CURING OF CONCRETE: A TECHNICAL STUDY TO INCREASE RATE OF CURING

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ABSTRACT

Pre-stressed Concrete is very useful now a days. It has less shrinkage, less creep and reduced deflection due to dead and live load. Material properties are improved in Pre-stressed concrete. Also total construction time is also less in case of pre-stressed concrete. One of the major properties of concrete that makes pre-casting economically feasible is its ability, under the proper conditions, to gain compressive strength extremely rapidly. In this paper, various methods to increase the curing rate for precast concrete are discussed. Different methods for accelerating the curing process are: 1) the use of physical processes, and 2) the use of admixtures to act as catalysts for the hydration process, resulting in the achievement of high compressive strengths in relatively short periods of time. Many physical processes used to increase the curing process are generally obtained by increases in curing temperature, introduction of moisture to curing environment. Numerous methods exist, including conductive/convective heating, electrical resistance heating, and steam curing (low and high pressure).

INTRODUCTION:

In modern construction practices main focus is set up on the faster and economical construction. This includes the use of waste materials and admixtures in concreting. As such, the construction industry is constantly searching for ways to improve their product. One means to this end is, rather than relying on improving construction implementation mechanisms such as scheduling, installation techniques, and quality control, is focusing on the industry’s improved knowledge and development of materials and their behavior.

One of such major method used for faster construction is Pre-stressed concrete. This type of concrete was developed in order to take advantage of the desirable properties of concrete and steel, chiefly compressive and tensile strength, respectively, in order to achieve structural solutions that were not previously possible. For many projects, the use of pre-stressed concrete is more desirable than reinforced concrete or steel for numerous reasons. Pre-stressed concrete takes the concept of reinforced concrete one step further, in order to truly maximize the efficiency of the materials. Rather than simply relying on reinforcing steel for tensile strength, pre-stressed concrete utilizes high-strength pre-stressing tendons in order to produce an initially favorable state of stress within the pre-stressed concrete member. The result is a more efficient section, capable of bridging extremely long spans, that is less prone to cracking and exhibits improved durability. These improved performance characteristics of pre-stressed concrete have made it an extremely popular product in many aspects of heavy construction, including in roads and bridges, in marine environments, in sanitation systems, and even in buildings.

Although a number of methods currently exist for the acceleration of the curing process, most precast manufacturers maintain relatively simple operations, and due to logistical and economic constraints, only employ one or two of the methods described herein. Despite recent advances in the use of admixtures, the primary method of accelerated curing in the precast industry today still seems to be the use of elevated curing temperatures, which are achieved through various means. The objective of this study is the description of the various methods employed in the precast industry for the purpose of accelerating the curing process of concrete, and their effects on the short and long term compressive strength of concrete. These various methods of accelerated curing can be divided into three main categories: physical processes, mineral admixtures, and chemical admixtures.

1. CURING PROCESS:

Curing is the process of watering concrete structure to understand the hydration process. When cement is added to water hydration reaction takes place. This hydration process is necessary for hardening of concrete. This curing process is done in three different steps. First curing stage is done immediately on addition of water to cement and aggregates to make a dry concrete mix. At first stage of curing the chemical reaction between water and cement occurs however the gain in hardness or compressive strength is minimum in first stage of curing.

Second stage or process of curing begins on the initial setting of concrete mix. It starts with the rapid hydration process i.e. hardening of concrete starts with hydration. The specific rates of strength gain and overall duration of stage two depend on the particular mix design and curing conditions. Stage two of curing generally lasts six to seven hours, and the rate of compressive strength development is approximately 40%. The efficacy of elevated curing temperatures regarding their ability to increase the rate of strength gain is greatest during stage two.

Third stage of curing begins when the proper reaction between cementious material and water occurs. During this phase less heat is generated by the hydration process, and a slower rate of strength development occurs. The application of elevated curing temperature has little effect on the rate of strength gain at this point.

2. CHEMICAL ADMIXTURES FOR ACCELERATING CURING:

3.1 Calcium:

Historically, the use of calcium, particularly in the form of calcium chloride, was thought to be an effective acceleration technique in concrete. However, numerous problems resulting from the inclusion of calcium-chloride in concrete mixes has resulted in its ban from use in concrete in several countries around the globe (Levitt, 1982). The inclusion of calcium chloride in reinforced and pre-stressed concrete can be extremely detrimental, as the chloride can contribute greatly to corrosion of the reinforcing steel.
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Regardless of these potential problems, the use of calcium chloride, usually specified by the contractor, still occurs with great frequency in the United States today. Additional forms of calcium that has been used, although not as effectively, in order to accelerate curing are calcium formate and sodium nitrite. These forms of calcium also tend to be extremely sensitive to the chemistry of the Portland cement. One example is that of tri-calcium aluminate, as previously mentioned, with which the acceleration effect is less significant as the CaA content rises above 8% (Levitt, 1982).

