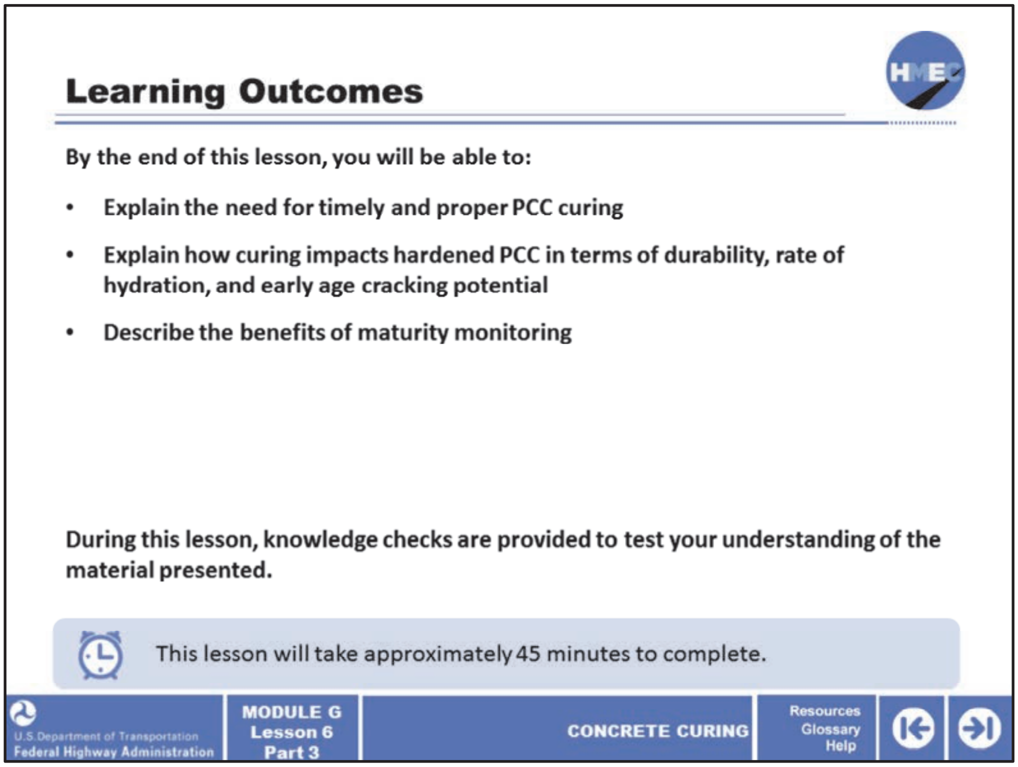
Welcome to the Highway Materials Engineering Course Module G, Lesson 6: Construction Practices, Part 3 of 3. This lesson focuses on concrete curing.

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:

- Explain the need for timely and proper PCC curing;
- Explain how curing impacts hardened PCC in terms of durability, rate of hydration, and early age cracking potential; and
- Describe the benefits of maturity monitoring.

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

This lesson will take approximately 45 minutes to complete.

Curing

- Adequate and timely curing is necessary to allow the PCC to develop the desired strength and durability properties envisioned in the mix design
- Curing includes managing the following three factors:
  1. Moisture
  2. Temperature
  3. Time

U.S. Department of Transportation
Federal Highway Administration

MODULE G
Lesson 6
Part 3

CONCRETE CURING

Resources
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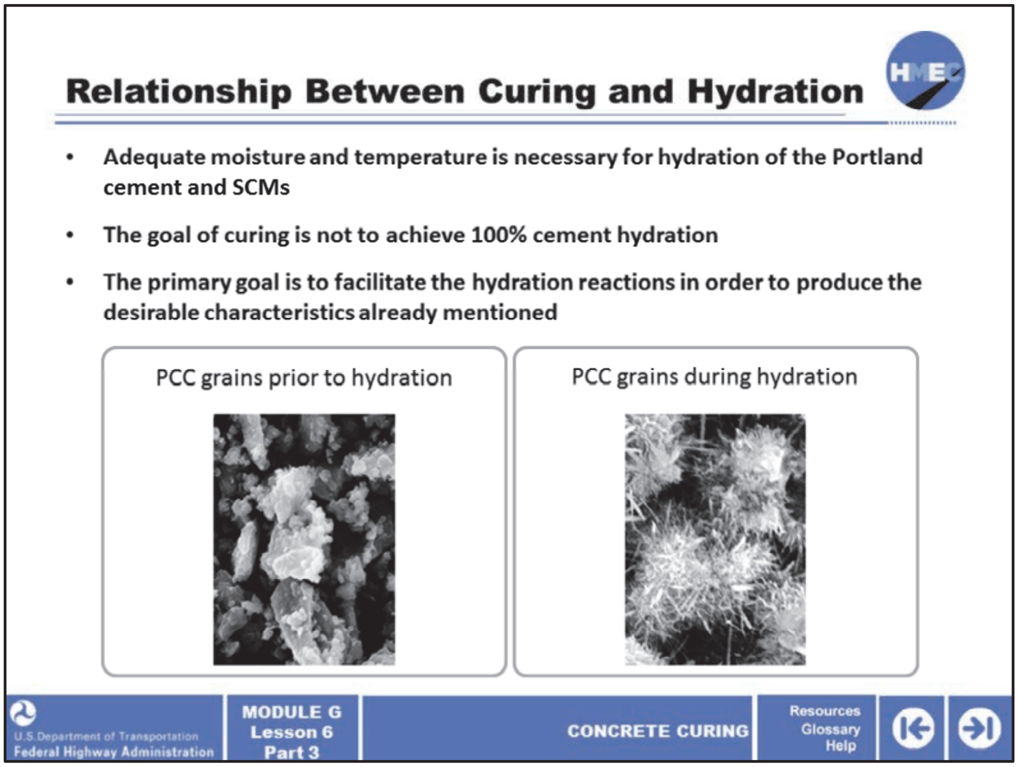
Help

Curing is one of the most important construction-related steps in ensuring quality PCC. Adequate and timely curing is necessary to allow the PCC to develop the desired strength and durability properties envisioned in the mix design.

Curing is generally thought of as controlling only moisture. However, temperature and time are also very important.

The photo shows pigmented curing compound being applied to a newly constructed pavement. This has to be done at the proper time and using the proper technique.

Image description: Photo of a pigmented curing compound being applied to a newly constructed pavement.



Adequate moisture and temperature are necessary for hydration of the Portland cement and supplementary cementing materials (SCMs), if present.

The goal of curing is not to achieve 100% cement hydration, which in practice, is not attainable due to a number of factors. The primary goal is to facilitate the hydration reactions in order to produce the desirable characteristics already mentioned.

The hydration of the Portland cement and SCMs are responsible for developing the reaction products.

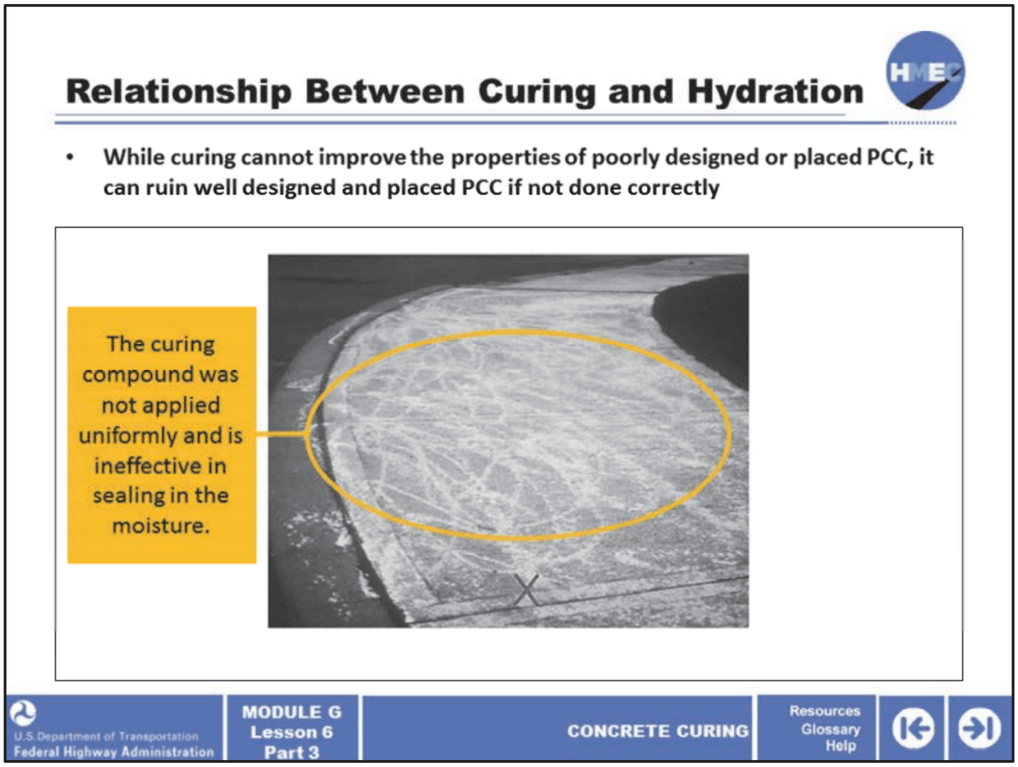
In order to develop dense reaction products, sufficient moisture must be retained in the PCC.

Curing “seals in” the moisture facilitating hydration.

Various curing techniques also help to maintain temperature in the PCC. Note that higher temperatures equate to faster hydration.

Image description: Photo of PCC grains prior to hydration.

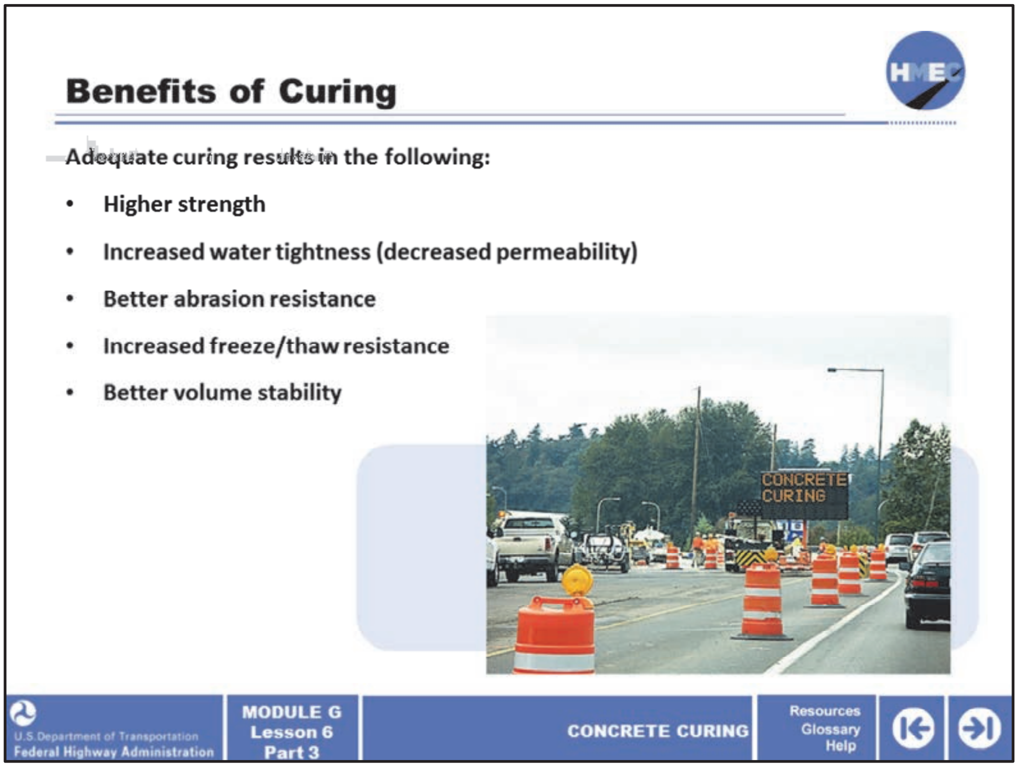
Image description: Photo of PCC grains during hydration.



While curing cannot improve the properties of poorly designed or placed PCC, it can ruin well designed and placed PCC if not done correctly.

In the photo, the curing compound was not applied uniformly and is ineffective in sealing in the moisture necessary for hydration. When membrane curing compounds are used, it is necessary to fully encapsulate the PCC in order to seal in moisture.

