Lessons from the TDOT/TCA/ACPA Maturity Project

Lesson 1: Cores versus Lab-cured Cylinders: The Influence of Temperature

By L. K. Crouch and T. Adam Borden

The recent TDOT/TCA/ACPA Evaluation of New PCC Maturity Technology Project generated a large quantity of data. The generated data can be analyzed to provide valuable lessons about PCC behavior. This paper is the first in a series of technology transfer articles. The authors appreciate the financial support of TDOT and TCA. We hope you find the information presented helpful in better understanding PCC behavior. In the first article, data from the recent project are analyzed using concepts presented by Dr. Ken Hover at the Second Annual TCA Concrete Conference on November 17, 2003.

Factors Influencing PCC Strength Development

Portland cement concrete (PCC) gains strength and durability from reactions between Portland cement, supplementary cementing materials and water. The continuation of these chemical reactions is commonly termed curing. Curing progress (compressive strength development) is a function of time, temperature and moisture conditions. Therefore, if adequate moisture is available and curing time is the same for core and cylinder specimens, temperature becomes the critical factor.

Testing Background

The compressive strength of PCC is tested using a variety of different samples for different purposes. Lab-cured cylinders [1, 2] are used to evaluate mixture proportions and the quality of mixture ingredients. Standard curing procedures are used to remove the influence of temperature from the evaluation. Therefore, lab-cured cylinders indicate the potential compressive strength of the PCC mixture using standard curing procedures, not the compressive strength of the PCC placed in a structure. PCC in the pavement structure has experienced a curing temperature history that is often very different from standard lab curing conditions. Thus, the compressive strength of core samples [3] cut from the pavement is the best measure of the strength of the pavement structure. Field-cured cylinders, maturity and the rebound hammer will be discussed in Lesson 2.

Tennessee Experience

Figures 1, 2, 3 and 4 show core and lab-cured cylinder compressive strengths from the recent TDOT/TCA/ACPA Project. Each column represents the mean compressive strength of a pair of 4x8 cores or the corresponding mean compressive strength of a pair of 6x12 lab-cured cylinders of the same age from the same batch of PCC.

Analysis

Figures 5 and 6 show core strength expressed as a percentage of lab-cured cylinder strength for I-65 Nashville and I-75 Chattanooga, respectively.

Table 1 shows a comparison of core and lab-cured compressive strengths at 4 and 28 days for I-65 Nashville and I-75 Chattanooga. Data taken from each location indicate substantially different relationships between core and lab-cured cylinder compressive strengths. Table 2 contains critical information (mean pavement temperatures) for interpreting Table 1. The pavement structure develops compressive strength at a rate dependent on curing temperature in the field. The relationship between core and lab-cured cylinder compressive strengths is dependent on the difference in their curing temperature histories.