3.2 Super Plasticizers (High-Range Water Reducers):

Although not technically characterized as accelerators, high-range water reducing (HRWR) admixtures contribute to, “large increases in early concrete strengths under both normal and accelerated curing conditions,” (Hester, 1978). The use of these admixtures results in either increased concrete workability while maintaining a target strength level, or increased strength while maintaining a desired workability.

In general, a water-reducing admixture results in reduced water demands for a given mix. Traditional water reducing admixtures consisted of lignosulfonic acids, hydroxyethylcarboxylic acids, or processed carbohydrates; these have been shown to provide up to approximately a 10% reduction in mix water requirements while maintaining the same workability (Hester, 1978). More recently, HRWR admixtures have been employed that are composed of, “organic polymers, either sulfonated melamine or sulfonated naphthalene formaldehyde condensates,…and may readily reduce the mix water content of up to 20-25% while maintaining the desired slump,” (Levitt, 1982).

The chemical composition of a cement also can affect the efficacy of HRWR admixtures. It has been shown that HRWR admixtures contribute more to strength development when used with cements that are lower in CaA, have finer grinds, and when used with greater cement contents (Hester, 1978). Therefore, the combination of admixtures used in order to accelerate the curing process should be carefully examined, as the use of high amounts of tricalcium aluminates with HRWR admixtures may result in decreased effectiveness.

When compared with standard concrete mixes, the inclusion of HRWR admixtures has showed a marked increase in early strength gain when exposed to a variety of curing temperatures.

3.3 Self-Consolidating Concrete:

A similar product involving the use of highly advanced HRWR admixtures is self-consolidating, or self-compactong concrete (SCC). Initially developed in Japan in the 1980s in response to a lack of skilled laborers for placing traditional concrete, “SCC is a highly workable concrete that can flow through densely reinforced or geometrically complex structural elements under its own weight and adequately fill voids without segregation or excessive bleeding without the need for vibration to consolidate it,” (Lanier et al., 2003). The development of this product has the potential to significantly alter the current precast concrete industry. Regarding accelerated curing, the use of SCC has primarily an indirect potential impact.

The use of SCC can greatly reduce the time required for placing concrete. To an extent, this can possibly reduce the need for accelerated curing (Lanier et al., 2003). While it is unlikely that the need for accelerated curing will be eliminated altogether, it is possible that the process will require less energy, and thus become more economical. The use of SCC is one of the newest innovations in the precast concrete industry, and will likely have the biggest effect on the evolution of the industry in the near future.
4. MECHANICAL METHODS FOR ACCELERATED CURING:
An increased curing temperature will result in an increased rate of strength gain. But this increase in temperature up to certain limits. After this limit this increase in temperature does not affect the compressive strength but can dismantle the structural properties of concrete. Typical curing mean temperature is 70°C.

Major drawback of increasing this temperature is increased rate of humidity loss to the surrounding environment, which can result in severe shrinkage and cracking. Another problem is the rapid change of temperature within concrete members, resulting in potentially large thermal stresses.

When using elevated temperatures in order to increase the curing rate of concrete, three main factors should be considered: rate of temperature rise, maximum curing temperature, and heating time. Traditionally, it has been thought that early strength gains are offset by lower 28-day strength. As such, specifications often restrict maximum curing temperatures to between 65° and 70°C.

An increased curing temperature also results in an increased rate of humidity loss to the environment. As such, “all efforts must be made to stop the evaporation of water from the surface of the sample by the use of a suitable covering.” (Heritage et. Al, 2000). If the effect of humidity lost to the environment is not controlled during the accelerated curing process, the impact on long-term compressive strength can be detrimental (Mehta and Monteiro, 2001).

The use of admixtures in order to accelerate the curing process can be further subdivided into the use of mineral and chemical admixtures. Calcium Chloride has proven to be an extremely effective accelerator; however, due to corrosion concerns, its use in concrete with embedded metal is not recommended. The most common mineral admixture used as an accelerator is micro silica, or silica fume. While fly ash is frequently used in order to improve other properties of concrete, it has a retarding effect on the initial set and early strength gain of concrete, and should not be used for accelerated curing purposes. Some chemical admixtures, such as high-range water reducers (HRWR), or super plasticizers, have been used as indirect accelerators, primarily due to their ability to reduce the water demand for a given mix.