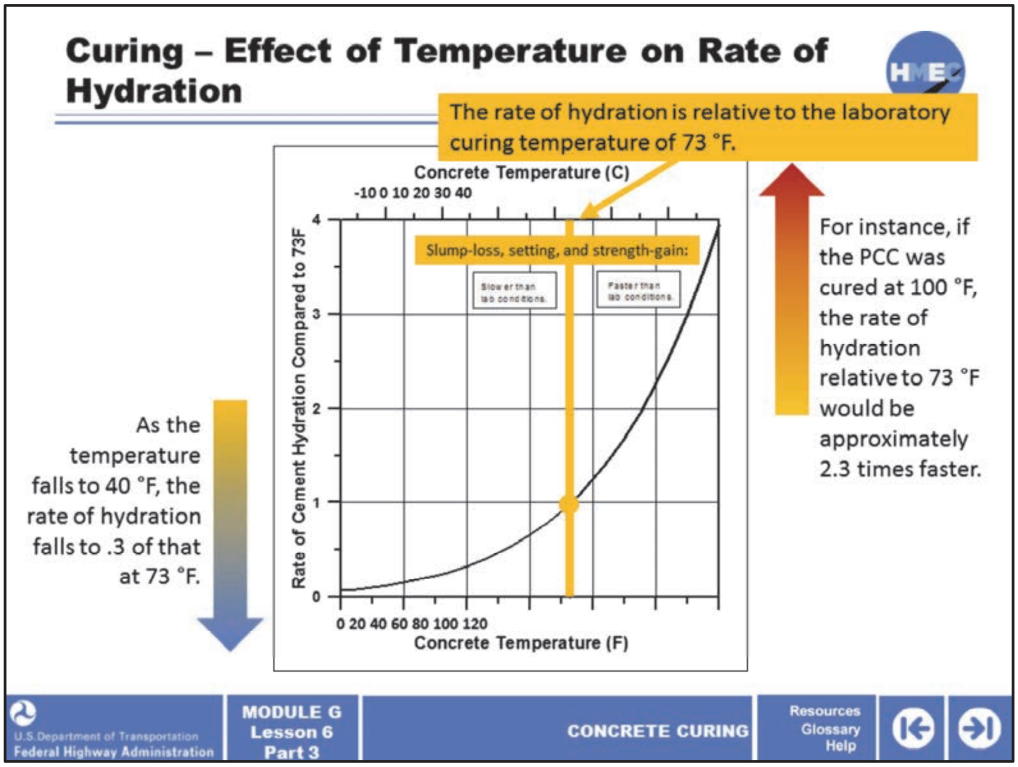
Image description: Photo of ruined cement sidewalk pour.



Adequate curing results in:

- Higher strength;
- Increased water tightness (decreased permeability);
- Better abrasion resistance;
- Increased freeze/thaw resistance; and
- Better volume stability.

Image description: Photo of highway construction sign showing Concrete Curing



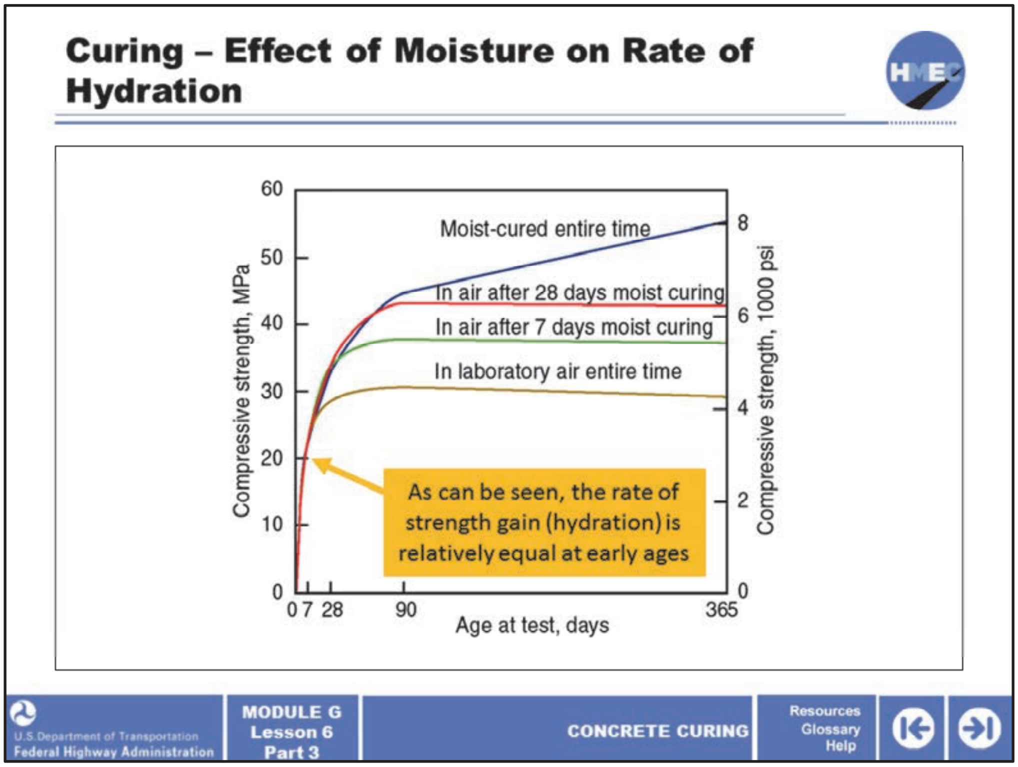
The effect of temperature on the degree of hydration is shown in this graph.

The rate of hydration is relative to the laboratory curing temperature of 73 °F.

As the PCC temperature increases above the 73 °F, the rate of hydration increases dramatically. For instance, if the PCC was cured at 100 °F, the rate of hydration relative to 73 °F would be approximately 2.3 times faster. As the temperature falls to 40 °F, the rate of hydration falls to .3 of that at 73 °F.

The increase in the rate of hydration equates to an increase in the rate of strength development while the reverse is also true. This relationship assumes that moisture is present for the hydration to occur, pointing out the need for adequate curing.

Image description: Change in rate of hydration chart.



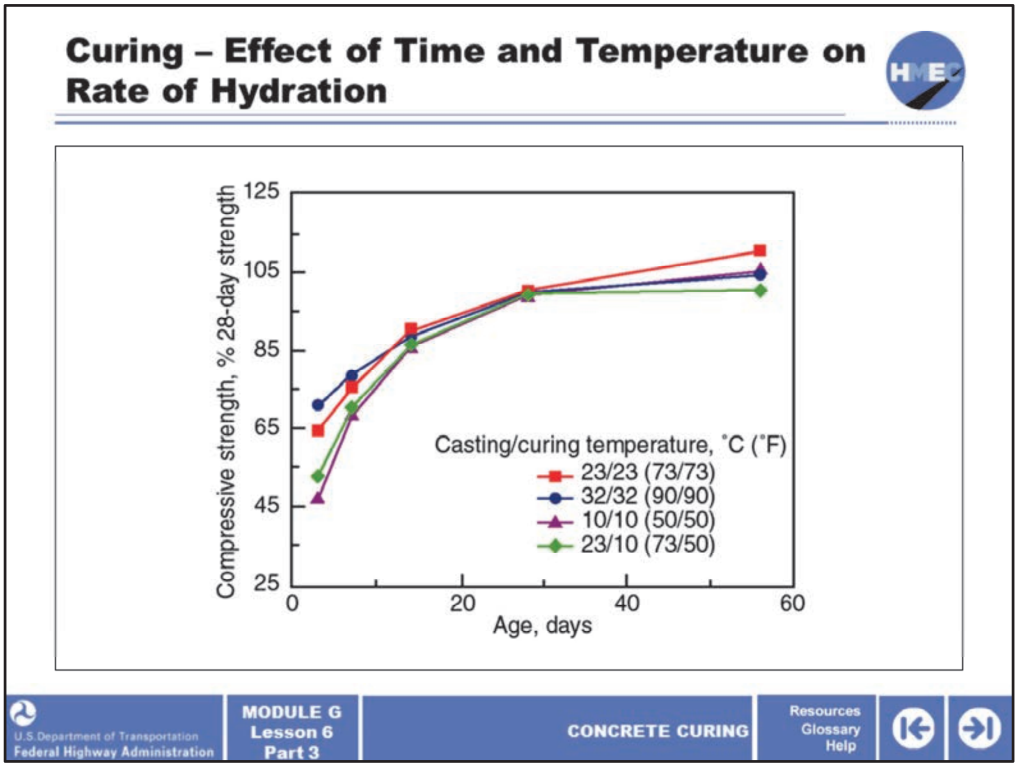
The effect of moisture on compressive strength is shown in this graph.

The rate of hydration closely approximates that of compressive strength development.

As can be seen, the rate of strength gain (hydration) is relatively equal at early ages. Properly designed mixes have sufficient mix water to provide for the early hydration reactions, assuming that adequate curing prevents evaporation of the water.

The effect of different levels of moisture due to curing become very pronounced at 14 days and longer. For example, a specimen without adequate curing might be expected to approximate the “laboratory air” curve above, while a high level of curing might approximate that of 28 days moist curing. The corresponding 28-day strengths are approximately 4,200 and 5,000 psi.

Image description: Graph showing the effect of moisture on compressive strength.



The effect of time and temperature on compressive strength is shown in this graph.

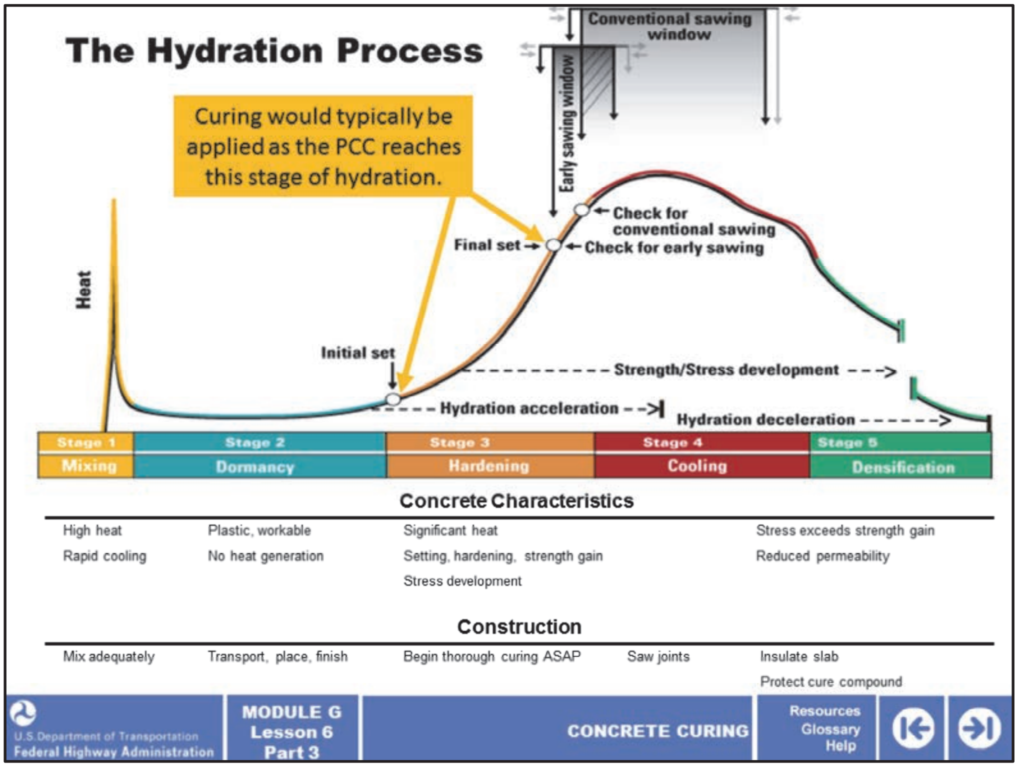
Note that the basis for this graph is the 28-day compressive strength for the different casting and curing temperatures. For instance, the curve at 73 °F (red line) would indicate that the strength at 3 days is approximately 65% of the 28-day strength.

The rate of hydration closely approximates that of compressive strength development.

As can be seen, the rate of strength gain (hydration) differs substantially based on the casting and curing temperatures. However, regardless of that relationship, all of the mixes gain strength quickly at first and then slow as the hydration reaction stabilizes.

The relationships shown in the graph assume adequate moisture is available through effective curing.

Image description: Graph showing the effect of temperature on compressive strength.

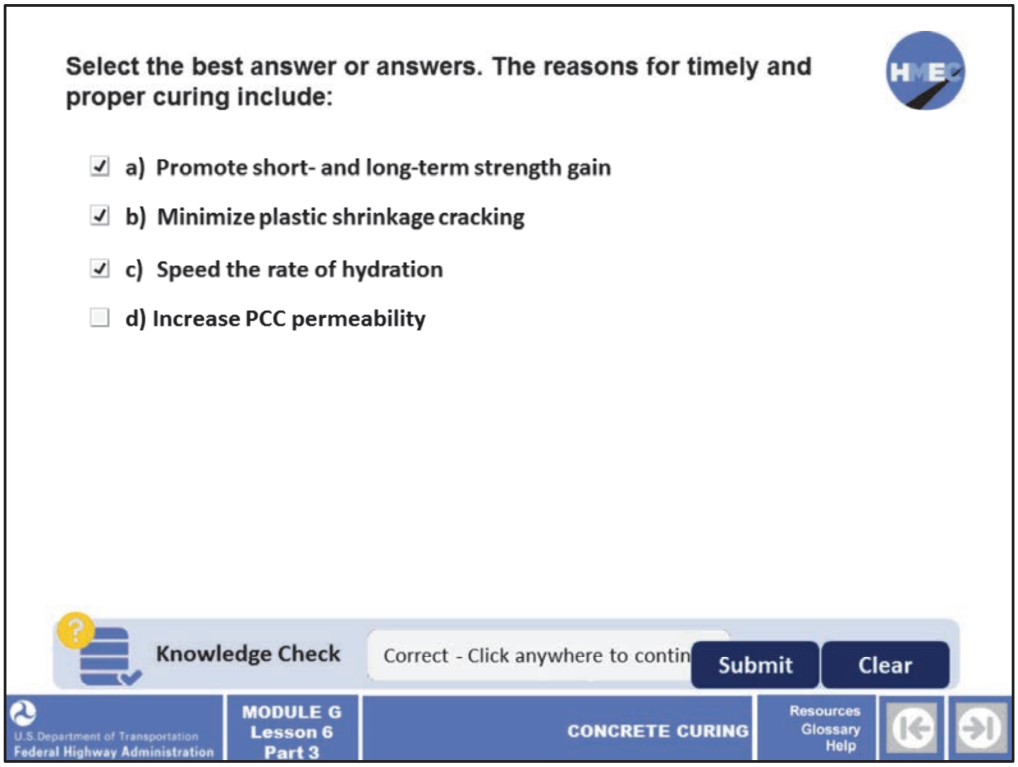


This figure represents typical hydration as a function of time and heat evolution. The PCC characteristics and typical construction operations are shown as well for each of the five primary stages of hydration.

