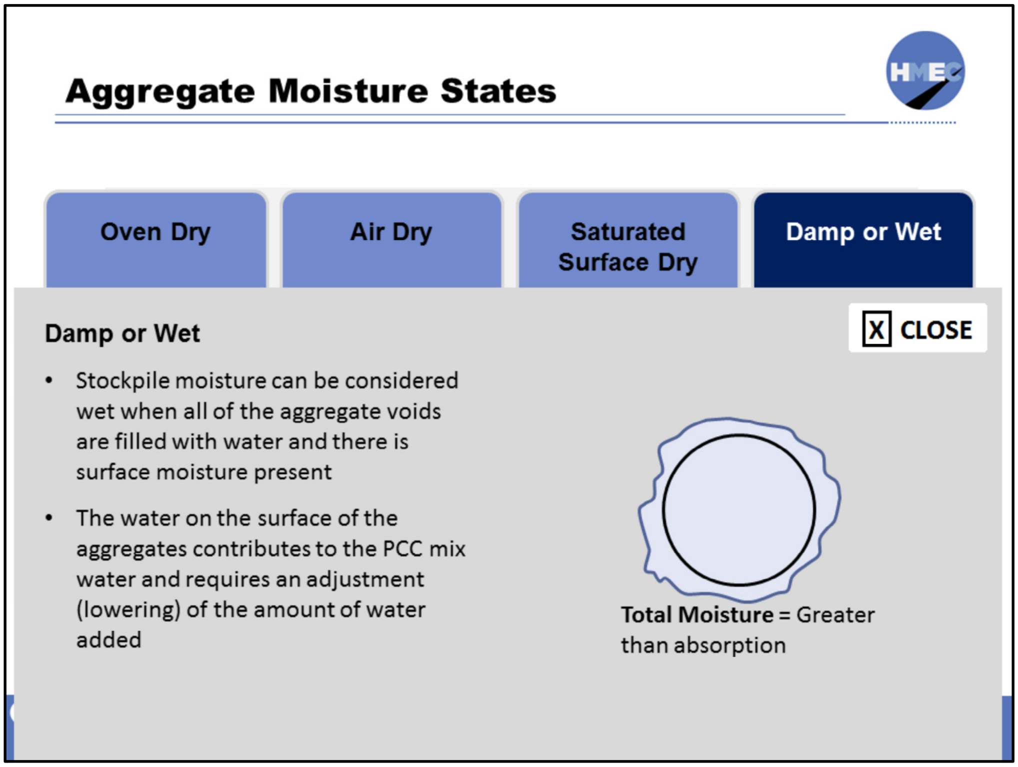

The air dry moisture state is when the outside of the aggregate particles are dry but the interior voids retain some moisture. Adjustments to the mix water require determining the capacity of aggregates in this state to absorb additional water.

Image description: Illustration of air dry aggregate.



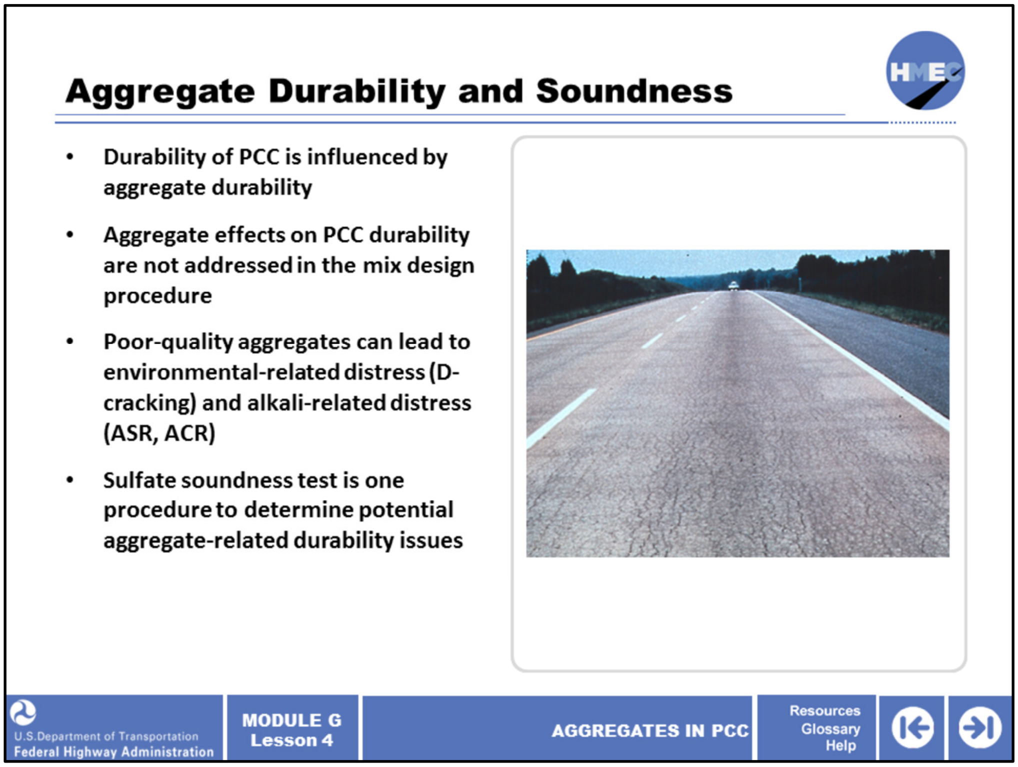

Aggregates in PCC tend towards a saturated surface dry (SSD) state. In this condition, all of the voids that can readily accept water are filled but the surface of the particles is dry. The net effect in a PCC mix is that the aggregates neither contribute excess water to the mix nor absorb additional water. PCC mix design procedures are based on aggregates in the SSD state.

Image description: Illustration of saturated surface dry aggregate.




Stockpile moisture can be wet, in which case the water on the surface of the aggregates contributes to the PCC mix water. If no adjustments were made to the mix proportions, the surface water would raise the w/c ratio. Note that this moisture state generally exists after periods of sustained rainfall (unprotected stockpiles) or when stockpiles are misted to reduce temperature or equilibrate moisture.

Image description: Illustration of damp or wet aggregate.




The durability of PCC is influenced by aggregate durability. Aggregate effects on PCC durability are not addressed in the mix design procedure. Poor-quality aggregates can lead to environmental-related distress (D-cracking) and alkali-related distress (alkali-silica reaction, ASR, or alkali-carbonate reaction, ACR). These types of durability issues are handled through aggregate specifications and testing as was discussed in the aggregates module. The sulfate soundness test is one such procedure to determine potential aggregate-related durability issues.

The photo shows a pavement with severe ASR damage due to an adverse reaction between the alkalis in the cement and the reactive silica in the aggregates.

Image description: Photo of a pavement with severe ASR damage due to an adverse reaction between the alkalis in the cement and the reactive silica in the aggregates.