Figure 1. 4-Day Core and Lab-cured Cylinder Strengths for I-65 Nashville

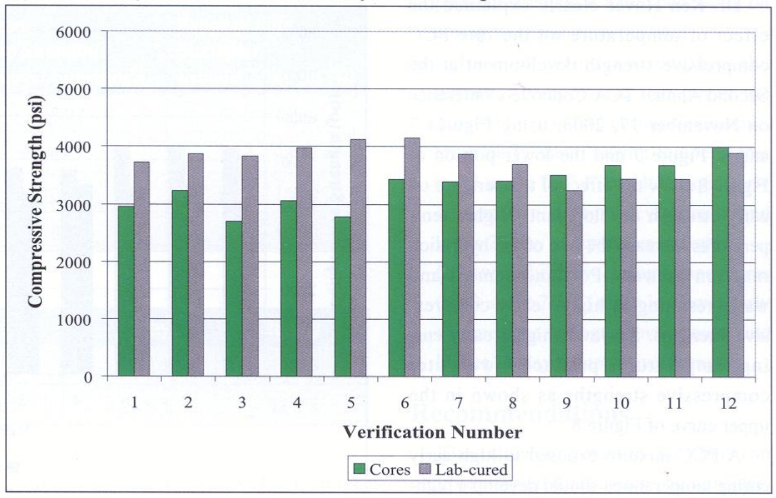


Figure 2. 4-Day Core and Lab-cured Cylinder Strengths for I-75 Chattanooga

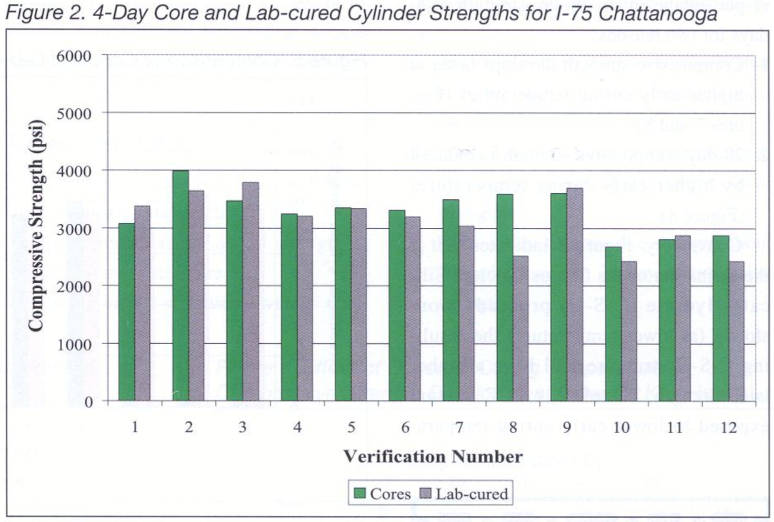
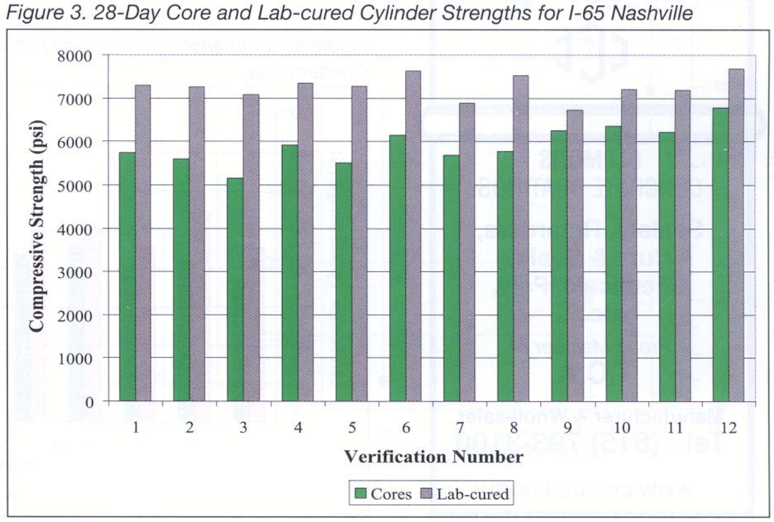


Figure 3. 28-Day Core and Lab-cured Cylinder Strengths for I-65 Nashville



Dr. Ken Hover clearly explained the effect of temperature on the rate PCC compressive strength development at the Second Annual TCA Concrete Conference on November 17, 2003, using Figures 7 and 8. Figure 7 and the lower portion of Figure 8 show the effect of temperature on early strength development. Higher temperatures increase the rate of the hydration reaction between Portland cement and water resulting in higher early compressive strengths. However, higher early curing temperatures produce lower later compressive strengths as shown in the upper curve of Figure 8.

A PCC mixture exposed to high early curing temperatures should develop a higher percentage of its 28-day strength at 4-days for two reasons:

1. Compressive strength develops faster at higher early curing temperatures (Figures 7 and 8);
2. 28-day compressive strength is reduced by higher early curing temperatures (Figure 8).

Conversely, Figure 8 indicates that if the formation of the fibrous Calcium-Silicate-Hydrate (C-S-H) proceeds more slowly (at lower temperature) the resulting C-S-H structure will have a higher later strength. Therefore, a PCC mixture exposed to lower early curing tempera-