Curing is used to control the moisture (and temperature in cold weather concreting) in the hydrating PCC. Curing would typically be applied as the PCC approaches the final set, but may be altered to suit job-specific circumstances.

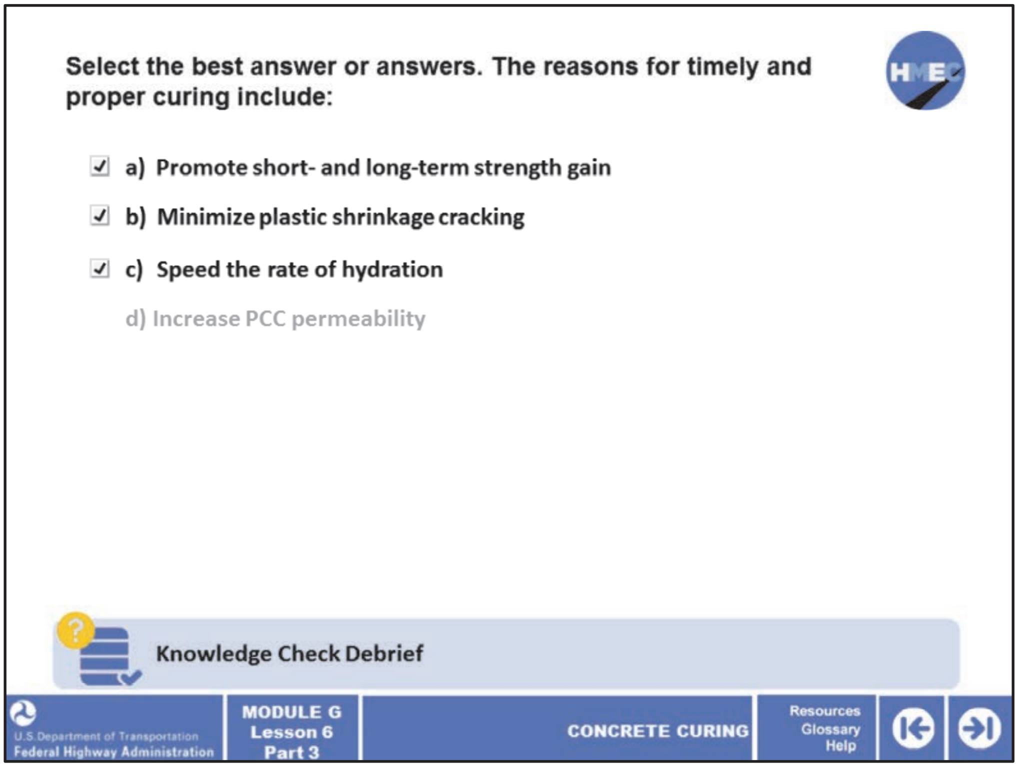
The presence of admixtures, SCMs, and proper curing may alter the curve shape somewhat, although the basic stages are always present.

Image description: Graph showing typical hydration as a function of time and heat evolution.



Select the best answer or answers. The reasons for timely and proper curing include:

a) Promote short- and long-term strength gain;
b) Minimize plastic shrinkage cracking;
c) Speed the rate of hydration; and/or
d) Increase PCC permeability.



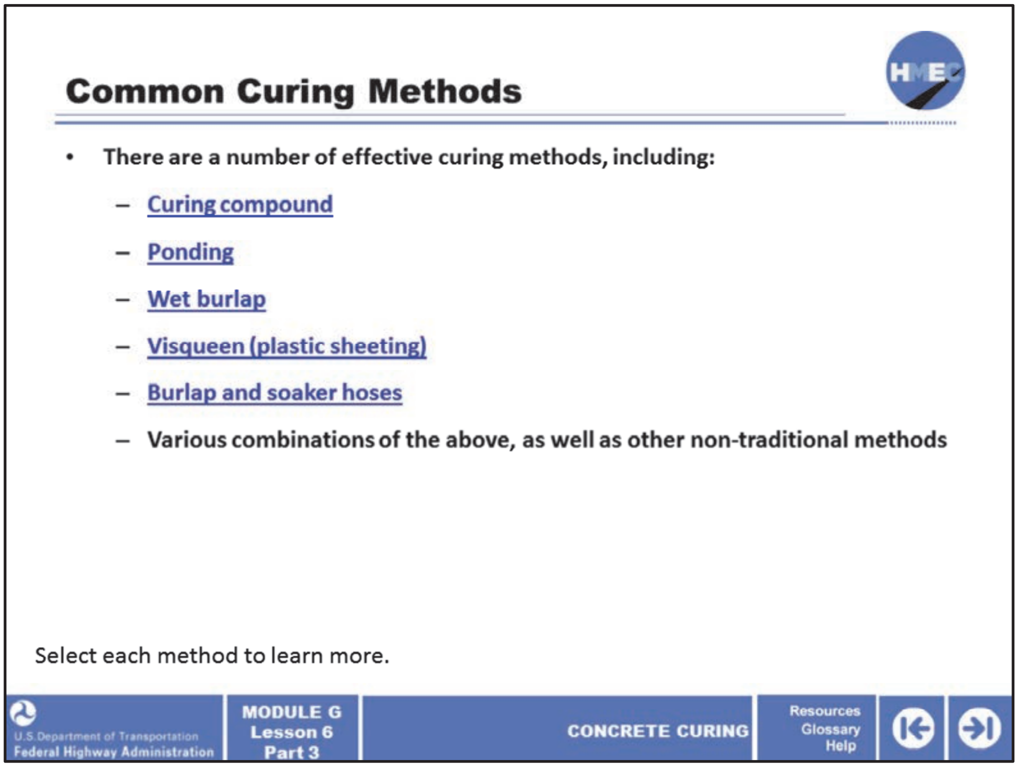
The correct answers are a, b, and c. The reasons for timely and proper curing include a) Promote short- and long-term strength gain; b) Minimize plastic shrinkage cracking; and c) Speed the rate of hydration.

In order for PCC to reach or exceed its desired short- and long-term strength, adequate curing is required to “seal in” the water required for hydration.

Adequate and timely curing is required to keep the surface of the PCC from developing plastic shrinkage cracks due to evaporation of the surface moisture and resulting desiccation.

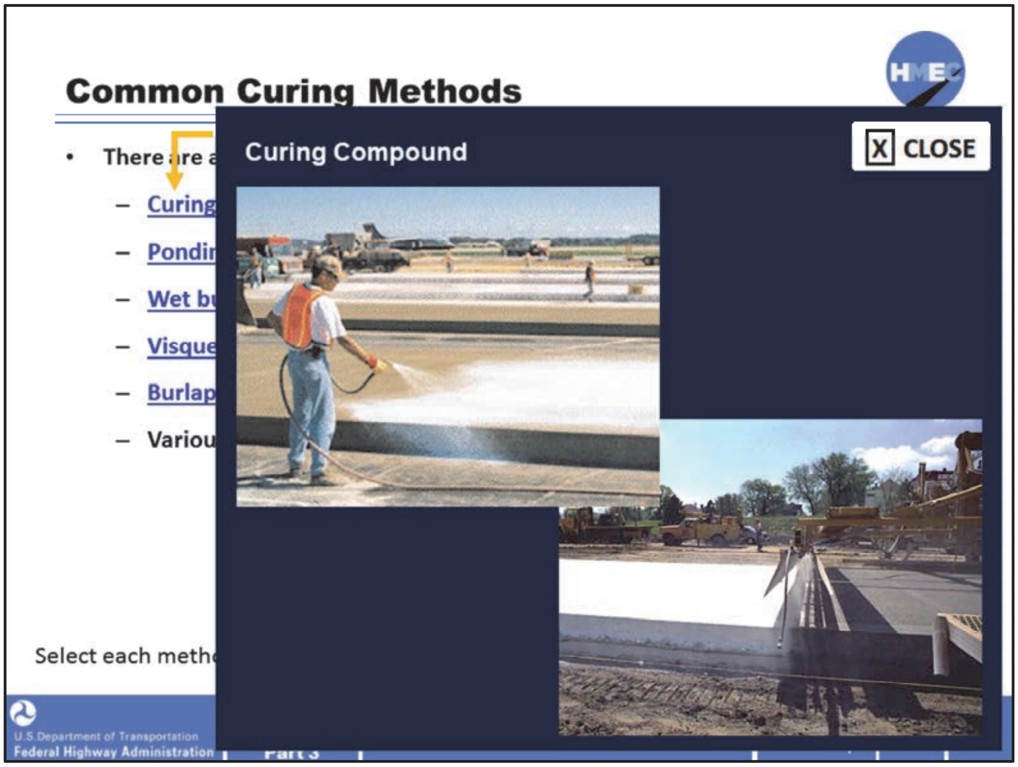
Hydration is dependent on temperature and adequate moisture, both of which are managed by curing.

In order to reduce permeability, the hydrated cement matrix must be as dense as possible. Curing promotes development of a dense matrix by assuring adequate water for a high degree of hydration.



There are a number of effective curing methods. Please take a moment to read the methods shown on the slide and select each one for more information.

Note that effective curing can also include various combinations of the above, as well as other non-traditional methods.



Curing compound is almost universally used for pavement curing due to the ease of application and effectiveness.

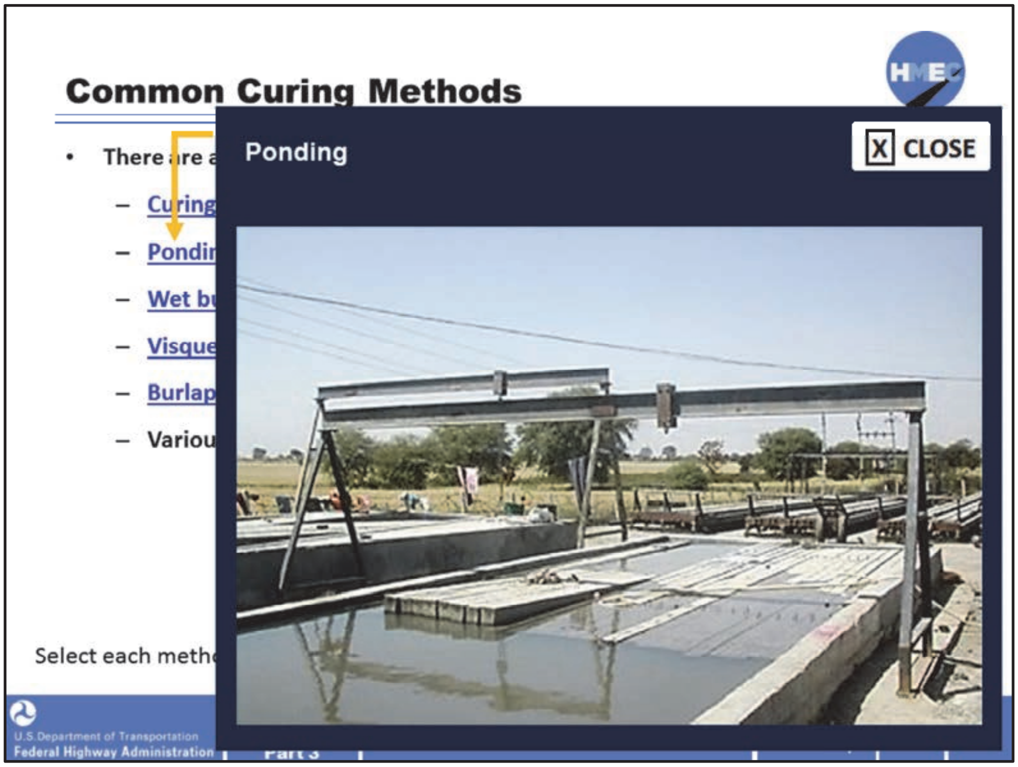
The key to adequate curing is to ensure uniform coverage and full encapsulation of the pavement. Generally white pigmented curing compound is used to allow for a visual check of the application rate.

A rule of thumb is that the surface and slab sides should be uniformly white with no gray areas showing.

Curing compound can be either machine applied, as shown in the photo on the right, or hand applied.