## Mineralogical Properties

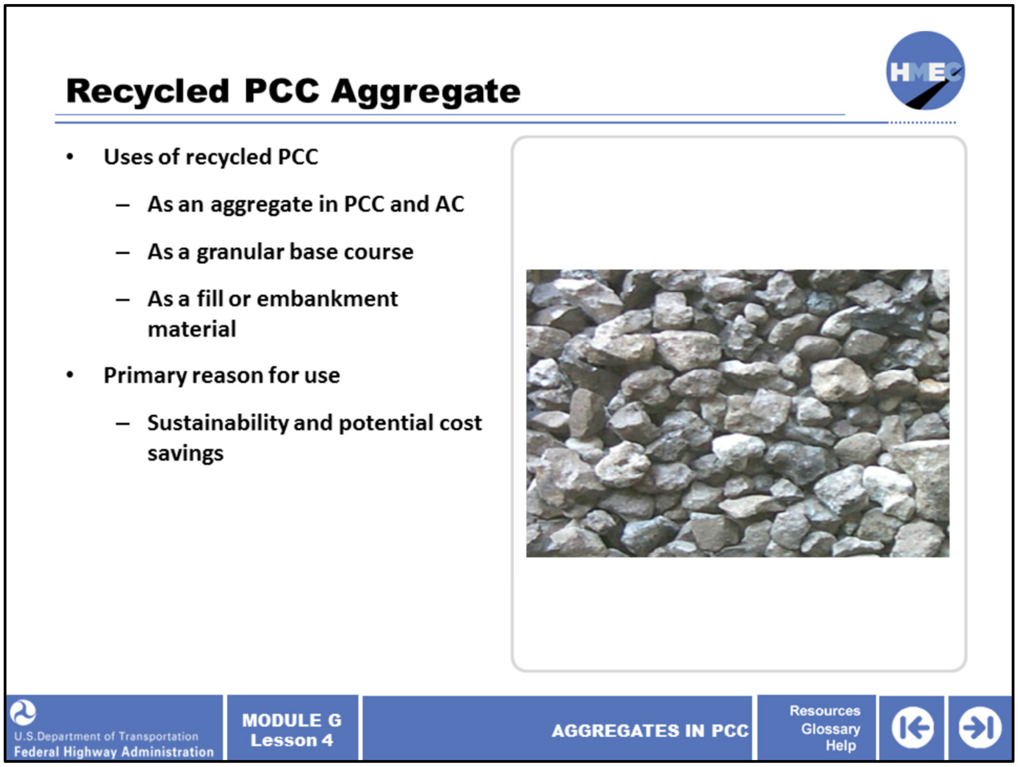
- Mineralogy of aggregates is not generally a major concern in aggregate selection
- An exception is when aggregates have a high percentage of amorphous (reactive) silica
- Dolomitic limestones with small amounts of clay are also potentially reactive and can lead to alkali-carbonate reactivity
- Mineralogical properties of aggregates are not routinely determined unless they have been shown to be problematic in regards to ASR or ACR



The mineralogy of the aggregates is not generally a major concern in aggregate selection. An exception to this is when the aggregates have a high percentage of amorphous (reactive) silica, which can lead to alkali-silica reactivity. In addition, dolomitic limestones with small amounts of clay are also potentially reactive and can lead to alkali-carbonate reactivity.

The mineralogical properties of aggregates are not routinely determined unless they have been shown to be problematic in regards to ASR or ACR. Mineralogy may also play an important role in the wear characteristics of aggregates. However, this is generally determined during testing of physical properties rather than mineralogical testing.

Image description: Photo of mineralogy of the aggregates.



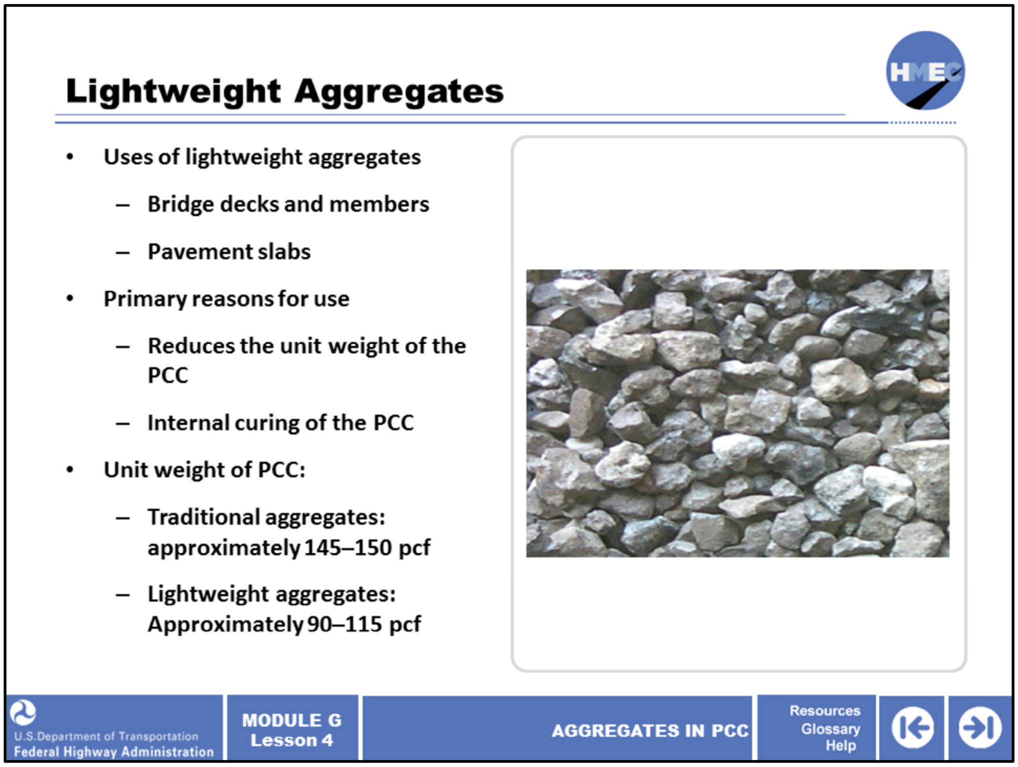

Recycled PCC is frequently used in both rigid and flexible pavement construction. The most common uses include an aggregate in PCC or asphalt concrete (AC) mixes, a base or subbase material, and as an embankment or fill material.

The recycled PCC aggregate particles produced by crushing have good particle shape, high absorption, and low specific gravity compared with conventional mineral aggregates.

The use of recycled coarse aggregate has no significant effect on mixture proportioning or workability compared with conventional PCC mixtures. When crushed recycled concrete pavement (RCP) is used as a fine aggregate, the mixture is less workable and requires more cement because of its increased water demand. As a result, most State agencies do not use recycled fines in concrete mixtures, and if they are used they are limited to a maximum of 30% of the fine aggregate portion of the mixture. The strength of PCC made with recycled PCC can be equivalent to conventional mixtures when recycled fines are omitted or used in small amounts.

Note that the unit weight should be closely monitored when used in a PCC mix. Given the variability that may be encountered in multiple sources, it is desirable to process and stockpile materials separately.

Image description: Photo of lightweight aggregates.




Lightweight aggregates are used in a variety of applications, including bridge decks and members and pavement slabs. The primary reason for using lightweight coarse aggregate is to reduce the unit weight of the PCC, thereby reducing the size of the structural elements due to dead loads. Normal weight PCC is approximately 145–150 pounds per cubic foot (pcf) compared to lightweight PCC at 90–115 pcf.

