Effects of Non-Standard Curing on Strength of Concrete

A Research Project at the NRMCA Research Laboratory – Series D 335 and D 338

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Introduction

Concrete properties vary considerably depending upon the temperature and humidity that they have been subjected to early on in their life. The standard that dictates the procedures for making and curing test cylinders, ASTM C 31, defines two different curing conditions to be used for specific purposes.

1. **Standard curing**: This condition involves subjecting the specimens to standard temperature and humidity conditions and the strength results are primarily used for concrete acceptance and quality control.
2. **Field curing**: This condition involves subjecting the specimens to the temperature and humidity that the actual structure experiences and the strength results are primarily used for determining whether a structure is capable of being put in service and scheduling form work removal.

It becomes a problem when the engineer or a purchaser argues that concrete must be accepted based on field-cured test cylinders. The engineer may argue his case by pointing out that his concrete structure does not experience standard cured conditions and he would like it to attain the specified strength required in the structural design based on the actual "field cured" conditions that the structure experiences. On the face of it this sounds like a valid argument. The concrete producer needs to point out: 1. Strength depends substantially on the curing conditions; 2. The producer has no control over the curing conditions; 3. The producer is responsible for providing concrete of consistent strength that will be subjected to a standard curing condition as defined by ASTM C 31. This point is stressed in all industry standards, such as ASTM C 94, ACI 318 and ACI 301.

ASTM C 31 "*Practice for Making and Curing Concrete Test Specimens in the Field*" requires that standard cured cylinders for concrete acceptance should undergo initial curing between 60ºF and 80ºF for up to 48 hours after which they should be transferred to a moist room or water tank. However, in the field this may not always be practiced.

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NRMCA Research Laboratory conducted two experimental programs where test cylinders were exposed to exterior conditions in summer and winter months and compared these results to standard cured specimens. In both cases, concrete cylinders prepared from a specific mixture were subjected to standard curing, field curing conditions and conditions not fully complying with standard curing requirements. The variation in the strength development in each of the conditions is shown and it is hoped that this report will support the producer's case.

Cold Weather Conditions (Series D 335)

The unusually cold weather in January in Maryland prompted the NRMCA laboratory staff to undertake a simple experimental study to quantify the effect of cold temperature exposure on concrete compressive strength development. A nominal 4000-psi air-entrained concrete mixture was prepared and a total of 32 4 x 8-inch cylinders were made and cured in various conditions immediately after casting.

Experimental Details

The 2.5 cu. ft. concrete batch was prepared at the NRMCA Research Laboratory. The mixture had a cement content of 475 lbs/yd^3 and fly ash content of 50 lbs/yd^3, at a water-cementitious materials (w/cm) ratio of 0.52. A Type A water reducer and an air entraining agent were also used.

The measured slump and air content were 4 inches and 5.9 percent, respectively. The initial concrete temperature was 71°F.

A total of 32 4x8 cylinders were cast for strength tests. Strength tests were planned for three, seven, 28 and 90 days with an average from two cylinder tests representing a strength test result.

Curing Conditions

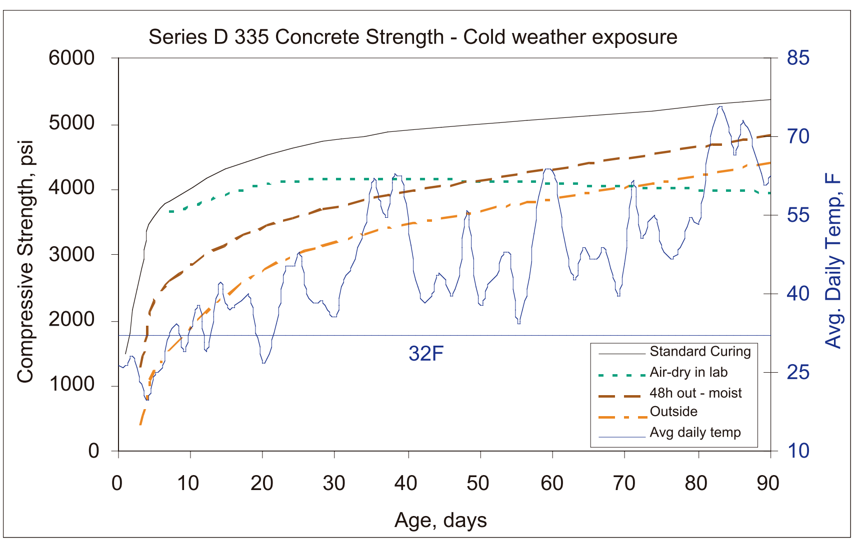
Cylinders were covered with plastic caps and cured in the following four methods immediately after they were made:

1. **Standard curing** in the lab in accordance with ASTM C 31 – cylinders were stored in the moist room (73°F and 100% relative humidity); stripped at 24 hours
2. **Lab air-dry** – cylinders were stored in lab air (73°F and no humidity control); stripped at 24 hours and continued to be cured in lab air
3. **Outside for 48 hours, moist cured** – cylinders were placed in covered 5-gallon buckets (2 cylinders per bucket) on the lab loading dock; stripped at 48 hours and placed in the moist room (73°F and 100% relative humidity)
4. **Outside until time of test** – cylinders were placed in covered 5-gallon buckets (2 cylinders per bucket) on the lab loading dock; stripped on the earlier of the day of test or at seven days.

The average daily ambient temperature based on averages from BWI (Baltimore) and DCA (Reagan National) airports (College Park is midway) during the first 48 hours was in the range of 26 to 28°F and it was below freezing for most of the first seven days. The average daily temperature during the course of the study is indicated on the chart below.

Test Results

The compressive strength results through an age of 28 days are illustrated in the chart below and the compressive strength as a percentage of the standard cured cylinders (control) at the various test ages is summarized in the Table.



Age, days	Control Strength, psi (1)	Percent of control strength at same age		
		Lab Air-dry (2)	Out 48 h, moist (3)	Outside (4)
1	1508			
3	2828		46%	14%
7	3852	95%	68%	40%
28	4745	88%	78%	66%
90	5374	74%	90%	82%

Conclusions

1. This study demonstrates the effects of curing test specimens in cold temperatures.
2. Cylinders that were cured by air drying in the laboratory at ambient temperatures similar to the moist curing resulted in a 12 percent reduction in measured strength at 28 days, with only a 5 percent reduction at seven days. But they showed a 26 percent reduction at 90 days with the 90-day strength slightly lower than the 28-day strength.
3. Cylinders that were cured for 48 hours in sub-freezing temperatures followed by standard moist curing resulted in a 22 percent reduction in strength at 28 days. This represents a potential condition where test cylinders are not protected during the initial curing period in the field. However, by 90 days the strength reduction was only 10 percent.
4. Cylinders that were kept in external conditions for the period prior to testing, where the average ambient daily temperature varied in the range of 20 to 45°F, resulted in a reduction of strength by 34 percent at 28 days. However, by 90 days the strength reduction was only 18 percent. It should be pointed out that between 28 and 90 days the external temperature varied between 40 to 75°F.
5. Dramatic strength reductions particularly at early ages (28 days or less) are possible if the initial curing conditions of ASTM C 31 are not followed. This can be the cause for acceptable concrete to be rejected. However, in certain situations by 90 days the lower strengths from non-standard curing were not as significant.

Hot Weather Conditions (Series D 338)

In the summer of 2004, the NRMCA Research Laboratory undertook a simple experimental study to quantify the effect of high temperature exposure on concrete compressive strength development. Other tests conducted for supplementary evaluations were the measurement of the elastic modulus, sorptivity (a newly approved ASTM test) and rapid chloride permeability (C 1202).

A nominal 4000-psi air-entrained concrete mixture was prepared and a total of 38 4 x 8-inch cylinders were made and cured in various conditions immediately after casting.

Experimental Details

The 2.8 cu. ft. concrete batch was prepared at the NRMCA Research Laboratory. The mixture had a cement content of 400 lbs/yd^3 and fly ash content of 125 lbs/yd^3, at a water-cementitious materials (w/cm) ratio of 0.52. A Type A water reducer and an air entraining agent were also used.

The measured slump and air content were 6.75 inches and 5.6 percent, respectively. The initial concrete temperature was 72°F.

A total of 38 4x8 cylinders were cast. Strength tests were planned for one, three, seven, 28 and 90 days with an average from two cylinder tests representing a strength test result. Rapid chloride permeability tests in accordance with ASTM C 1202 were conducted at an age of 90 days for the standard and outside curing conditions only. Static Modulus of Elasticity tests in accordance with ASTM C 469 and sorptivity tests in accordance with the new ASTM C 1585 were also conducted. Only the strength and Rapid chloride permeability test (RCPT) results are discussed here. The sorptivity test will be discussed in greater detail in a later article.

Curing Conditions

Cylinders were covered with plastic caps and cured in the following three methods immediately after they were made:

1. **Standard curing**
2. **Outside for 48 hours, moist cured**
3. **Outside until time of test** – cylinders were placed in covered 5-gallon buckets (2 cylinders per bucket) on the lab loading dock; stripped at 24 hours.

The average daily ambient temperature based on averages from BWI (Baltimore) and DCA (Reagan National) airports (College Park is midway) during the first 48 hours was in the range of 81 to 83°F and the peak daily temperature over the first seven days was about 89°F. The average daily temperature during the course of the study is indicated on the chart below. The average daily temperature was about 10°F above the standard curing temperature even though the peak temperature ranged over 90°F on certain days.

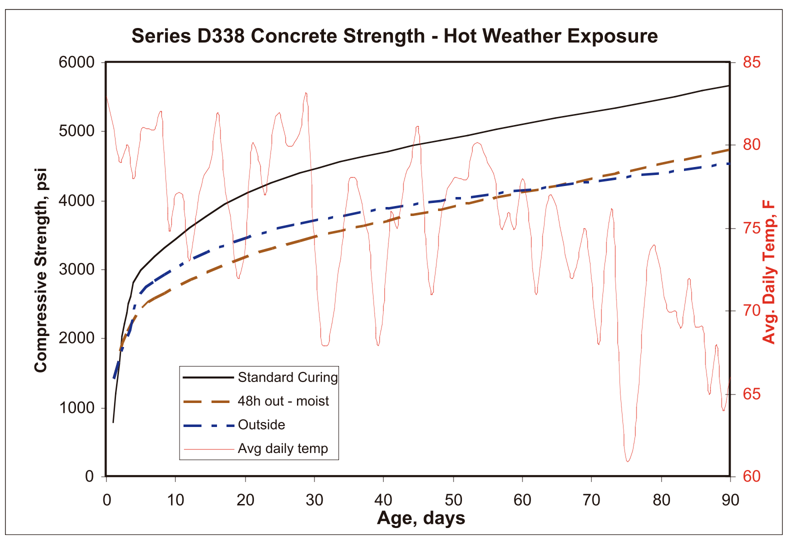
Test Results

The compressive strength results through an age of 90 days are illustrated in the chart below and the compressive strength as a percentage of the standard cured cylinders (control) at the various test ages is summarized in the Table.

The standard cured cylinders gave an average RCPT value of 1536 coulombs, which indicates a "Low" chloride ion penetrability (ASTM C 1202), while the outside cured cylinders gave a higher RCPT value of 2475 coulombs, which indicates a "Moderate" chloride ion penetrability.

Conclusions

1. This study demonstrates the effects of curing test specimens in high temperatures.
2. Cylinders that were cured in a high temperature external environment displayed 80 percent higher one-day strength as compared to the standard cured cylinders. The low one-day strength of the standard cured cylinders is likely due to the 24 percent fly ash used in the concrete and the resulting slower strength gain in standard curing conditions.
3. Cylinders cured for 48 hours in high temperatures followed by standard moist curing resulted in a 22 percent reduction in strength at 28 days. This represents a potential condition where test cylinders are not protected during the initial curing period in the field. By 90 days the strength reduction was 16 percent.
4. Cylinders that were kept in external conditions for the entire period prior to testing, where the average ambient daily temperature varied in the range of 61 to 83°F, resulted in a reduction of strength by 16 percent at 28 days and 20 percent by 90 days. The peak daily temperatures were in excess of 90°F on some days. This does not represent the higher summer temperatures seen in southern states where the effects of non-standard initial curing in the field could have been more significant.
5. The modulus of elasticity did not vary very much in the different curing conditions.
6. The RCPT values measured were much lower for the standard cured cylinders, confirming that good curing practices substantially improve concrete durability. ■



Age, days	Control Strength, psi (1)	Percent of control strength at same age	
		Out 48 h, moist (2)	Outside (3)
1	784	180%	180%
3	2370	89%	86%
7	3176	81%	90%
28	4384	78%	84%
90	5659	84%	80%