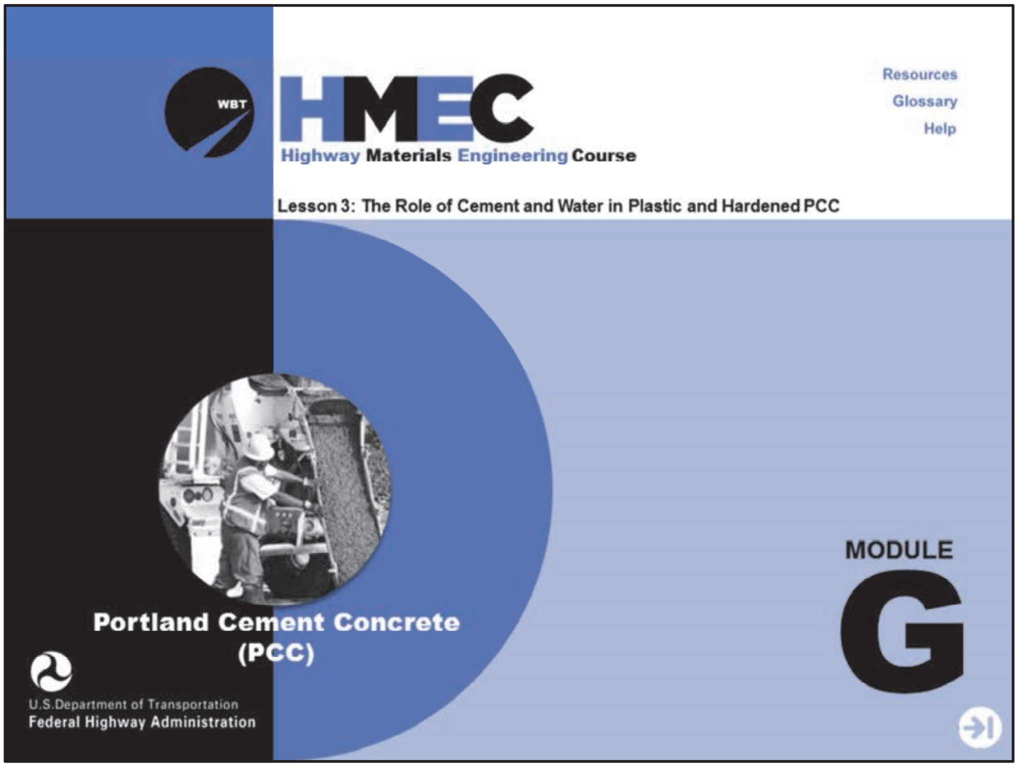
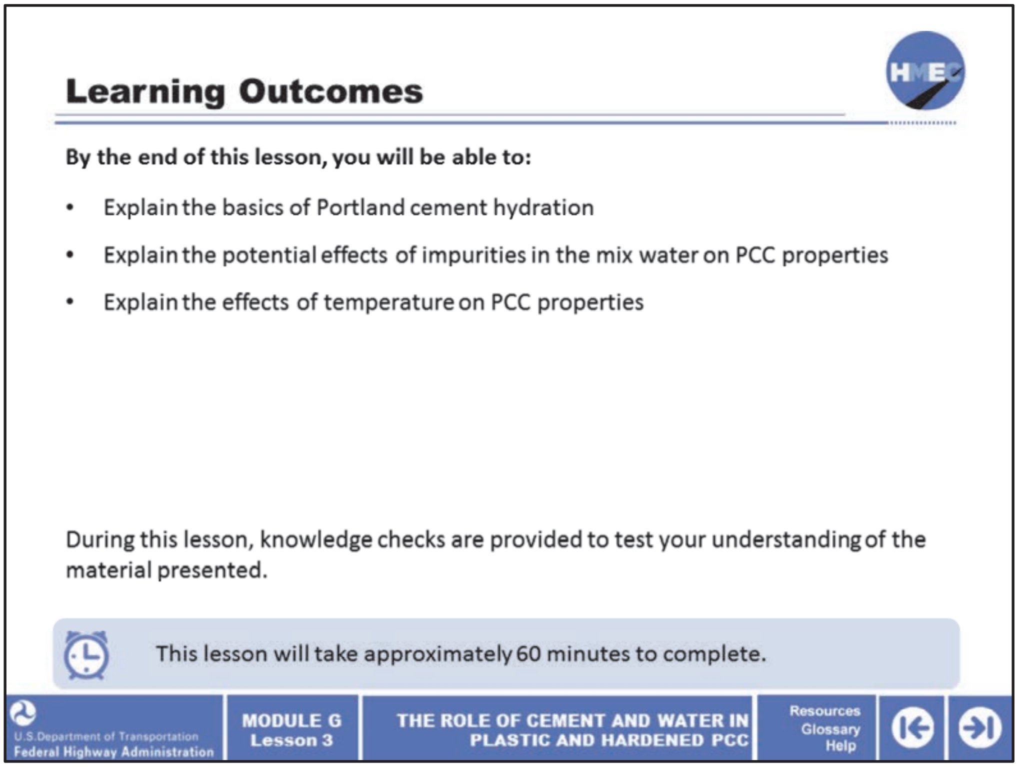


Welcome to the Highway Materials Engineering Course Module G Lesson 3: The Role of Cement and Water in Plastic and Hardened Portland Cement Concrete (PCC). In this lesson, we will cover the basics of hydration and the resulting impacts on the properties of plastic and hardened PCC.

A printer-friendly version of the lesson materials can be downloaded by selecting the paperclip icon. Only the screens 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.

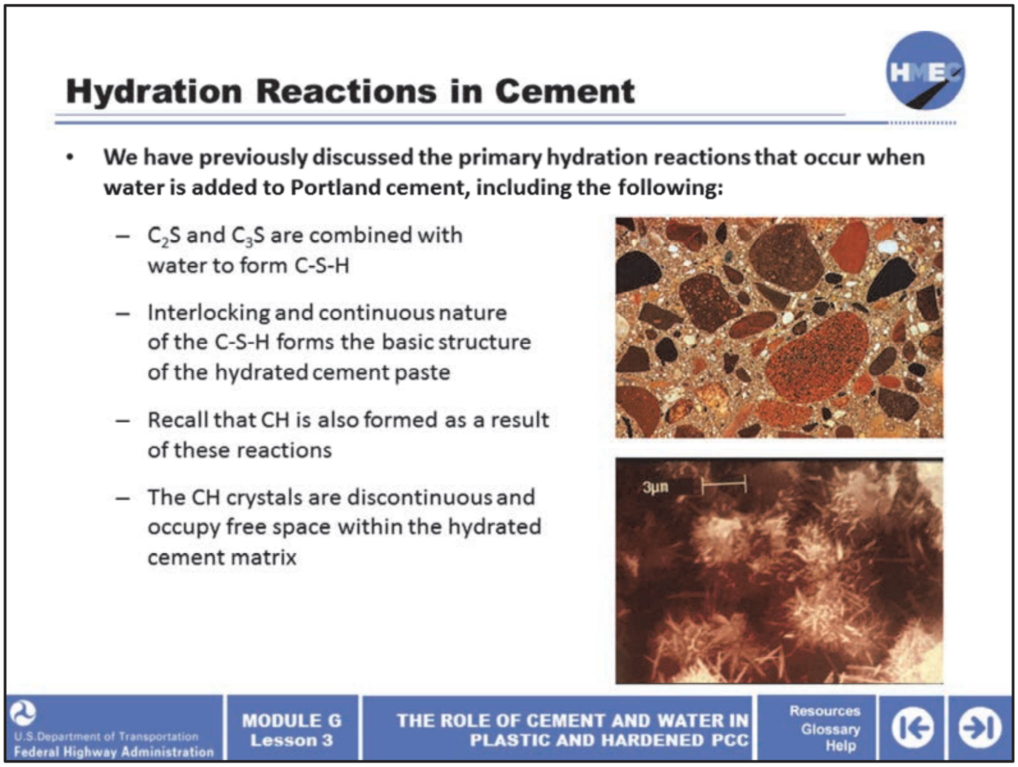


By the end of this lesson, you will be able to:

- Explain the basics of Portland cement hydration;
- Explain the potential effects of impurities in the mix water on PCC properties; and
- Explain the effects of temperature on PCC properties.

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

This lesson will take approximately 60 minutes to complete.



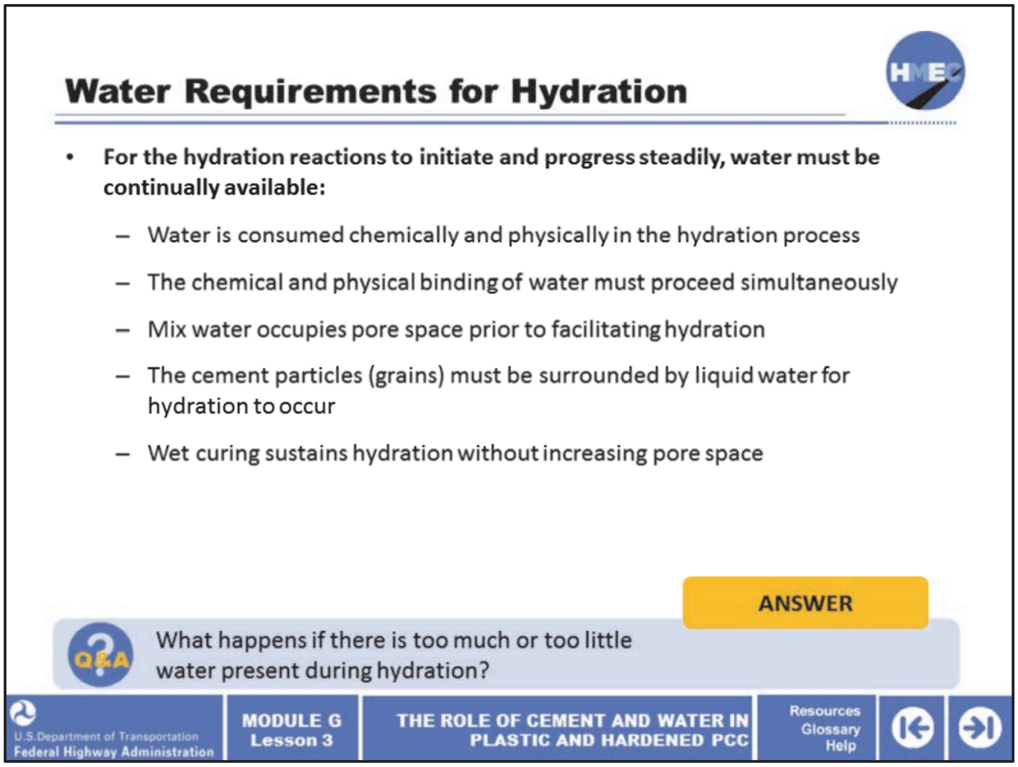
We have previously discussed the primary hydration reactions that occur when water is added to Portland cement.

- The **C_2S** (dicalcium silicate) and **C_3S** (tricalcium silicate) are combined with water to form C-S-H (calcium silicate hydrates);
- The interlocking and continuous nature of the C-S-H forms the basic structure of the hydrated cement paste;
- Recall that CH is also formed as a result of these reactions; and
- The CH crystals are discontinuous and occupy free space within the hydrated cement matrix. CH is much less important than the C-S-H in determining overall properties of the PCC.

In this discussion, we are going to concentrate only on the primary reaction products and how they influence behavior.

Image descriptions: Photo of a cross-sectional view of a PCC sample.

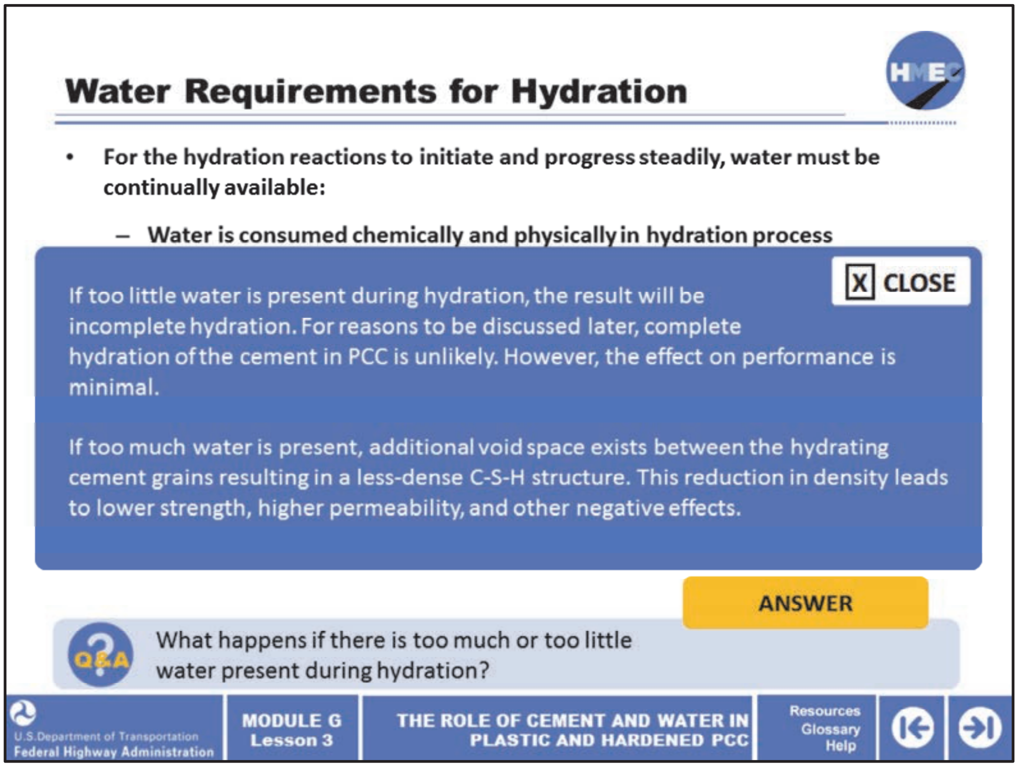
Image descriptions: Photo of a scanning electron microscope (SEM) photo of hydrating cement grains.



For the hydration reactions to initiate and progress steadily, water must be continually available:

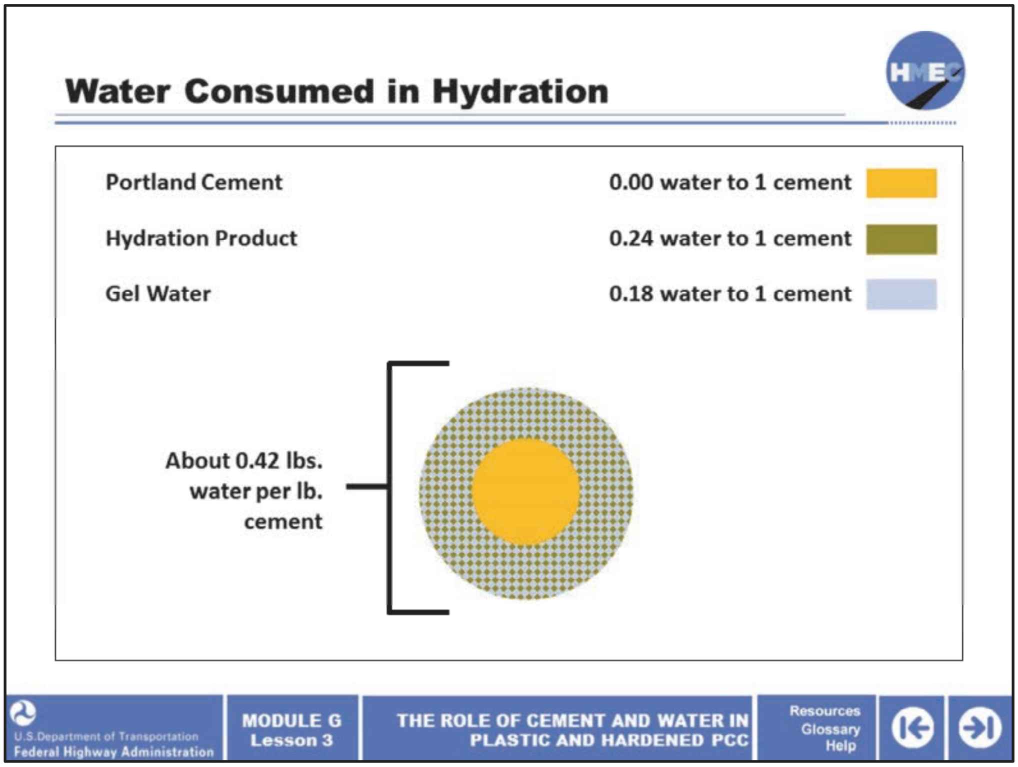
- Water is consumed chemically and physically in the hydration process;
- The chemical and physical binding of water must proceed simultaneously;
- Mix water occupies pore space prior to facilitating hydration;
- The cement particles must be surrounded by liquid water for hydration to occur; and
- Wet curing sustains hydration without increasing pore space.

Select the box to answer the question: What happens if there is too much or too little water present during hydration?



If too little water is present during hydration, the result will be incomplete hydration. For reasons to be discussed later, complete hydration of the cement in PCC is unlikely. However, the effect on performance is minimal.

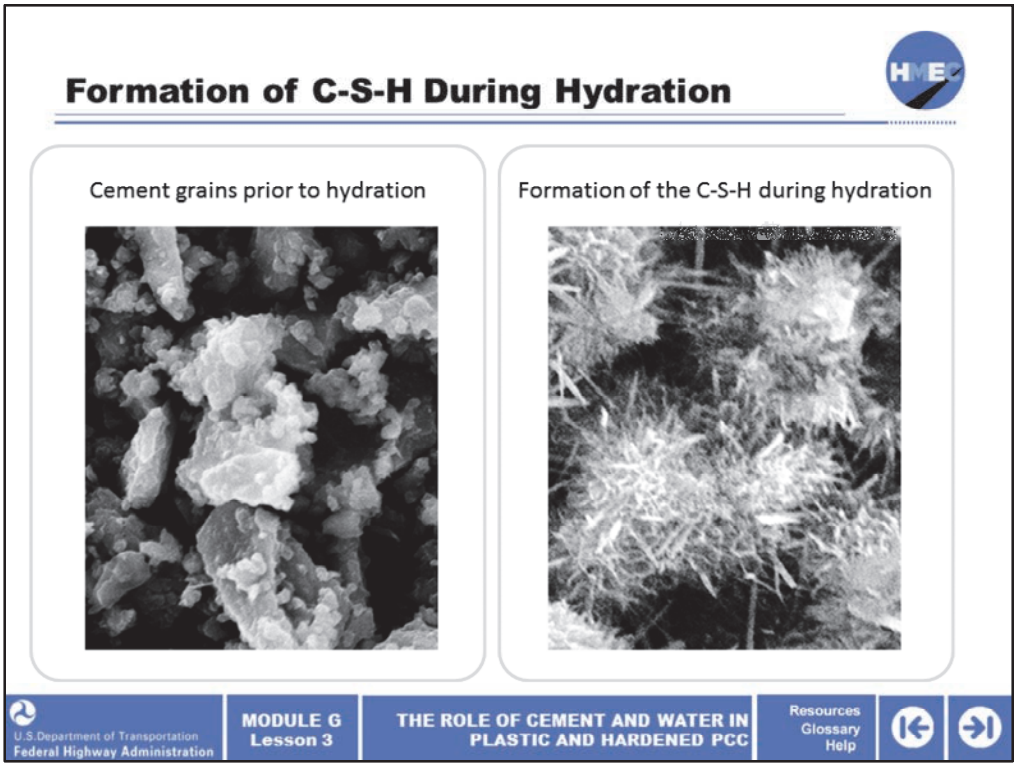
If too much water is present, additional void space exists between the hydrating cement grains resulting in a less-dense C-S-H structure. This reduction in density leads to lower strength, higher permeability, and other negative effects.



This screen depicts how the mix water is used during the hydration reaction.

The cement grain, shown in yellow, is the nucleus (center) of the hydration products, which grow more or less uniformly in three dimensions unless they interact with an aggregate or a neighboring cement grain. The hydration products (primarily C-S-H) are not a completely solid mass and contain residual water in the structure of the hardened paste. As shown in this slide, approximately 0.24 times the weight of cement is used to form the hydration products while 0.18 is “bound water” contained in the structure of the hydration products. Refer to the following slide for a photograph illustrating this point.

Image description: Image of mix water during the hydration reaction.



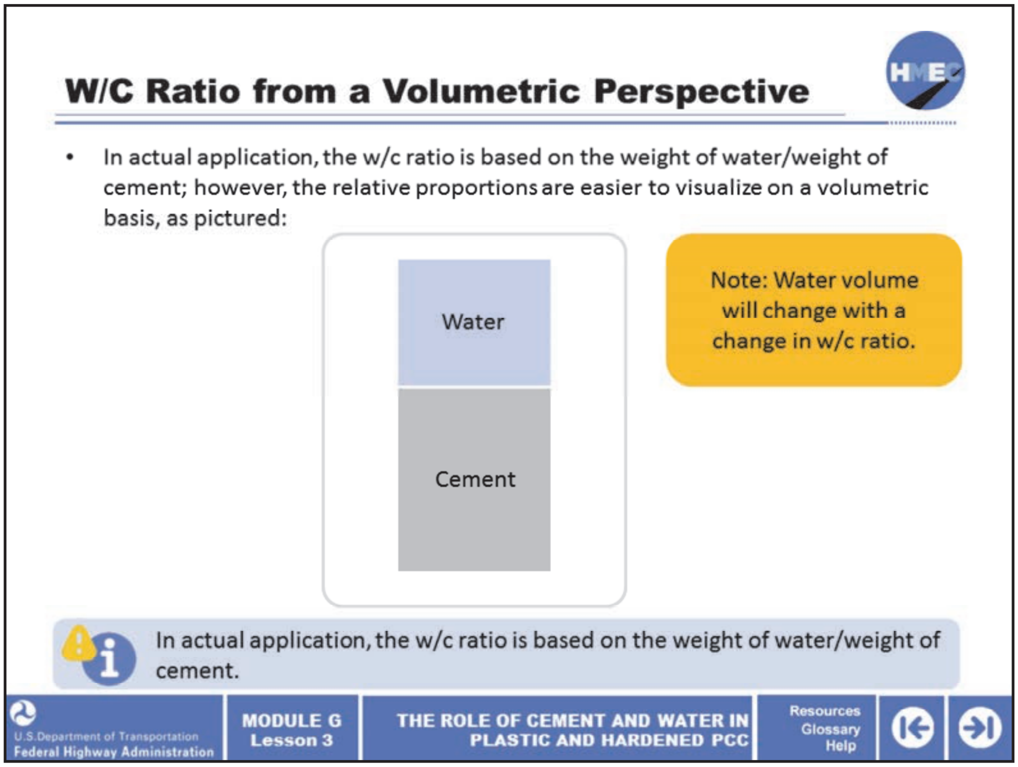
The scanning electron microscope (SEM) photo on the left shows a number of cement grains prior to hydration.