Lightweight aggregates are naturally occurring (volcanic) or manufactured products with a high degree of internal void space. Lightweight coarse aggregates are used primarily in structures to reduce the amount of dead load. Lightweight fine aggregates are sometimes used to provide internal curing by providing moisture within low w/c ratio PCC during hydration.

Saturated lightweight fine aggregate is added to low w/c ratio PCC mixes to provide an internal supply of water for curing. The result is less drying shrinkage and more complete hydration, particularly under difficult placement conditions, such as high temperature, low humidity, and wind, which result in a high rate of surface evaporation.

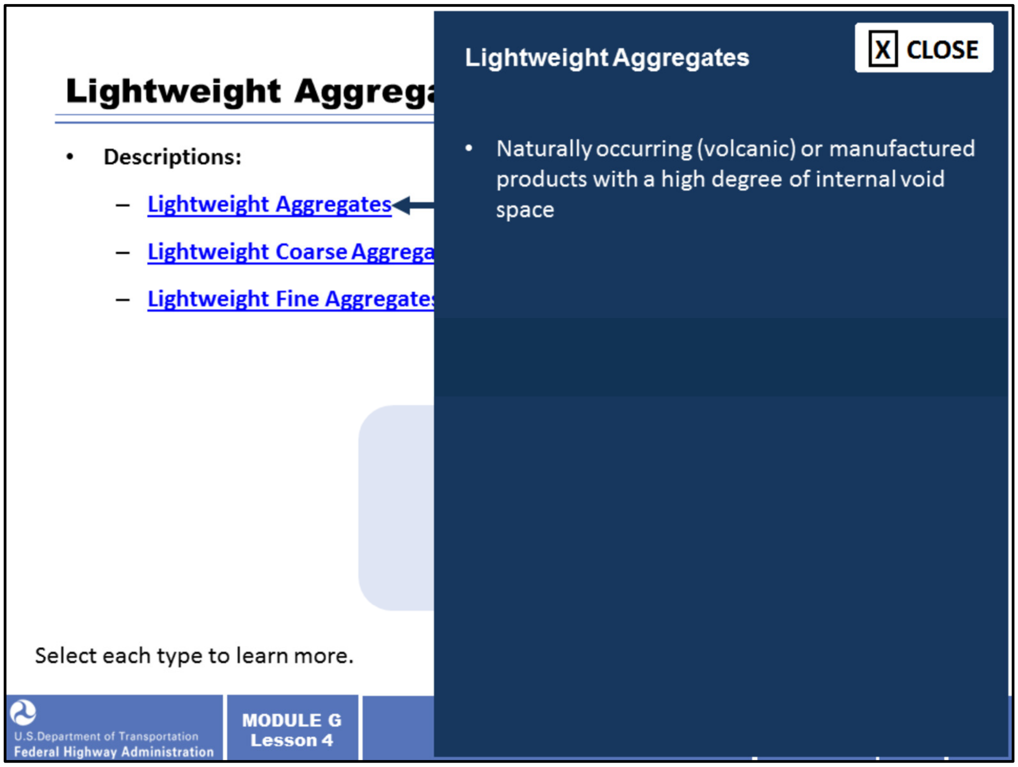
Image description: Photo of lightweight aggregates.


Here are the different types of lightweight aggregates.

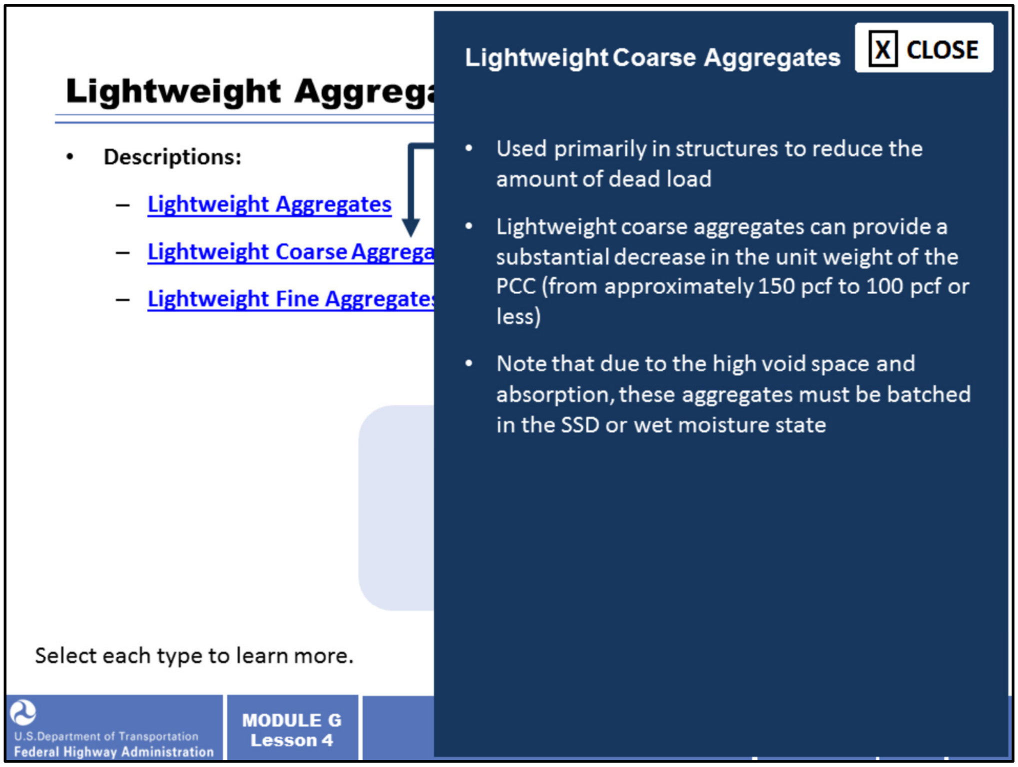
- Lightweight aggregates;
- Lightweight coarse aggregates; and
- Lightweight fine aggregates.

Select each type to learn more.

Image description: Photo of lightweight aggregates.



