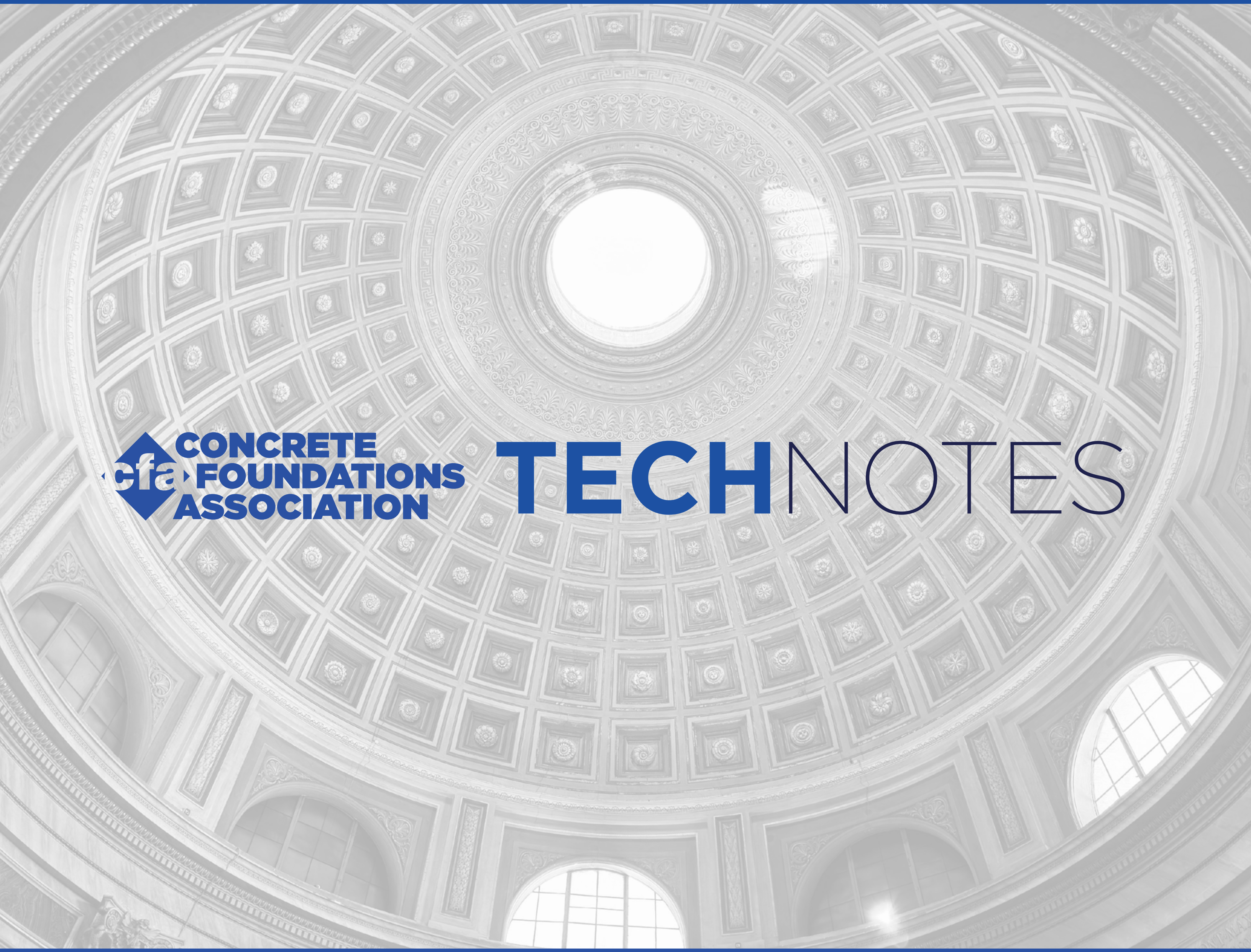

CFA-TN-012

Concrete Basics for the Residential Contractor

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What the Residential Contractor Needs to Know about Concrete