The photo on the right shows the formation of the C-S-H during hydration. The structure of the hardened paste depends primarily on the interlocking of the C-S-H surrounding each of the cement grains.

The interlocking of the CSH “spines” controls both the behavior of the fresh concrete after hydration begins (workability, initial set) and the properties of the hardened PCC (strength, permeability, and others).

Image description: Photo of cement grains prior to hydration.

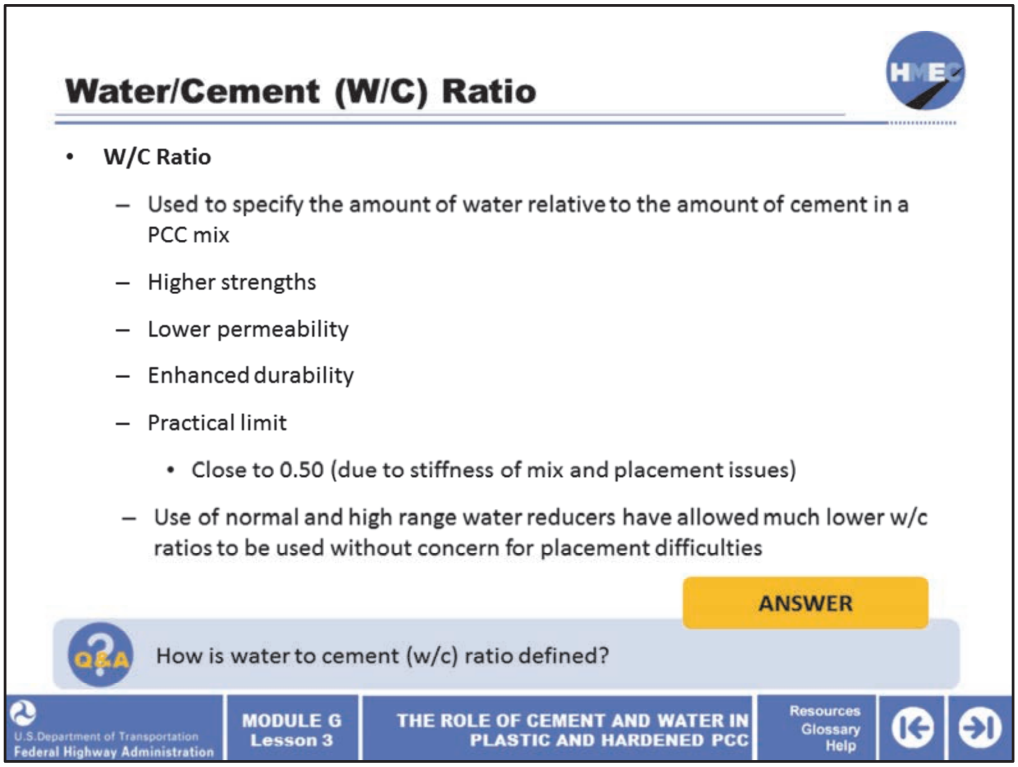
Image description: Photo of formation of the C-S-H during hydration.



In actual application, the water to cement (w/c) ratio is based on the weight of water/weight of cement. However, the relative proportions are easier to visualize on a volumetric basis, as pictured. Note that the water volume will change with a change in w/c ratio.

While defined as weight ratio, the meaning of w/c is clearer when the associated volumes are considered. Even though we all recognize that the water/cement ratio is the most important single characteristic defining the quality of concrete, this key parameter remains somewhat abstract. The purpose of this screen is to make the concept of water/cement ratio more tangible.

Due to the specific gravity of cement being approximately 3.15, the volume of water per unit volume of cement is relatively large. For example, if we consider a PCC mix with 564 pounds of cement per cubic yard and a w/c ratio of 0.42, the relative volume of water to cement is approximately 2.4/2.8, or 85%.



We have discussed the need for water to facilitate the hydration reactions in cement. The question is: how much?

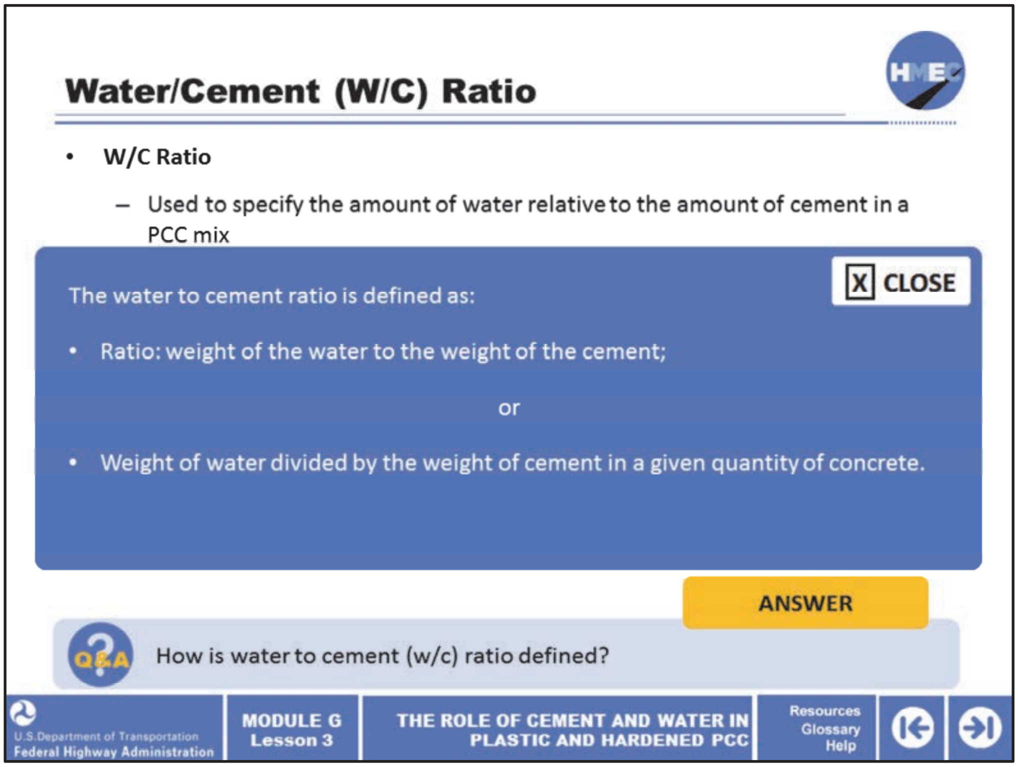
The term w/c ratio is used to specify the amount of water relative to the amount of cement in a PCC mix. We have equated higher strengths, lower permeability, enhanced durability and other benefits with low w/c ratios.

Prior to the advent of water reducing admixtures, the practical limit for water to cement was close to 0.50 because of the stiffness of the mix and placement issues.

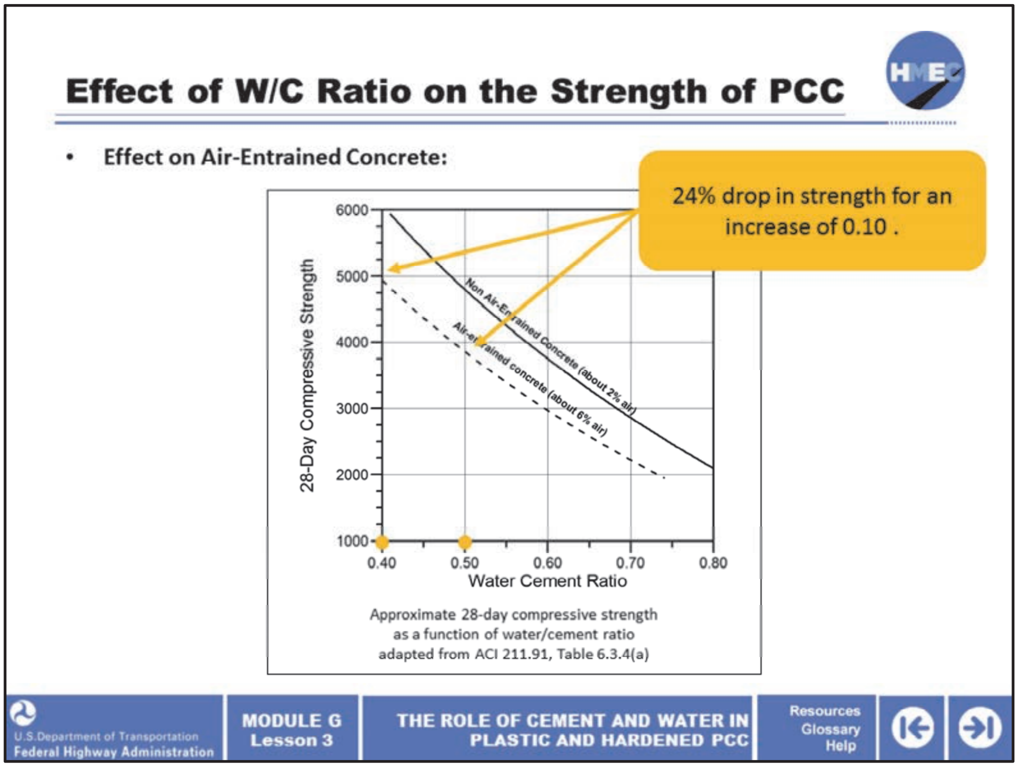
The use of normal and high range water reducers have allowed much lower water to cement ratios to be used without concern for placement difficulties.

The following screens illustrate the importance of this parameter in the performance of PCC mixes.

Select the box to answer the question: How is water to cement (w/c) ratio defined?



The water to cement ratio is defined as the ratio between the weight of the water and the weight of the cement, or the weight of water divided by the weight of cement in a given quantity of concrete.



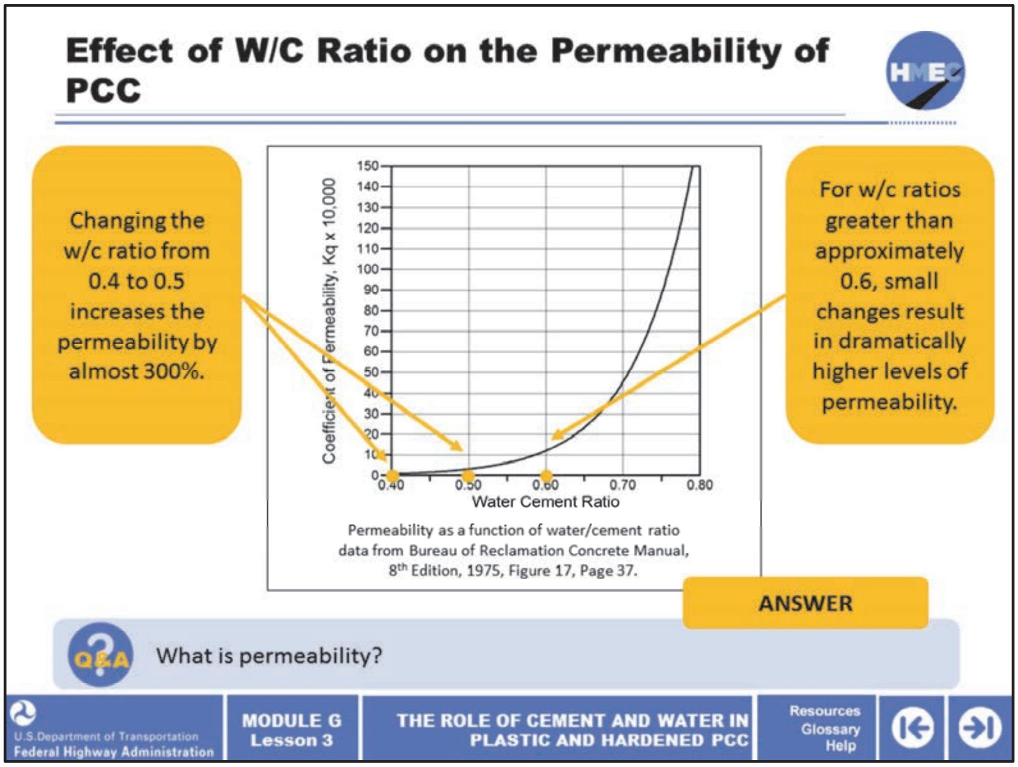
The w/c ratio has a significant effect on almost all PCC properties, but perhaps none more important than strength.

This graph shows the effect of w/c ratio on compressive strength, all other variables are held constant. Let's look at the effect on air-entrained concrete:

- If the w/c is specified as 0.40, the resulting compressive strength is approximately 5,000 psi;
- If the w/c ratio is increased to 0.50, the compressive strength falls to approximately 3,800 psi; and
- This figures out to be about a 24% drop in strength for an increase of 0.10 in w/c.

Or looking at it another way, if we assume a PCC mix has 564 pounds of cement per cubic yard, the difference between a w/c of 0.4 and 0.5 is approximately 6.8 gallons of water per cubic yard of concrete.

Image description: Graph showing the effect of w/c ratio on compressive strength.

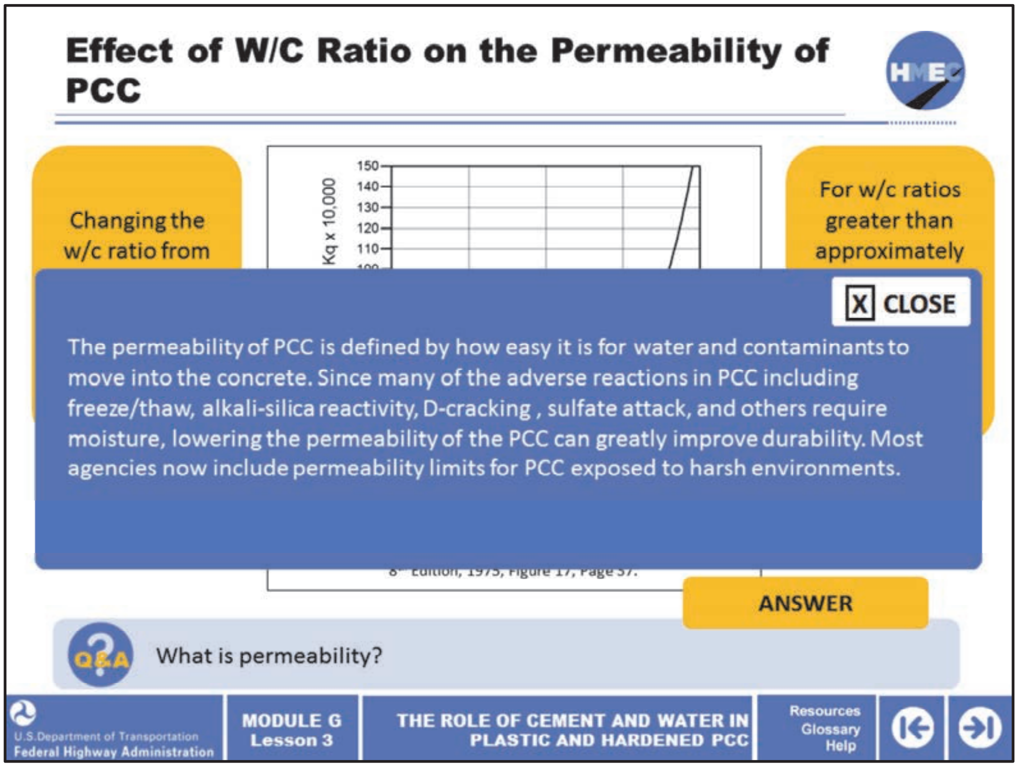


Another critical aspect of the w/c ratio is the effect on permeability. Using the example from the previous screen, changing the w/c ratio from 0.4 to 0.5 increases the permeability by almost 300%. Although this difference seems minor, consider that permeability relates to freeze/thaw durability, sulfate attack, and potentially the ingress of deleterious chemicals.

For w/c ratios greater than approximately 0.6, small changes result in dramatically higher levels of permeability.

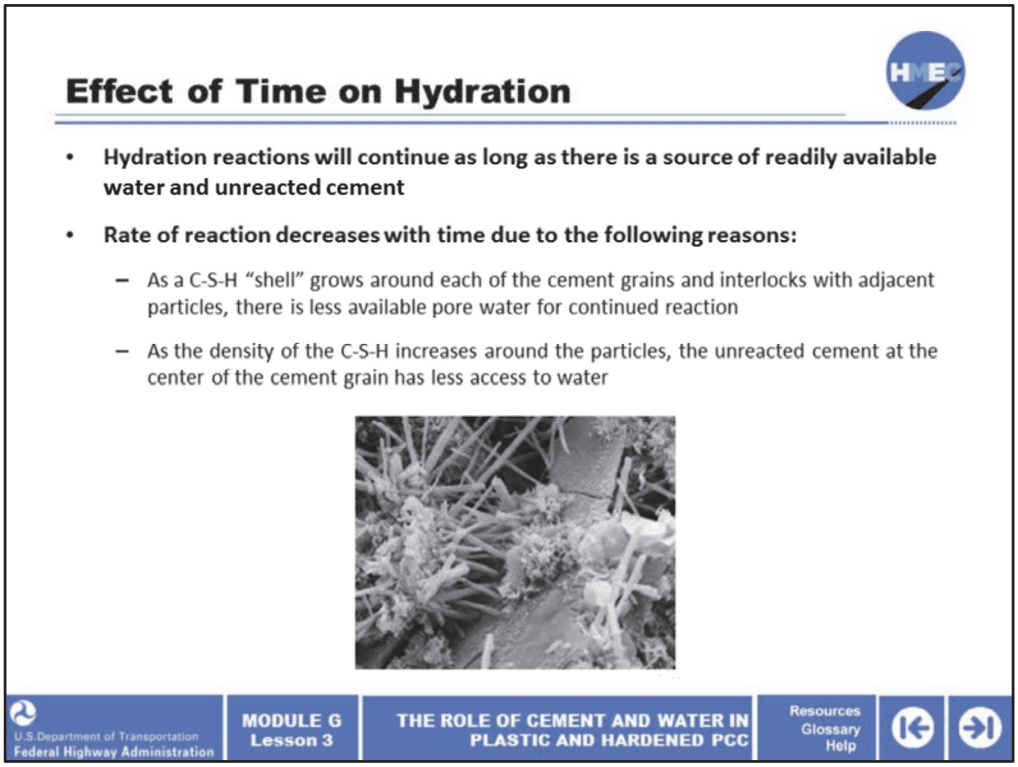
Select the box to answer the question: What is permeability?

Image description: Graph showing the effect of w/c ratio on permeability.



The permeability of PCC is defined by how easy it is for water and contaminants to move into the concrete. Since many of the adverse reactions in PCC including freeze/thaw, alkali-silica reactivity, D-cracking , sulfate attack, and others require moisture, lowering the permeability of the PCC can greatly improve durability. Most agencies now include permeability limits for PCC exposed to harsh environments.

Image description: Graph showing the effect of w/c ratio on permeability.



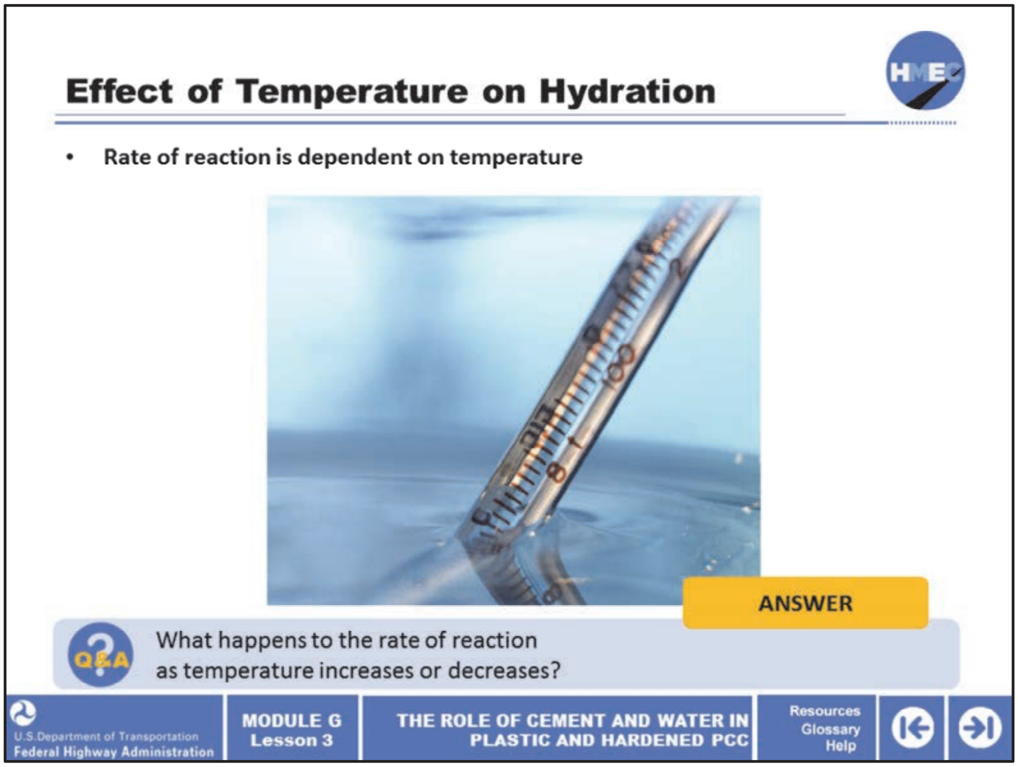
The hydration reactions will continue as long as there is a source of readily available water and unreacted cement.

However, the rate of reaction decreases with time due to the following reasons:

• As a C-S-H "shell" grows around each of the cement grains and interlocks with adjacent particles, there is less available pore water for continued reaction; and
• As the density of the C-S-H increases around the particles, the unreacted cement at the center of the cement grain has less access to water.

It is not unusual to examine decades-old PCC and find unreacted cement. This is not problematic but rather a function of normal hydration and the access that unreacted cement has to water.