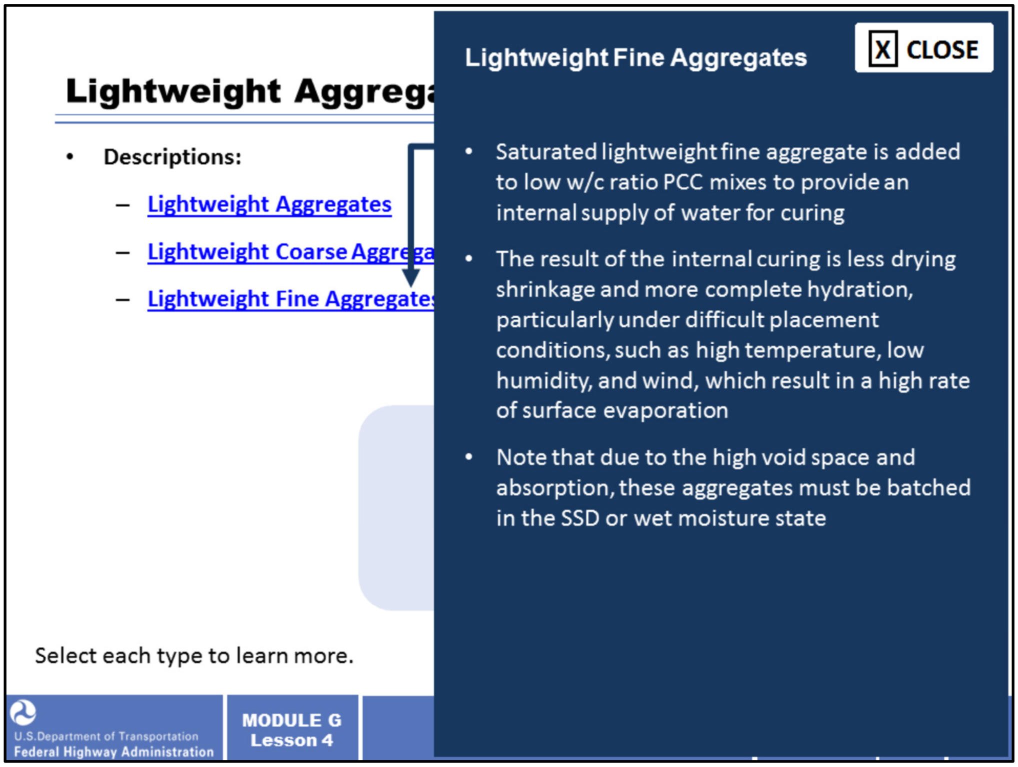

Lightweight aggregates are naturally occurring (volcanic) or manufactured products with a high degree of internal void space.




Lightweight coarse aggregates are used primarily in structures to reduce the amount of dead load.

Lightweight coarse aggregates can provide a substantial decrease in the unit weight of the PCC (from approximately 150 pcf to 100 pcf or less).

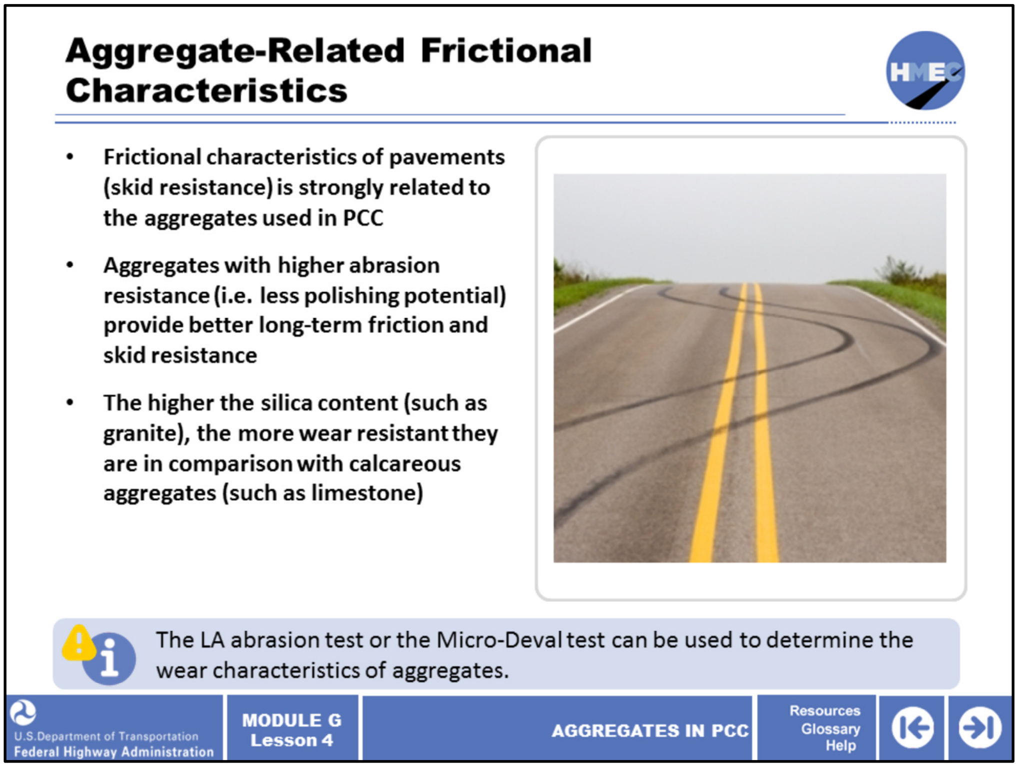
Note that due to the high void space and absorption, these aggregates must be batched in the SSD or wet moisture state.




Lightweight fine aggregates are sometimes used to provide internal curing by providing moisture within low w/c ratio PCC during hydration.

The result of the internal curing is less drying shrinkage and more complete hydration, particularly under difficult placement conditions, such as high temperature, low humidity, and wind, which result in a high rate of surface evaporation.

Note that due to the high void space and absorption, these aggregates must be batched in the SSD or wet moisture state.

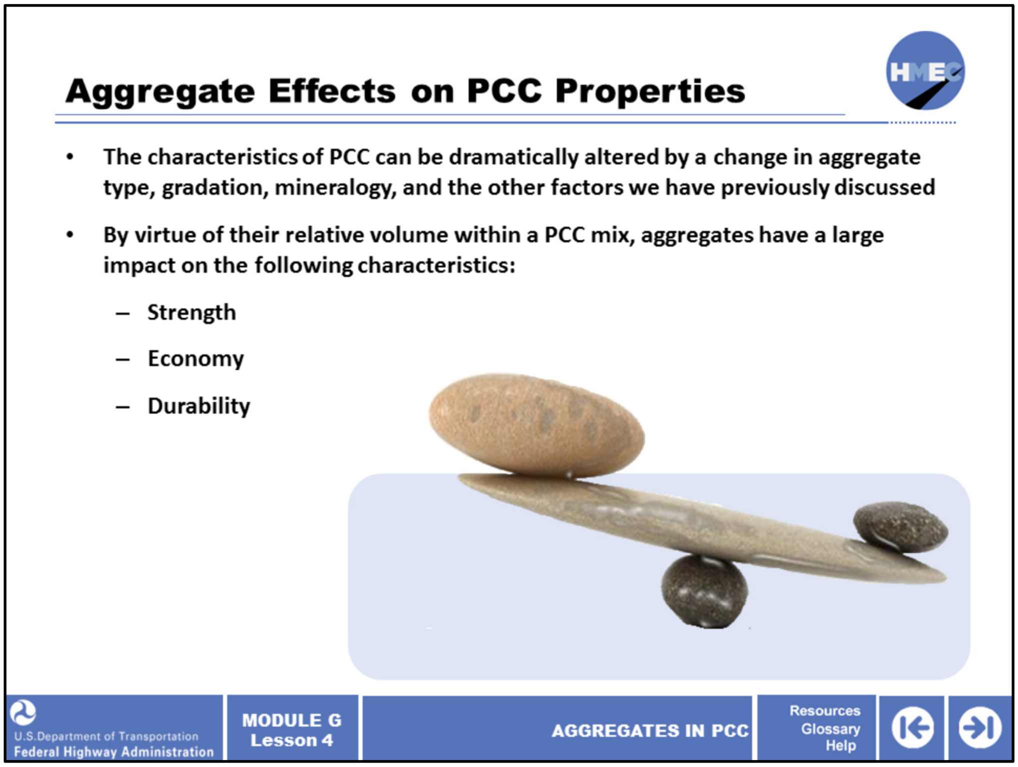



The frictional characteristics of pavements (skid resistance) is strongly related to the aggregates used in PCC. Although there is not a definitive relationship established, higher abrasion resistance results in improved long-term friction and better skid resistance.