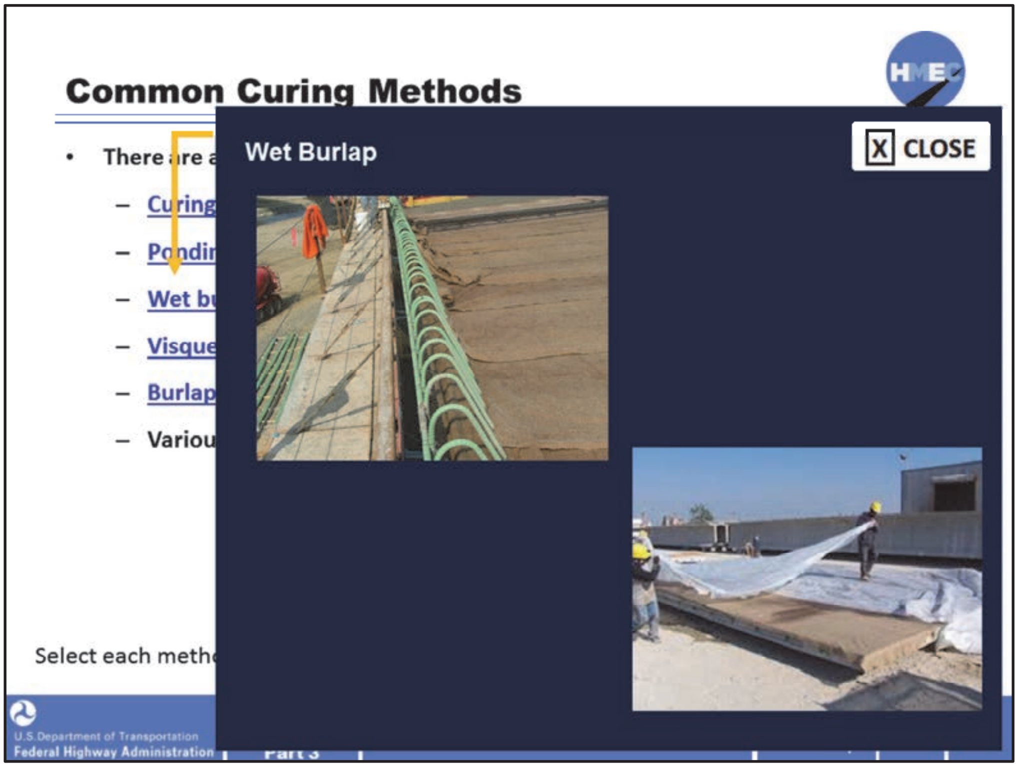
Image description: Photo of curing compound being sprayed on pavement.

Image description: Photo of curing compound being applied by machine.



As the name implies, ponding involves flooding the PCC with a minimal depth of water. This technique has limited application but is very effective under the proper circumstances.

Image description: Photo of PCC flooded with water.

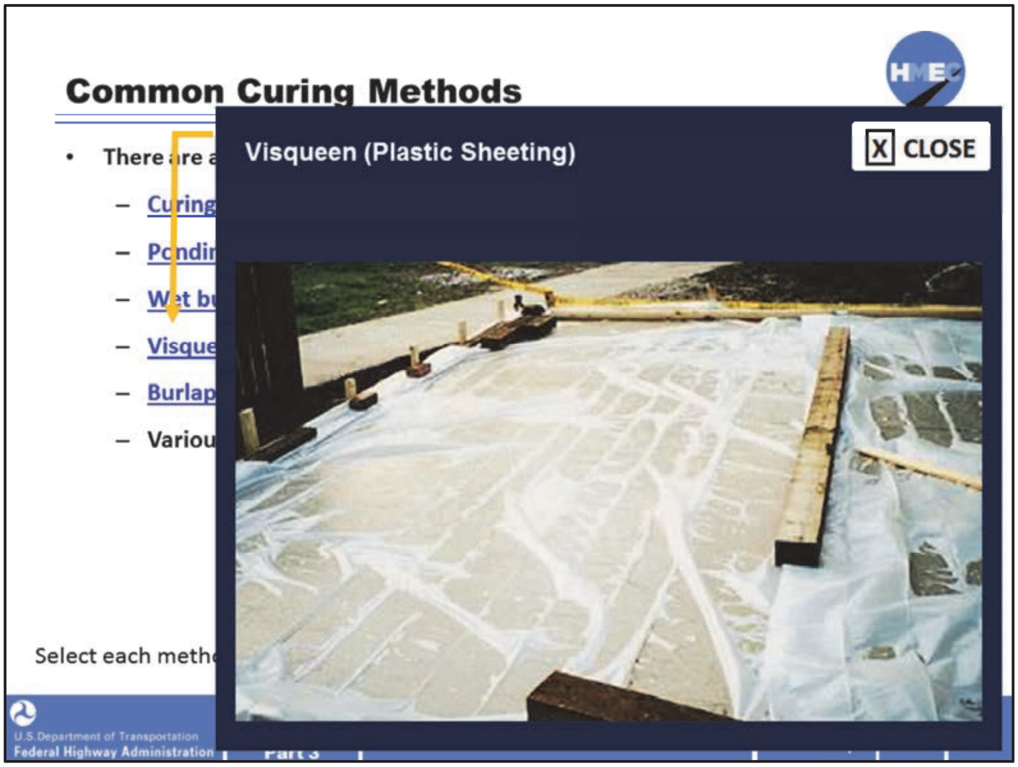


Wet burlap is a commonly used curing method, particularly for bridge decks and for pavement restoration projects. To achieve full effectiveness, the burlap must be applied as soon as possible after placement and finishing. In order to be an effective curing method, the burlap must be kept continuously wet for the duration of curing.

Wet burlap is commonly covered with plastic sheeting to hold in the moisture and increase the effectiveness. This process is shown in the picture on the right.

Image description: Photo of wet burlap applied over PCC.

Image description: Photo of workers covering the wet burlap with plastic sheeting.

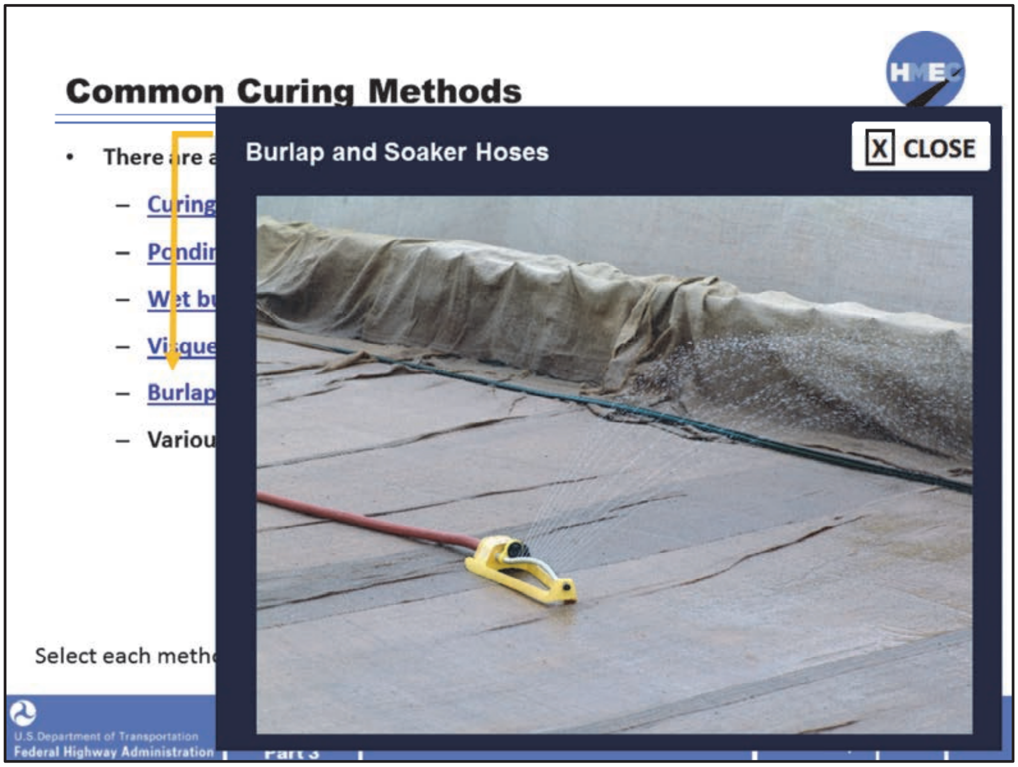


Plastic sheeting is a popular form of temporary curing and is used in a variety of applications. Although the sheeting is effective at preventing evaporation, it cannot supply extra moisture and will typically allow the PCC to dry unless the sheeting is removed, water applied, and the sheeting replaced.

Note that plastic sheeting has been shown to increase the temperature of the PCC during hot weather placement and can lead to significant thermal gradients in the PCC, potentially leading to crack formation.

White or clear sheeting is typically used in the summer to reflect sunlight and aid in lowering the peak PCC temperature. Black sheeting is generally used in the spring or fall to help raise the temperature of the PCC and aid hydration.

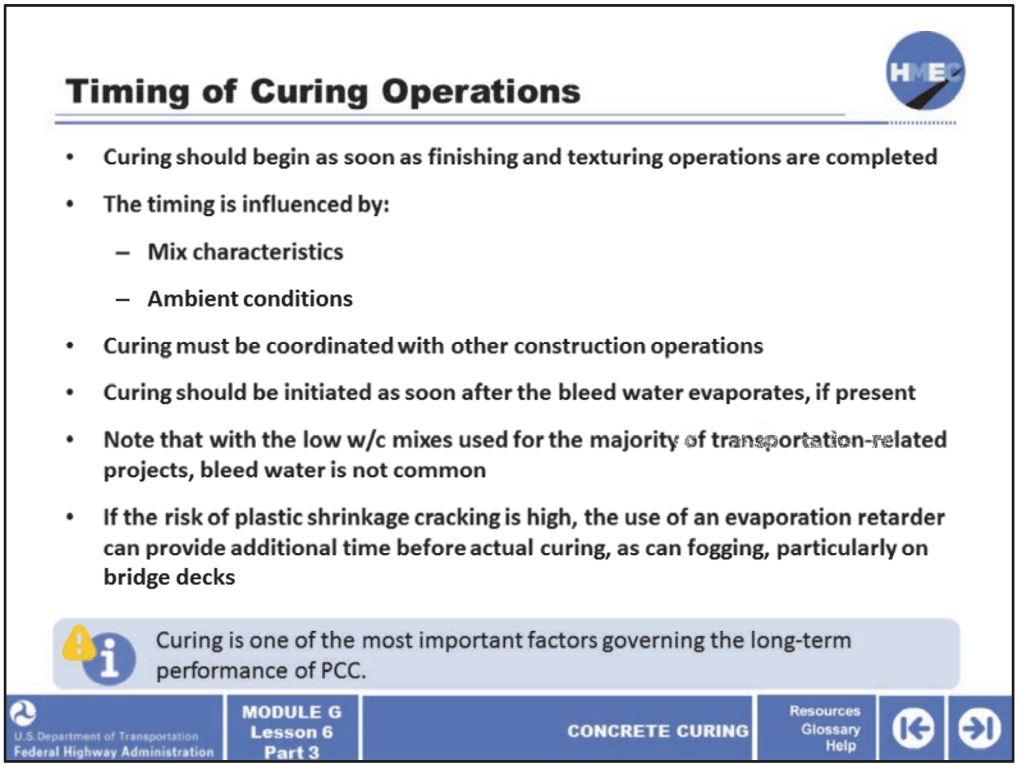
Image description: Photo of clear plastic sheeting over PCC slab.



Burlap and soaker hoses (or a sprinkler, as pictured) are a good combination in that the burlap provides a degree of protection of the PCC surface while the soaker hoses supply continuous moisture.

The water does not require continuous application as long as the burlap remains uniformly wet.

Image description: Photo of burlap over PCC with sprinkler running.



Curing is one of the most important factors governing the long-term performance of PCC.

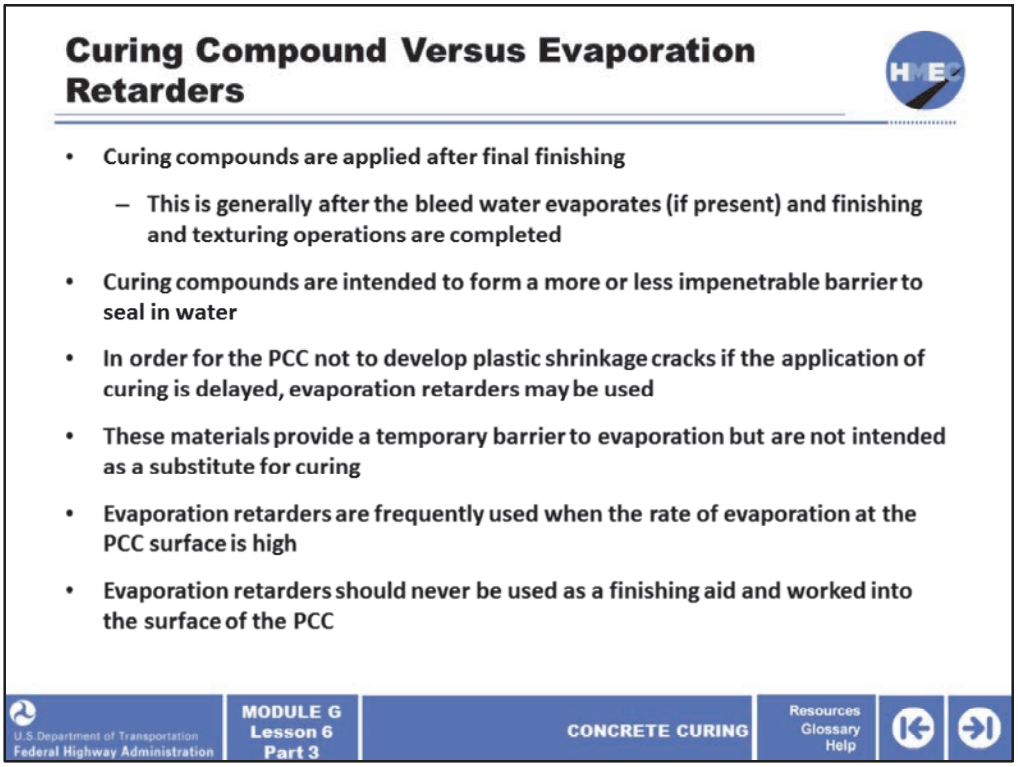
Curing should begin as soon as finishing and texturing operations are completed. The timing is influenced by:

- Mix characteristics (rate of hydration); and
- Ambient conditions (particularly temperature).