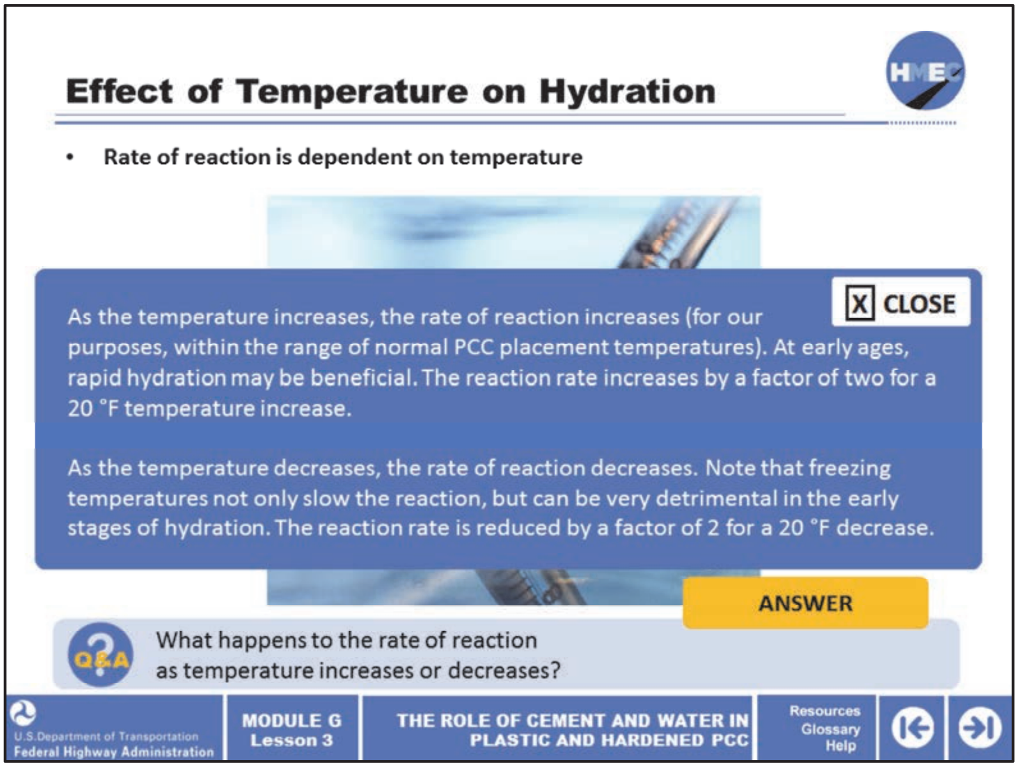
Image description: Photo of cement grain and hydration products.



As is common with all other chemical reactions, the rate of reaction is dependent on temperature.

Select the box to answer the question: What happens to the rate of reaction as temperature increases or decreases?

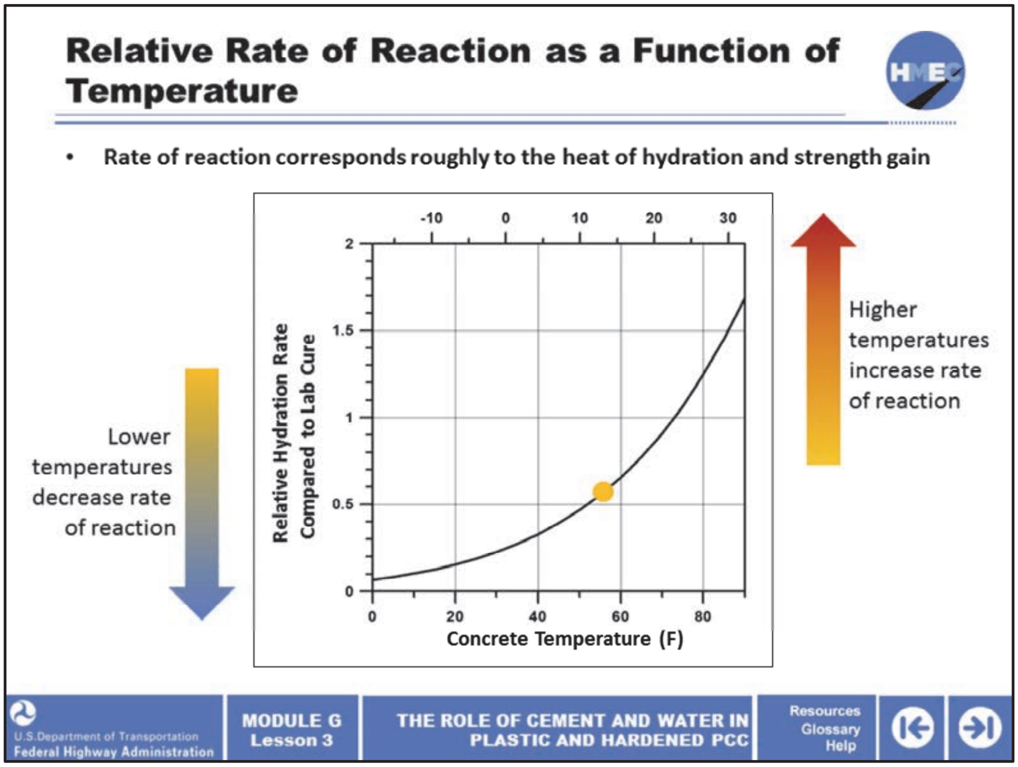
Image description: Photo of a thermometer in liquid.



As the temperature increases, the rate of reaction increases (for our purposes, within the range of normal PCC placement temperatures). At early ages, rapid hydration may be beneficial. The reaction rate increases by a factor of 2 for a 20 °F temperature increase.

As the temperature decreases, the rate of reaction decreases. Note that freezing temperatures not only slow the reaction, but can be very detrimental in the early stages of hydration. The reaction rate is reduced by a factor of 2 for a 20 °F decrease.

Image description: Photo of a thermometer in liquid.



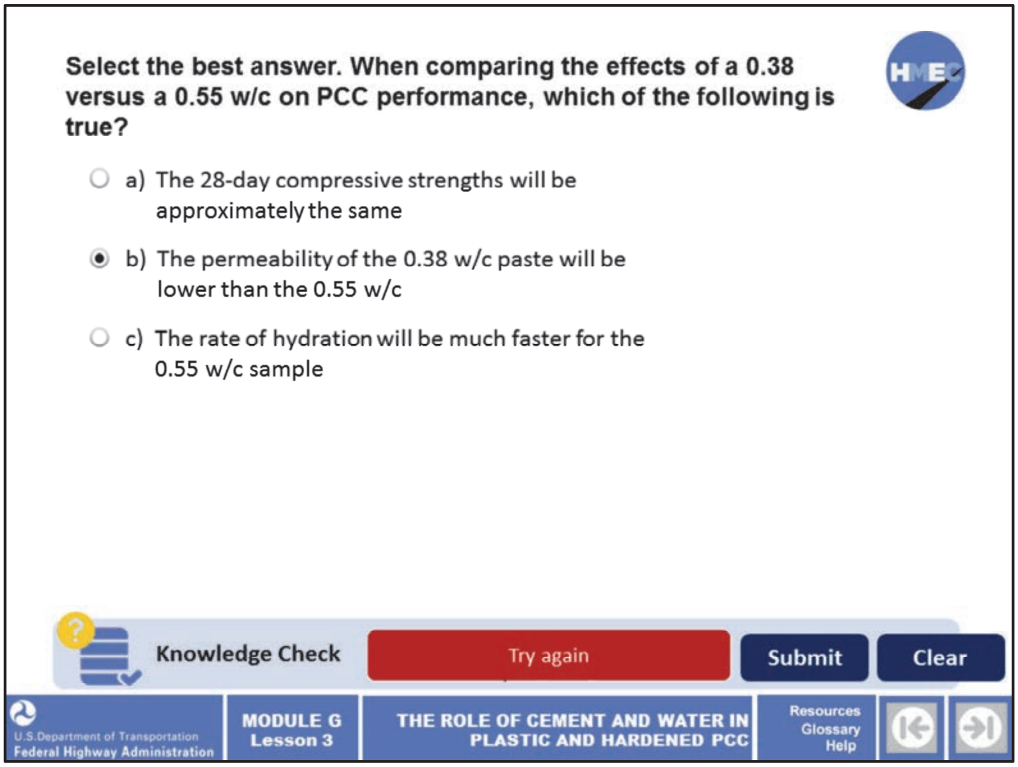
The rate of reaction corresponds roughly to the heat of hydration and strength gain. The graph shown on this screen is presented in terms of relative differences based on laboratory conditions, as indicated by the red dot.

The effect of higher temperatures is to increase the rate of reaction while lower temperatures reduce the rate of reaction, as indicated by the blue dot.

In practical terms, this means that PCC will gain strength faster at higher temperatures than at lower temperatures. Again, this forms the basis for maturity monitoring of PCC to assess strength gain non-destructively.

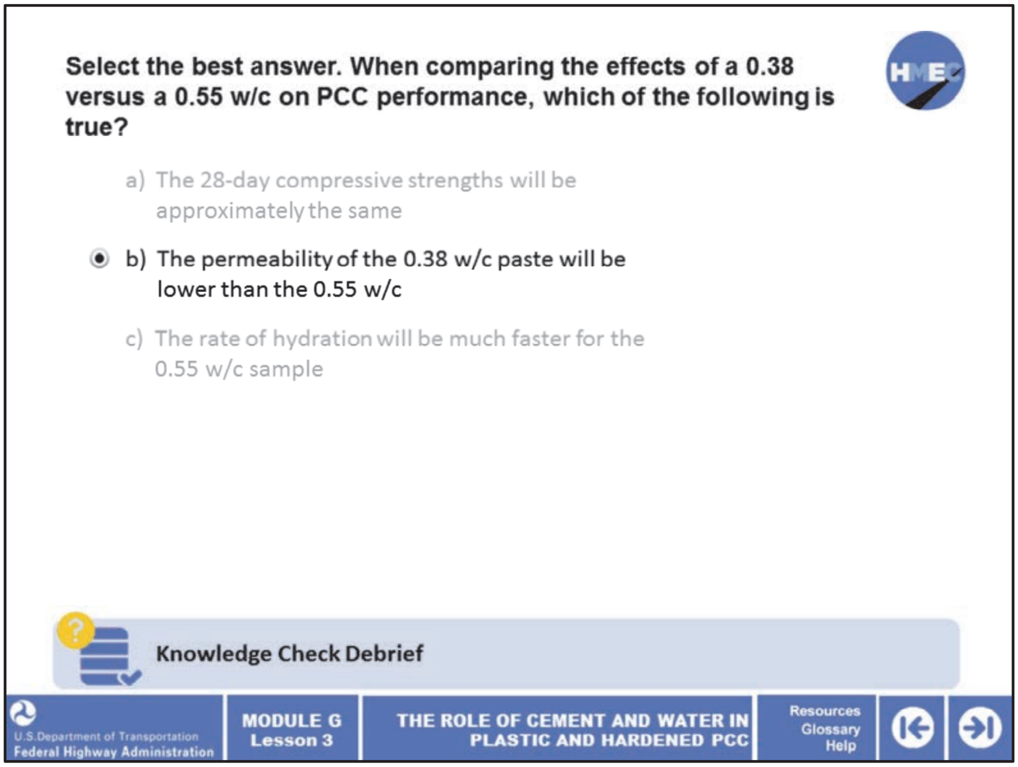
Note that the rate of reaction is significantly slowed at temperatures below freezing but not completely stopped. As will be discussed later in this Module, although the rate of reaction does not stop, significant damage can be done to the PCC if sufficient strength is not achieved prior to freezing.

Image description: Graph corresponding to heat of hydration and strength gain.

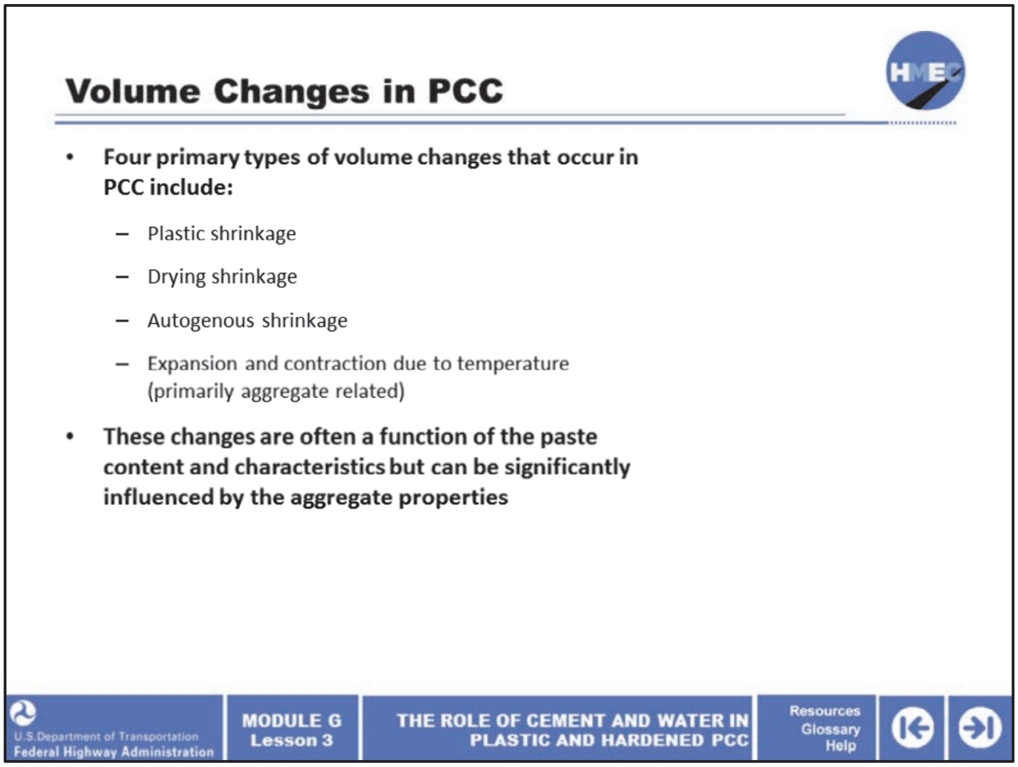


Select the best answer. When comparing the effects of a 0.38 versus a 0.55 w/c on PCC performance, which of the following is true?

a) The 28-day compressive strengths will be approximately the same;
b) The permeability of the 0.38 w/c paste will be lower than the 0.55 w/c; or
c) The rate of hydration will be much faster for the 0.55 w/c sample.



The correct answer is b) The permeability of the 0.38 w/c paste will be lower than the 0.55 w/c. The permeability of the paste is strongly influenced by the w/c ratio. Lower w/c ratios result in lower permeability, all other factors being equal.



Four primary types of volume changes that occur in PCC include:

- Plastic shrinkage;
- Drying shrinkage;
- Autogenous shrinkage; and
- Expansion and contraction due to temperature (primarily aggregate related).

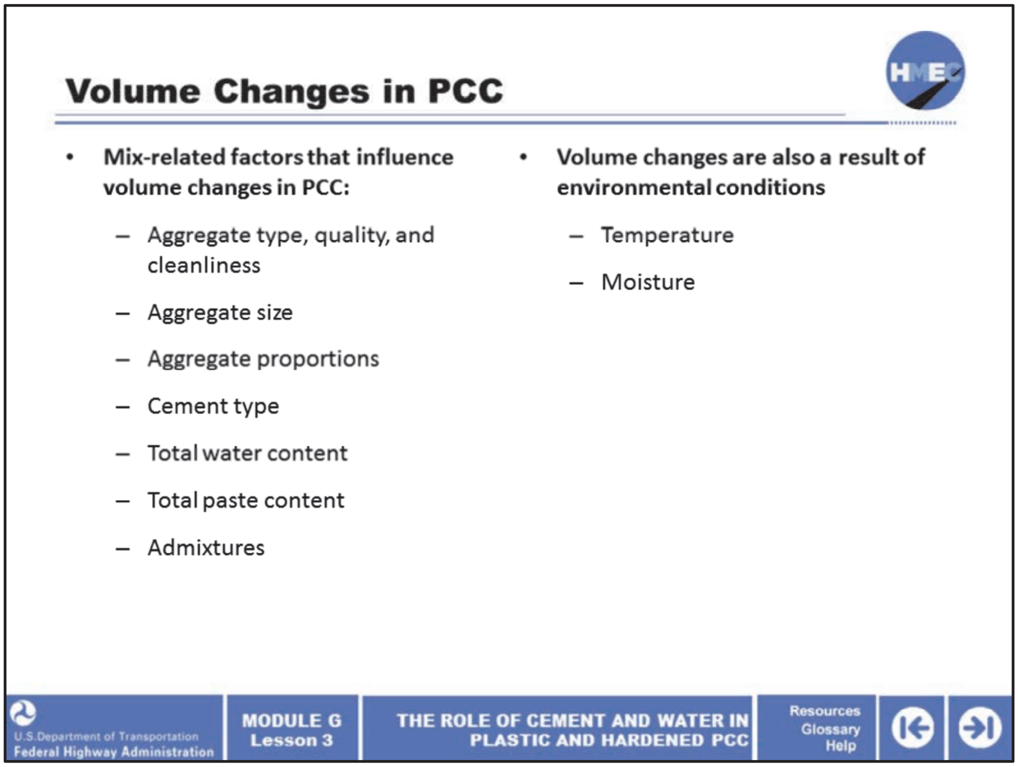
Plastic shrinkage is caused by the evaporation of water from the surface of the fresh PCC as it begins to hydrate.

Drying shrinkage is caused by a reduction in water as hydration progresses in the hardened PCC. There are many factors effecting drying shrinkage as will be discussed later in this module.

Autogenous shrinkage is due to the reaction products occupying less space than the unhydrated cement and water volume. This can also be thought of as self-desiccation where the mix water is consumed during the hydration until the PCC basically dries internally (only at low w/c).

These changes are often a function of the paste content and characteristics but can be significantly influenced by the aggregate properties.

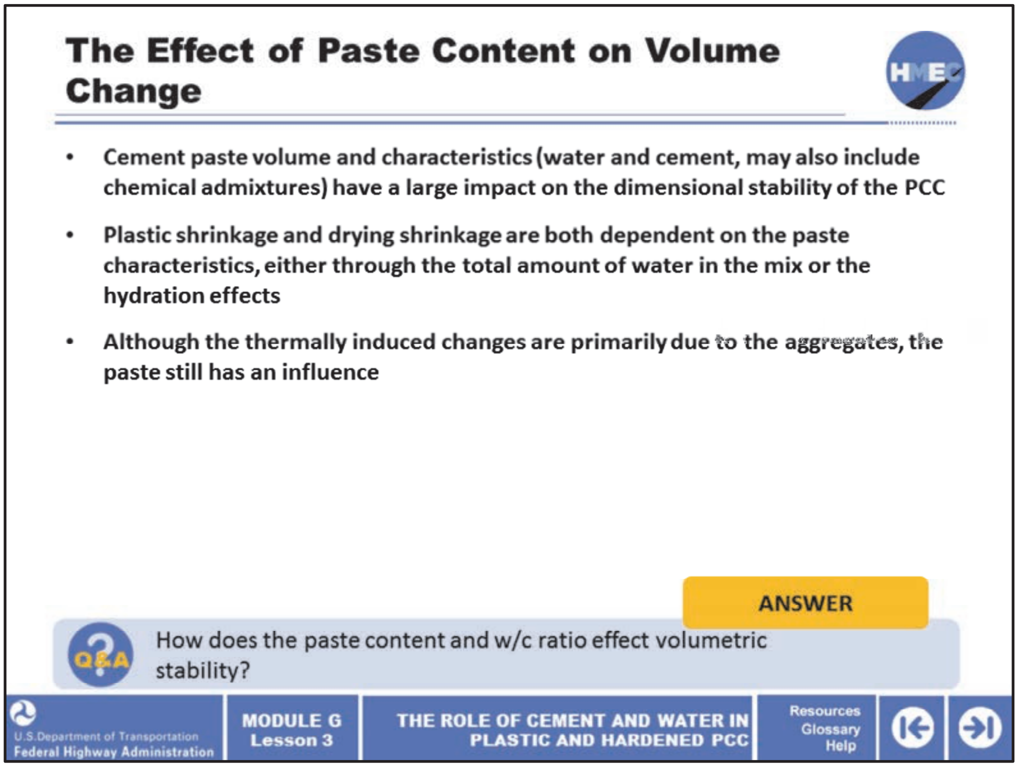
Volume changes in PCC are inherent in the behavior of the material. We can, however, control the magnitude of the changes. The following screens will address why the changes occur and the most effective means of control.



There are a number of mix-related factors that influence volume changes in PCC including:

- Aggregate type, quality, and cleanliness;
- Aggregate size;
- Aggregate proportions;
- Cement type;
- Total water content;
- Total paste content; and
- Admixtures.

Volume changes are also a result of environmental conditions, such as temperature and moisture.

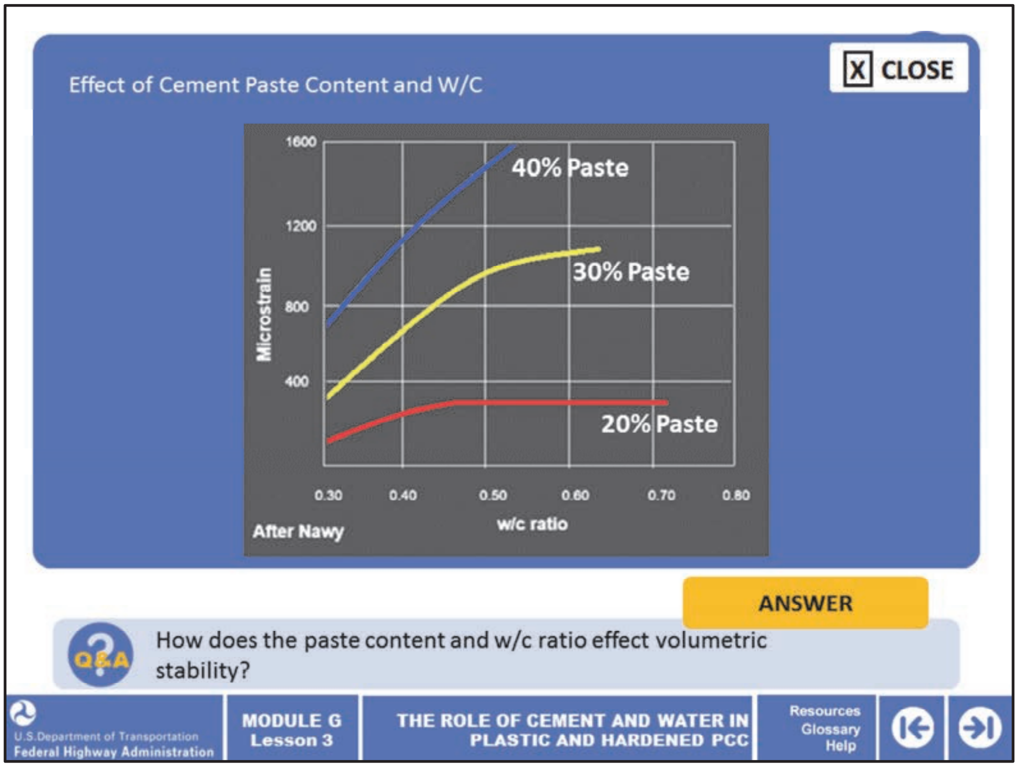


The cement paste volume and characteristics have a large impact on the dimensional stability of the PCC.