Concrete is the most widely used man-made material on earth, but it is also a misunderstood product. The most common misconception is perhaps the interchangeable use of the words **cement** *and* **concrete**. *Another is the assumption that a slab or wall crack is a failure. Our challenges are to educate people about the product that provides our livelihood, and to deliver the best possible concrete installation we can produce. There are two infallible characteristics of concrete: it gets hard; and, it cracks. The procedures and methods by which we manufacture, mix, handle, place and cure concrete however, can make a tremendous difference in how hard the concrete gets, how it weathers and performs, and how many or how wide the inevitable cracks become. Having a better understanding of this resilient and versatile material will enable you to be better at your job and deliver a better product to the customer.*

Concrete Materials

Concrete can be described as a basic mix of four main constituents: cement, coarse aggregate (rock), fine aggregate (sand) and water. Each of these materials plays an important role in delivering an economical, yet strong and serviceable concrete building component. Concrete is relatively heavy, weighing between 140-150 pounds per cubic foot and it is very strong when placed in compression. Special concrete mixes can produce much heavier or lighter weights if conditions warrant but the properties of these special mixes will also vary. Let's take a look at each of these four basic constituents in greater detail.

CEMENT

Concrete is able to achieve its first infallible characteristic because of the presence of a fine powder-like substance commonly referred to as cement. Today, the complexity of mix design and the goal for sustainability in the environment mean we should actually use the phrase cementitious materials. The most common form of this material in today's concrete remains portland cement. Portland cement is a hydraulic cement which means that it sets and hardens by reacting chemically with water. Portland cement is manufactured from limestone, sand, clay and iron ore along with small amounts of alumina, fly ash and other minor additives. The limestone is first exposed to very high temperatures, typically between 2600 - 3000 degrees F, in a long (or tall) rotary kiln. The heat breaks the limestone down in a process called calcination, which drives off CO_2 from the limestone.

Fig. 1: The basic constituents of concrete are coarse aggregate (rock), fine aggregate (sand), portland cement and water.

Fig. 2: Pantheon, Rome, circa 130 A.D.

The resultant lime "clinkers" are then mixed with gypsum and limestone, which regulates setting time, and ground to a fine powder to give us the cement product we use today. The American Society of Testing and Materials (ASTM) defines standards for many of the materials used in construction, including cement. ASTM C 150 is the standard used to define the five primary types of portland cement. The categories are based on the properties or behaviors exhibited during the hydration process or in-place durability. The most common is Type I portland cement. Type III portland cement is the second most common type as it obtains higher early strengths from a finer powder that reacts more quickly with water. The finer consistency provides more surface area to speed the hydration process resulting in higher early strengths, and elevated temperatures. ASTM also defines types of portland cement for other applications that are less common throughout most markets. Type II and Type V cements are for moderate and high sulfate resistance respectively and Type IV (not available in the U.S. market) is designed to produce a lower heat of hydration and slower set time.

SUSTAINABILITY

The manufacturing process just described for cement results in the release of CO_2 from the limestone as well as the combustion of the fuel to produce the high temperatures for the kiln. Cement manufacturing contributes approximately 96% of the carbon footprint of concrete during a very short duration and before it ever becomes part of the concrete. The emission during calcination accounts for about 65% of the CO_2 and burning of fuels to heat the kilns accounts for the remaining balance. The industry is making great strides to reduce its carbon footprint by utilizing waste materials such as old tires in the fueling of kilns, and modernizing manufacturing plants.

Fig. 3: Rotary cement kiln.

Cement, however, is only one component of concrete comprising between 7-15% of the total content and the remaining 85-90% offers very low embodied energy and produces virtually insignificant emission of greenhouse gasses. **Figure 4** demonstrates the relationship of some common mix designs and the comparison of cement content to the remaining three primary constituents. When water, locally quarried sand and large aggregate, as well as the local production of and delivery of the mix, are factored into the process, concrete compares very favorably to other building materials.