Curing must be coordinated with other construction operations, particularly finishing and texturing. Curing should be initiated as soon after the bleed water evaporates, if present.

Note that with the low w/c mixes used for the majority of transportation-related projects, bleed water is not common.

If the risk of plastic shrinkage cracking is high, the use of an evaporation retarder can provide additional time before actual curing, as can fogging, particularly on bridge decks.

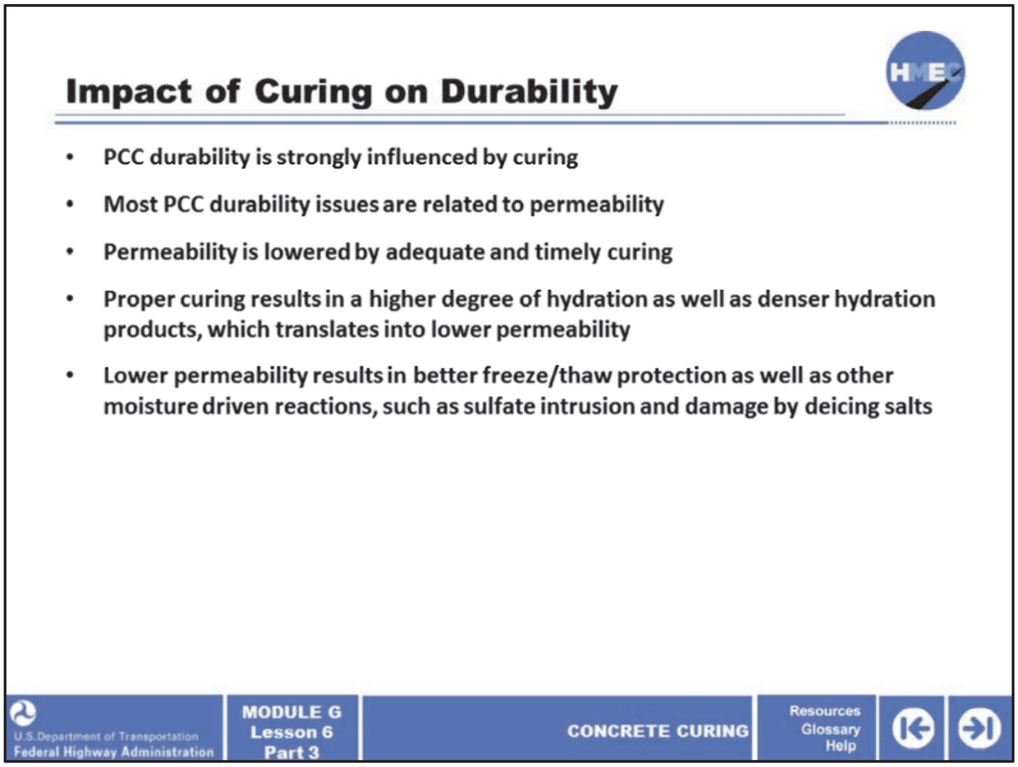


Curing compounds are applied after final finishing. This is generally after the bleed water appears and begins to evaporate.

Curing compounds are intended to form a more or less impenetrable barrier to seal in water. Note that many paving mixes do not have bleed water due to the low water-cement (w/c) ratio.

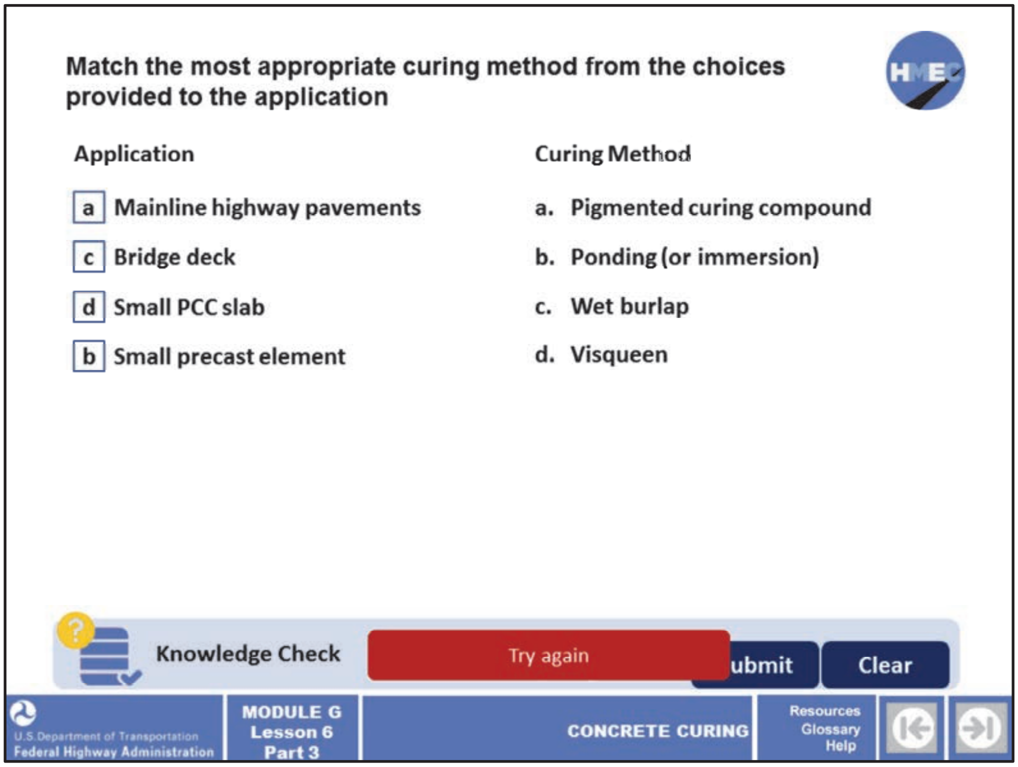
In order for the PCC not to develop plastic shrinkage cracks and provide adequate time for finishing and texturing operations, evaporation retarders may be used. These materials provide a temporary barrier to evaporation but are not intended as a substitute for curing.

Evaporation retarders are frequently used when the rate of evaporation at the PCC surface is high. These are only a temporary aid and are not effective as a curing compound.



PCC durability is strongly influenced by curing. Most PCC durability issues are related to permeability. Permeability is lowered by adequate and timely curing.

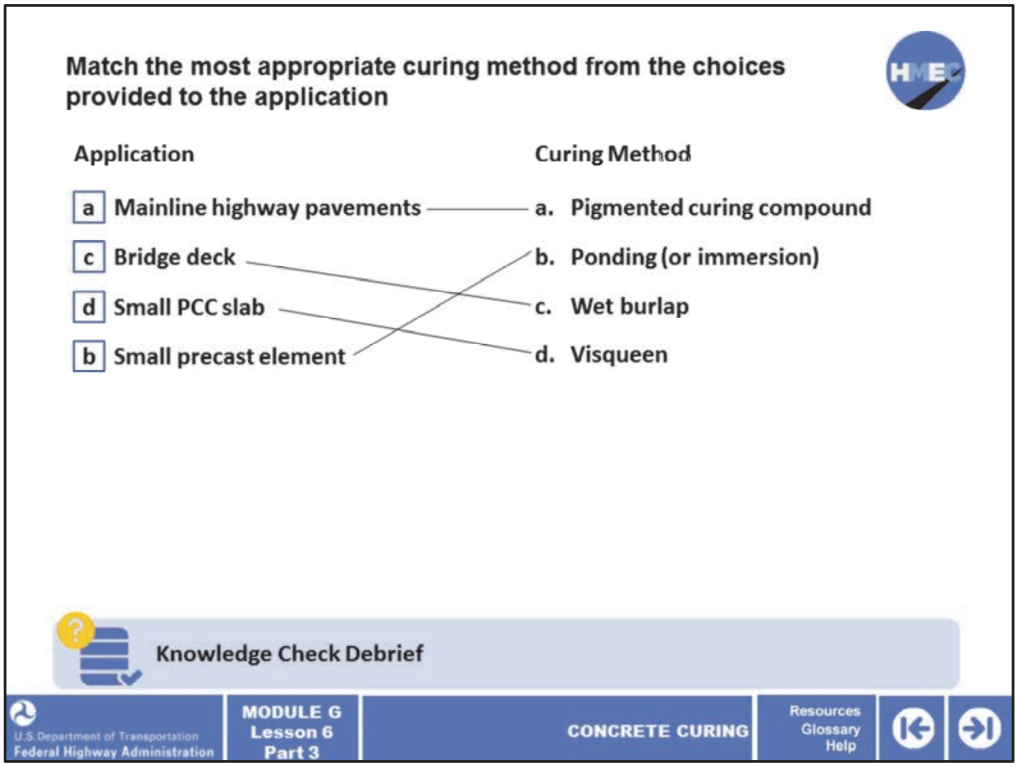
Proper curing results in a higher degree of hydration as well as denser hydration products, which translates into lower permeability. Lower permeability results in better freeze/thaw protection as well as other moisture driven reactions, such as sulfate intrusion and damage by deicing salts.



Match the most appropriate curing method from the choices provided to the application

Application:
• Mainline highway pavements;
• Bridge deck;
• Small PCC slab; and
• Small precast element.

Curing Method:
a) Pigmented curing compound;
b) Ponding (or immersion);
c) Wet burlap; and
d) Visqueen.



The correct answers are:

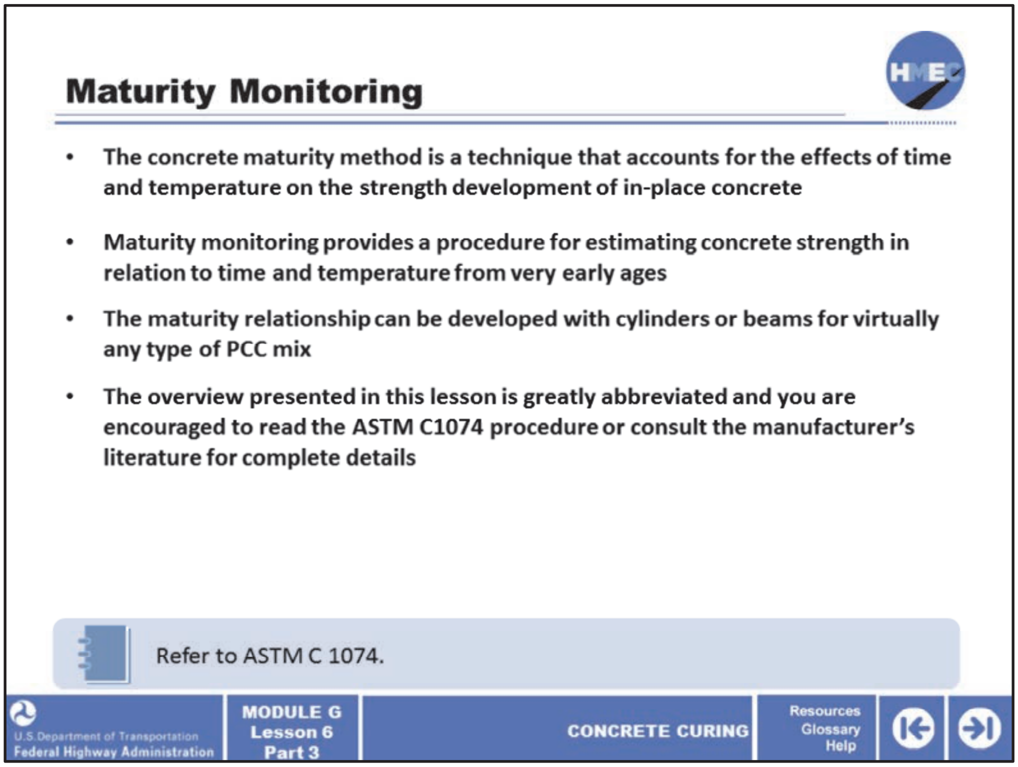
- Mainline highway pavements is a) Pigmented curing compound;
- Bridge deck is c) Wet burlap;
- Small PCC slab is d) Visqueen; and
- Small precast element is b) Ponding (or immersion).

Mainline pavements are typically cured with pigmented curing compound due to the large amount of pavement typically placed in a day's operation. This option has proven both effective and economical if done correctly.

Bridge decks are often cured with wet burlap as it provides a continued source of moisture if kept continually wet.

Small PCC slabs or small scale repairs are often cured with plastic sheeting as a matter of convenience and economy. White sheeting is useful in hot weather to reflect sunlight and reduce temperature buildup in the PCC while black sheeting is useful in cold temperatures to absorb sunlight and speed hydration.

One of the most effective means of curing is immersion as both moisture and temperature are controlled.



The concrete maturity method is a technique that accounts for the effects of time and temperature on the strength development of in-place concrete. Maturity monitoring (ASTM C1074) provides a procedure for estimating concrete strength in relation to time and temperature from very early ages (less than 1 day). The maturity relationship can be developed with cylinders or beams (compressive strength or flexural strength) for virtually any type of PCC mix.

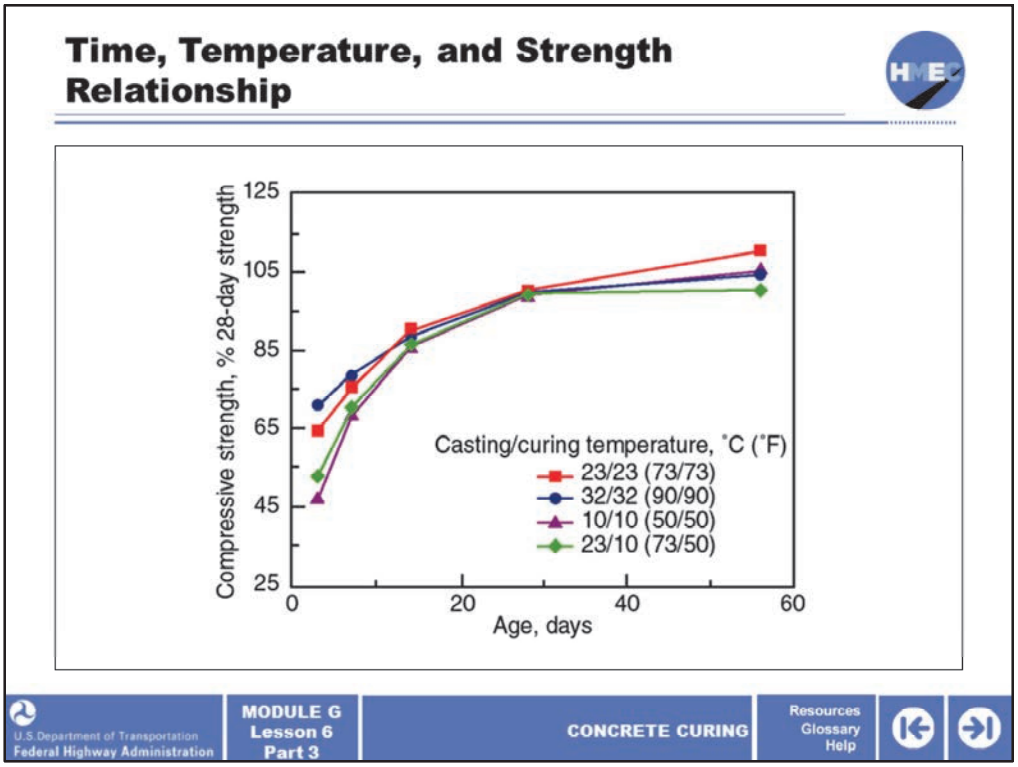
The overview presented in this lesson is greatly abbreviated and you are encouraged to read the ASTM C1074 procedure or consult the manufacturer's literature for complete details.

There are a number of manufacturers of maturity monitoring equipment. They differ in the type of probe, data logging capabilities, and functions. However, they all serve a similar purpose: to log time and temperature of the PCC and then estimate strength based on the s maturity curve that is input into the device.

Image description: Illustration of an Engius IntelliRock (Sensor and Reader).

Image description: Photo of COMMAND Center Software (Sensor and Reader).

Image description: Photo of Identec Solutions i-Q Tag (Pocket PC Not Shown).



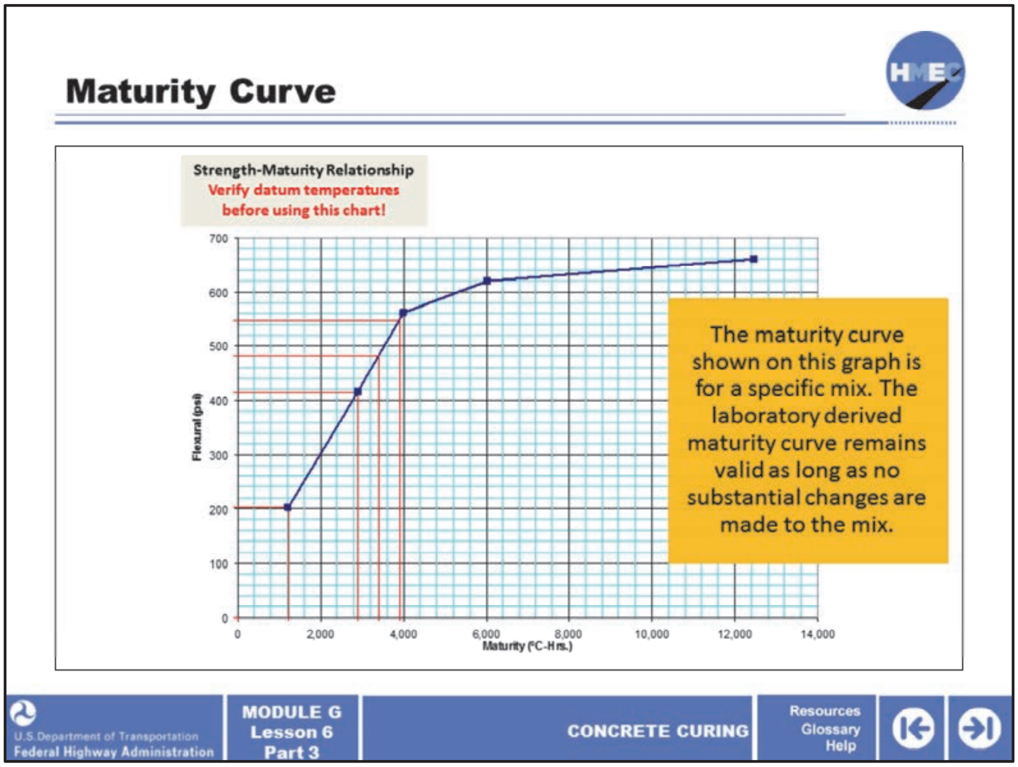
We briefly looked at the relationship between time, temperature, and strength. This mix-specific relationship is the basis for maturity testing.

To illustrate the point, let's say a PCC specimen was cast and cured at a constant temperature of 73 °F. For the mix shown in this graph, assume the 28-day strength is 5,000 psi. Therefore, the 3-day strength would be approximately 65% of 5,000 or 3,250 psi. At 7 days, approximately 75% or 3,750 psi.

Unfortunately in the real world, curing temperatures rarely stay constant. Using the same example, what if on day 1 the temperature remained at 73 °F, on day 2 the temperature was 90 °F, on day 3, 64 °F, and so on. Since the rate of strength gain is dependent on temperature, each day corresponds to a different strength curve.

Maturity takes into account these varying temperatures and the duration at each temperature.

Image description: Graph showing time, temperature, and strength relationship.



The maturity method simply combines both time and temperature into an index value:

For example, a specimen cured at 90° for 2 days = 90 x 2 = 180 degree-days, or a specimen cured at 60° for 3 days = 60 x 3 = 180 degree-days.

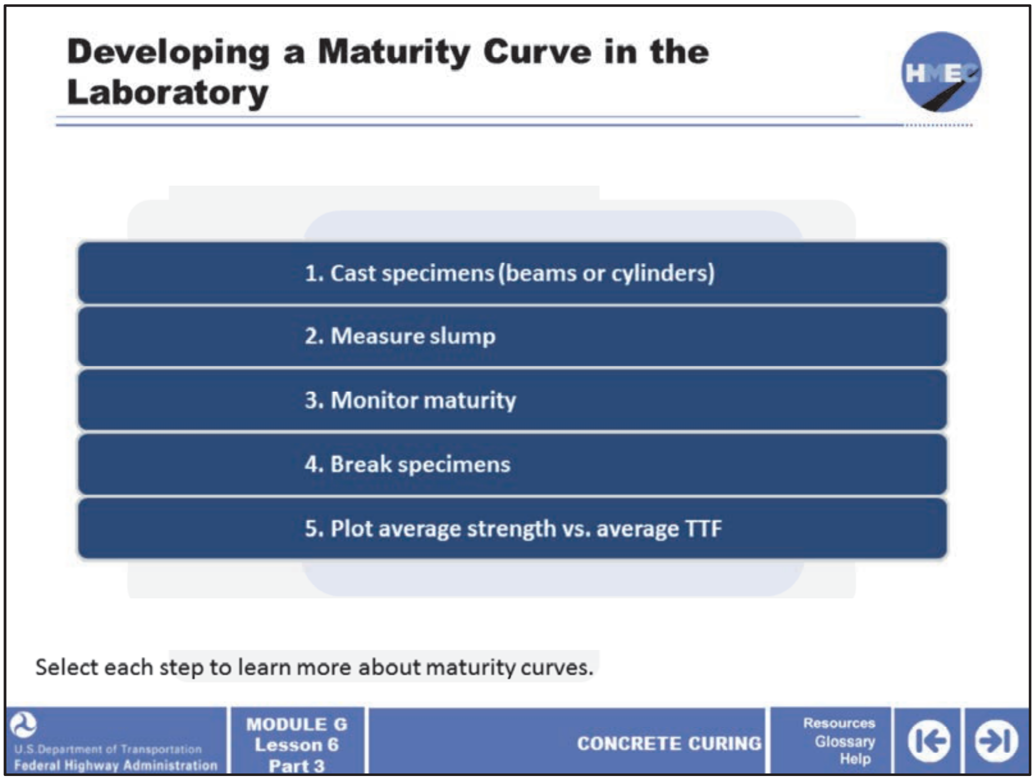
Based on the maturity concept, both samples have the same maturity, which means they are the same strength.

The maturity curve shown on this graph is for a specific mix. The laboratory derived maturity curve remains valid as long as no substantial changes are made to the mix.

Maturity is also based on the assumption that best practices for placement and curing are adhered to.

It is very important to note that significant changes in mix proportions or materials (cement, aggregates, admixtures) will necessitate development of a new maturity curve. Remember, maturity curves are mix specific.

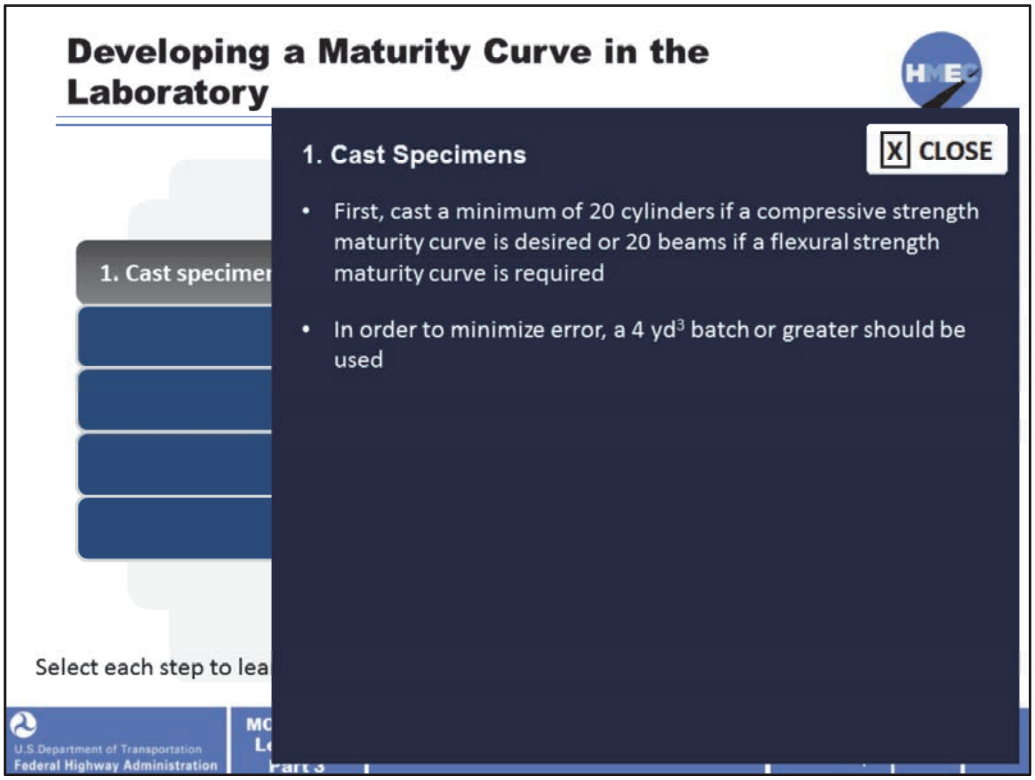
Image description: Graph showing a maturity curve for a specific mix.



In order to develop a maturity curve, the following steps are required.

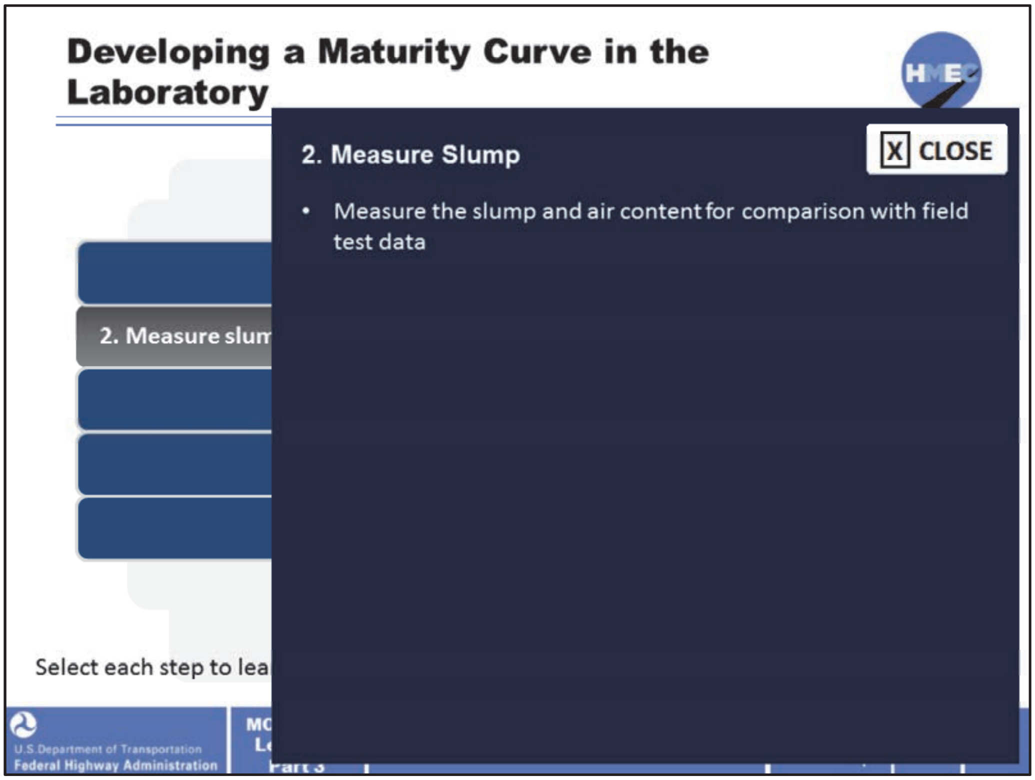
1. Cast specimens (beams or cylinders);
2. Measure slump;
3. Monitor maturity;
4. Break specimens; and
5. Plot average strength vs. average TTF.

