Be Sure of Your Cure

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Of all the procedures involved in the preparation and testing of concrete specimens for strength evaluation, that of proper curing is perhaps the most abused. A great many unpleasant arguments have been caused by improper or inadequate curing of concrete test cylinders or beams which resulted in strengths that did not reflect the quality of concrete as it was delivered to the job. True, there are many other testing factors that can contribute to abnormal concrete strengths, such as non-representative sampling, improper molding, poor caps, and deficiencies of testing equipment and personnel. But not even the most carefully prepared concrete test specimens can survive a lack of proper curing.

Practically all modern construction contracts incorporate ASTM standards for test methods and materials specifications either by reference or by direct quotation. All requirements for concrete strength tests, therefore, must comply with ASTM C 31, “Making and Curing Concrete Compression and Flexure Test Specimens in the Field.” This method requires that for the first 24 hours specimens must be maintained in an atmosphere between 60 and 80°F and means must be taken to prevent loss of moisture. Laboratory tests have shown that this initial curing is perhaps the most important period in the development of strength, especially during summer months when air temperatures are high and humidity is low, and in winter during periods of freezing weather.

ASTM C 31 requires further curing of specimens depending on conditions as follows:

1. When specimens are to be used for checking the adequacy of laboratory mixture proportions for strength or as the basis for acceptance or for quality control.

   Specimens must be removed from the molds after 24 hours and “stored in a moist condition with free water maintained on all surfaces of the specimens at all times at 73.4°F+3°F until the time of test.” These are known as standard-curing conditions. Free water does not mean dripping or running water. A saturated lime solution is required if specimens are stored in a water bath.

2. When specimens are to be used for determining form removal time or when a structure may be put into service.

   In this case specimens are to be stored near the point where the concrete was used and given the same protection as the structure, “insofar as practicable.”

Many architects and engineers have ordered field curing as a method for acceptance of concrete in lieu of the standard curing method and, as a result, low strength tests have erroneously indicated poor quality concrete as delivered to the job. Reports of low strength tests are not accepted gracefully regardless of the circumstances surrounding the making and handling of test specimens. If this happens to a part of the structure considered to be critical, the architect or engineer might require that cores be cut from the questionable concrete. And, if the structure has not had proper curing, it is doubtful that cores taken from it will be satisfactory proof of the concrete quality. In the event of the failure of the cores, a load test might be ordered. Both check methods are expensive and time-consuming.

Because of the complex nature of concrete serving as a structural material, specific strength relationships cannot be stated to cover the entire range of relative curing methods. The type of aggregates, type of cement and cement factor, and the water and air contents of a concrete mixture all have a bearing on the measured strength of test specimens even when they are cured under uniform conditions. It is for this reason that ASTM has established close tolerances both for temperature and humidity in the conditions stated for standard curing.

Storage of specimens in air for the full period before testing, as is frequently the case with job-made cylinders, will generally incur high strength losses, often as much as 50 percent. Laboratory experiments have shown that maintaining a high relative humidity is even more important than controlling the molding or initial curing temperature of specimens. Curing at 73°F in air at a relative humidity of 60 percent for 28 days will reduce strength about 30 percent from that obtained under standard conditions. Approximately the same reduction in strength will result from curing in air at 37°F but at 100 percent relative humidity. Normally, low relative humidity is associated with higher temperatures unless provision is made to introduce moisture into the air. Cool air might show a higher relative humidity, but lacks the heat necessary to normal cement hydration. Both heat and available moisture are necessary for proper strength gain of concrete.

Test data show that compressive strength specimens, when exposed to field curing conditions for the full
period before testing, will show reductions of strength from standard curing of approximately 50 percent at 7 days, 34 percent at 14 days, and 30 percent at 28 days. Concrete with high cement factors will be affected to a much greater degree than leaner concretes, due to the higher water content per unit volume of concrete in the richer mix. Mixes of 4.5 and 6.5 sacks of cement per cubic yard might each contain about 38 gallons of water per cubic yard and produce a nominal 4-inch slump concrete, but for a given volume of concrete the mix containing 6.5 sacks would have less water available to complete hydration of the cement than would the leaner mix. Test specimens have a large surface area in relation to their volume and therefore dry rapidly when exposed to moving air. For this reason cylinders or beams should receive special attention during their initial curing period. Flexural strength specimens are even more vulnerable to strength reductions due to drying than are compressive strength specimens because of the development of shrinkage cracks in critical areas of stress.