Another factor reducing the carbon footprint of concrete is the use of supplementary cementitious materials (SCMs) to replace a portion of the portland cement. These products include blended cements (ASTM 595R) and batched cements, add waste materials such as fly ash, silica fume, and slag, have similar properties to portland cement and are materials that otherwise would be disposed of in landfills.

Up to 50% of the portland cement can be replaced with SCMs if proportioned properly. The workers and specifiers must understand that some concrete properties, such set and early-age times affecting finishing and curing might be altered. It is best to have working knowledge of these impacts if you are using large percentages of SCMs.

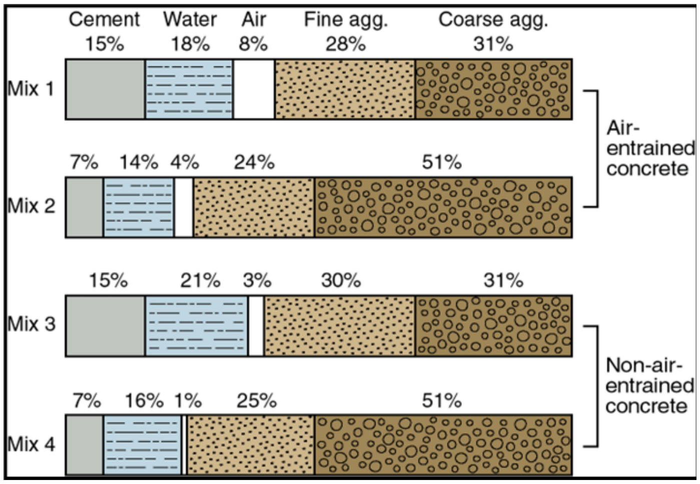

Fig. 4: Proportions of basic concrete materials.

WATER

It was mentioned previously that cement is a hydraulic material, that is activated when introduced to water. Water then, is necessary to support the process of concrete hardening. The water should not have impurities or other chemicals. Potable (drinking) water is considered adequate for concrete manufacturing. You must also have a sufficient amount of water to insure that hydration occurs and that the concrete can be placed and worked, but too much water reduces the strength of concrete and causes excessive shrinkage which results in wider and more frequent cracks. Too much water also increases the porosity of concrete, making it more vulnerable to problems related to freeze/thaw conditions. A ratio called the water/cementitious material ratio (w/cm) is used to express the amount of water relative to the amount of total cementitious product (both portland cement and SCMs). This is determined by dividing the weight of the water by the weight of the cementitious material in a given batch.

w/cm = total water – absorbed water in
aggregates/weight of cementious materials
or
w/cm = free (net) water/weight of cementious material

Generally, in terms of strength development then, a lower w/cm ratio (stiffer mix) is best, assuming enough water is present to fully activate the amount of cementitious material.

AGGREGATES

Aggregates are an essential component of concrete. Size, hardness, shape, and surface absorption are characteristics of the large aggregates that impact the quality and strength prop-

Fig. 5: Supplementary cementitious materials.

Fig. 6: Regular slump shown in a cone and SCC concrete shown in a puddle or flow.

erties of the concrete. Crushed rock, or gravel, is the most common type of aggregate used. The angularity of the crushed rock adds to the strength of the mix. Round stones, such as river gravel, can be used to produce special concrete mixes such as exposed aggregate concrete but allowances must be made for potential changes in properties, like reduction of in-place strength. The strength of the aggregates will also directly impact the strength of the concrete since strength is largely based on compression. This is particularly evident when light weight aggregates, that are less dense and often softer, are used.