In general terms, the higher the silica content in aggregates (such as granite), the more wear resistant they are in comparison with calcareous aggregates (such as limestone). The relative proportion of the aggregates in the PCC mix as well as the construction practices (drag texture versus tining, for instance) contribute to the short- and long-term frictional characteristics of the pavement.

The LA abrasion test or the Micro-Deval test can be used to determine the wear characteristics of aggregates.

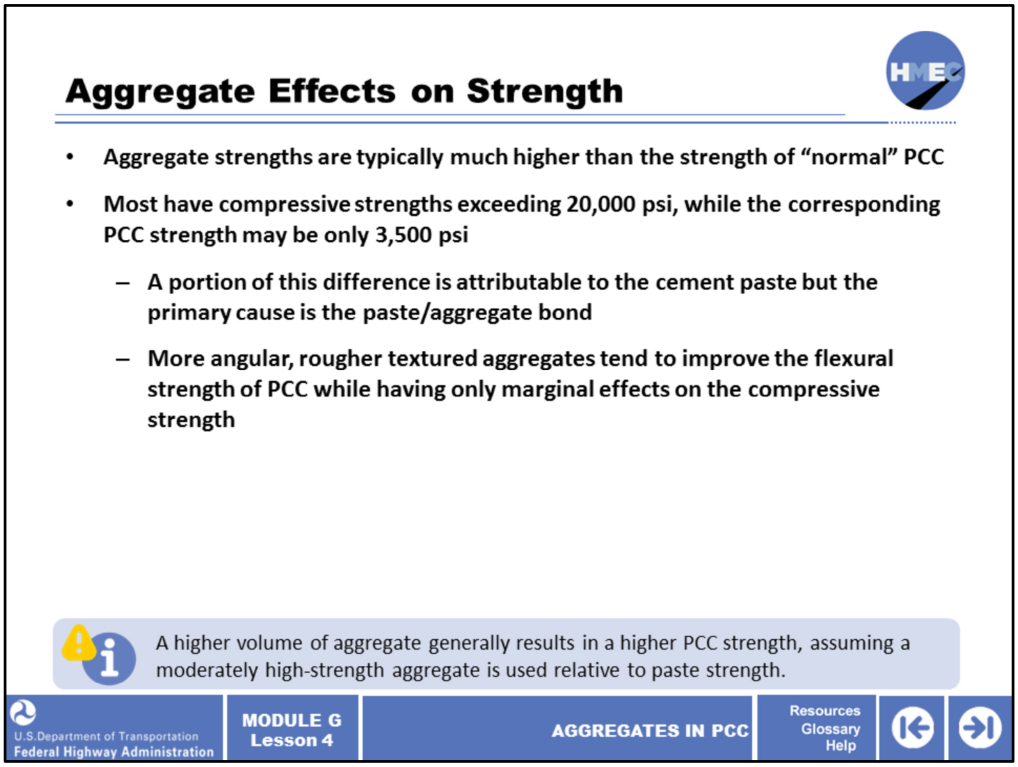
Image description: Photo of a stretch of road with skid marks.




The characteristics of PCC can be dramatically altered by a change in aggregate type, gradation, mineralogy, and the other factors we have previously discussed. We are now going to look at the primary influences on each of these properties. By virtue of their relative volume within a PCC mix, aggregates have a large impact on the following characteristics:

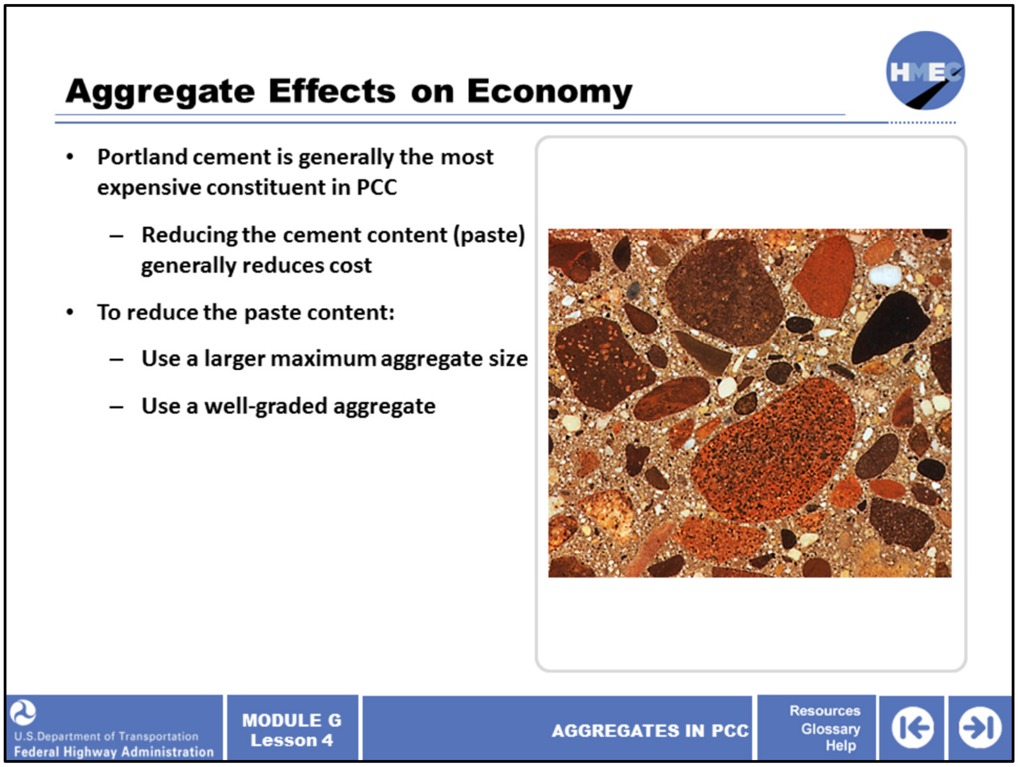
- Strength;
- Economy; and
- Durability.

Image description: Photo of a scale made out of rocks.




Aggregate strengths are typically much higher than the strength of “normal” PCC. The exception to this is high strength, high performance mixes where the difference is not considerably different. Most aggregates have compressive strengths exceeding 20,000 pounds per square inch (psi), while the corresponding PCC strength may be only 3,500 psi.

A portion of this difference is attributable to the cement paste but the primary cause is the paste/aggregate bond. More angular, rougher textured aggregates tend to improve the flexural strength of PCC, while having only marginal effects on the compressive strength. It should be noted that a higher volume of aggregate generally results in a higher PCC strength, assuming a moderately high-strength aggregate is used relative to paste strength.