Figure 4. 28-Day Core and Lab-cured Cylinder Strengths for I-75 Chattanooga

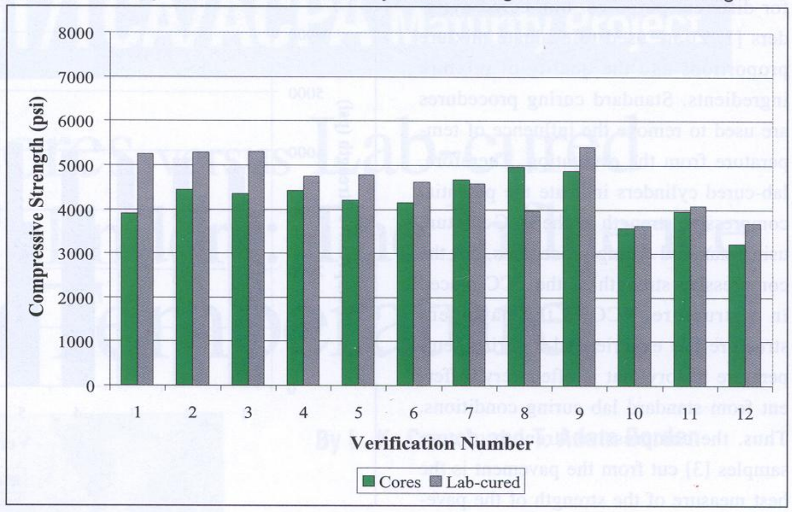


Figure 5. Comparison of Core and Lab-cured Cylinder Strengths for I-65 Nashville

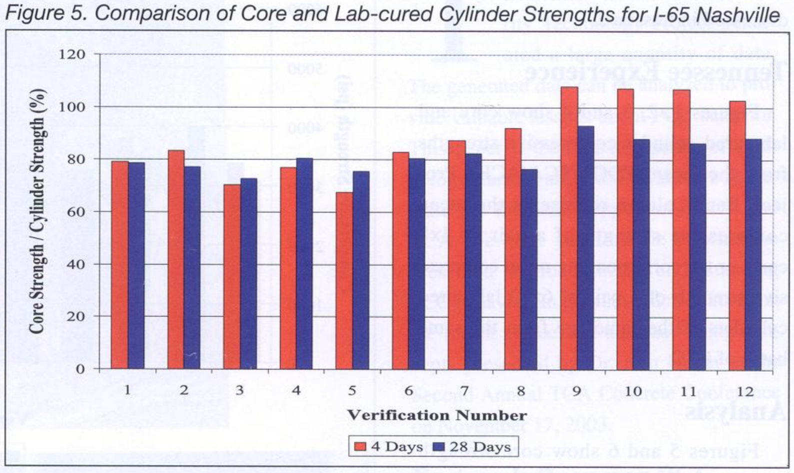


Figure 6. Comparison of Core and Lab-cured Cylinder Strengths for I-75 Chattanooga

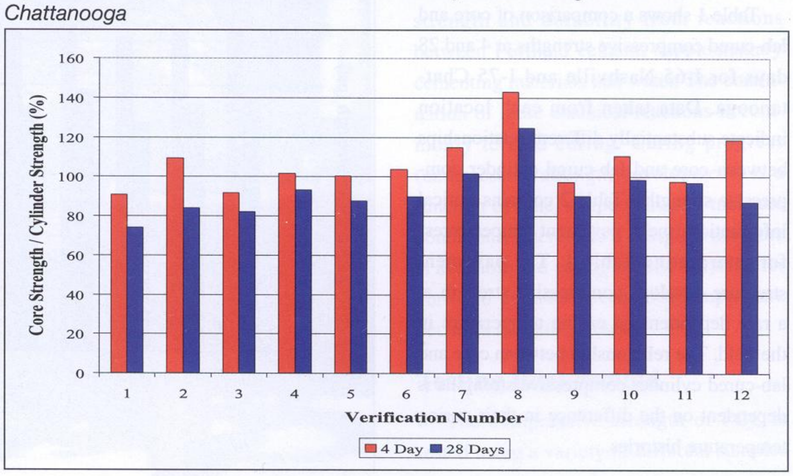


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Table 1. Comparison of Core and Lab-cured Cylinder Strengths

Location	Age (days)	Percentage Core Strength > Lab-cured Cylinder Strength	Mean Core Strength/ Cylinder Strength(%)	Range of Core Strength / Cylinder Strength (%)
I-65	4	33	88.7	67.5 – 108.0
	28	0	81.7	72.8 – 93.1
I-75	4	67	106.6	90.7 – 143.0
	28	16.7	92.5	74.1 – 124.8

Table 2. Mean Pavement Temperatures

Location	Placement Date	24 Hour	4 Day	28 Day
I-65	October 2002	67.1°F	65.8°F	61.3°F
I-75	August 2003	98.4°F	94.9°F	92.3°F

tures should have a lower percentage of its 28-day strength at 4-days. Figure 9 shows that the concepts presented by Dr. Hover are supported by Tennessee evidence. The PCC for I-65 Nashville, exposed to mean curing temperatures in the 60 to 70°F range, developed a much lower percentage of its 28-day compressive strength at 4-days (mean of 55.9 percent, all values between 50 and 60 percent). However, the PCC for I-75 Chattanooga, exposed to mean curing temperatures in the 90 to 100°F range, developed a much higher percentage of its 28-day compressive strength at 4-days (mean of 78.1 percent, all values between 70 and 90 percent).

Lesson Summary

Based on the data available, the following conclusions may be drawn:

1. Core strength is the actual strength of the pavement structure.
2. The pavement structure develops compressive strength at a rate dependent on curing temperature in the field.
3. Lab-cured cylinder strength is the potential compressive strength of the mixture for standard curing conditions.
4. High early mean curing temperatures (> 73 and < 100° F) result in rapid early compressive strength development and lower 28-day compressive strengths.
5. Low early mean curing temperatures (> 60 and < 73° F) result in slower early compressive strength development and higher 28-day compressive strengths.

Recommendations

The following common questions can only be answered accurately by considering the effects of curing temperature history.

1. Are core compressive strengths higher or lower than lab-cured cylinder compressive strengths?
2. Is the 3-day compressive strength about 50 percent of the 28-day compressive strength?
3. Is the 7-day compressive strength about 70 percent of the 28-day compressive strength?