Plastic shrinkage and drying shrinkage are both dependent on the paste characteristics, either through the total amount of water in the mix or the hydration effects. Although the thermally induced changes are primarily due to the aggregates, the paste still has an influence.

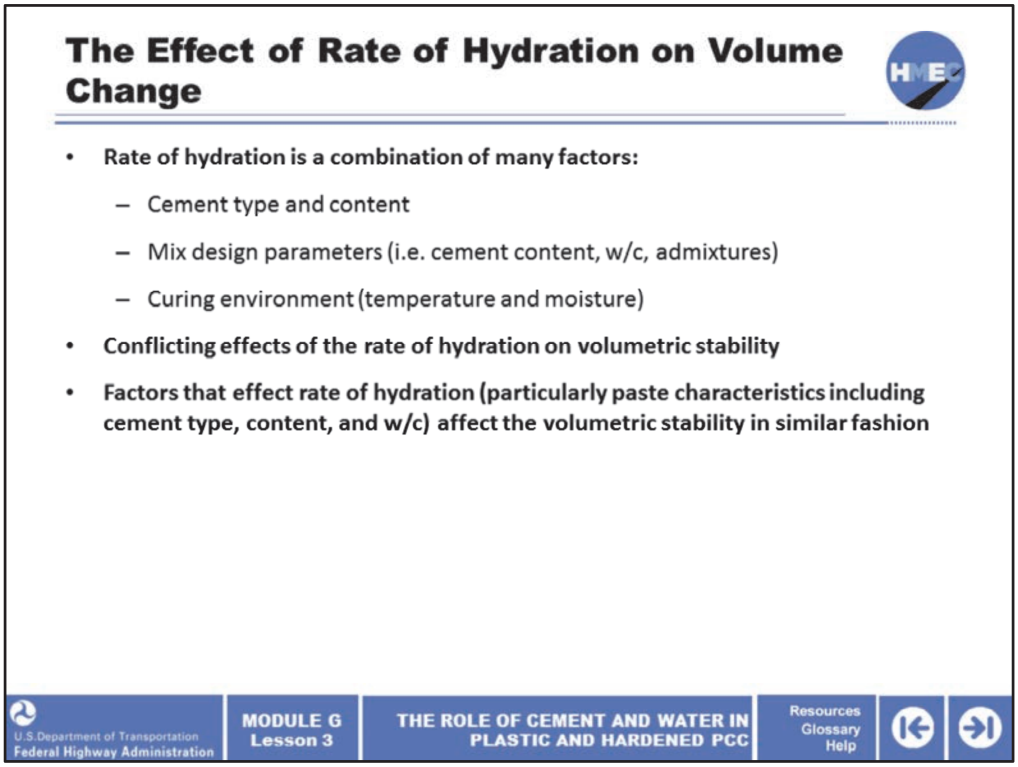
In order to control the dimensional stability of PCC, it is necessary to control the amount of paste as well as its characteristics. For instance, minimizing the cement content will reduce the amount of water required thereby leading to a reduction in drying shrinkage.

Select the box to answer the question: How does the paste content and w/c ratio effect volumetric stability?



As can be seen in this graph, increasing either the paste content or w/c ratio has dramatic effects on dimensional stability. Keep in mind that increasing the paste content at a fixed w/c has the effect of adding additional mix water to the PCC. This translates directly into increased drying shrinkage.

Image description: Graph of the effect of cement paste content and w/c.



The rate of hydration is a combination of many factors, such as:

- Cement type and content;
- Mix design parameters; and
- Curing environment.

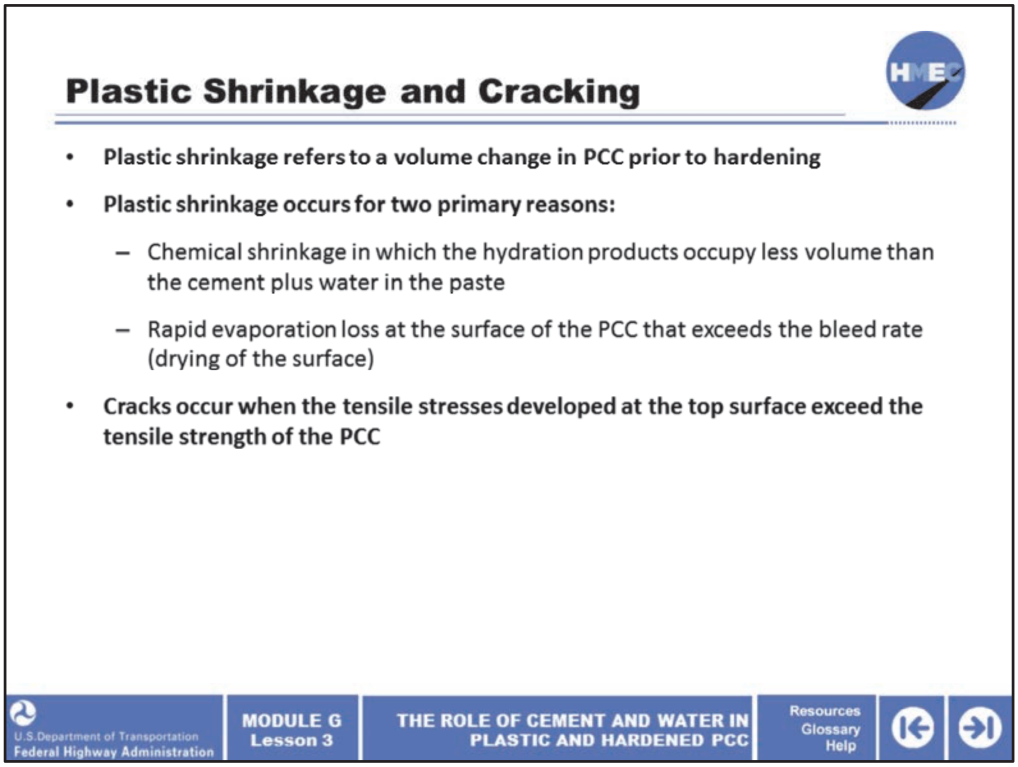
There are somewhat conflicting effects of the rate of hydration on volumetric stability. In the previous lesson, we looked at the factors above and how they influence the rate of hydration, evolved heat, and rate of strength gain.

The effects of the rate of hydration covered in the previous lesson should be looked at in terms of the current topic.

In other words, the factors that effect rate of hydration (particularly paste characteristics including cement type, content, and w/c) affect the volumetric stability in a similar fashion.

For instance, a rapid setting mix using a high cement content and low w/c ratio still requires a large volume of mix water. The result is increased drying shrinkage. The rapid strength gain also means that under adverse weather conditions (hot, windy, low humidity), the chances for plastic shrinkage cracking are high.

The following screens will provide additional information regarding the implications of rate of hydration.



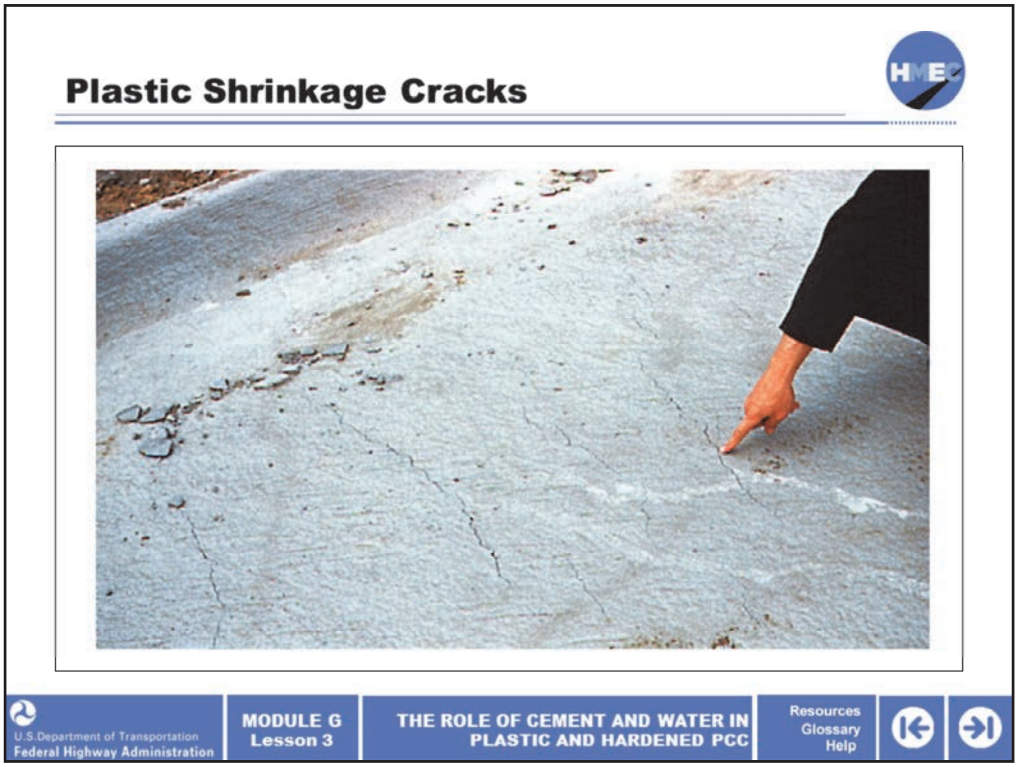
Plastic shrinkage refers to a volume change in PCC prior to hardening. Plastic shrinkage occurs for two primary reasons:

- Chemical shrinkage in which the hydration products occupy less volume than the cement plus water in the paste; and
- Rapid evaporation loss at the surface of the PCC that exceeds the bleed rate.

Cracks occur when the tensile stresses developed at the top surface exceed the tensile strength of the PCC.

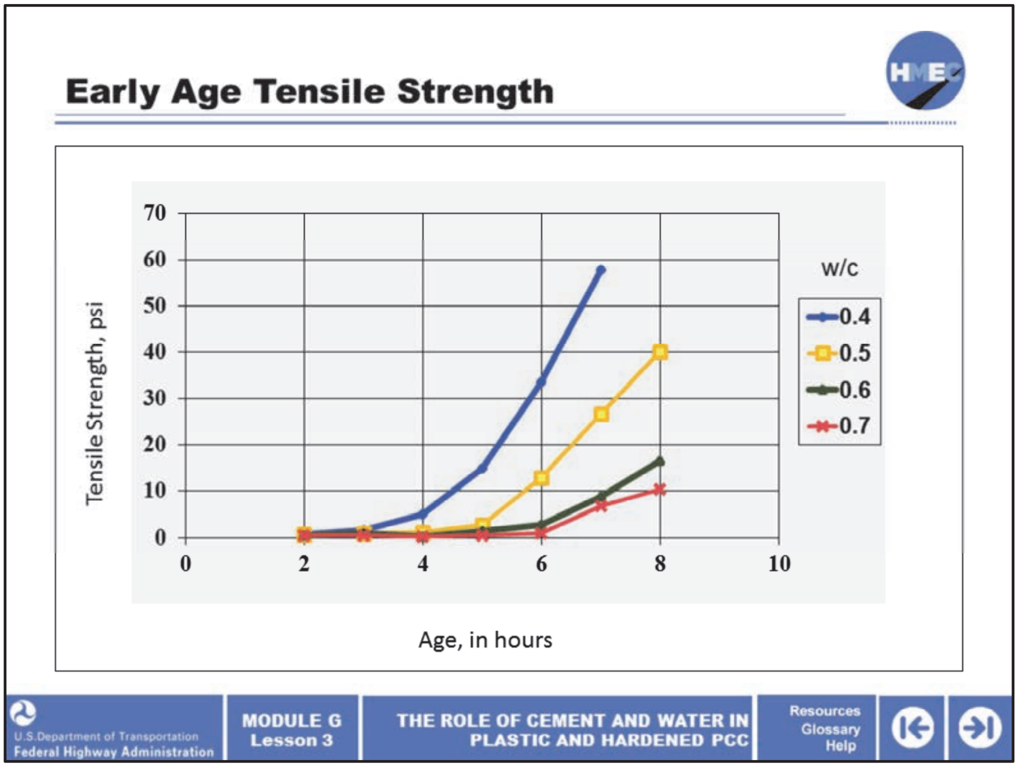
Plastic shrinkage cracking is generally a hot weather concreting issue but it can occur anytime the rate of evaporation is very high (for instance hot, windy conditions with low humidity).

In order to control or eliminate plastic shrinkage cracking, the rate of surface evaporation must be controlled until the PCC has sufficient tensile strength to resist the tensile stresses.



The cracks in this photo are roughly parallel to one another. Plastic shrinkage cracks are usually perpendicular to the wind direction unless the wind is swirling in multiple directions.

Image description: Photo of plastic shrinkage cracks.

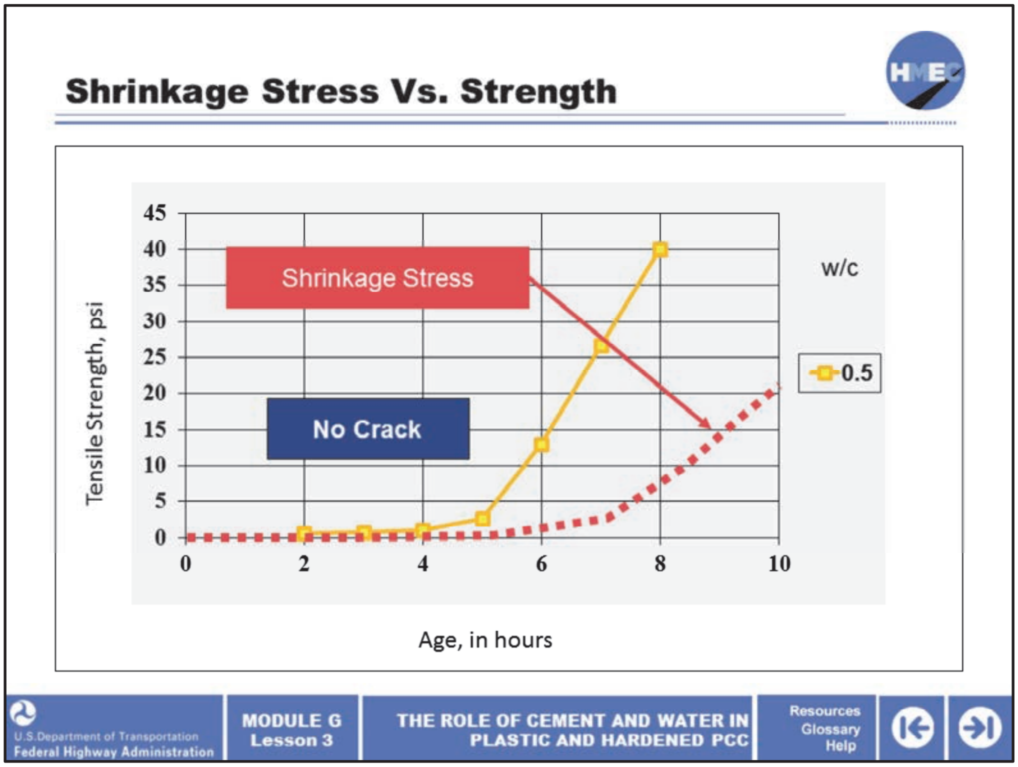


The tensile strength of PCC at early ages is a function of mix design, cement type, and ambient conditions.

As can be seen in the graph, the effect of w/c ratio is very pronounced.

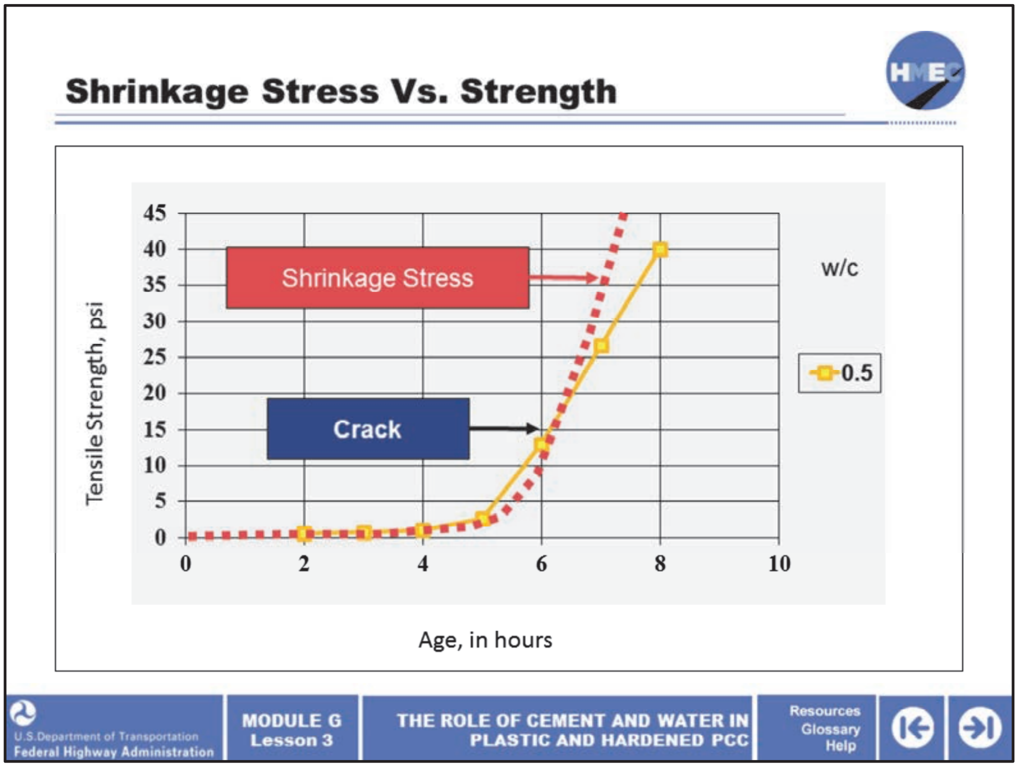
Because of the difficulty (and cost) required to dramatically improve the tensile strength development at early ages, controlling other factors are generally more feasible.

Image description: Graph of tensile strength of PCC.



When the shrinkage stress remains below the level of tensile strength, no cracks will develop.

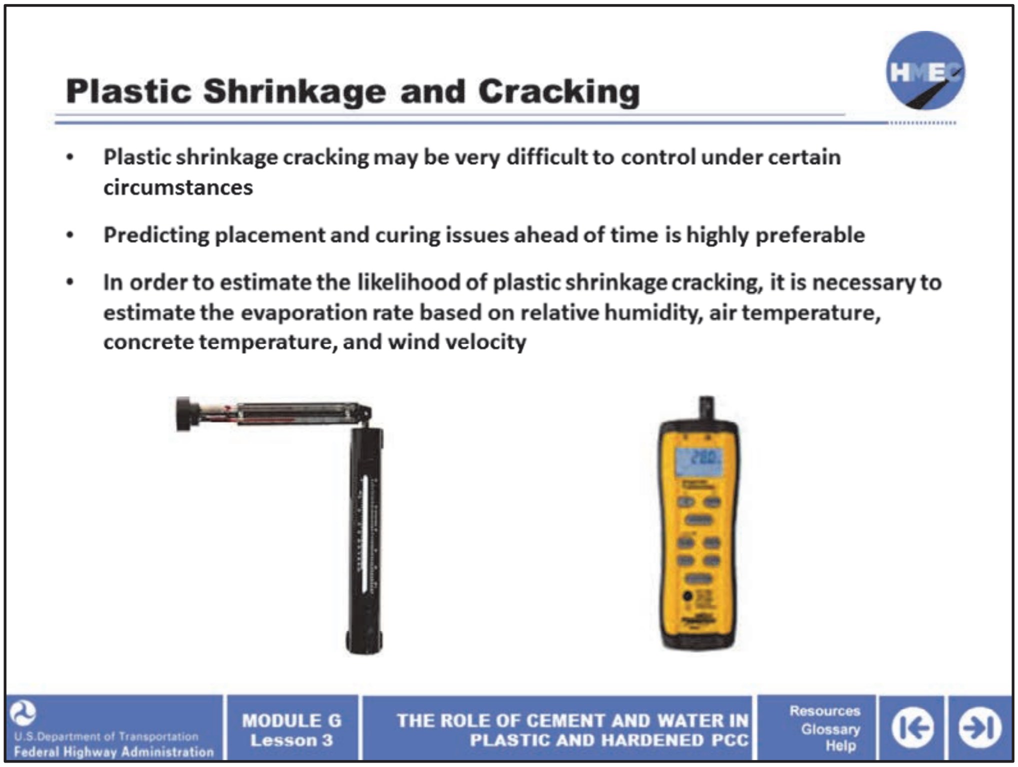
Image description: Graph of shrinkage stress.



When the shrinkage stress exceeds the tensile strength of the PCC, stress relief resulting in a crack will occur. In the graph above, cracking will occur in one or more locations at approximately six hours after batching.

Note that the tensile strength development is a function of when the hydration reactions initiated. This occurred at the time of batching, not the time of final placement, assuming that retarding admixtures were not used.

Image description: Graph of shrinkage stress exceeding tensile strength of the PCC.