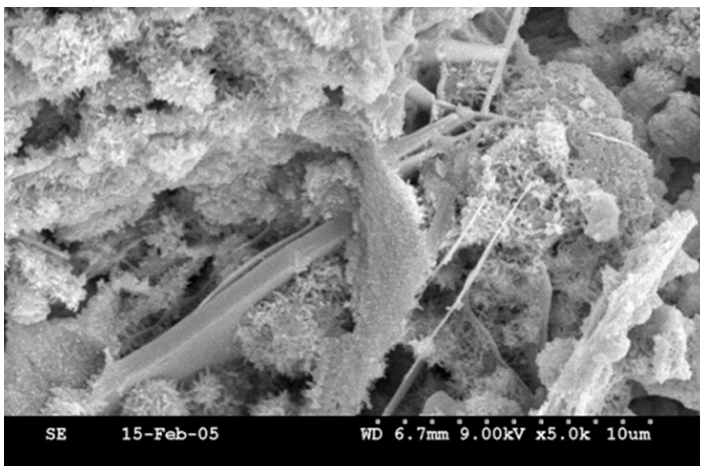

Fig. 7: Electron microscope photo of hydroxide crystals.

Another requirement for aggregates is that they be graded. The small aggregate size of sand is important for filling much smaller holes but large aggregates must contain a variety of sizes to ensure a more cohesive cross section. Grading is the process where aggregate is run across screens of different size holes. The actual aggregate used in the mix is then assembled from rock pieces or sizes fitting through many different hole sizes. This is also called continuous-grading.

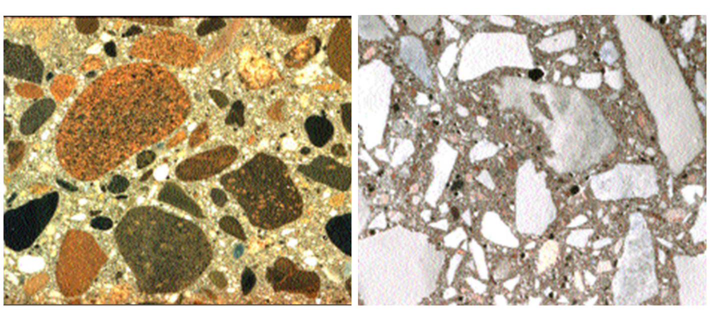

Fig. 8: Typical concrete with graded aggregates.

AIR, ENTRAINED AND ENTRAPPED

The process of combining cementitious material and water into a paste naturally results in the presence of air bubbles. These may increase throughout the mixing process. This type of air is called entrapped air. The entrapped air is in the form of tiny bubbles approximately the same size as the sand or fine aggregate. The amount is typically less than 2 percent by volume. These air bubbles can allow moisture to enter into the concrete, which can decrease resistance to freeze/thaw in some climates and greater porosity. Therefore, a vibration process is important during the concrete placement process in an effort to drive these air bubbles to the surface and consolidate the paste more thoroughly throughout the volume.

Different than entrapping air through the natural mixing process, entrained air is an intentional mix design specifically desired for the long-term performance of some types of concrete. Air entrainment is achieved with a chemical that can be added to the concrete to increase weatherability. While the larger entrapped air bubbles will allow water to penetrate the concrete resulting in increased porosity as well as greater degradation in freeze/thaw cycles, entrained air is the introduction of microscopic air bubbles. Millions of microscopic air bubbles (as small as 0.003-inch diameters), that are too small to allow moisture to penetrate, provide voids to absorb the expansion of water molecules as they freeze. Air entrainment can also improve the workability of the concrete, acting like tiny ball bearings to help the concrete flow more easily across or through surfaces.

ADMIXTURES

Modern chemistry has come to the aid of concrete with a wide variety of chemicals that can be added during the mixing operation. These are called admixtures. These chemical admixtures alter both the fresh and hardened concrete properties including placement characteristics, hydration performance and durability as well as others. Admixtures known as retarders slow down the curing rate of concrete, which can be helpful in hot weather or extremely intricate configurations. Accelerators are admixtures that can speed up the hydration process which can be advantageous when placing concrete in cold weather or when a higher early strength is required. Accelerators are an example of an admixture class that can accomplish the same goal using different forms. Accelerators are most often divided into two categories, calcium-chloride and non-chloride. The type of concrete application and the applicable code will instruct whether one or the other can be used. Calcium-chloride can increase the potential for corrosion of the reinforcement and other metals under certain exposure conditions.

Water reducers (also known as plasticizers) include both mid-range (MRWR) and high-range (HRWR). They can be used to increase the flowability of concrete without the negative impact that adding water can produce. This aids in the pumping of concrete as well as placement in tight forming conditions or where a large amount of reinforcement is present. Flowability is increased without sacrificing the strength since the w/cm can remain as designed or even lowered. Where water runs the risk of inducing separation of the aggregate from the paste, water reducers allow the aggregates to remain suspended in the matrix instead of settling to the bottom of the element.

Advancements in mix design have also resulted in a liquefying chemical admixture to produce a concrete mix called self-consolidating concrete (SCC). Concrete mix designs as SCC are very flowable and give great definition of forms while reducing placement time, labor and vibration.

Other admixtures include air entrainment, coloring agents, finely ground minerals, corrosion inhibitors, pumping aids, and latex modifiers to name a few.

MIX PROPORTIONING

Fig. 9: Chemical admixtures.

Determining the amount of each material, including admixtures, that comprise a given concrete mix is called mix design or mix proportioning. Proportions and materials for a mix can be varied to meet specific design requirements such as strength or durability; use and placement considerations such as cold or hot weather; differences in available materials such as aggregate types and cements; set time and finishing characteristics; environmental goals including sustainability; and, aesthetic concerns such as form definition, exposing of aggregates, and colored concrete.

The ready-mix supplier, admixture supplier as well as the engineer and architect may all have input regarding their special requirements. Typically, these requirements are part of the specifications for a project. Ideally, a ready-mix supplier will have standard mix designs previously tested to fit the most common requests or criteria in a given area.

In addition to the specific job criteria, the mix designer also tries to meet the following job specifications:

1. The hardened concrete will have the strength, durability and wear resistance to meet the project requirements;
2. The concrete will be workable enough for the intended application;
3. It will be economical, and;
4. Shrinkage is minimized.

HYDRATION

The hydraulic nature of the cementitious material means that concrete hardens due to a chemical reaction called hydration. Since chemical reactions always have one or more byproducts, that of the hydration process in concrete is heat. This heat of hydration can be helpful in cold weather applications and it is a good indicator that concrete setting is occurring. Conversely, during the hotter months of summer or in warmer climates, this heat of hydration combined with the higher ambient temperatures can result in the concrete setting too rapidly. Control of the working concrete temperature is important in both cold and hot weather applications.

Hydration can be likened to a crystallization growing process where the crystals grow to surround the aggregate particles, reinforcement and any other embedded object creating an intertwined mass. When moisture is no longer present, hydration ceases and the concrete no longer gains strength. Concrete that is submerged under water can continue to gain strength for a long period of time.

CURING CONCRETE

Curing is the process by which we try to optimize the conditions allowing the concrete to harden. Three factors effect the curing of concrete and the rate at which strength gain occurs: moisture, temperature, and time. Moisture is a necessity to support hydration, the process by which concrete gets its strength. The use of curing compounds is the most common method for curing in residential concrete. Leaving forms in place for foundation walls also aids in curing by reducing the amount of exposed surfaces of fresh concrete to evaporation. Covering fresh concrete with

Fig. 10: Burlap and plastic curing.

plastic sheeting or burlap as well as misting the surface may also be used if project conditions are conducive. The purpose of all of these efforts is to retain the optimum amount of moisture so that the hydration process can continue.

Temperature is also important. The temperature must be at a sufficient level so that the water can hydrate the cement paste. If the temperature is too hot, the moisture will evaporate too quickly and not enough water will be present for hydration to occur. This is of particular concern on hot, windy days, especially with slabs. Time is the third necessity. The longer ideal conditions for hydration are present, the stronger the concrete will get.

Temperature is more difficult to control and we must protect the concrete from both extremes. If concrete becomes too hot, the water will evaporate, resulting in a weakened surface that impacts the durability of concrete. Concrete can also become too cold. When the water in the concrete drops below freezing, the hydration process stops.