Figure 7. Effect of Concrete Temperature on Cement Hydration Rate (After Dr. Ken Hover)

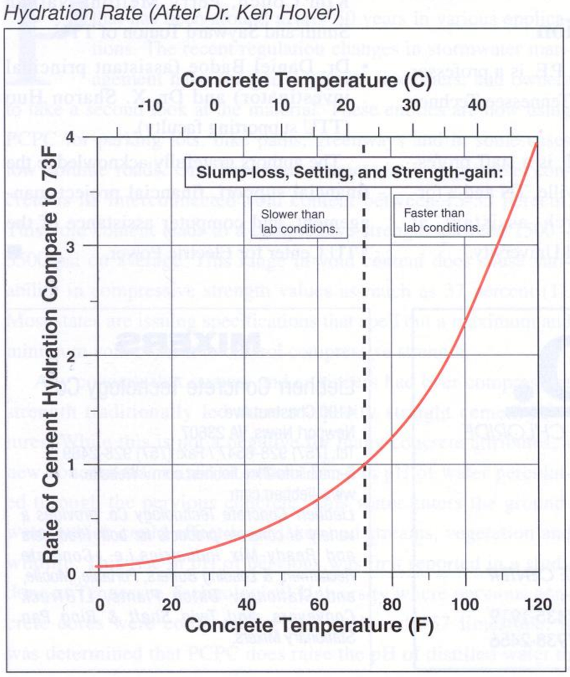


Figure 8. Effect of Concrete Curing Temperature on Compressive Strength Development (After Dr. Ken Hover)

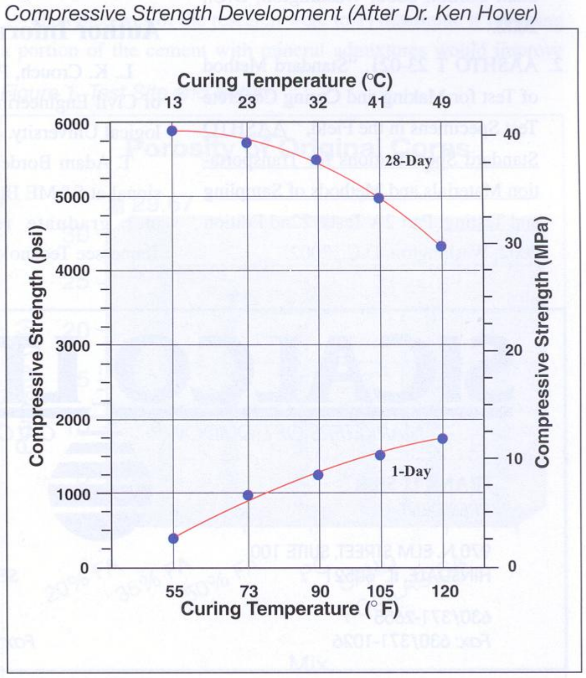
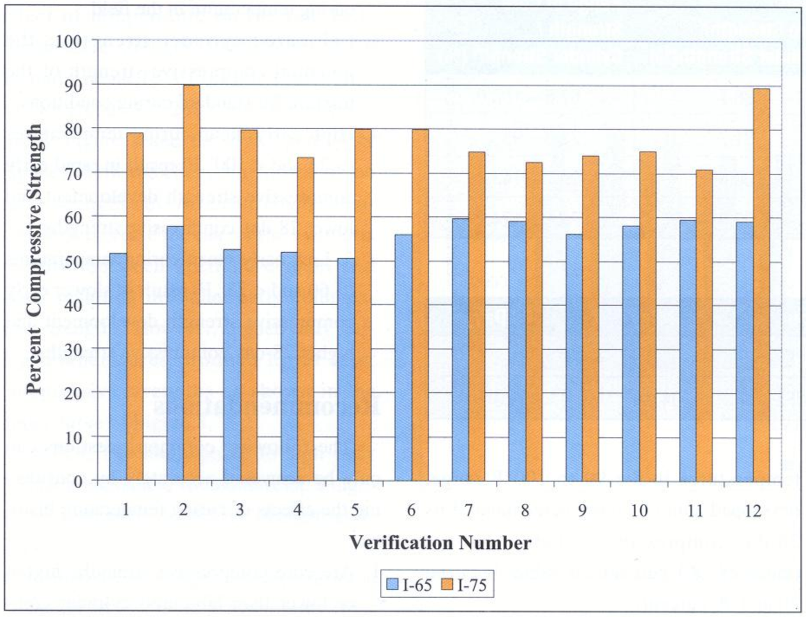


Figure 9. 4-Day Core Compressive Strengths as a Percentage of 28 Day Core Compressive Strengths



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