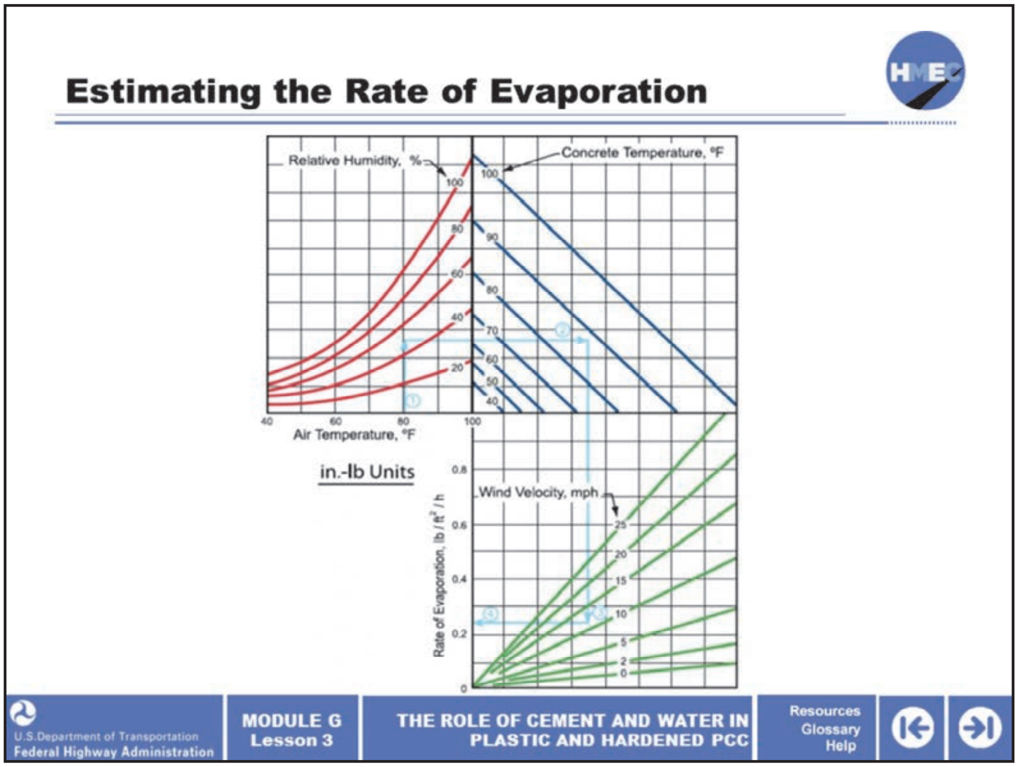
Plastic shrinkage cracking may be very difficult to control under certain circumstances. Predicting placement and curing issues ahead of time is highly preferable. Instruments are readily available that will permit estimation of the evaporation rate based on relative humidity, air temperature, concrete temperature, and wind velocity.

The electronic measurement tools to estimate the evaporation rate at the time of placement are both easy to use and relatively accurate.

However, the decision of whether to allow placement under highly adverse conditions will still have to be made .

Image description: Photo of a manual sling psychrometer.

Image description: Photo of a digital version of a sling psychrometer.



This is a common method for estimating the rate of evaporation of water from the surface of a body of water for a given water temperature, air temperature, air humidity, and wind speed. This estimates the potential for evaporation due to environmental conditions, and does not necessarily estimate the rate of evaporation of water from a concrete surface. It is sometimes used to approximately assess the severity of environmental conditions on a given job site.

To use the chart, the wind speed is measured on site, 20 inches above evaporating surface. The air temperature and humidity are also measured on site, upwind, and 4–6 feet above the evaporating surface.

Image description: Chart showing evaporation of surface moisture from concrete.

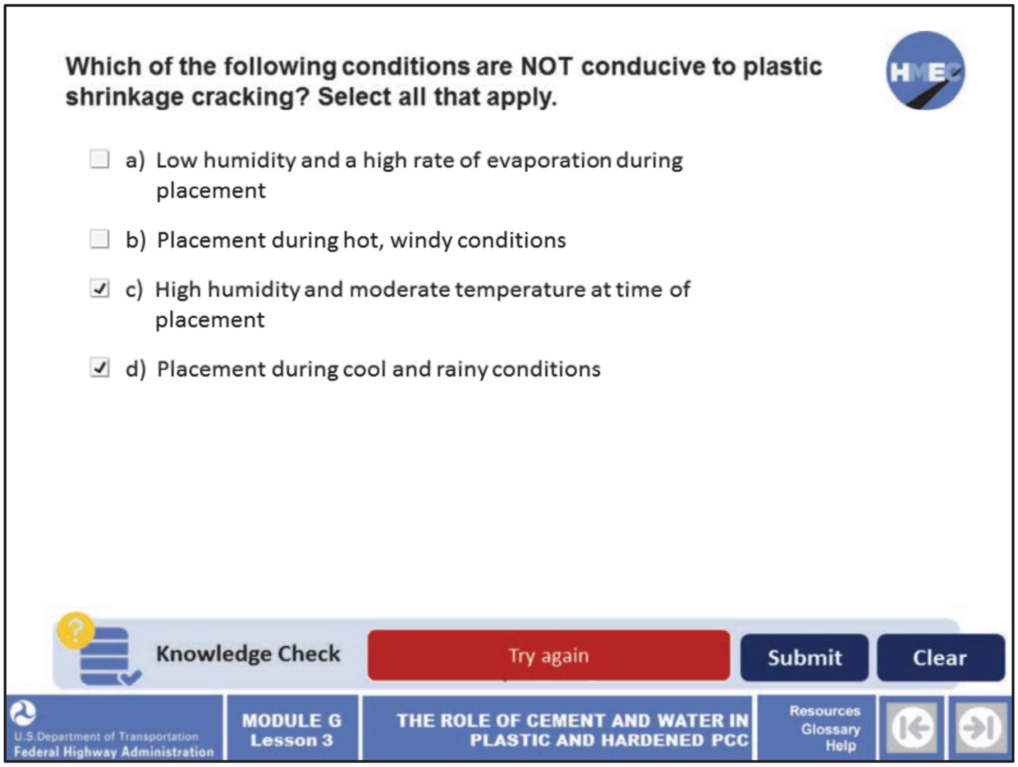
When environmental conditions make it likely that water will be evaporated too quickly from the concrete surface, it is good practice to alter this environment by increasing the humidity of the air.

This is done with the fog-sprayer. The intent of the fog-sprayer is not to dampen the concrete surface but to humidify the air above the concrete surface.

This is an important procedure for concretes that have a low bleeding rate and therefore a low tolerance to evaporative water loss.

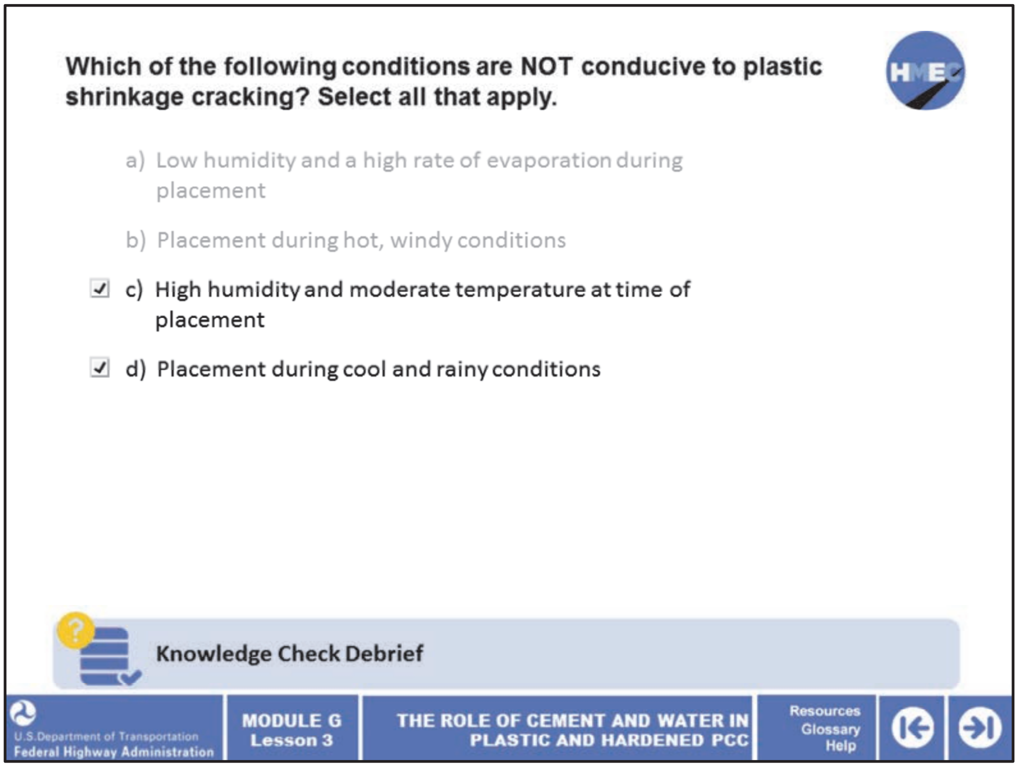
Mixes with fly ash, silica fume, superplasticizer, or high air content can have a low bleeding rate.

Image description: Photo of fogging a bridge deck.

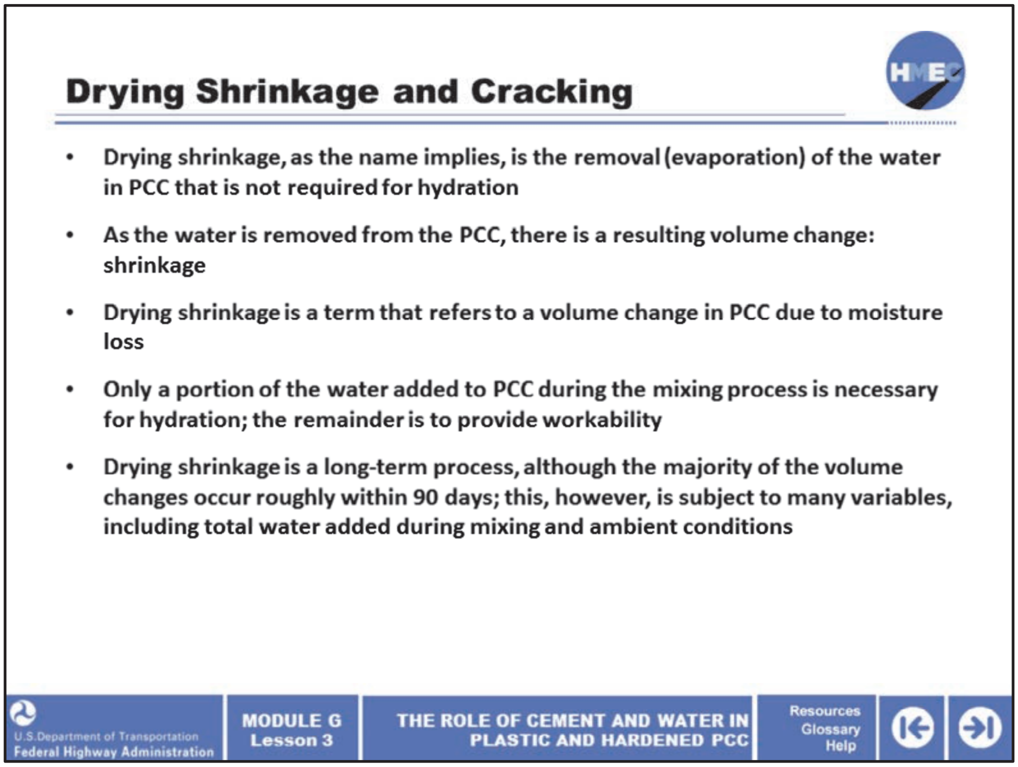


Which of the following conditions are NOT conducive to plastic shrinkage cracking? Select all that apply.

a) Low humidity and a high rate of evaporation during placement;
b) Placement during hot, windy conditions;
c) High humidity and moderate temperature at time of placement; and
d) Placement during cool and rainy conditions.



The correct answers are c) High humidity and moderate temperature at time of placement and d) Placement during cool and rainy conditions. The ideal conditions for plastic shrinkage cracking to occur are hot, windy conditions with low humidity. The rate of evaporation at the surface of the PCC is the controlling factor.

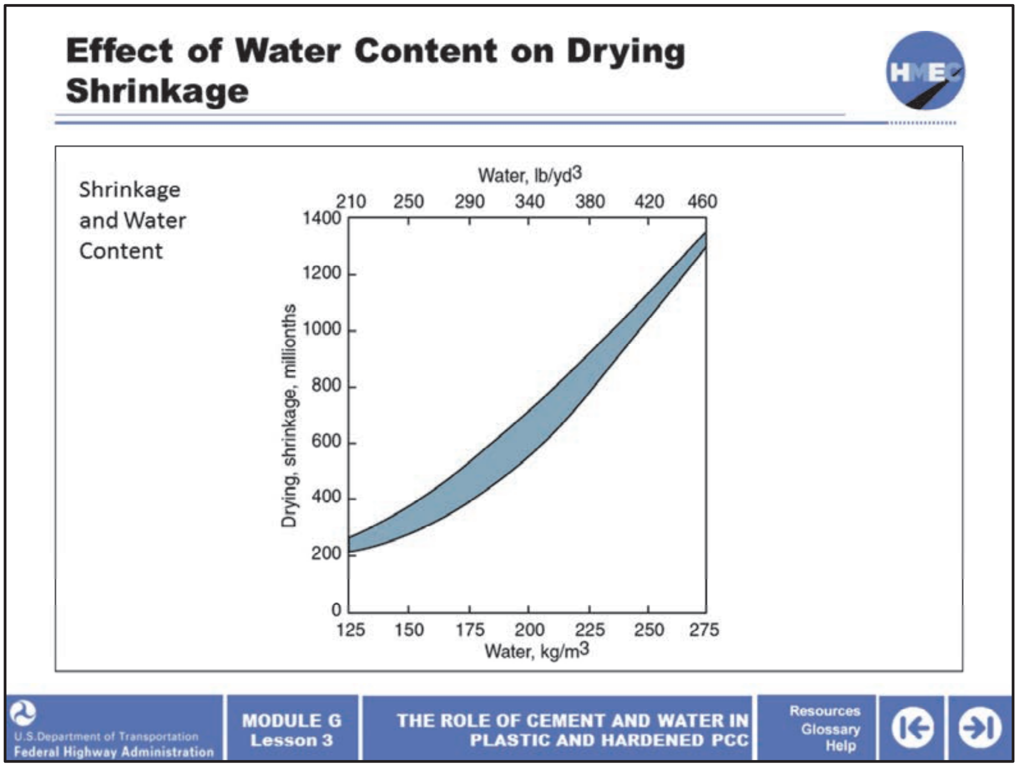


Drying shrinkage, as the name implies, is the removal (evaporation) of the water in PCC that is not required for hydration. As the water is removed from the PCC, there is a resulting volume change: shrinkage. Drying shrinkage is a term that refers to a volume change in PCC due to moisture loss.

Only a portion of the water added to PCC during the mixing process is necessary for hydration; the remainder is to provide workability. Drying shrinkage is a long-term process, although the majority of the volume changes occur roughly within 90 days. This, however, is subject to many variables, including total water added during mixing and ambient conditions.

Hardened concrete experiences slight expansion and contraction throughout its life as a function of moisture (i.e., relative humidity). However, drying shrinkage is a substantial change in volume and occurs at a relatively early age.

For typical mixes, approximately ½ of the water is used for hydration; the remaining water is responsible for the early stages of drying shrinkage.



This graph illustrates the effect of water content on drying shrinkage potential.

Drying shrinkage is primarily a function of the volume of water in the PCC mix. As can be seen in the graph, relatively minor changes in total water content can have a significant impact on drying shrinkage.

The drying shrinkage is also somewhat controlled by environmental conditions (primarily humidity).

Image description: Shrinkage and water content graph.

Effect of W/C Ratio on Drying Shrinkage

- **Drying shrinkage is difficult to eliminate, but is relatively easy to control by lowering the amount of total water in the mix**

Cement Content and Drying Shrinkage*

Cement Content, bags/cu yd.	Water Content, cu yd.	Water-Cement Ratio	Shrinkage, %
5	0.20	0.72	0.03
6	0.21	0.62	0.03
7	0.21	0.54	0.03
8	0.21	0.46	0.03

* 3x3x10-in. prisms cured wet 7 days, dried 14 days

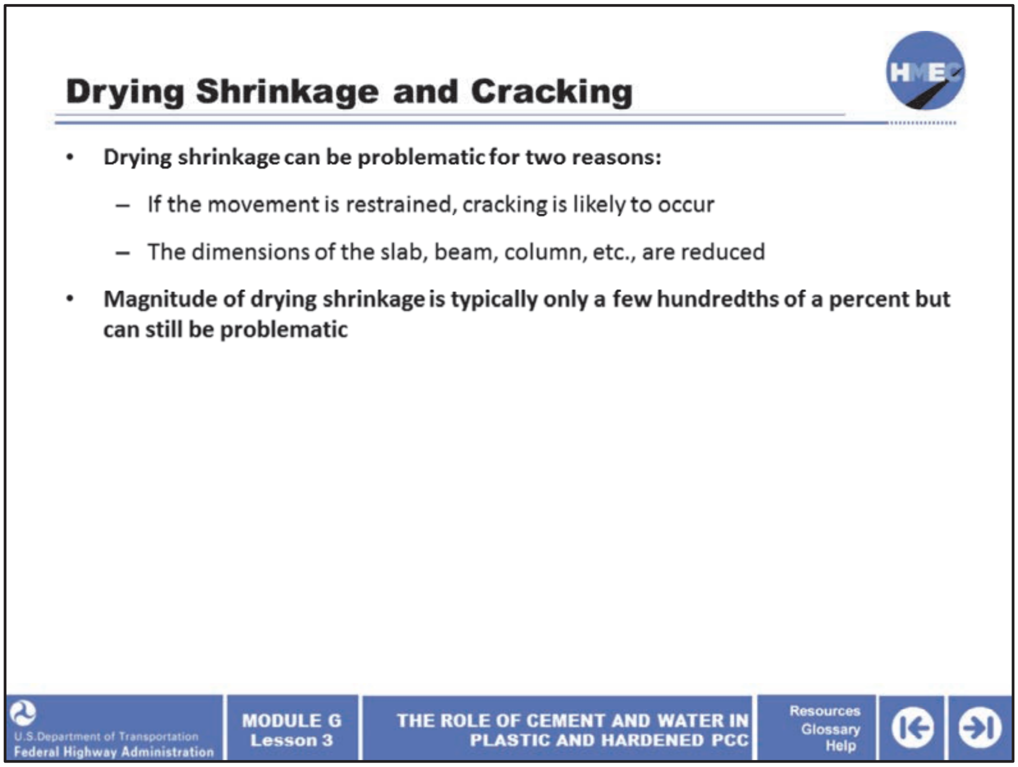
Total water, not w/c ratio, is important in controlling drying shrinkage

Drying shrinkage is difficult to eliminate but is relatively easy to control by lowering the amount of total water in the mix. This screen illustrates the effect of w/c ratio. It is interesting to note that the w/c ratio seems to have no appreciable effect on the drying shrinkage.

Taking this to the next level, you have to lower the cement content if you need to reduce the overall water content at an already low w/c ratio. We will discuss this in greater detail in the mix proportioning lesson.

The important point to remember is that total water, not w/c ratio, is important in controlling drying shrinkage.

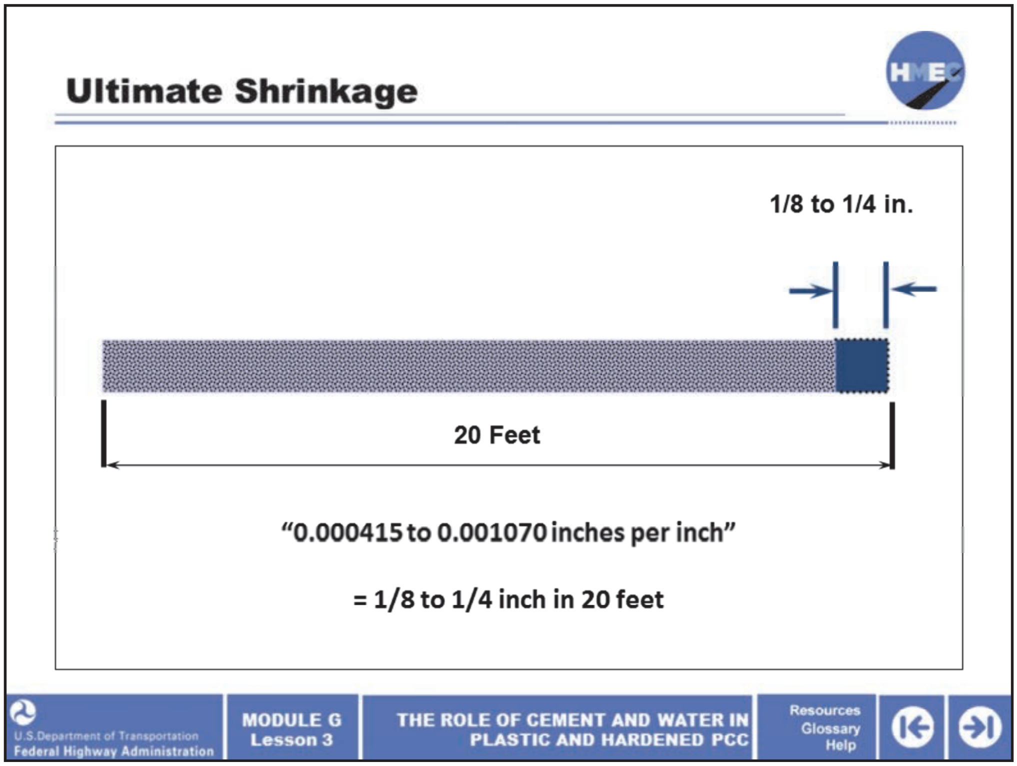
Image description: Cement content and drying shrinkage table.



Drying shrinkage can be problematic for two reasons:

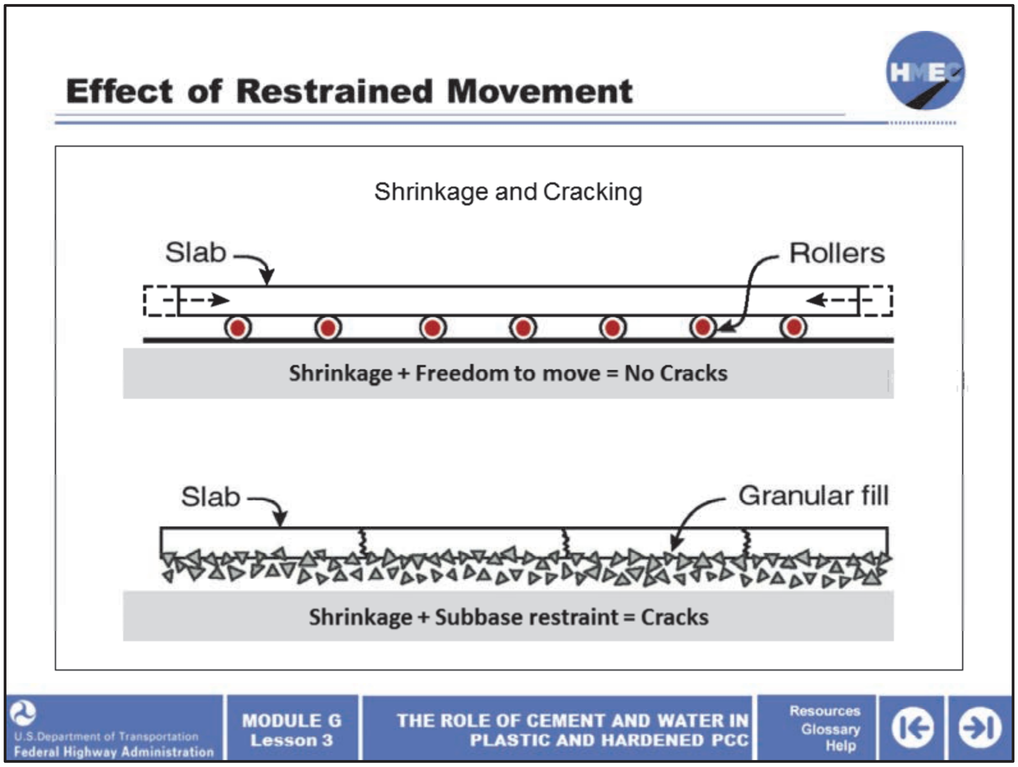
- If the movement is restrained, cracking is likely to occur; and
- The dimensions of the slab, beam, column, etc., are reduced.