It will continue once it thaws as long as moisture is present but continued freezing and thawing will again produce weaker concrete. One thing worth noting however is that hydration produces heat. Concrete can typically withstand a temperature at freezing or slightly below since it is producing heat internally. If the concrete is covered with thermal blankets then much of this heat of hydration will be held in the confines of the element.

Cold weather concrete is an area that has received considerable attention in the past several years. Independent testing conducted by the Concrete Foundations Association has resulted in the conclusion that as long as concrete is protected from freezing until it reaches 500 psi strength, it will continue to gain strength when the temperature rises above freezing. The CFA 'Cold Weather Concrete' report has tested a variety of mix designs and protection measures to determine the best practices in cold weather conditions.

CONCRETE STRENGTH

There are two basic measures of concrete strength we need to understand: compressive strength and tensile strength (often called modulus of rupture). A compressive load is the force that tend to compress the concrete element. Walls are typically very good a resisting compressive forces. Walls, however, may also be subjected to horizontal loads which introduce bending force. A bending force produces tension on the side opposite the applied load (such as soil or wind) and compressive force on the load side. Since the compressive forces on a residential foundation wall are so low relative to its capacity, the load on the tension side is the most critical force that must be analyzed. The tensile strength of standard concrete is roughly 10% of the compressive strength. Fortunately, most codes have empirical tables that

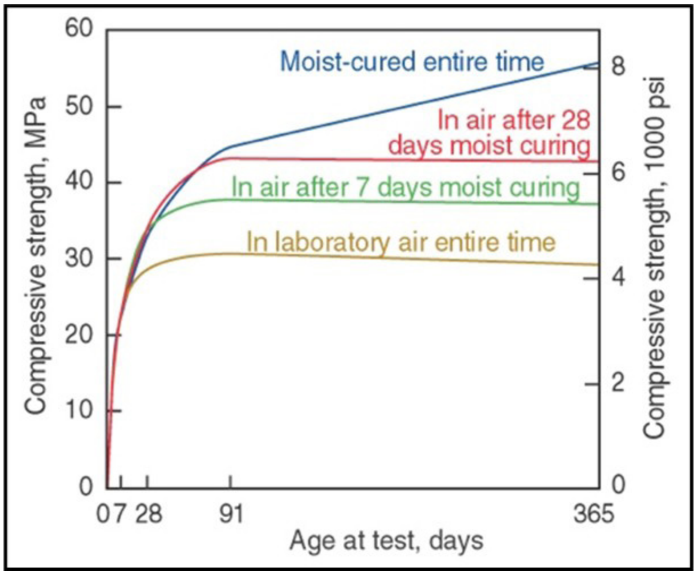

Fig. 11: Concrete strength with age.

identify wall configurations to meet most loading conditions.

Compressive strength ($f'c$) is measured in pounds per square inch (psi). Strength at 28 days from placement is typically the specified measure by we judge concrete. The 28-day compressive strength is the typical design parameter for engineers for structural elements. The compressive strength can be varied depending on the amount of cement, water, and the nature of aggregates used but it typically varies from 2,500 psi to 4,500 psi for standard concrete elements. These mixes perform well and are economical for most concrete structures. Strengths of up to 10,000 psi are attainable and are sometimes used in structural frames and other high-performance structures.

Cylinders are generally used to determine whether or not concrete has attained the specified strength. Multiple cylinders should be taken and prepared in accordance with ACI recommended practices. The standard size is 6" in diameter by 12" long although ASTM C31 does allow for 4" x 8" cylinders. At least three cylinders should be prepared for each batch. Multiple cylinders can be of considerable value if, for example, the first one tested does not meet specifications. Testing multiple cylinders at different time periods can predict the strength you should attain as time progresses. Cylinders should be stored and cured in accordance with ASTM C31, which directs for both lab and field curing. Lab curing cylinders will indicate relationship to design strength. Field curing cylinders will only indicate the in-place strength.

Fig. 12: Concrete cylinders.