4.1 Conduction/Convection Used for Accelerated Curing:
One of the most fundamental methods for rapidly increasing the curing temperature of concrete is through the employment of simple conduction/convection techniques. The temperature of the forms may be increased either electrically or by pumping hot oil or hot water through them (Gerwick, 1993). The direct contact between the concrete and the forms with an elevated temperature results in conductive heat transfer. By utilizing convection as well, in the form of flowing hot oil or water, the rate of thermal energy transfer is increased, thereby increasing the rate of curing temperature increase. As with all accelerated curing methods involving elevated temperatures, precautions should be taken to provide sufficient humidity to prevent drying of the concrete, and proper insulation of the formwork will result in a more energy efficient increase in curing temperature.

4.2 Electrical Resistance Curing:
Electrical resistant curing includes the use of special coils of wire i.e. the generation of heat through electrical resistance. By imposing an electrical current through reinforcing steel, or through additional wires, heat is generated inside the concrete as a result of the provided electrical resistance, resulting in an increased curing temperature. When steel forms are used, this method may also be used by applying electrical currents directly to the formwork, or by attaching electrical resistance elements to the forms.

It has been shown that the effects of increased water-cement ratio on compressive strength are less for concrete that has been electrically cured when compared to concrete that has been cured under standard conditions (Heritage, 2000). Figure 1 shows a relationship between compressive strength and water-cement ratio for both electrically cured and normally cured concrete. The electrically cured concrete exhibited a decrease in strength of approximately 28% when the water-cement ratio was increased from 0.55 to 0.7, while the normally cured concrete displayed a decrease in strength of approximately 83% for the same change.

It is unclear whether this effect is a result of the electrical curing process, or simply a result of the elevated curing temperature. Regardless, the implications of this result are significant, as a decreased water-cement ratio may be less important when employing accelerated curing processes, which is contrary to common practice. Additional research to determine the precise relationship between the decreased impact of water-cement ratio on the compressive strength and the method of curing temperature elevation is necessary.

4.3 Low-Pressure Steam Curing:
Steam curing is a process in which elevated curing temperatures and the addition of moisture during the curing process are both used in order to accelerate the rate of strength gain. These methods can be applied simultaneously, with an increase in temperature as a direct result of steam injection, or individually, in which case an initial temperature elevation is achieved through some alternate means and is followed by an increase in humidity through steam injection. Low-pressure steam curing is frequently used in very dry climates and in applications when the controlling the loss of moisture is imperative (Gerwick, 1993). The basic method of steam curing at atmospheric pressure, for the most part, follows the same stages present in any accelerated curing process involving elevated curing temperatures. First, an initial delay period, usually of three to four hours, is necessary for the concrete to attain its initial set. Next, a heating period, with a temperature rise of 40 to 60 F per hour, is employed in order to reach a maximum curing temperature, generally between 140 and 160 F. This is followed by a steaming period, typically lasting six hours while maintaining the maximum curing temperature. Next, a cooling period is employed, during which time it is sometimes necessary release the boundary constraints of the forms, prestressing tendons, etc., in order to prevent damage from the development of thermal stresses. In general, the concrete elements
are still covered with the steam hoods, or with tarps, during this process. Finally, a stage unique to steam curing, an exposure period, is necessary. At this time, the steam hoods or tarps are removed, and the concrete surface is exposed to the natural environmental conditions (Gerwick, 1993). The combined use of high curing temperatures and moist curing conditions results in the attainment of very high early strength.

4.4 High-Pressure Steam Curing (Autoclaving): Although generally reserved for the production of concrete masonry units in the United States, high-pressure steam curing, also known as autoclaving, has been successfully employed in the production of pre-stressed precast concrete elements in Japan and Germany (Gerwick, 1993). During this process, the increase of curing temperature and humidity are combined with an increase in pressure; as such, elements in this manner must be cured in some type of enclosed vessel. This restriction limits the use of the technique to relatively small elements for typical applications.

One of the benefits of this technique is that extremely low water-cement ratios can be utilized in the initial mix design. In the case of concrete blocks, the elements are produced through extrusion machines, without the use of formwork, using no-slung concrete. By utilizing high-pressure steam curing, sufficient moisture necessary to complete the hydration process is introduced to the concrete elements (Polisner and Snell, 1985).

Some major concerns regarding the use of autoclaving do exist. Stress relaxation of pretensioned bars can be as much as 20% during autoclaving, and must be accounted for during the design phase (Gerwick, 1993). In addition, creep is accelerated during the curing process, also resulting in a loss of prestressing force. There does not seem to be any evidence that the addition of high pressure during the curing process has any detrimental impacts on the long term strength of the concrete, however.