The magnitude of drying shrinkage is typically only a few hundredths of a percent but can still be problematic.



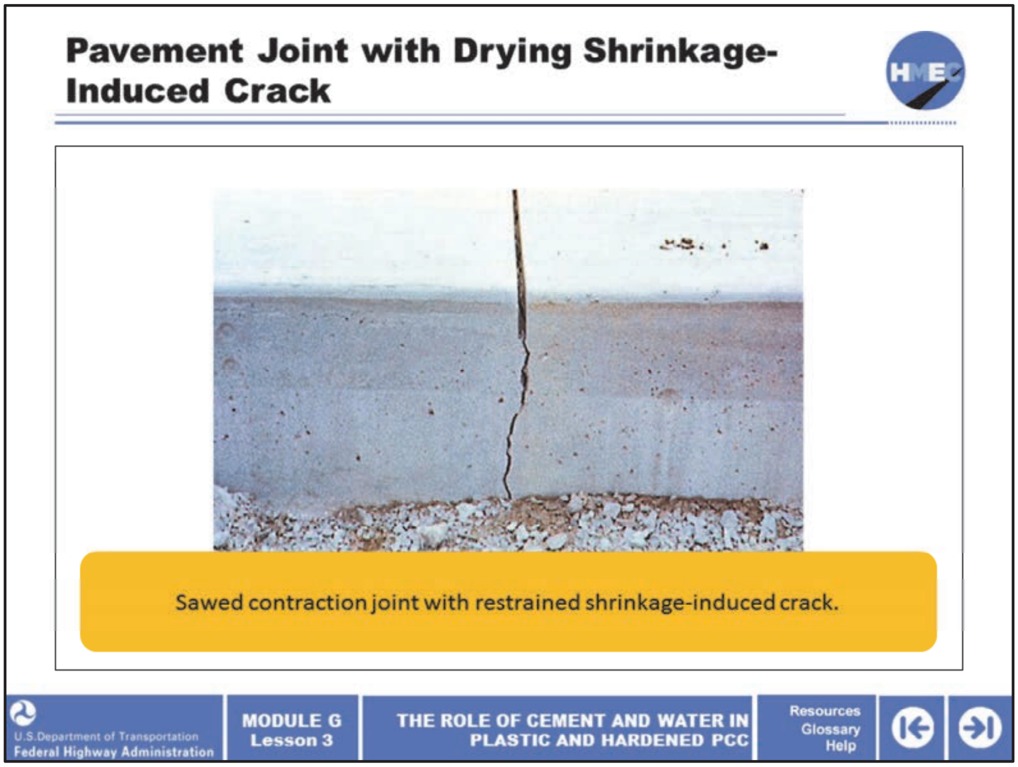
This image represents an example of typical drying shrinkage in a concrete pavement slab.

Image description: Typical drying shrinkage illustration.



It is important to note that unrestrained drying shrinkage does not result in the build-up of significant internal stresses. Therefore, there is no cracking. However, external restraint of the drying shrinkage-induced movement will typically result in cracking.

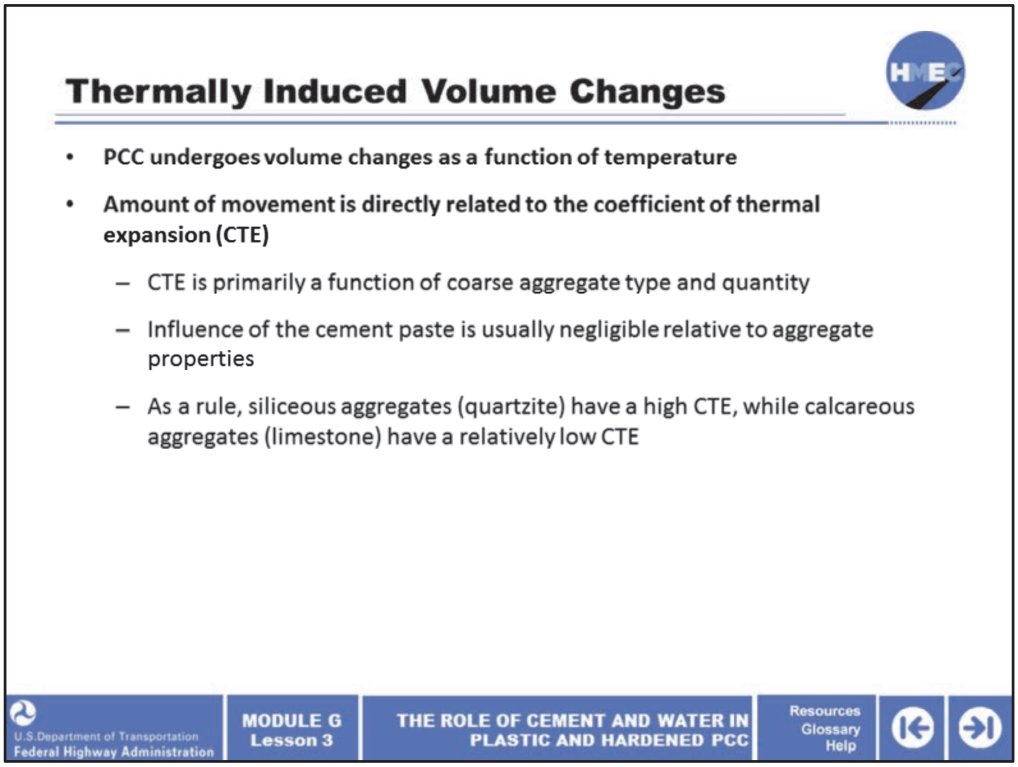
Image description: Illustration of shrinkage and cracking with rollers and shrinkage and cracking with granular fill.



Pavement contraction joints are sawed to control where cracks will occur, not to prevent them. The photo shows a sawed joint with a restrained movement crack (due primarily to drying shrinkage). The saw cut results in a weakened plane, which leads to the development of a crack as the pavement undergoes initial drying shrinkage and later, thermal movement.

The controlled crack, as shown in the photo, is desirable to relieve internal stresses in the pavement slab. The spacing of the saw cuts (jointing pattern) is based on the PCC material characteristics, environmental conditions, and the friction developed at the base/PCC interface.

Image description: Photo of a sawed contraction joint in a pavement.

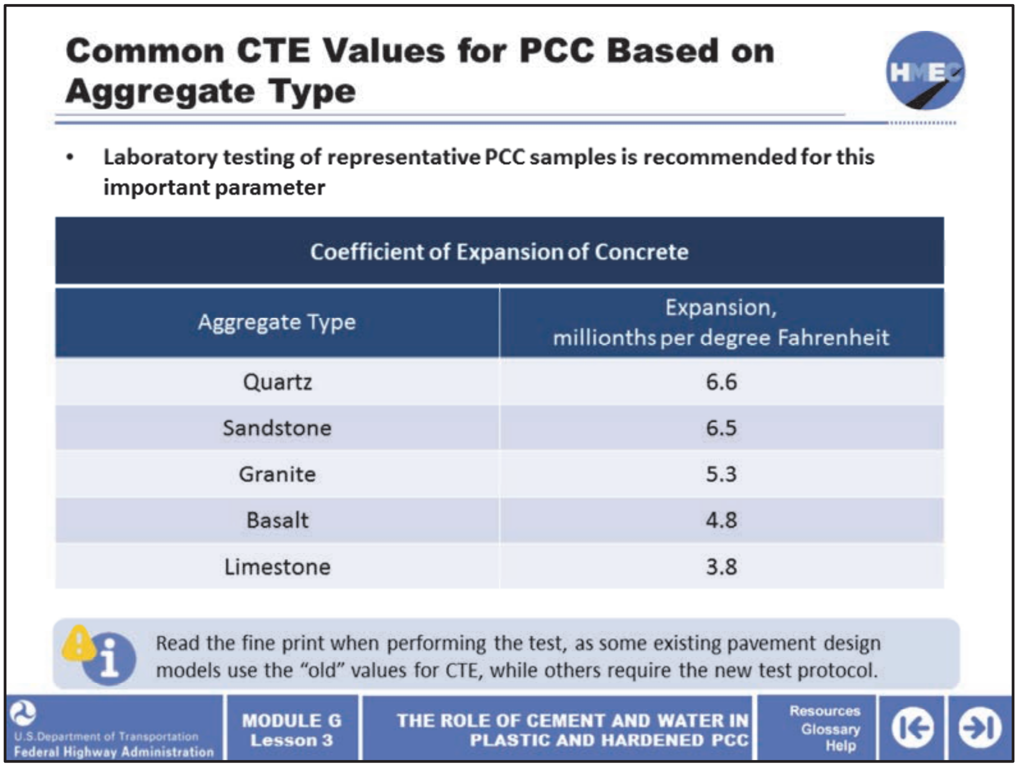


PCC undergoes volume changes as a function of temperature. The amount of movement is directly related to the coefficient of thermal expansion (CTE).

• The CTE is primarily a function of coarse aggregate type and quantity;
• The influence of the cement paste is usually negligible relative to aggregate properties; and
• As a rule, siliceous aggregates have a high CTE, while calcareous aggregates have a relatively low CTE.

The thermal expansion and contraction of PCC is now considered a very important parameter in pavement design following the adoption of the Mechanistic-Empirical Pavement Design Guide (MEPDG).

Curling stresses in slabs due to differential temperatures with slab depth are a predominant design consideration to changes in slab shapes and the location of imposed loads.

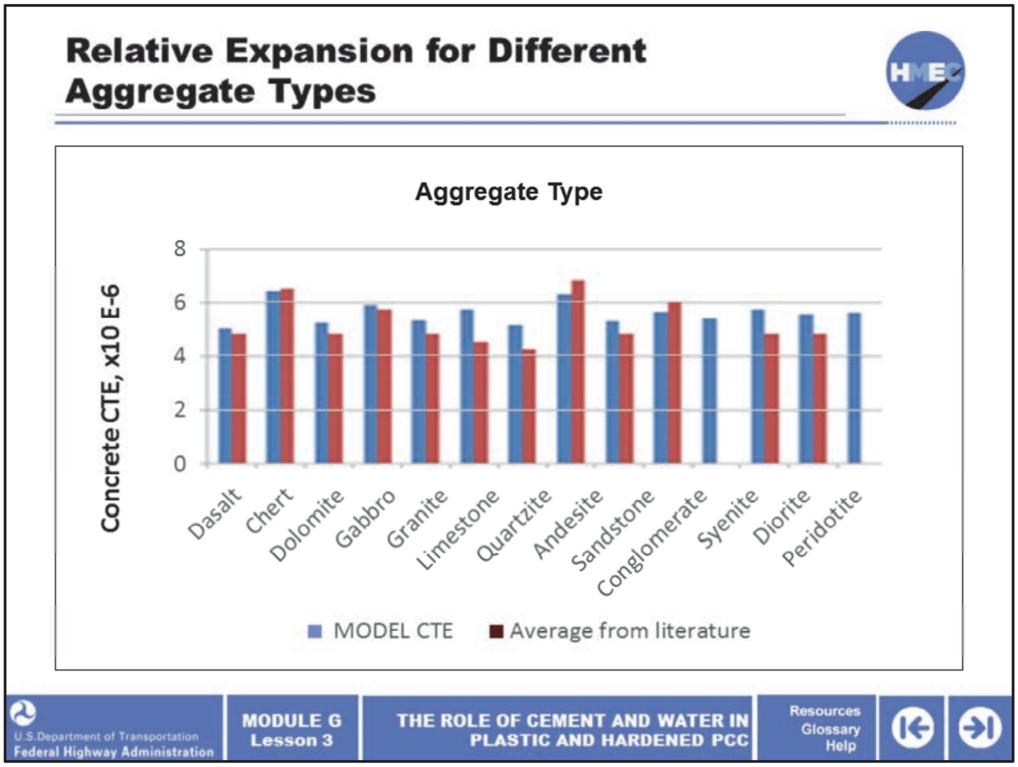


This table shows the approximate CTE values for a variety of common aggregate types. Note that the testing protocol for determining the CTE has changed in recent years.

Laboratory testing of representative PCC samples is recommended for this important parameter.

Read the fine print when performing the test, as some existing pavement design models use the “old” values for CTE, while others require the new test protocol.

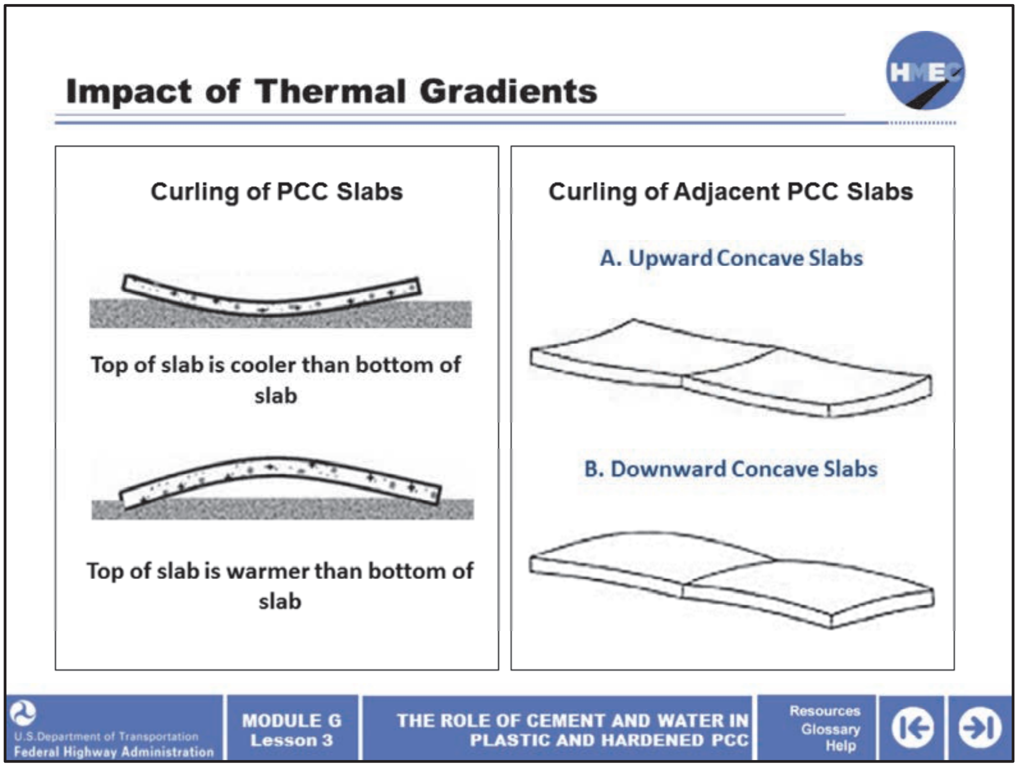
Image description: Coefficient of expansion of concrete table.



Depending on the aggregate type, the amount of expansion and contraction in PCC can be quite high with dramatic fluctuations in temperature.

Note that calcareous aggregates (i.e. limestone) have a relatively low CTE, while siliceous aggregates (i.e. quartzite) are very high by comparison. This difference has significant implications as shown on the following slide.

Image description: Graph of CTE as a function of aggregate type.



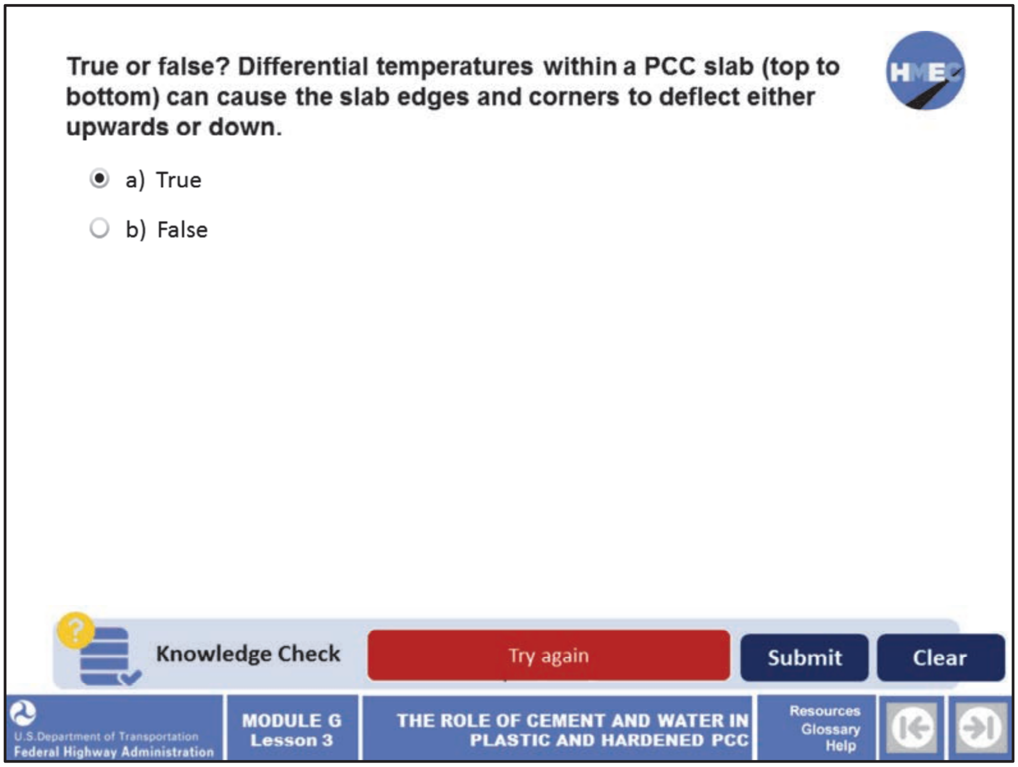
This screen shows the effects of non-uniform temperatures or temperature gradients on expansion characteristics. Temperature differentials in PCC slabs, as pictured here, are a significant design consideration.

The primary issue is when the top of the slab is cool relative to the bottom. The result is that the slab edges, and particularly the corners, are raised relative to the center of the slab. These "unsupported corners" are then subjected to much higher tensile stresses at the top when a load is applied or simply by the weight of the slab.

The use of low CTE mixes (aggregates) minimizes this effect.

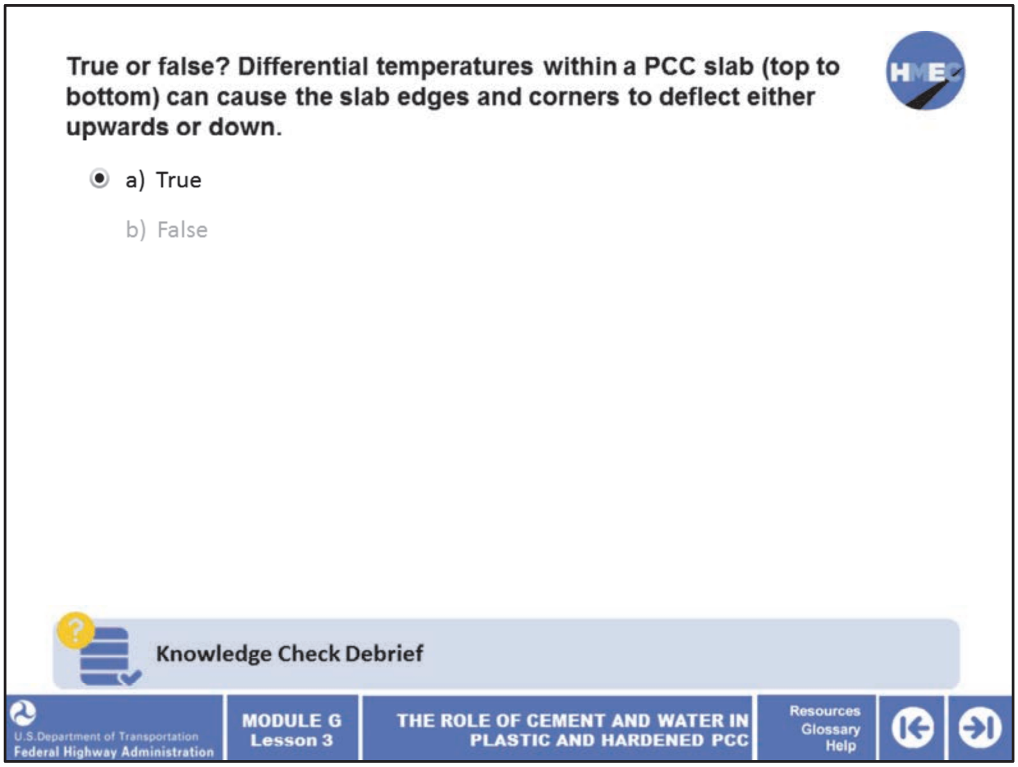
Image description: Diagram showing curling of PCC slabs.

Image description: Diagram showing curling of adjacent PCC slabs.

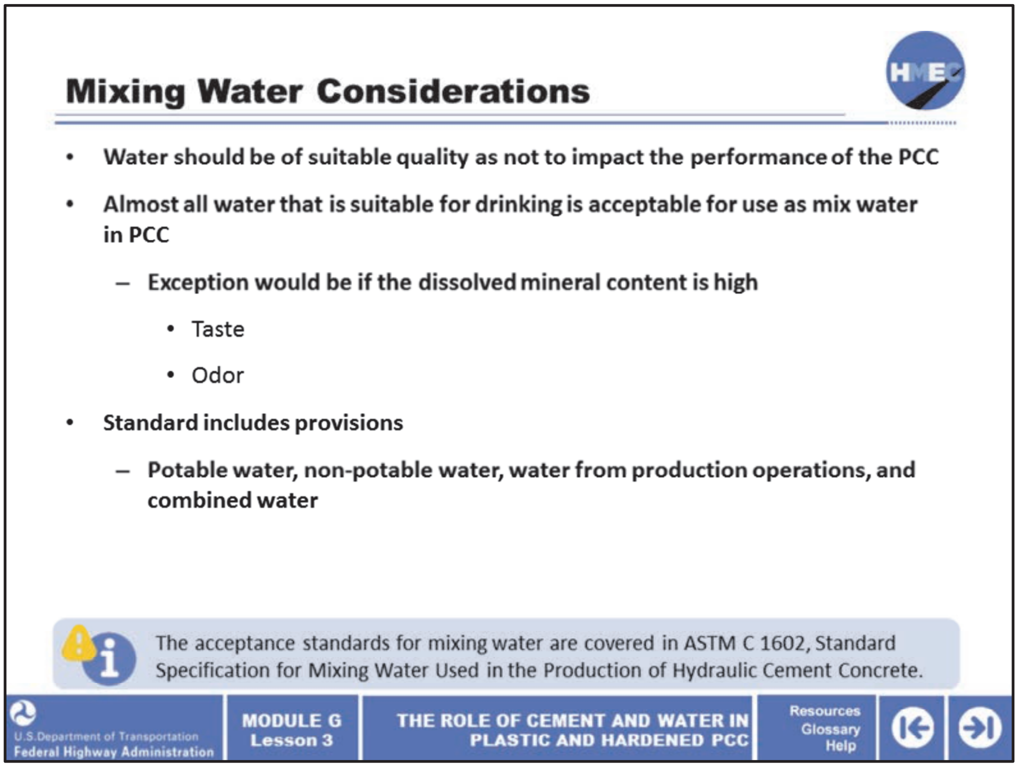


True or false? Differential temperatures within a PCC slab (top to bottom) can cause the slab edges and corners to deflect either upwards or down.

a) True; or
b) False?



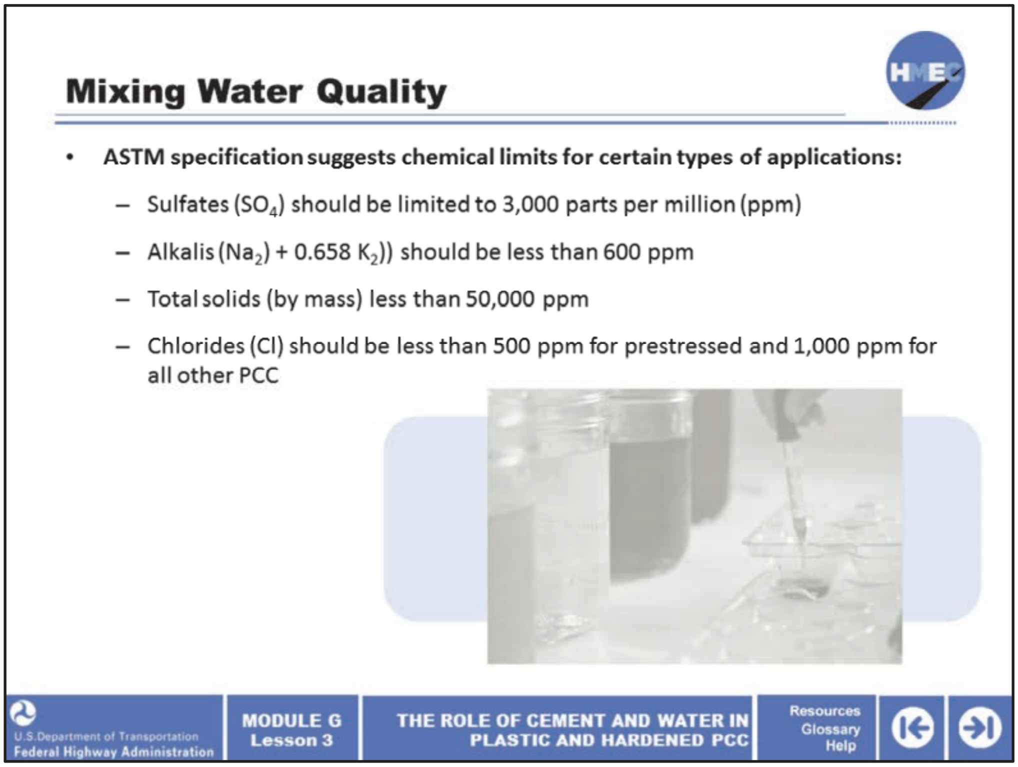
The correct answer is a) True. Curling in pavement slabs is based on the coefficient of thermal expansion (CTE) of the PCC and the difference in temperature between the top and bottom of the slabs. PCC with a high CTE can move a significant amount with large temperature fluctuations.



Water is required for the hydration of cement and therefore must be of suitable quality so as not to interfere with the hydration reactions. In other words, water should be of suitable quality as not to impact the performance of the PCC. As a rule, almost all water that is suitable for drinking is acceptable for use as mix water in PCC. The exception would be if the dissolved mineral content is high. (Taste and odor would be good indicators of this).

This standard includes provisions for potable water, non-potable water, water from production operations, and combined water. Under the specification guidelines, all potable water is automatically qualified for used in PCC production. If the water from the other sources is questionable, it should be tested to ensure that it does not impact performance. The most common impacts of poor quality mixing water is a reduction in strength and a deviation from normal set time.

Note that the acceptance standards for mixing water are covered in ASTM C 1602, Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete.



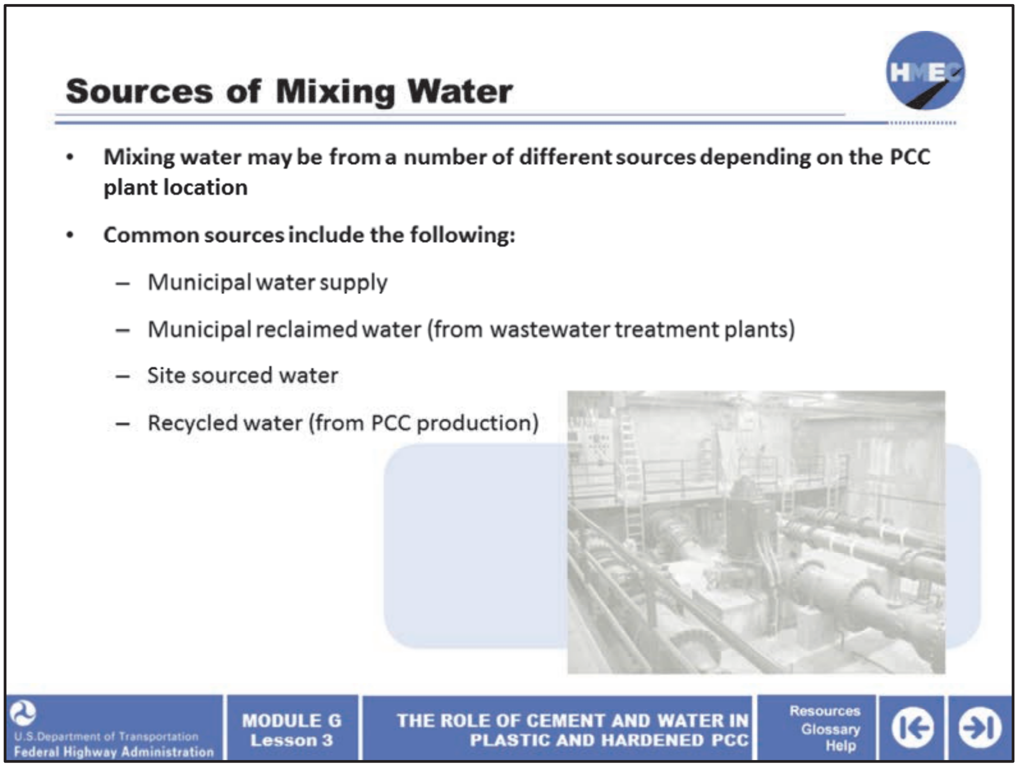
The ASTM specification suggests chemical limits for certain types of applications.

- Sulfates (SO_4) should be limited to 3,000 parts per million (ppm);
- Alkalis (Na_2) + 0.658 K_2)) should be less than 600 ppm;
- Total solids (by mass) less than 50,000 ppm; and
- Chlorides (Cl) should be less than 500 ppm for prestressed and 1,000 ppm for all other PCC.

In addition, organic impurities in the water can have a sizable effect on set time, rate of strength gain, and entrained air content.

The ASTM specification establishes guidelines for mixing water. However, the limitations for dissolved chemicals are considered optional and are frequently waived if it can be demonstrated that the water will not adversely affect performance. If $CaCl_2$ accelerating admixtures are used, the calcium limitation is always waived.

Image description: Photo of beakers filled with chemicals in a lab.



Mixing water may be from a number of different sources depending on the PCC plant location.

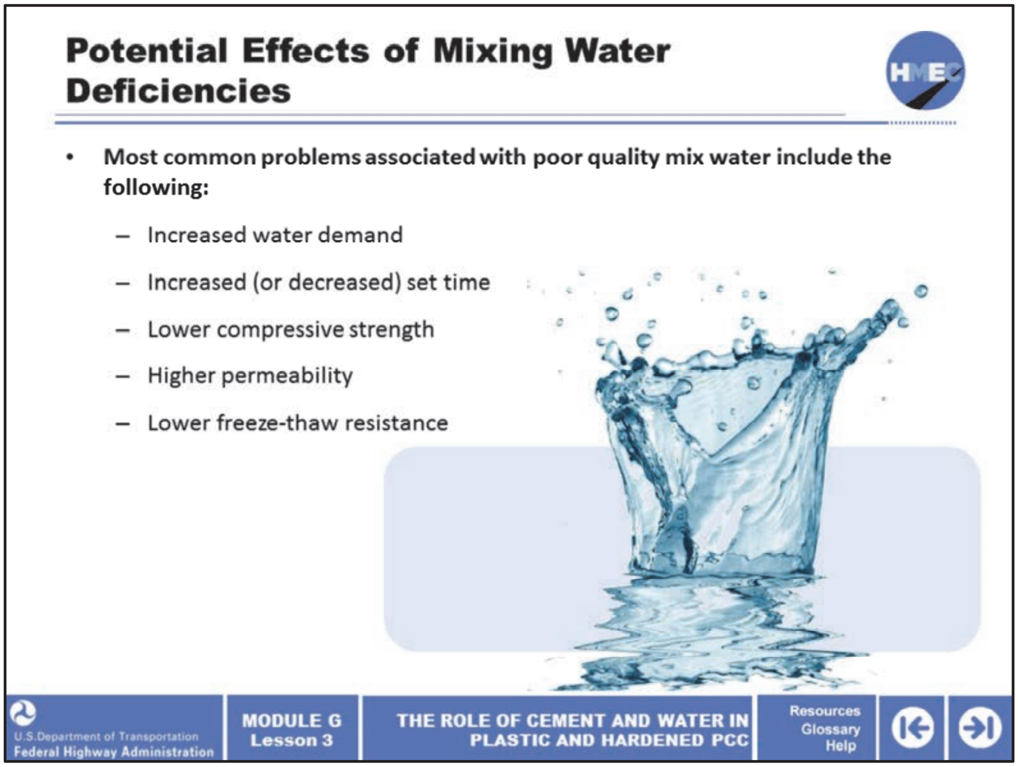
Common sources include:

• Municipal water supply – this is generally acceptable without testing;
• Municipal reclaimed water (from wastewater treatment plants) – this is also generally acceptable without testing;
• Site sourced water – remote PCC plants sometimes use well water or water from ponds, rivers, streams, etc. If there is a high solids content or algae present, testing is highly suggested;
• Recycled water (from PCC production) –this water is highly variable and may have significant impacts on performance. Most times, the water will be from settling ponds that will remove the high solids content. However, these sources should be tested and carefully monitored for changes in PCC behavior.

Note that when using recycled or reclaimed water, variations in the dissolved minerals and changes in pH can significantly alter the initial set time and the rate of strength gain (and in some cases, ultimate strength and durability). For instance, a high sulfate concentration will adversely affect hydration as will a high or low pH value.

The effects of poor quality mixing water may be readily apparent (for example, changes in initial set time), or it may be a delayed effect such as a reduction in strength. The testing procedures for water are straightforward and do not require extensive sample preparation and time. Therefore, if there is a question about the impact of a particular water source, test it or refer to historical use to see if problems were encountered.

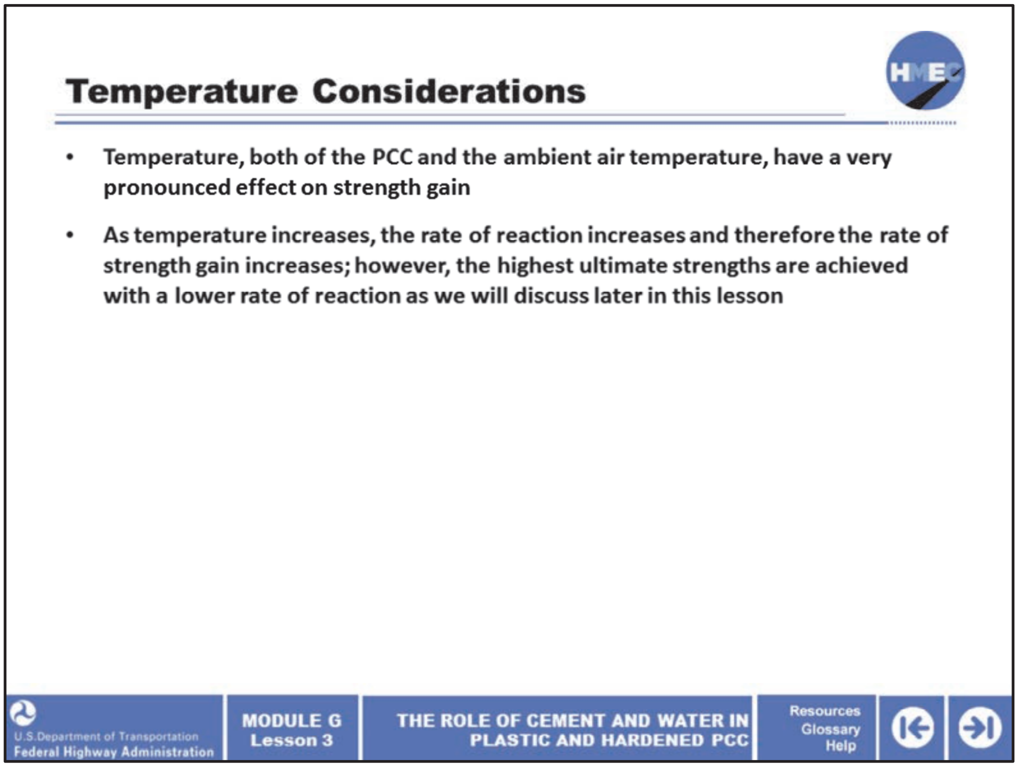
Image description: Photo of the inside of a municipal water supply plant.



The most common problems associated with poor quality mix water include:

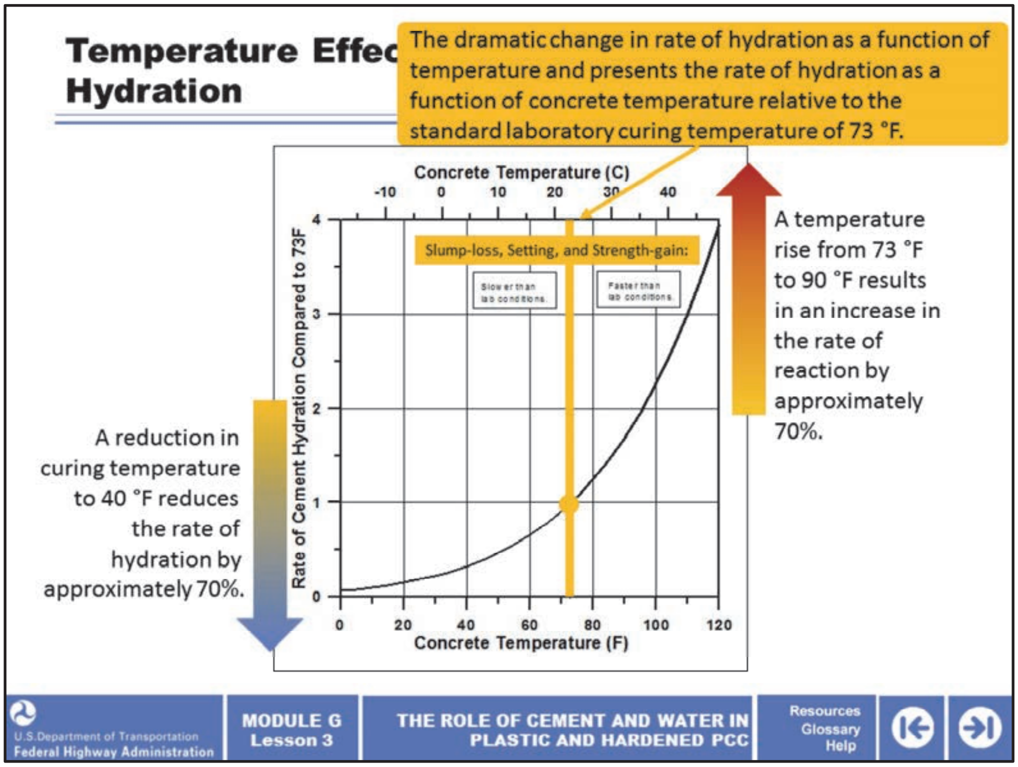
- Increased water demand;
- Increased (or decreased) set time;
- Lower compressive strength;
- Higher permeability; and
- Lower freeze-thaw resistance.

Image description: Photo of water drops.



Temperature, both of the PCC and the ambient air temperature, have a very pronounced effect on strength gain.

Temperature plays a major role in the initial set time and the rate of hydration (strength gain). High temperatures result in a faster initial set and rate of reaction while cooler temperatures have the opposite effect.

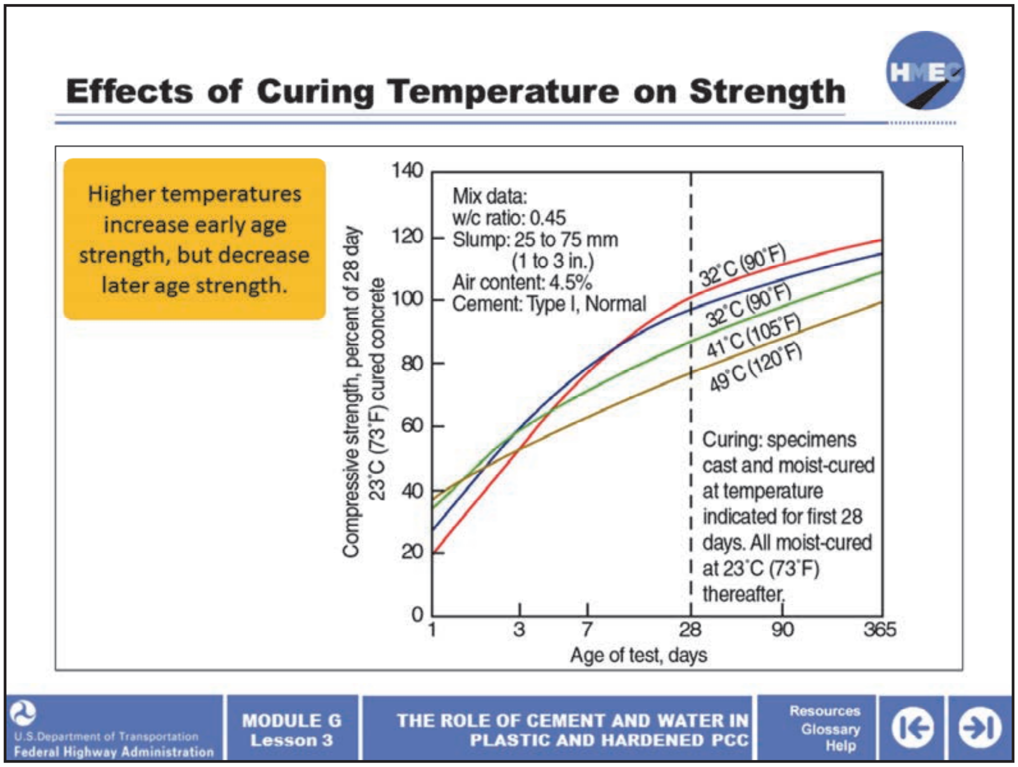


This graph shows the dramatic change in rate of hydration as a function of temperature and presents the rate of hydration as a function of concrete temperature relative to the standard laboratory curing temperature of 73 °F.

A curing temperature higher than standard conditions results in an increase in the rate of hydration. Note the non-linearity of this relationship. For instance, a temperature rise from 73 °F to 90 °F results in an increase in the rate of reaction by approximately 70%. A reduction in curing temperature to 40 °F reduces the rate of hydration by approximately 70%.

In terms of actual field placement, if a temperature of 73 °F is considered a baseline temperature, higher temperatures will result in a faster initial set time and an increased rate of strength gain. This translates into a reduction in allowable placement time (due to a loss in workability), decreased time until sawing operations can begin (pavements) or form stripping, decreased time until loads can be applied and reaching target strength more quickly. The opposite is true at temperatures less than 73 °F. This topic will be discussed at greater length in Lesson 6.

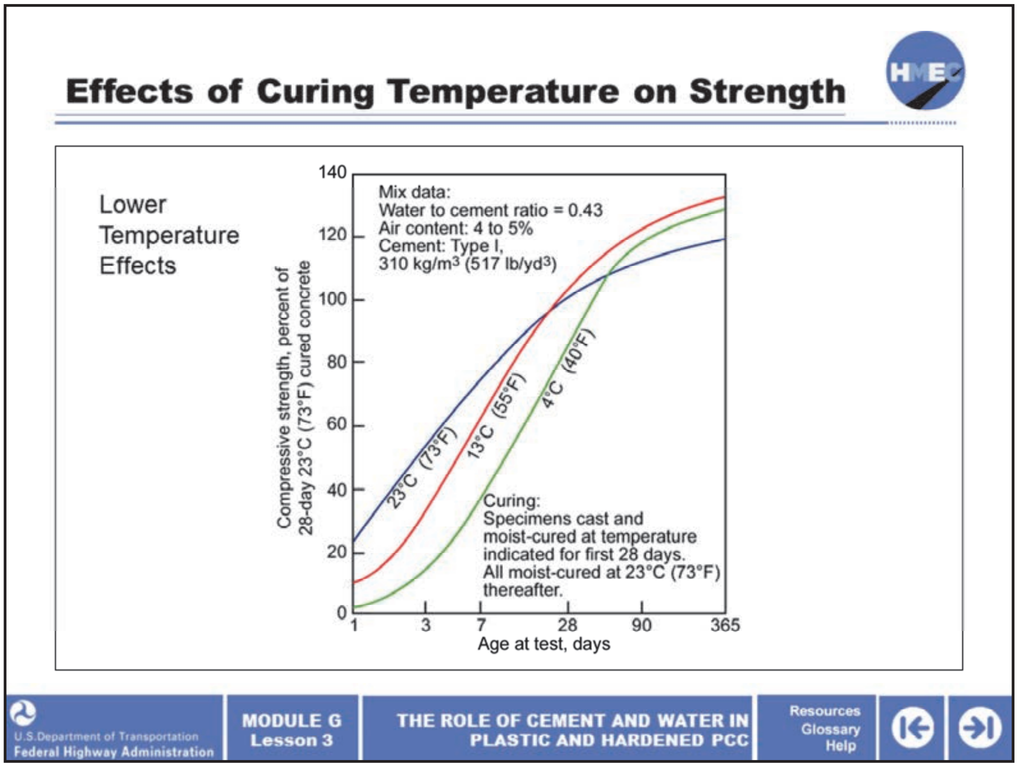
Image description: Graph showing change in rate of hydration.