Sometimes it is important to obtain fast early strengths such as in precast and prestressing operations to facilitate early stripping and handling of the products. Concrete specimens molded and cured moist at high temperatures (100°F. and above) produce higher strengths up to 7 days but give lower strengths at later ages when compared to standard-cured specimens. Concrete molded and cured moist at 120°F. might lose as much as one-fourth of its comparative 28-day strength under standard curing conditions.

Low temperature initial air curing will also cause serious reduction of strengths. Cement hydration is slowed to the point that specimens may not be hard enough to handle after 24 hours. Field experience indicates that 3- and 7-day strengths generally are impaired; however, 28-day strengths might show only slight losses after an initial low temperature exposure.

Although much could be said about the many other factors that can affect the strength of concrete specimens, such topics are beyond the scope of this discussion. A word of caution might be given, however, on the use of paraffined cardboard molds. ASTM C 31 states that they “should be used only under expert supervision.” Cylinders cast in cardboard molds should never be placed in water or extremely wet sand or sawdust. ASTM C 470 sets a maximum limit of 0.020 inch for vertical elongation and a maximum absorption of 25 grams when a cardboard mold is filled with water and allowed to stand for 3 hours. A continued swelling of the mold due to absorption of water, either from the concrete or from its wet environment, can cause a specimen to rupture and seriously affect its compressive strength.

Following are some suggestions that will help to obtain better test results:

1. Mold and maintain specimens in an area that is isolated from construction traffic and is not subject to vibration. Often specimens are left in a construction office or tool shed for better protection from the weather, but they might be worse off due to the unstable condition of their platform during the very critical setting period.

2. Temperature and humidity are extremely important during the first 24 hours. Temperature can be controlled in the summer by storing under wet burlap or in damp sand. If wet burlap is used it should be covered with polyethylene at night to retain moisture. During cold weather specimens should be stored in an insulated box and provided with a heater (such as an electric light bulb) if left outside. Specimens placed in heated areas should be covered with polyethylene or other non-absorbent cover to prevent drying out. Air temperature must be maintained between 60 and 80°F. and moisture loss must be prevented.
3. Specimens should be stripped from their molds the morning after casting and transferred to a moist environment that complies with the standard curing method prescribed by ASTM C 31. If specimens are desired for field curing they should be in addition to those required for concrete acceptance. Specimens for standard curing should never be left on the job after the first day.

4. If it is necessary to transport specimens they should be cushioned to prevent possible fracture and covered to prevent further loss of moisture. Single use molds offer good protection during transfer to the lab and should be left in place until the specimens reach the point of final curing. Where the transportation of specimens is a frequent occurrence, a sturdily built box for such purpose is a good investment.

5. Cylinders in cardboard molds should never be immersed in water or placed in very wet sand or sawdust for curing at any time. Expansion of the molds due to absorption can cause significant reduction in strengths.

A reliable record can be a valuable asset where test specimens are concerned. Very often the conditions under which specimens are prepared or cured can explain unusual test results. Testing costs are high and tests frequently are considered a nuisance by the contractor. Unfortunately, most contracts require that testing costs must be borne by the contractor. He will attempt to keep the cost as low as possible, but often with a substantial sacrifice in the precision of the tests. In doing so he is being unfair to the owner, the architect-engineer, the concrete supplier, and especially himself. It is quite obvious that no one would deliberately invite trouble by careless handling of test specimens. The time involved in arguing about concrete quality that is suspect because of improper curing and testing is valuable to everyone involved. Certainly, the testing inevitably required and so vitally important to an overall appraisal of the quality of a job deserves all the proper attention it can get.

Approximate reductions in measured compressive strength of concrete resulting from field exposure of test specimens.