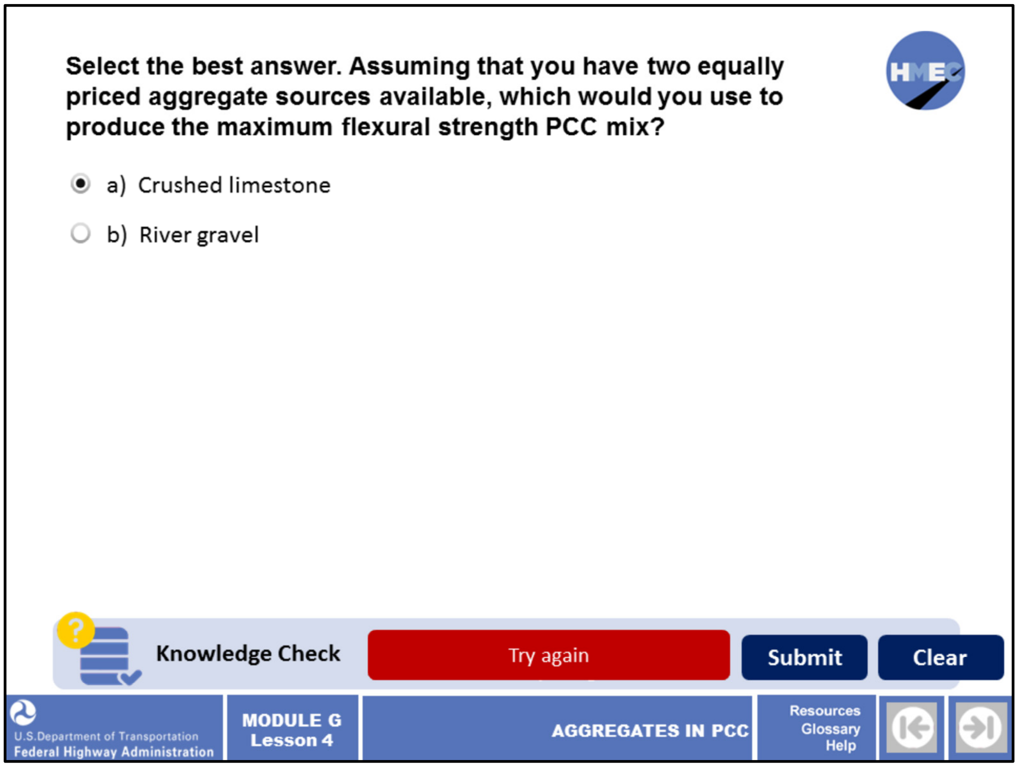

Portland cement is generally the most expensive constituent in PCC, therefore, reducing the cement content (paste) generally reduces cost. To reduce the paste content, you can do the following:

- Use a larger maximum aggregate size; and
- Use a well-graded aggregate.

The use of a well-graded aggregate with a larger maximum aggregate size (typically 1½ in. for transportation-related uses) results in a lower paste requirement because of denser particle packing and less void space. A well-graded aggregate (combined grading) consists of coarse, intermediate, and fine fractions combined to give a densely packed aggregate matrix. The dense-packed aggregates have less void space that must be filled with cement paste. The result is lower cost. The exception to this is when suitable aggregates are not available and must be shipped from a significant distance. The cost of shipping may impact the balance between the cost of Portland cement and aggregates.

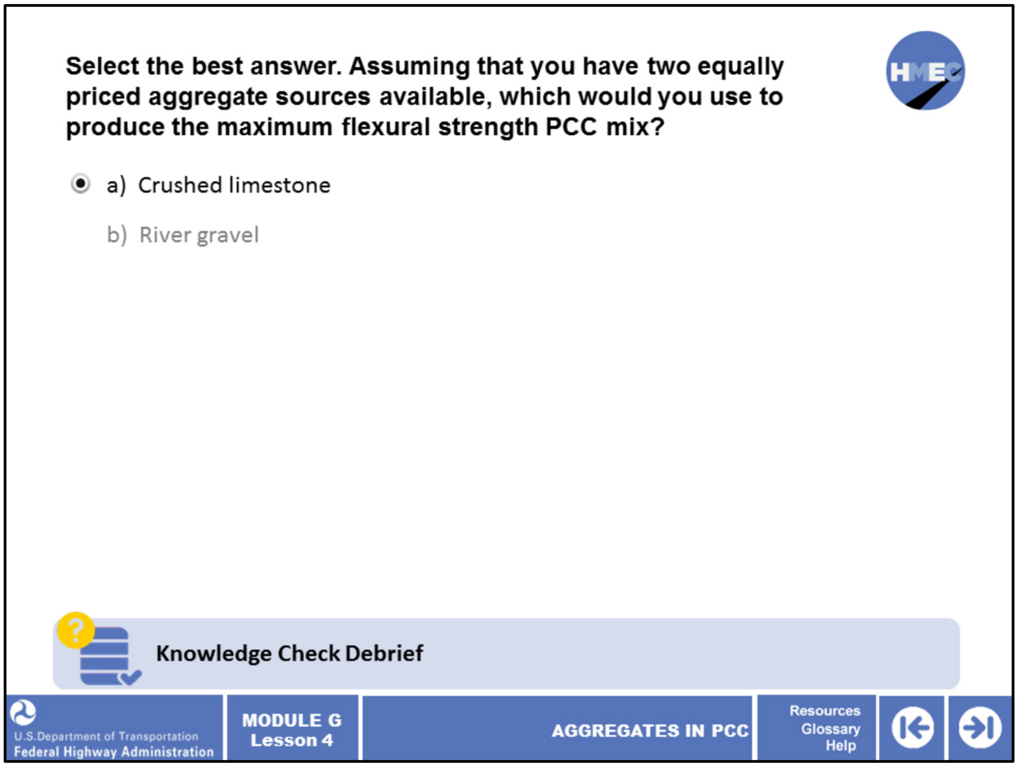
The photo illustrates a dense- or well-graded aggregate with combined grading used to minimize paste content. Note the many sizes of aggregates present.

Image description: The photo of a dense or well graded aggregate combined grading.