The property most often considered when considering temperature effects is compressive strength. The relationship of curing temperature to strength is moderately complex and very non-linear.

These relationships were developed for a specific mix design and although the trends are valid, the absolute numbers may vary with different mixes. This graph shows that higher temperatures increase early age strength, but decrease later age strength.

Image description: Graph showing relationship of curing temperature to strength.

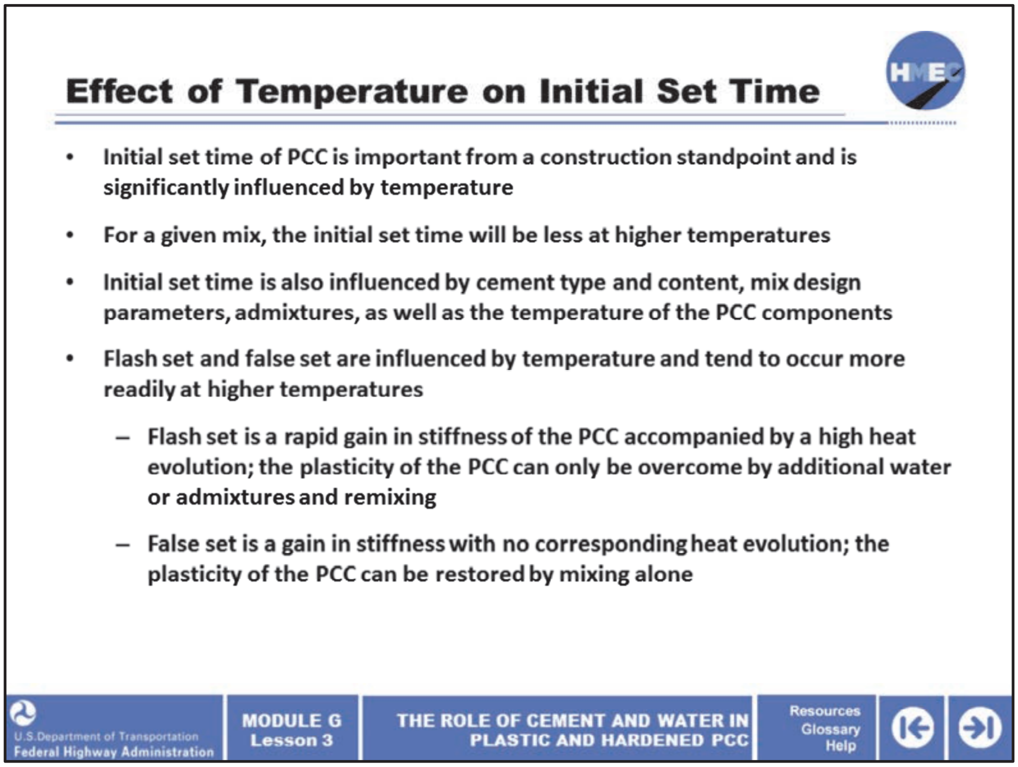


Note that cooler temperatures decrease early age strength, but increase later age strength.

Note also that the peak 28-day strength is achieved at 55 °F rather than 73 °F. This difference becomes more pronounced with increased age and is approximately a 13% increase at one year. At an age of two to three days the 73 °F strength is about double the 55 °F strength.

Hydration gives off heat and, at the molecular level, is a "violent" reaction; cooling the concrete, thereby slowing the reaction, allows it to proceed in a more orderly fashion and the results are a more thorough hydration process resulting in higher ultimate strengths.

Image description: Relationship of curing lower temperature to strength chart.



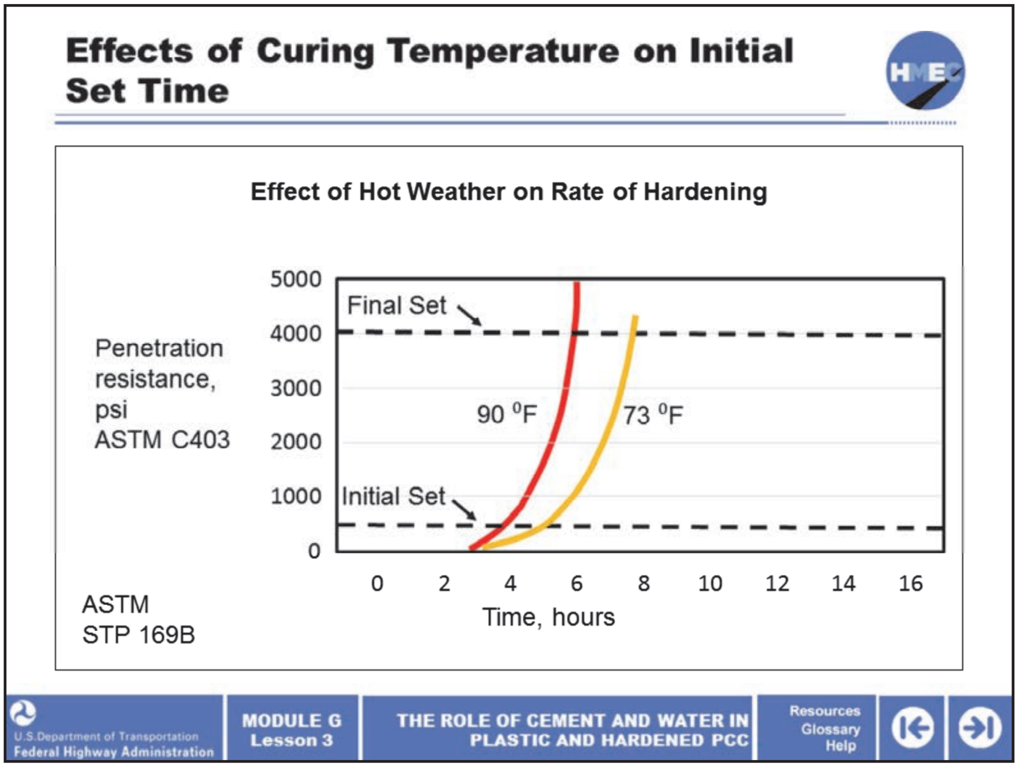
The initial set time of PCC is important from a construction standpoint and is significantly influenced by temperature. For a given mix, the initial set time will be less at higher temperatures. However, the initial set time is also influenced by cement type and content, mix design parameters, admixtures, as well as the temperature of the PCC components.

In practical terms, the set time has bearing on the time available to place, consolidate, and finish the PCC.

Two other set-related issues are also somewhat a function of temperature: flash set and false set.

Flash set and false set are influenced by temperature and tend to occur more readily at higher temperatures.

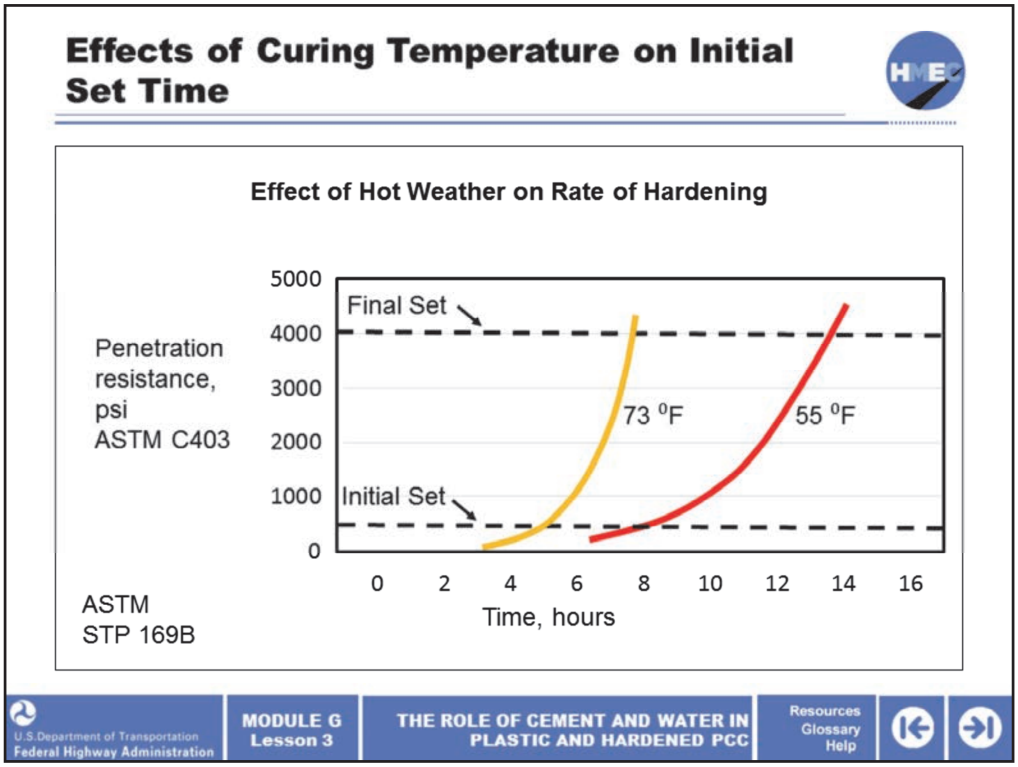
• Flash set is a rapid gain in stiffness of the PCC accompanied by a high heat evolution. The plasticity of the PCC can only be overcome by additional water or admixtures and remixing.
• False set is a gain in stiffness with no corresponding heat evolution. The plasticity of the PCC can be restored by mixing alone.



This image depicts the setting time as influenced by PCC temperature at time of batching. Initial set (of mortar sieved from PCC) is at 6 hours at 73 °F and at 4 hours after batching at 90 °F. Final set is at about 9 hours at 73 °F and at 6 hours at 90 °F.

Note that in "real world" conditions, the ambient temperature will have a significant impact on these values as will different mix characteristics.

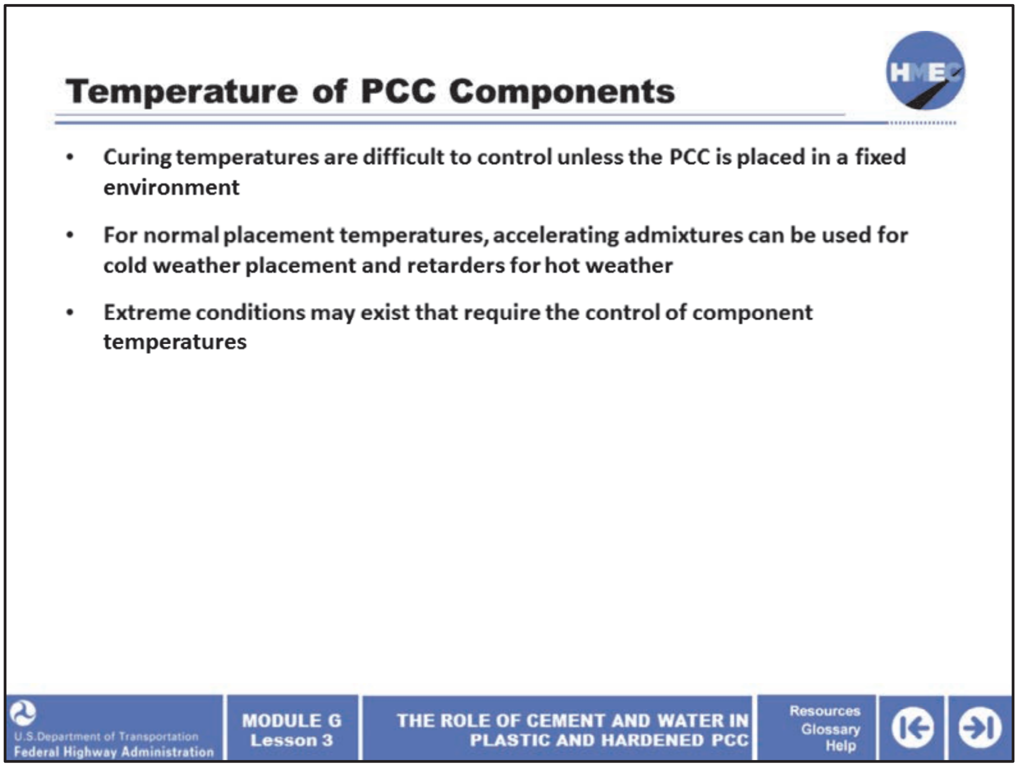
Image description: Graph showing the effects of curing temperature of warm PCC.



This image shows the setting time as influenced by PCC at time of batching. Initial set (of mortar sieved from PCC) is at 4.5 hours at 73 °F and at 8.5 hours after batching at 55 °F. Final set is at about six hours at 73 °F and at 14 hours at 55 °F.

Note that in "real world" conditions, the ambient temperature will have a significant impact on these values as will different mix characteristics.

Image description: Graph showing the effects of curing temperature of cold PCC.

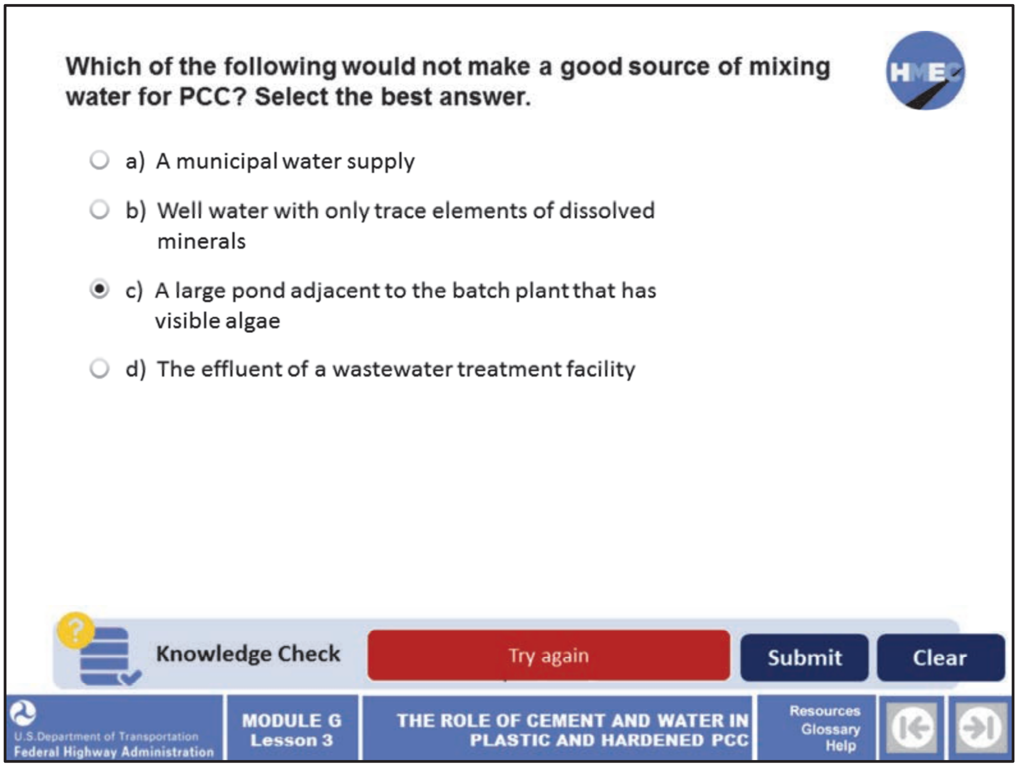


Curing temperatures are difficult to control unless the PCC is placed in a fixed environment. For normal placement temperatures, accelerating admixtures can be used for cold weather placement and retarders for hot weather. Extreme conditions may exist that require the control of component temperatures.

It is not uncommon in hot weather placement conditions to use chilled water or ice as a substitute for a portion of the mix water.

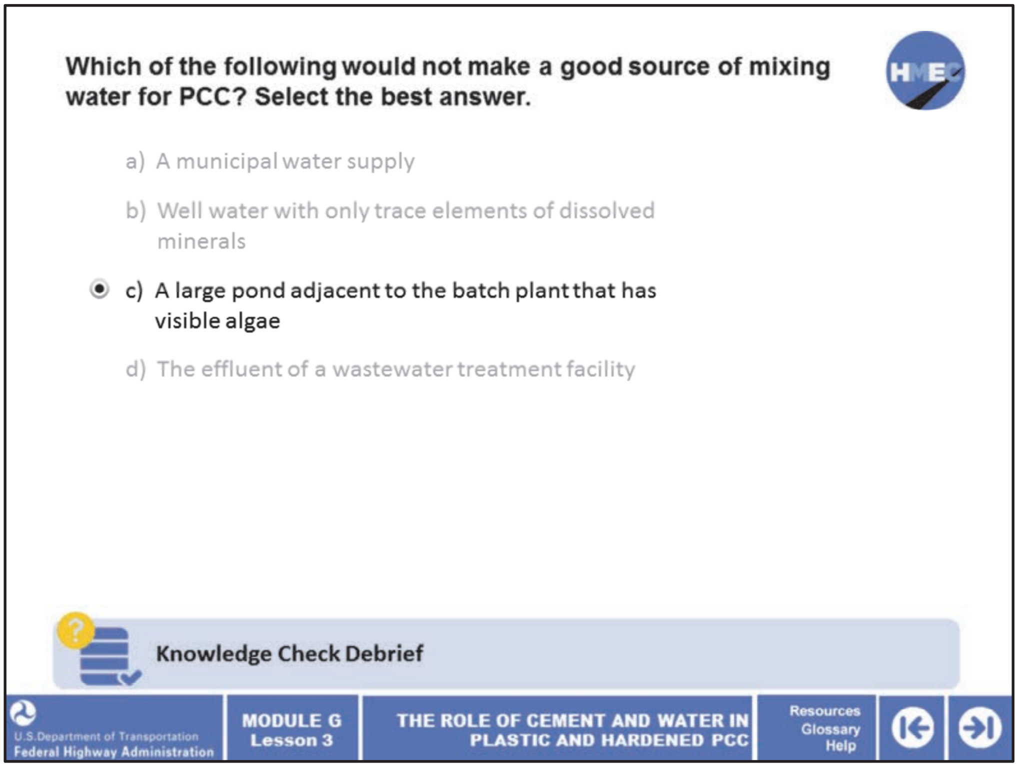
Spraying a fine mist of water on the coarse aggregate stockpile to facilitate evaporative cooling is also common.

The use of hot water for cold weather placement as well as protecting the aggregate stockpiles (occasionally tenting and heaters are used) are viable options.

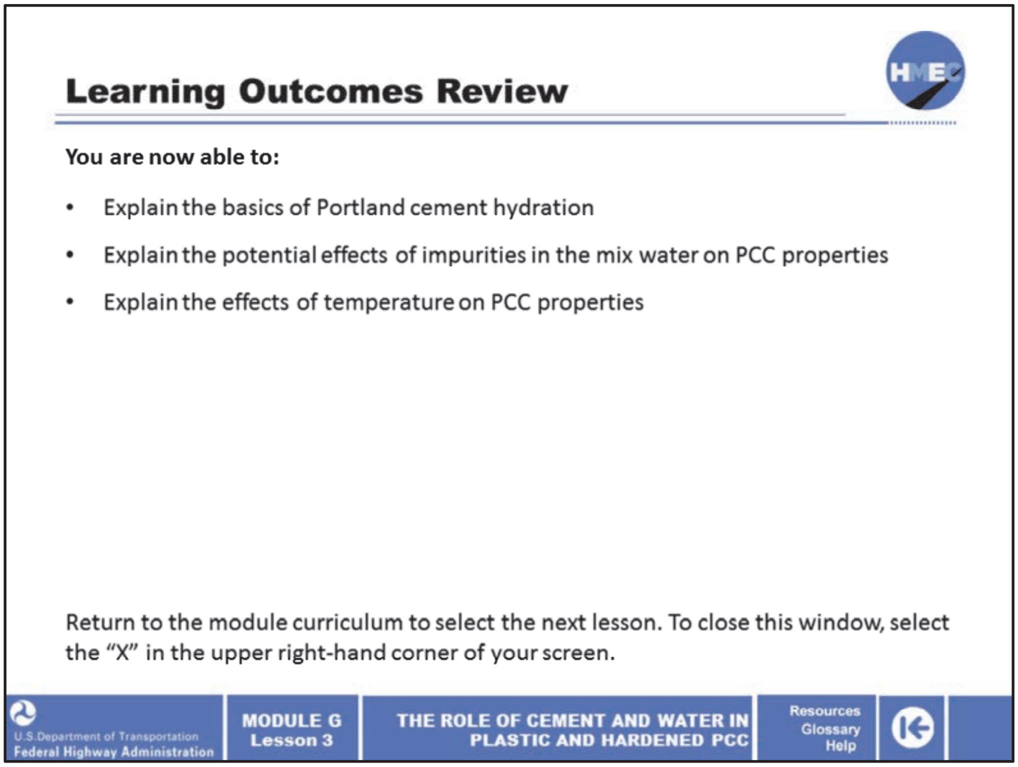


Which of the following would not make a good source of mixing water for PCC? Select the best answer.

a) A municipal water supply;
b) Well water with only trace elements of dissolved minerals;
c) A large pond adjacent to the batch plant that has visible algae; or
d) The effluent of a wastewater treatment facility.



The correct answer is c) A large pond adjacent to the batch plant that has visible algae. Algae and other organic materials in mixing water can retard the set of the cement and have an adverse effect on the strength, air content, and other properties.



You have completed Module G Lesson 3: The Role of Cement and Water in Plastic and Hardened PCC.

You are now able to:

- Explain the basics of Portland cement hydration;
- Explain the potential effects of impurities in the mix water on PCC properties; and
- Explain the effects of temperature on PCC properties.

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.