5. MINERAL ADMIXTURES FOR ACCELERATING CURING:

5.1 Cement:
Whenever rapid strength gain is of concern, such as in precast applications, type III Portland cement should be used in order to maximize early strength achievement. Type III Portland cement is both chemically and physically similar to type I Portland Cement; the primary difference is that type III Portland cement particles have been ground finer. The use of type III cement, when combined with any of the numerous additional curing techniques described below, can result in the achievement of very high strengths in very short periods of time.

5.2 Silica Fumes:
Micro-silica, or silica fume, is an extremely reactive, pozzolanic material. In one study it was used as a cement replacement for the primary purpose of increasing overall concrete compressive strength (French et. Al, 1998). Not only did the results show an increase in long term strength, but they indicated an increase in concrete strength at all ages. Figure 4 demonstrates the relationship between compressive strength and time for the concrete with the addition of micro-silica compared to concrete without micro-silica.

In these tests, 7.5% by weight of cement was replaced with micro-silica. It can be seen that the combination of heat cured concrete with the addition of micro-silica has much higher early strength than any of the other combinations.

5.3 Fly Ash:
Like silica fumes, fly ash can be used as a cement replacement material. Fly ash is one of the byproducts formed by modern power plants; it is a coal-combustion byproduct, and is collected by electrostatic precipitators used to filter combustion gases.

Unlike silica fumes, however, fly ash does not result in improved early strength of concrete. In fact, the results of the same study mentioned previously in which silica fumes was shown to increase concrete strength show that the replacement of cement by fly ash resulted in decreased early strengths (French et al., 1998). For moist-cured specimens, the decrease in compressive strength was limited to relatively early ages, up to 180 days, while nearly all the specimens subjected to heat-curing exhibited lower compressive strengths at all ages (up to 365 days). While the use of fly ash may improve other properties of concrete, namely the plasticity of the mix (Corcoran, 2004), the discussion of which is beyond the scope of this paper, it should not be used as a curing accelerator.

6. CURING METHODS CURRENTLY USED IN INDUSTRY:
The use of increased curing temperatures is the predominant method used to accelerate the curing, and is occasionally supplemented with the use of micro silica and super plasticizers. As such, the expenses associated with additional chemical and mineral admixtures outweigh the potential benefits. However, in order to take advantage of the effect of chemical composition on curing rate, the use of type III portland cement whenever possible. By producing a type III portland cement that is very similar to types I and II portland cement in terms of chemical composition, the primary difference being the increased Blaine fineness. When high-strength concrete is required, the addition of microsilica, usually at approximately 50 lb/yd³, is common. While this does increase the rate of strength gain, it is usually employed to increase long term strength, rather than to directly increase the short term rate of strength gain. In addition, although HRWR admixtures have a positive impact on an accelerated curing process, they are generally used for other purposes.

The most basic method involves the placement of forms directly over pipes, through which hot water is pumped during the curing process. This conductive/convective technique, while effective, provides the least amount of control and automation. The next step up involves the use of forced-air, gas-fired heaters. This method provides a bit more control during the curing process. In addition, one byproduct of the gas-fired heaters is moisture, which is very beneficial. For both of these methods described above, continual monitoring of the internal temperature of the concrete, through thermocouples attached to the reinforcing, is essential. In addition, formwork is completely covered with tarps for the purpose of both insulation and moisture-loss prevention.
A temperature cycle is programmed, and based on the electronic monitoring of thermocouples, this time located at the form/concrete interface, the electric current is continuously adjusted. With such a process, the target temperature can usually be maintained throughout an entire curing cycle within a few degrees.

7. SUMMARY AND CONCLUSIONS:
With recent advances in material technology, a number of admixtures (mineral and chemical) can be used, both directly and indirectly, as accelerating agents. However, compared with increased curing temperatures, the use of admixtures as accelerators can introduce numerous potential problems and difficulties.

The major methods that exist for the purpose of accelerating the curing process of concrete is of two types: physical processes and admixtures. Like most chemical reactions, the rate at which hydration occurs is very susceptible to temperature changes; with increased temperatures, the rate significantly increases. The implementation of elevated curing temperatures is a relatively straight forward process, and can be achieved without the need for a great deal of research and development. As a result, this is the primary method currently employed by commercial precast manufacturers.

Until the behavior of admixtures and their effects on other properties of concrete are readily understood, their use as primary accelerating agents in the commercial precast industry will likely remain relatively sparse. Until some significant incentive or motivation is provided, such as significant increases in energy costs and decreases in admixture costs, currently employed curing methods involving elevated curing temperatures will likely continue to prevail.

REFERENCES: