Effect of Moisture Condition on Concrete Core Strengths

Principle Investigators:
Wally Heyen, PCC Engineer
Lieska Halsey, Assistance Material Engineer

Background

The strength of the concrete measured by tests of cores is affected by the amount and distribution of moisture in the specimen at the time of testing according to ASTM C42: Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete, “There is no standard procedure to condition a specimen that will ensure that, at the time of test, it will be in the identical moisture condition as concrete in the structure.”

According to ASTM C42, it is current practice to allow the cores to remain in a sealed condition with a plastic bag or non-absorbent containers for at least 5 days prior to testing unless otherwise specified by the engineer. Currently, Nebraska Department of Transportation (NDOT) follows the ASTM C42 with the exception of all cores obtained for compressive strength testing must be stored immediately in a moisture cured room until the required 28-day testing; after being delivered in a sealed bag.

Objective of the Investigation

The main objective of this in-house investigation was to determine the magnitude of the difference between the strengths of moisture cured and sealed plastic bag cured cores. The Department launched this investigation to examine if there is a major strength difference between the moisture cured and sealed plastic bags cured specimens for drilled cores in Nebraska.

Description of the Investigation

1. Sample and test NDOT’s paving mix in accordance to the provisions of according to ASTM C42 and ASTM C39.
2. Evaluate compressive strength at 28 days for drilled cores at age of 14, 21, and 26 days.
    a. After collecting drilled cores at the determined ages, approximately 30 cores will be immediately placed in sealed bags and cured in the sealed plastic bag until time of testing; and approximately 30 drilled cores will be immediately placed in sealed bags, transported to the cure room, un-bagged immediately upon delivery to the lab and cured in the cure room until time of testing at 28 days.
3. Evaluate same day compressive strength for drilled cores at age of 28, 32, 35, and 56 days.
4. Evaluate the permeability for drilled cores at age of 26, 28 and 32 days.
5. Evaluate the Coefficient of Variation (CV) between the strengths of cores moisture cured and cores cured in the sealed plastic bag.

Conducted in the Field

The cores were obtained from the project on HWY 30 (Schuyler to Rogers) during the summer of 2018 from 10-inch pavement. Sampling and testing was conducted according to specification ASTM C42 and tested in accordance with ASTM C39 - Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. Some cores were tested for permeability in accordance to AASHTO T277, the results are found below in this document. The mix used on this project is a standard 47B mix design (70% sand/gravel and 30% limestone) with compressive strengths of 3500 psi at 28 days. Table 1 shows the concrete plastic characteristics.

Figure 1 - The coring crew cuts research cores in a grid on the Hwy 30, Schuyler-Rogers project.

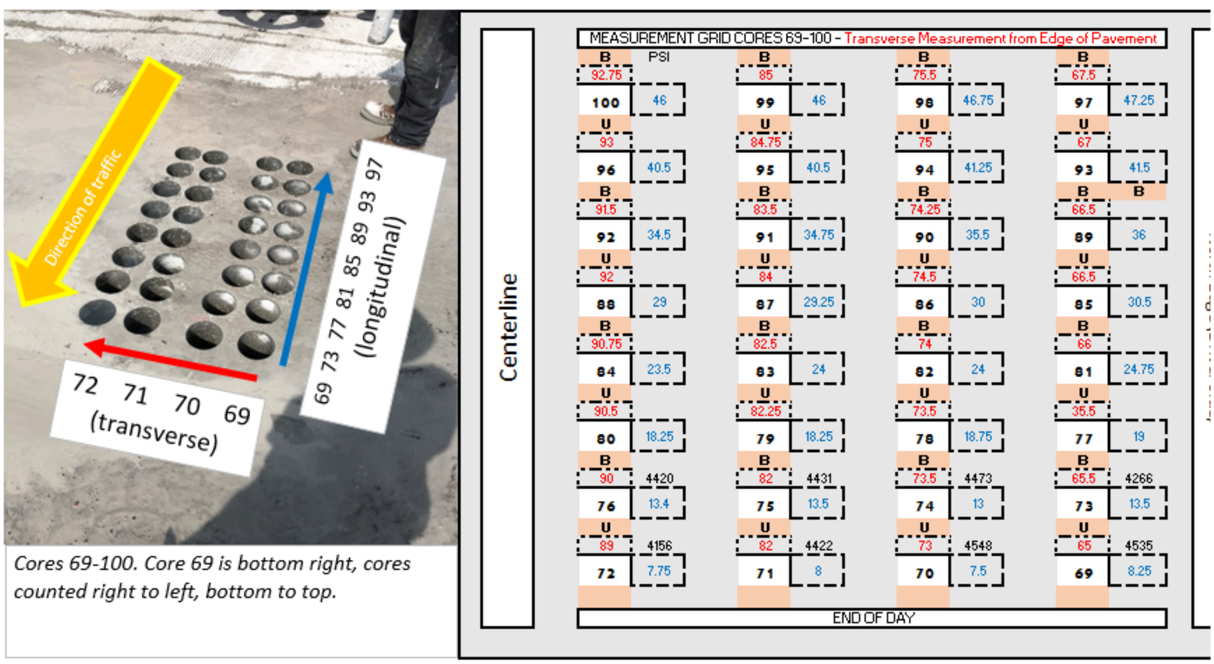
Table 1 - Concrete Mix Plastic Characteristics

Concrete Type	W/C Ratio	Air Percentage (%)	Compressive Strength (psi)	Cementitious Contents Lbs./cy
47B	0.40	7.5	3500	564

Two panels were chosen near the end-of-the-day placement on the eastbound side of Highway 30 between Schuyler and Rogers, Nebraska. Cores were obtained at the respective ages designated for evaluation in this investigation. Four-inch diameter cores were drilled vertically through slab thickness using a water-cooled diamond bit in a grid pattern as seen in Figure 1.

The grid was designed by the principal investigators. Cores were obtained by the department's coring crew using 2 coring-machines due to the large number of cores obtained at the respective ages designated for evaluation. The first machine, core drill #1, was capable of cutting four cores within its range. After 4 cores were obtained, the truck was moved forward and the next set of 4 were cut. This created a 2 x 8 grid totaling of 16 cores. The machine was then positioned to cut a second 2 x 8 grid next to the first. The first machine cut 32 cores each day it was on the project. The second machine, core drill #2, operated in the same manner as the first with the exception that the second machine could cut 9 cores within its range. It cut 36 cores each day it was on the project.

The 21-day coring grids for core drill #1 and core drill #2 are shown in Figure 2 and in Figure 3. Core strengths represent the quality of the in-place, or in-situ, concrete which in addition to concrete batching, mixing, transportation and testing is influenced by jobsite practices such as placing, consolidating and curing. Strengths of cores are also influenced by the drilling operation, core handling and moisture conditioning before testing. The measurement details where each core was cut is included in Figure 2 and Figure 3 to consider these influences. Core IDs are shown in the white cells, the red and green numbers are transverse measurements(in inches)from the edge of pavement and the centerline, respectively. The Blue numbers are the longitudinal measurements(in inches) from the doweled transverse joint.



Cores 69-100. Core 69 is bottom right, cores counted right to left, bottom to top.

Figure 2 - Core grid for Core Drill #1 on research day 21.

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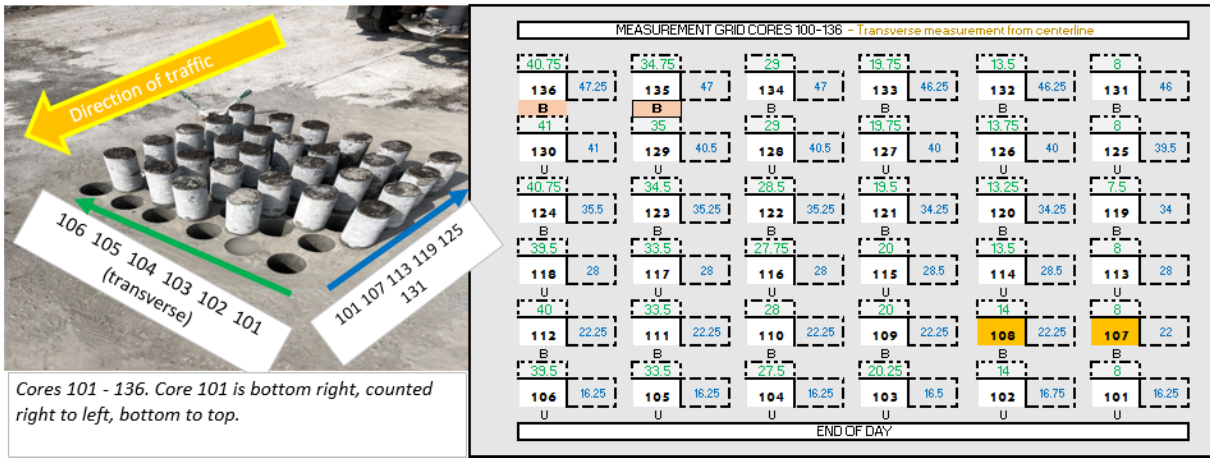

Figure 3 - Core grid for Core Drill #2 on research day 21.

Once the cores were obtained from the slab, the cores were air dried, labeled and bagged for transportation in accordance of ASTM C42. Upon arrival at the Portland Cement Concrete (PCC) lab in Lincoln, the designated un-bagged cores were removed from transportation bags and placed in the moist curing room. The bagged cores remained sealed until the designated day of testing. Sixty core specimens were obtained for each day designated for evaluation as in shown in Table 2. All cores were end-ground before testing.

The in-situ concrete temperature was monitored by SmartRock2TM sensors to measure temperature gradient change. The maximum temperature recorded from the slab reached 112.1 ˚F and the minimum temperature recorded was 58.5 ˚F. Figure 4 shows the temperature gradient of the pavement from time of pouring to 28 days. SmartRock2TM sensors may be used to estimate the compressive strength of the concrete placement by obtaining the Time Temperature Factor (TTF). Due to schedule changes on the project, the maturity curve was not completed for the concrete placed for this research.

Maturity method requires pre-calibration of a concrete mix before it can be used to correlate the maturity to the strength on a project. Maturity calibration is specific to a mix design. Once the maturity calibration curve is developed in the laboratory for a specific mix, it can be used for on-site estimation of compressive strength of concrete in real-time.

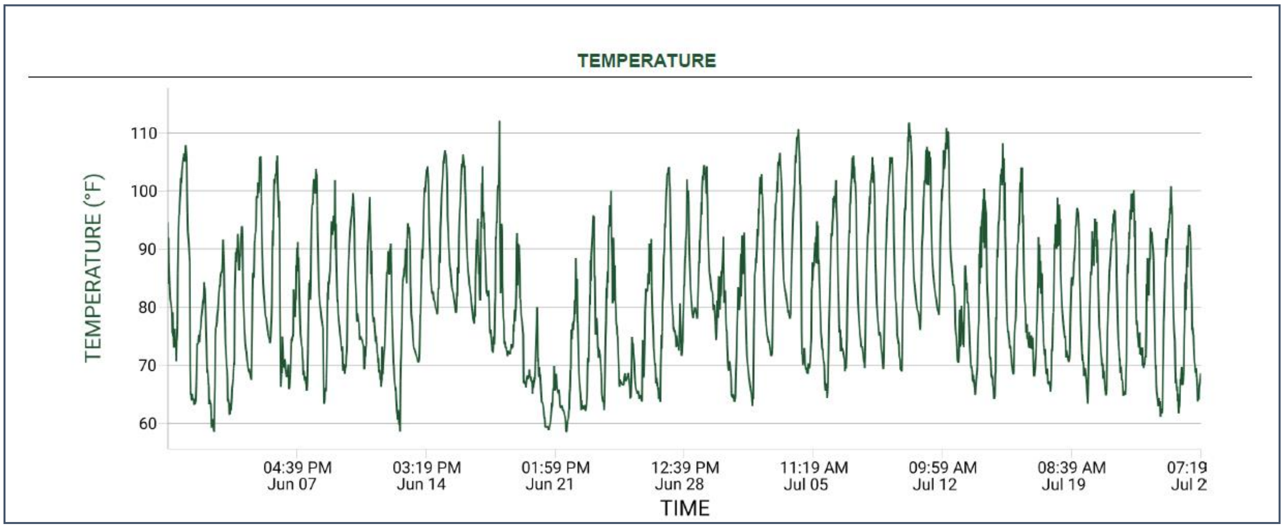

Figure 4 - SmarkRock recorded slab temperature

Table 2 shows the number of specimens obtained at 14, 21, 26, 28, 32, 35, and 56 days. Researchers evaluated the compressive strength at 28 days for cores drilled at ages of 14, 21, and 26 days. After collecting drilled cores at the determined ages, 30 cores were sealed in a plastic bag and 30 cores were sealed in bags at time of coring, stripped upon delivery at the lab, and cured in the cure room until time of testing at 28 days.

The compressive strength for drilled cores at age of 28, 32, 35, and 56 days was evaluated on the same day that cores were collected. The 30 cores obtained at their specified ages were labeled and bagged for transportation from the field to the lab in accordance of ASTM C42 and tested in accordance of ASTM C39.

Table 2 - Schedule of core sampling, number of cores, and curing methods.

	Time of Testing Slab (Age)									
	14 days		21 days		26 Days		28 Days	32 Days	35 Days	56 Days
	Tested at 28 days						Test on same day			
	Sealed Bag Cured	Moisture Cured	Sealed Bag Cured	Moisture Cured	Sealed Bag Cured	Moisture Cured	Number of Specimens			
	30	30	34	34	36	36	36	32	36	32
Total Number of Specimens	60		68		72		36	32	36	32

Figure 5 shows compressive strength test results. The compressive strength data for all cores was checked for statistical outliers using ASTM E178: Standard Practice for Dealing with Outlying Observations. No cores were deemed outliers and therefore all were retained for analysis. In order to quantify variation in the data the standard deviation (STDEV) was evaluated. It is important to note core strengths represent the quality of in-situ concrete which in addition to concrete batching, mixing, transportation and testing is influenced by jobsite practices such as placing, consolidating and curing. The STDEV measures the data spread from the average (mean), or expected value. A low STDEV means that most of the numbers are very close to the average while a high STDEV means that the numbers are spread out. The 21 and 26 day data sets show the highest STDEV. The lowest STDEV was found at 32 days. The greater STDEV observed on 21 and 26 dates seems to narrow as age of the concrete increased.

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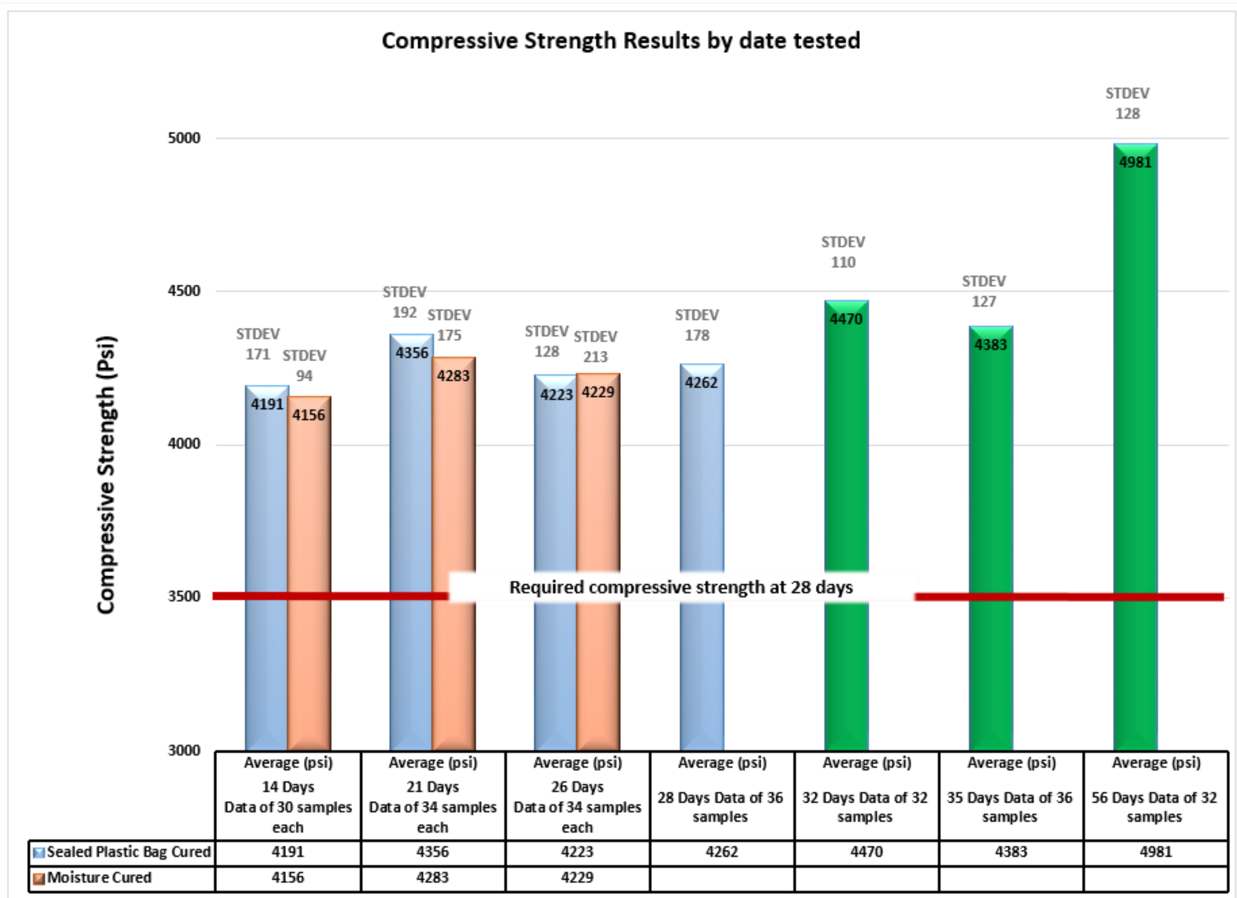