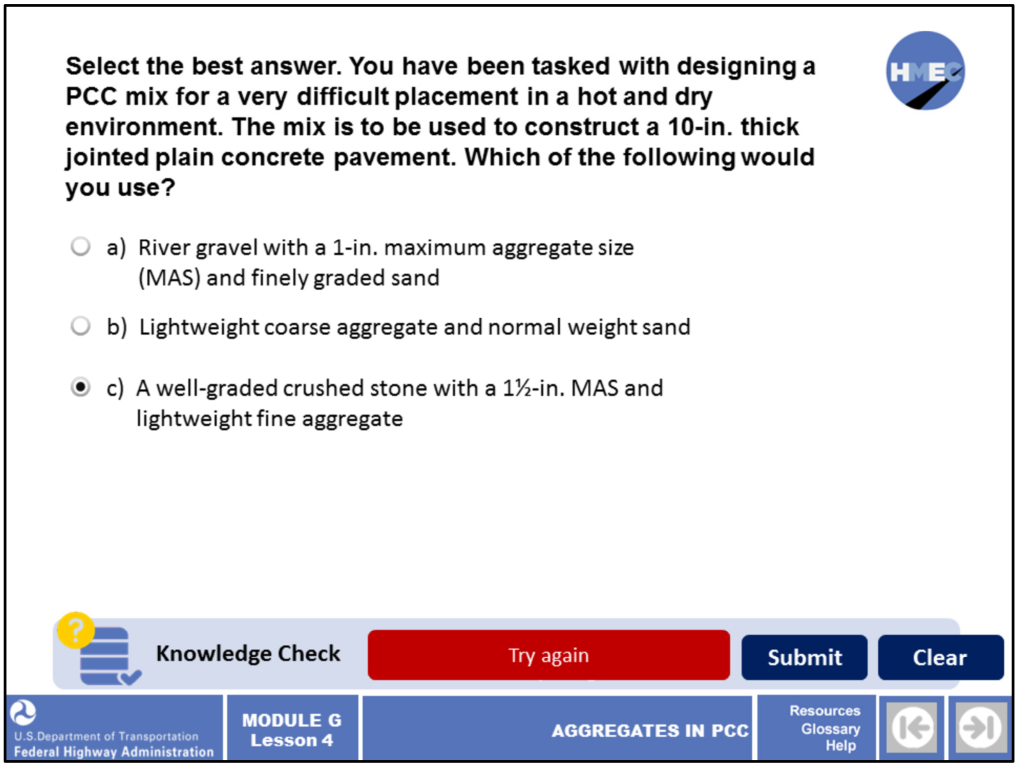

Select the best answer. Assuming that you have two equally priced aggregate sources available, which would you use to produce the maximum flexural strength PCC mix?

a) Crushed limestone; or
b) River gravel.



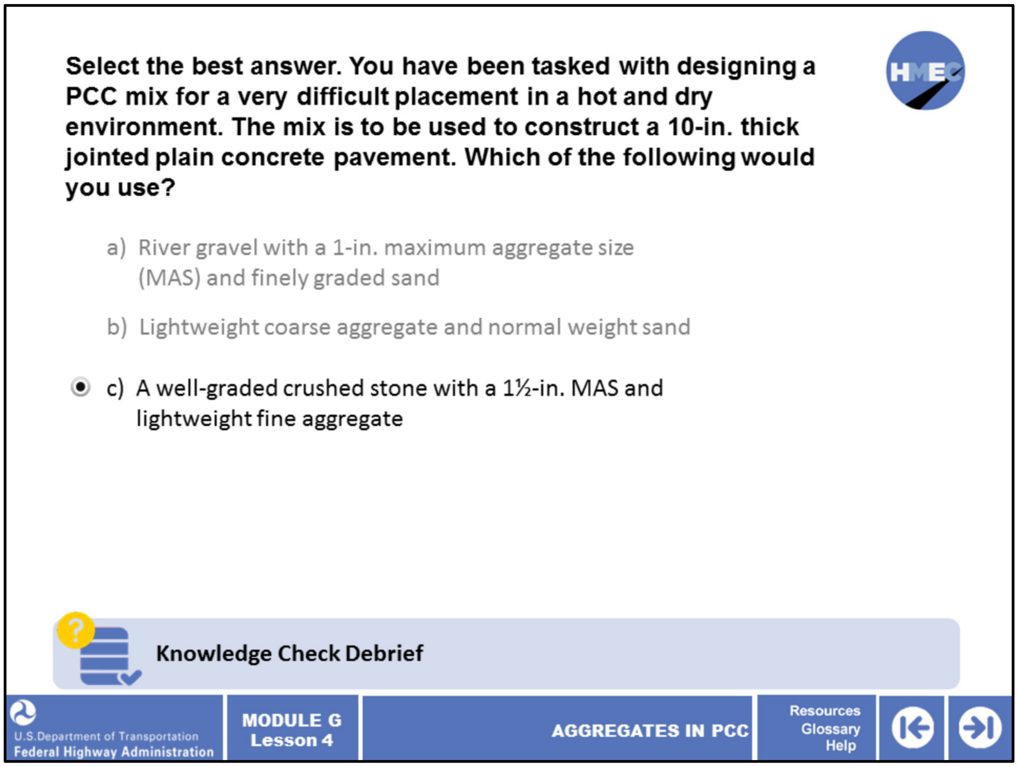

The correct answer is a) Crushed limestone.

The crushed limestone would be expected to have a rougher surface texture than river gravel, therefore resulting in improved flexural strength. (Refer to slide 7.)



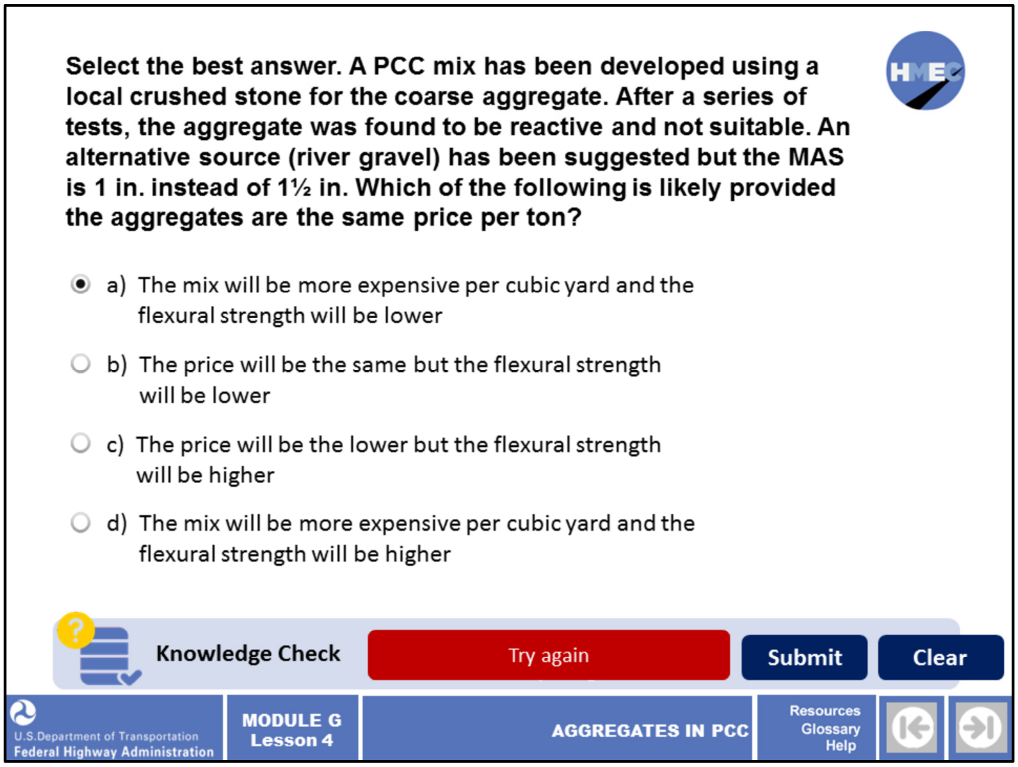

Select the best answer. You have been tasked with designing a PCC mix for a very difficult placement in a hot and dry environment. The mix is to be used to construct a 10 in. thick jointed plain concrete pavement. Which of the following would you use?

a) River gravel with a 1-in. maximum aggregate size (MAS) and finely graded sand;
b) Lightweight coarse aggregate and normal weight sand; or
c) A well-graded crushed stone with a 1½-in. MAS and lightweight fine aggregate.