Select each step to learn more about maturity curves.

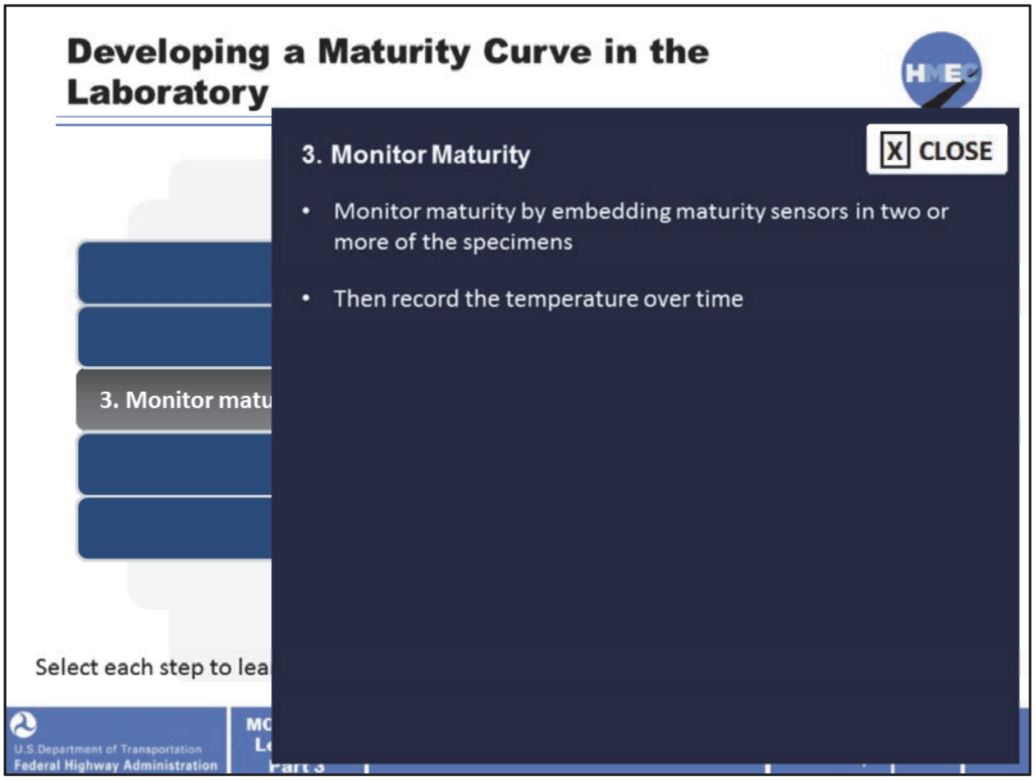


The first step is to cast a minimum of 20 cylinders if a compressive strength maturity curve is desired or 20 beams if a flexural strength maturity curve is required. In order to minimize error, a 4 yd^3 batch or greater should be used.

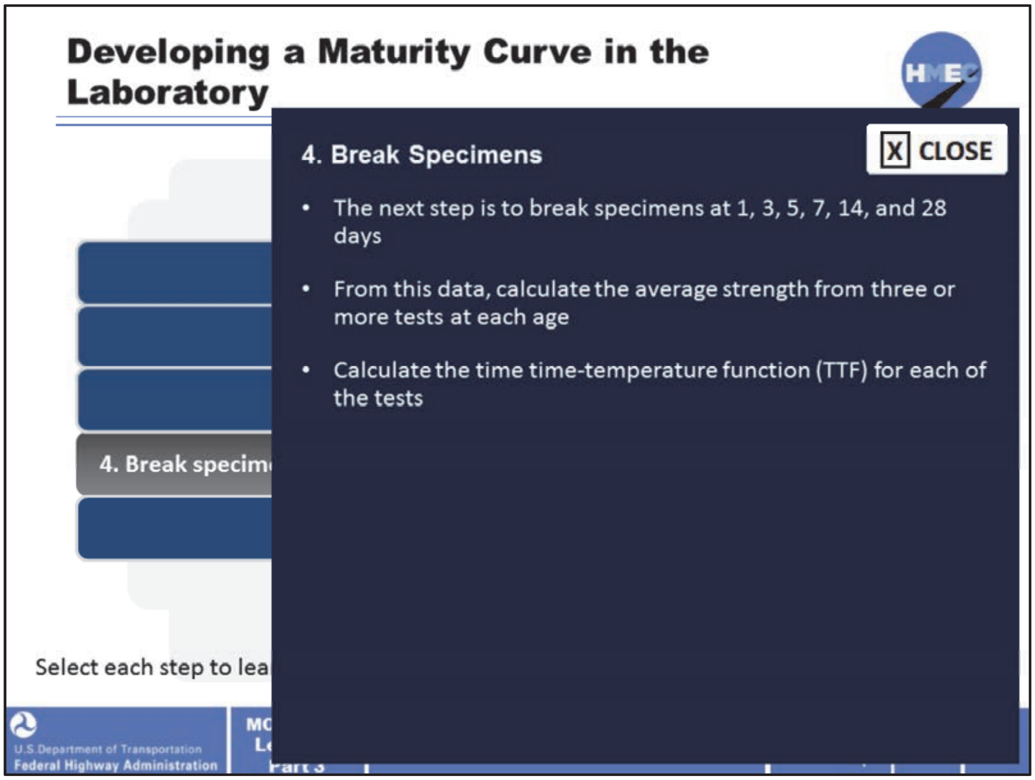
Note that developing a maturity curve for a specific strength parameter (compressive or flexural) eliminates the need to use a correlation relating the two. In other words, if the specification calls for a flexural strength, a flexible strength maturity curve is desirable.



The second step is to measure the slump and air content for comparison with field test data.



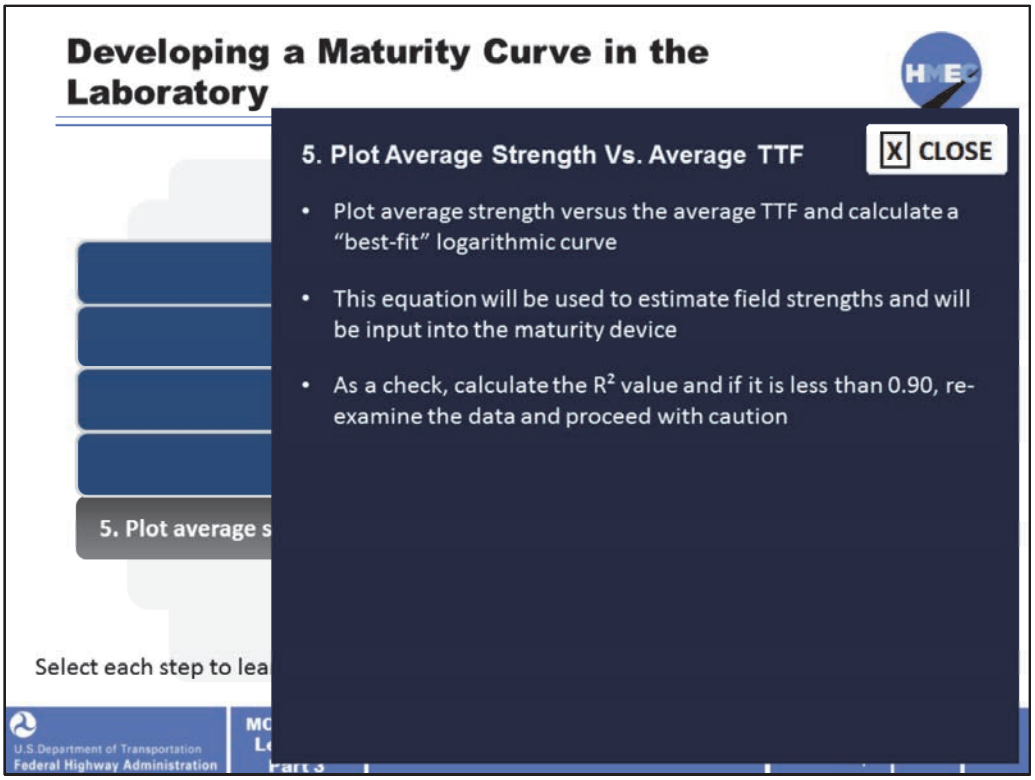
The third step is to monitor maturity by embedding maturity sensors in two or more of the specimens. Then record the temperature over time.



The fourth step is to break specimens at 1, 3, 5, 7, 14, and 28 days.

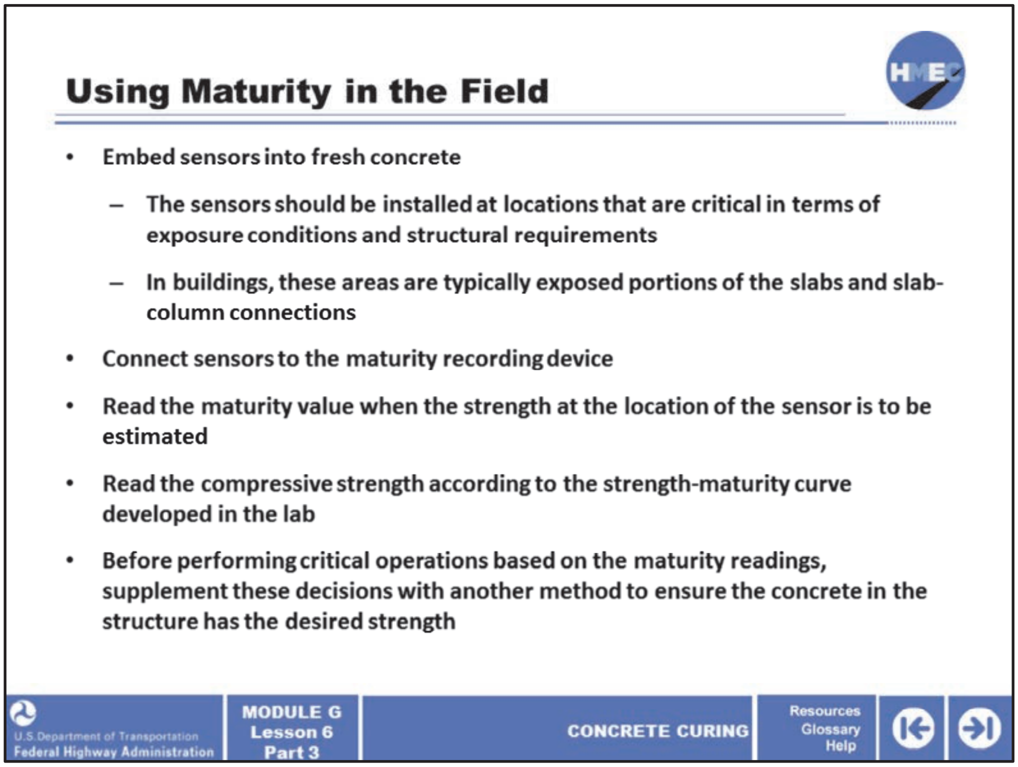
From this data, calculate the average strength from three or more tests at each age.

Calculate the time time-temperature function (TTF) for each of the tests.



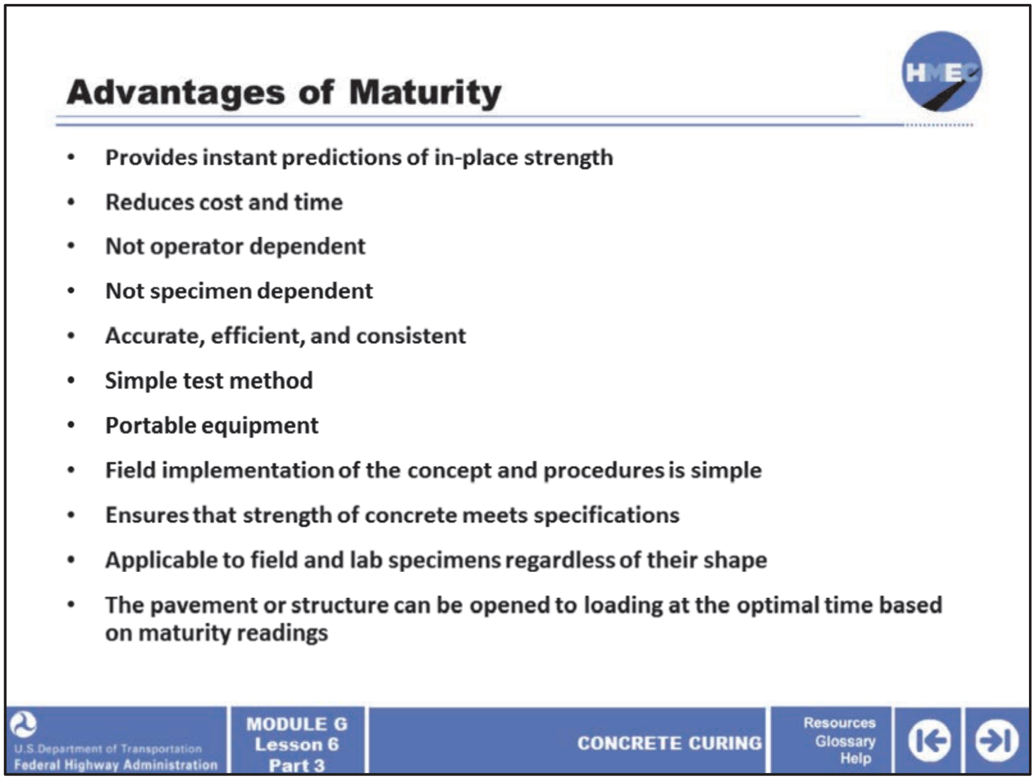
The fifth and last step is to plot average strength versus the average TTF and calculate a "best-fit" logarithmic curve. This equation will be used to estimate field strengths and will be input into the maturity device.