Figure 5 – Compressive Strength Results per day Tested
Note: Green color represent compressive strength for informational purposes

Table 3. Min-Max values from Standard Deviation Variation

	Min-Max values from Standard Deviation Variation									
	14 days		21 days		26 Days		28 Days	32 Days	35 Days	56 Days
	Tested at 28 days						Test on same day			
	Sealed Bag Cured	Moisture Cured	Sealed Bag Cured	Moisture Cured	Sealed Bag Cured	Moisture Cured				
Max (psi)	4362	4250	4548	4458	4351	4442	4440	4580	4509	5108
Min (psi)	4020	4062	4164	4108	4095	4016	4084	4360	4256	4853

Table 3 shows the maximum and minimum values from the STDEV for each day tested. The 32, 35 and 56 days compressive strength were evaluated to determine the rate of strength growth from 28 days strength and are for informational purposes only.

The weighted average Coefficient of Variation (CV) of the 98 core samples of the 14, 21 and 26 day cores for each curing method was evaluated as shown in Table 4. Equation 1 shows the overall calculation used for the COV of moisture cured and sealed plastic bag cured for 14, 21 and 26 days.

$$COV_{weighted\ average} = [(\textit{14 days specimens} / \textit{Total Specimens} @_{14,\ 21\ and\ 26\ days})*COV_{14\ days})]+[(\textit{21 days specimens} / \textit{Total Specimens} @_{14,\ 21\ and\ 26\ days})*COV_{21\ days})]+[(\textit{26 days specimens} / \textit{Total Specimens} @_{14,\ 21\ and\ 26\ days})*COV_{26\ days}]$$

Equation 1.

The overall coefficient of variation for 14, 21 and 26 days with a total 98 specimens tested based on the equation 1 shows that there is essentially no difference between the strengths of moist cured and sealed plastic bag cured specimens.

Table 4 - Coefficient of Variation weighted average for the moist cured and sealed plastic bag cured specimens.

Overall Coefficient of Variation Weighted average for 14, 21 and 26 days – 98 Samples	
Sealed Plastic Bag Cured	**Moisture Cured**
3.84%	3.86%

Table 5 below shows the error between the average compressive strengths of sealed plastic bag cured cores in accordance with ASTM C42 and moist room cured cores at 14, 21, and 26 days. The two positive values represent un-bagged core strengths as lower than bagged cores. The negative value indicates the average un-bagged core strength is higher than the bagged cores.

Table 5 – Percent Strength difference between sealed plastic bag and moist cured cores.

	14 days	21 days	26 Days
	Tested at 28 days		
	Average (Psi)		
Sealed Plastic Bag Cued Compressive Strength	4191	4356	4223
Moisture Cured Compressive Strength	4156	4283	4229
	Percent Strength Difference		
Sealed Plastic Bag Cured Vs. Moisture Cured	0.84%	1.70%	-0.14%

Permeability Test

Table 6 shows an average of 4 sealed plastic bag cured cores and average of 4 cores moist cure tested in accordance of AASHTO T 277 for 26, 28 and 32 days. The results for 28 and 32 are from an average of 12 cores immediately tested after transported to Lincoln and show a low to very low chloride ion permeability.

Table 6 – Chloride Ion Permeability Test Results

		Surface Resistivity (SR) Readings Total (Kohm-cm)		
Days		26	28	32
Average (4 cores)	Sealed Plastic Bag Cured	34.13	NA	
Average (4 cores)	Moist Cured	32.63	NA	
Average (12 cores tested immediately after being transported to the testing facility)		NA	47.43	52.39

Conclusion

The main purpose of this study was to determine if there would be any major differences between curing methods of cores taken for acceptance testing from a highway slab on a project. The comparison provided data to determine the effect of the moisture gradients created by these different curing treatments on core strength and core permeability. The strengths were measured of moist cured cores and sealed plastic bag cured cores from the day cores were obtained (14, 21 and 26 days) until they reached 28 days. Permeability was also measured at 26, 28 and 32 days. According to ASTM C42, it is current practice to allow the cores to remain in a sealed condition with a plastic bag or non-absorbent containers for at least 5 days prior to testing unless otherwise specified by the engineer. Currently, Nebraska Department of Transportation (NDOT) follows the ASTM C42 with the exception that all cores obtained for compressive strength testing must be delivered to the PCC Lab in a sealed bag, un-bagged and stored immediately in a moist cure room until the required 28-day testing. The findings from this study show no significant difference in strength nor in permeability between curing concrete core samples in bags versus storing them in a moist room.

Acknowledgements

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