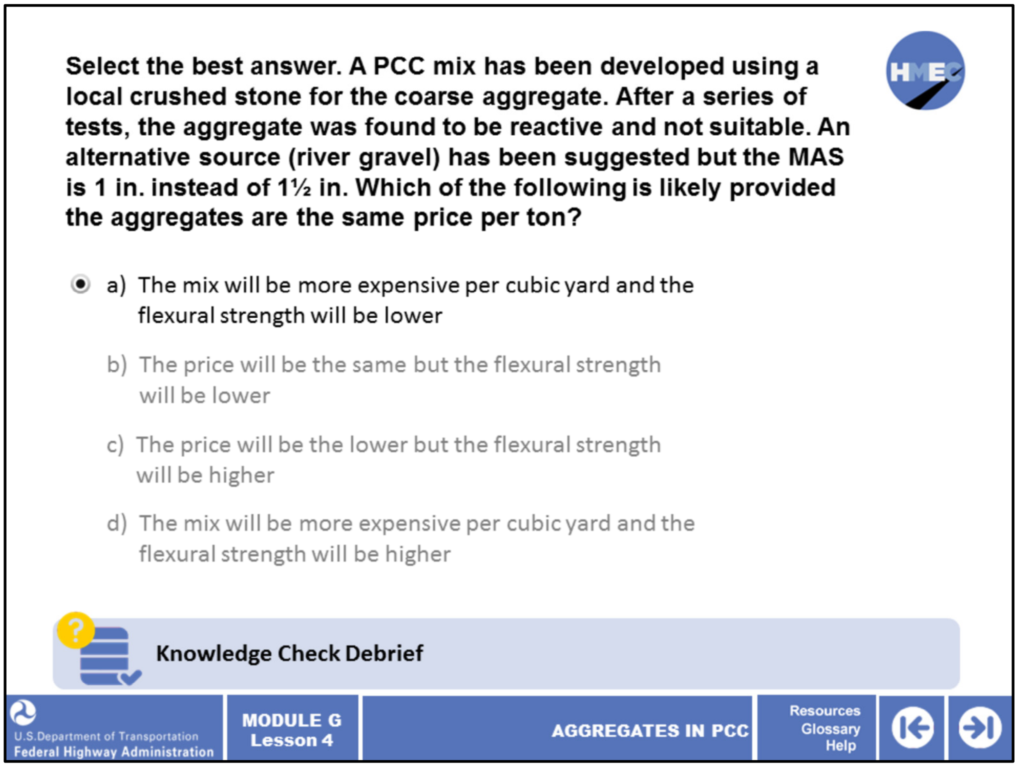

The correct answer is c) A well-graded crushed stone with a 1½-in. MAS and lightweight fine aggregate.

The well-graded crushed stone with 1½-in. MAS would provide good economy and minimal paste content (low drying shrinkage). In terms of performance, the lightweight fine aggregate would supply a source of water for internal curing to offset the harsh placement conditions.



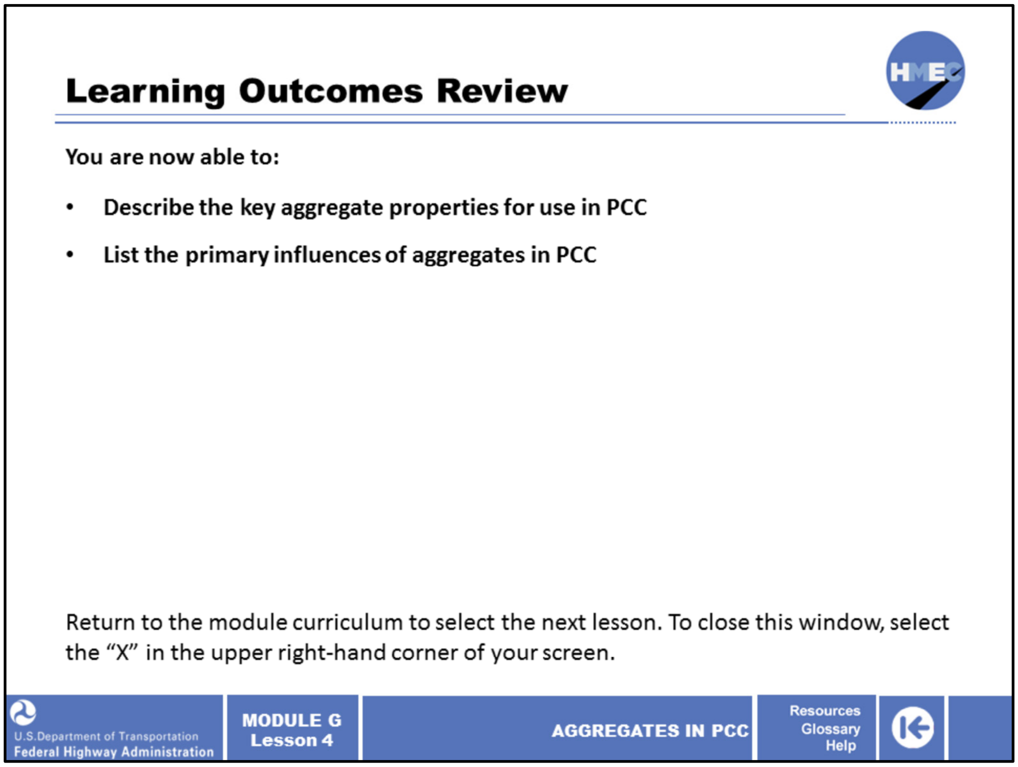

Select the best answer. A PCC mix has been developed using a local crushed stone for the coarse aggregate. After a series of tests, the aggregate was found to be reactive and not suitable. An alternative source (river gravel) has been suggested but the MAS is 1 in. instead of 1½ in. Which of the following is likely provided the aggregates are the same price per ton?

a) The mix will be more expensive per cubic yard and the flexural strength will be lower;
b) The price will be the same but the flexural strength will be lower;
c) The price will be the lower but the flexural strength will be higher; or
d) The mix will be more expensive per cubic yard and the flexural strength will be higher.




The correct answer is a) The mix will be more expensive per cubic yard and the flexural strength will be lower.

The smaller MAS will result in a higher paste content. Since cement is generally the most expensive PCC component, the price per cubic yard will be higher. In addition, the river gravel will likely have a smooth surface texture, resulting in a lower expected flexural strength.




You have completed Module G, Lesson 4: Aggregates in PCC.

You are now able to:

- Describe the key aggregate properties for use in PCC; and
- List the primary influences of aggregates in PCC.

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.