Test cylinders represent only a fraction of the mass of any larger placement. Whether lab-cured or field-cured using proper techniques, smaller samples of concrete are hard to correlate to the actual in-place concrete condition, simply due to the difference in mass. Research has proven that by monitoring the internal concrete temperature, the in-place strength of any concrete can be estimated with significant accuracy. This is called the Maturity Method, as defined by ASTM. Maturity monitoring and prediction demonstrates effectively that the in-place concrete strength is usually higher than that of test cylinders at the same (early) age. Additionally, since the Maturity Method uses instantaneous data and prediction software, contractors do not have to wait excessively for strength prediction from cylinder testing for construction operations such as stripping formwork or construction loading.

The steps to implement the Maturity Method successfully are relatively simple, but critical. Specific mix designs must be calibrated using lab-cured cylinder data before field testing begins. Once these cylinders are obtained and broken according to ASTM C31, a graph is plotted based on the time and temperature conditions of the controlled environment. Maturity system software is then able to use this baseline adjusted for in-place field conditions to accurately determine the strength gain of the concrete element, assuming the mix design does not change.

Required strength for concrete is dictated by project specifications, building codes or owner requirements. Most concrete reaches the specified strength before 28 days but even if it hasn't, it is likely to reach design strength as long as it continues to cure so as to be serviceable for the intended use.

If flexural strength is a design consideration, the use of beam test are best for determining if the correct strength has been obtained.

REINFORCED CONCRETE

Concrete is much weaker in tensile strength. Tension is the force that tends to pull things apart and we express that force as tensile strength. The side of a beam or wall opposite the applied load is generally placed in a tensile mode. When the tensile strength of concrete is exceeded, it will crack. Another cause of tensile cracks is shrinkage. If the ends or portions of the concrete are retrained such as corners or the ground in a slab, the concrete will crack as excess moisture evaporates from the element, thus causing shrinkage or tensile load.

Steel reinforcement is used to withstand or take the tensile forces resulting from applied loads or shrinkage. Steel has a much greater tensile capacity than concrete. The steel that is used in most applications such as walls and footings, has tensile strength of either 40,000 pounds per square inch (40 ksi) or 60 ksi. Higher strengths are used in special applications. The steel is classified as cold rolled deformed bar reinforcement. The deformations are critical as they are what allows the concrete and steel to interact. Another important aspect of steel is that the rate at which steel expands and contracts in response to temperature change (coefficient of expansion) is very similar to that of concrete. If it wasn't, putting reinforcement in concrete would cause it to break apart when exposed to large temperature swings. Steel should be mill-certified to ensure that what is being provided meets specification.

The steel must be placed in the correct location to work according to design. In the case of simply supported structural elements such as beams or reinforced walls, this location is generally on the side opposite the applied load. ACI standard prescribe distances that must be maintained from the outside of the concrete element to the steel based on exposure. Cover requirements are indicated in the respective reference governing the elements or type of construction where the concrete is placed.

Temperature and shrinkage steel is placed to minimize cracking that occurs when concrete shrinks as unused water evaporates or as concrete dimensions change in response to temperature change. Steel placed for this purpose should be closer to the center of the concrete element. A wall that has only temperature and shrinkage steel is classified as plain structural concrete. The reinforcement is not included in the design to resist applied loading although it no doubt will increase the load carrying capacity of the element.

SAFETY

There are many hazards workers must be aware of when working on a job site where concrete is being placed. One thing that is often ignored, however, is the wet concrete itself. Fresh concrete is highly alkaline (caustic) and can cause significant irritation or burning of unprotected skin or eyes. Proper equipment must be worn to protect the skin and eyes.

Safety glasses, gloves, proper shoes, pants and shirts should be worn whenever placing concrete. If your skin comes in contact with the fresh concrete, wash the affected areas as soon as possible with water. It can take as little as 45 minutes to several hours for the impact to be felt.

The information presented in this section should provide you with the basic knowledge you need to converse intelligently with the homeowner, building official or other lay person regarding the concrete you are providing. For more information, consult documents published by the American Concrete Institute (ACI), the National Ready-Mixed Concrete Association (NRMCA), the Portland Cement Association (PCA) or the Concrete Foundations Association (CFA). ■

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