As a check, calculate the R^2 value and if it is less than 0.90, re-examine the data and proceed with caution.

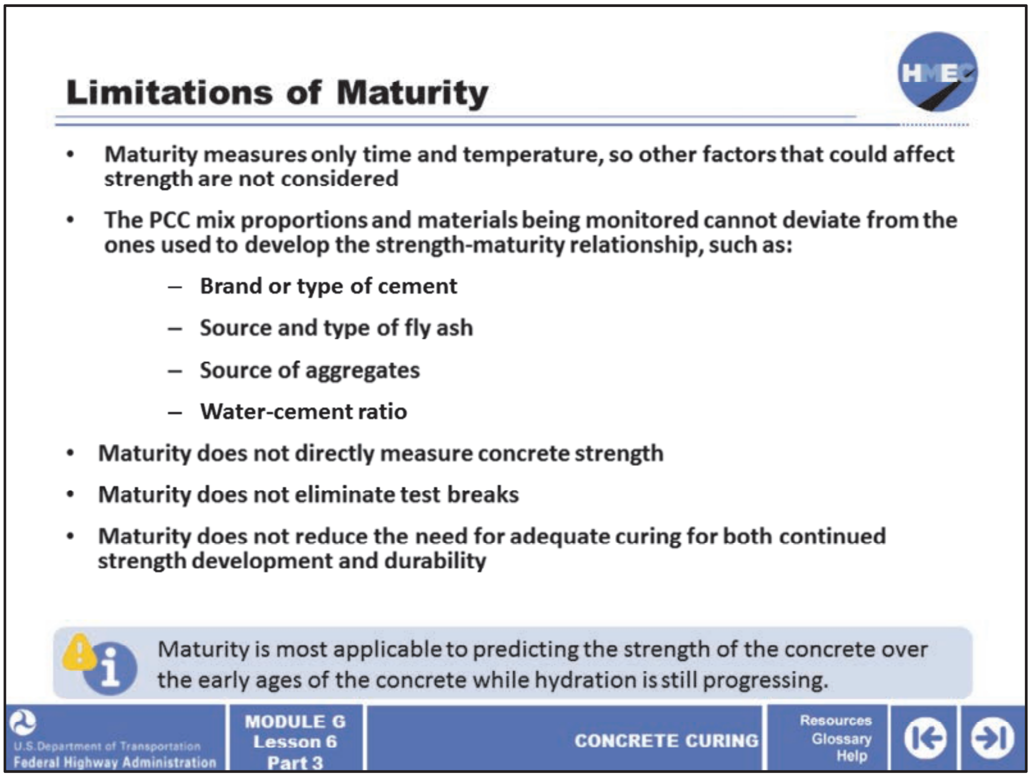


The laboratory developed maturity curve is then used in conjunction with one of the maturity devices to estimate strength. The steps involved with field monitoring include:

• Embed sensors into fresh concrete. The sensors should be installed at locations that are critical in terms of exposure conditions and structural requirements. In buildings, these areas are typically exposed portions of the slabs and slab-column connections;
• Connect sensors to the maturity recording device;
• Read the maturity value when the strength at the location of the sensor is to be estimated;
• Read the compressive strength according to the strength-maturity curve developed in the lab; and
• Before performing critical operations based on the maturity readings, supplement these decisions with another method to ensure the concrete in the structure has the desired strength.



Please take a moment to read the advantages of maturity listed on this slide.



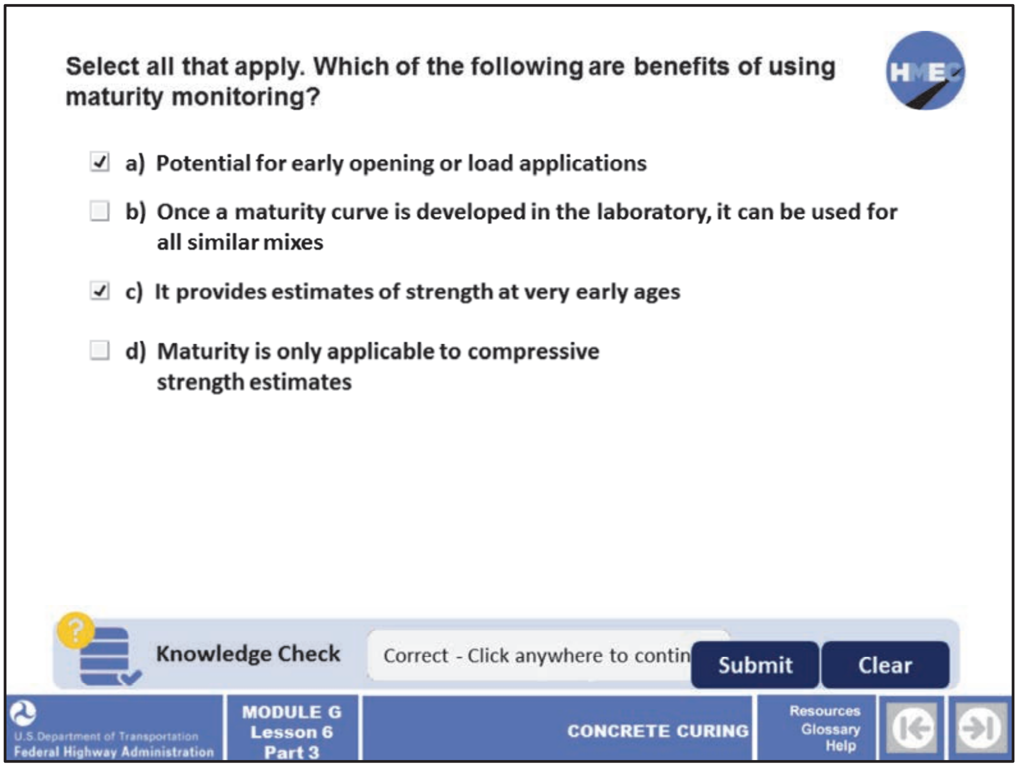
Like any technology, the maturity concept is not a “cure all” and we must recognize its limitations in order to use it properly in the field. Maturity measures only time and temperature, so other factors that could affect strength are not considered.

The PCC mix proportions and materials being monitored cannot deviate from the ones used to develop the strength-maturity relationship, such as:

- Brand or type of cement;
- Source and type of fly ash;
- Source of aggregates; and
- Water-cement ratio.

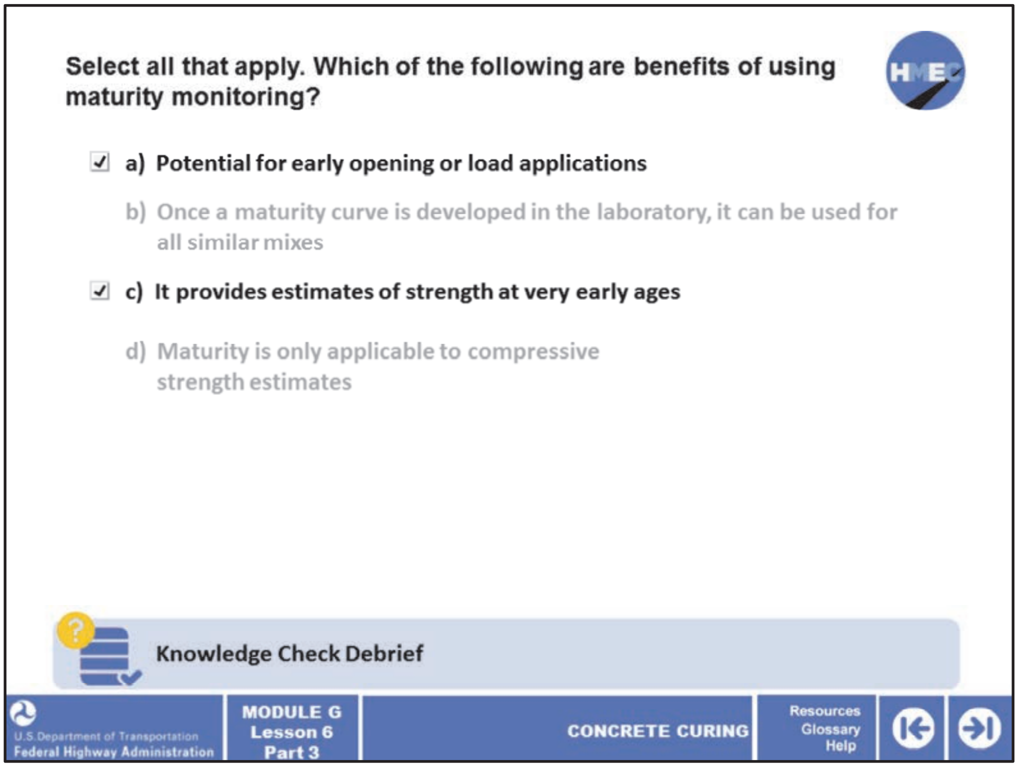
Maturity does not measure concrete strength, it estimates it. Maturity does not eliminate test breaks, but it can significantly reduce the number required. Maturity is most applicable to predicting the strength of the concrete over the early ages of the concrete while hydration is still progressing.

It is important to note that while maturity is a very useful tool for early loading considerations, it does not reduce the need for adequate curing for both continued strength development and durability.



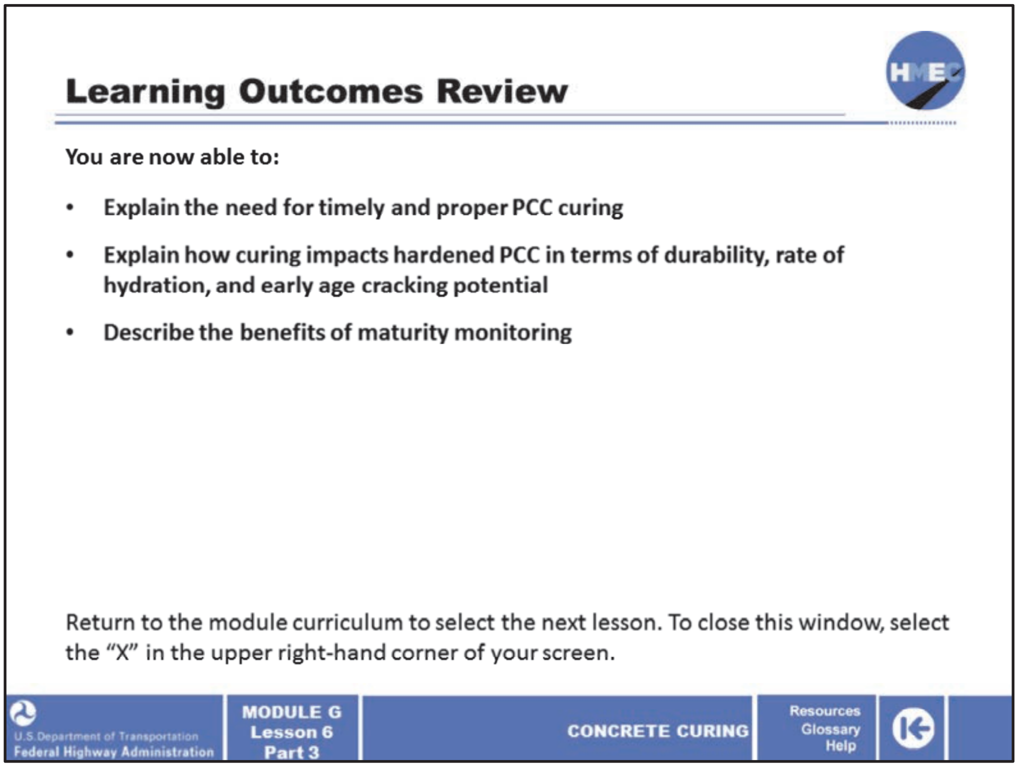
Select all that apply. Which of the following are benefits of using maturity monitoring?

a) Potential for early opening or load applications;
b) Once a maturity curve is developed in the laboratory, it can be used for all similar mixes;
c) It provides estimates of strength at very early ages; and/or
d) Maturity is only applicable to compressive strength estimates.



The correct answers are a) Potential for early opening or load applications; and c) It provides estimates of strength at very early ages.

The use of maturity monitoring permits estimating PCC strength at early ages. As soon as a predetermined target strength is reached, early loading may be permissible on a limited basis. Beam breaks or cylinder breaks cannot be effectively used at these very early ages to accurately determine strength.



You have completed Module G, Lesson 6: Construction Practices, Part 3 of 3.

You are now able to:

- Explain the need for timely and proper PCC curing;
- Explain how curing impacts hardened PCC in terms of durability, rate of hydration, and early age cracking potential; and
- Describe the benefits of maturity monitoring.

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.