The Importance of Concrete Temperature Control During Concrete Pavement Construction in Hot Weather Conditions

by

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ABSTRACT

The development of high concrete temperatures could cause a number of effects that have been shown to be detrimental to long-term concrete performance. High concrete temperatures increase the rate of hydration, thermal stresses, the tendency for drying shrinkage cracking, permeability, and decrease long-term concrete strengths, and durability as a result of cracking. Data from the Texas Rigid Pavement database was analyzed to reveal that there are an increased number of failures as the air temperature at placement increases. It was further shown that this was the case for both major coarse aggregate types: limestone and siliceous river gravel. The result of this analysis emphasizes the importance of concrete temperature control during concrete pavement construction in hot weather conditions.

Most States specify a maximum concrete temperature at placement, to mitigate the detrimental effects of hot weather placement. The specified limit remains the same irrespective of the type of mineral or chemical admixtures used. In order to produce specifications that encourage contractor innovation and the use of improved materials, modern specifications should account for these materials in order to ensure improved concrete performance under all placement conditions. To provide improved performance for section paved under hot weather conditions, it is proposed that the CRC pavement reinforcement standards be re-designed to provide steel quantities for specific use during hot weather conditions, and that an end-result specification that limits the maximum in place concrete temperature during hydration be implemented.

INTRODUCTION

The hydration of a concrete mixture is a process that liberates heat and the rate of heat generation is accelerated with an increase in concrete temperature. Concrete is a poor conductor of heat, and the rate of heat evolution due to the hydration process is, therefore, much greater than the rate of heat dissipation. Consequently, the temperature inside the concrete rises during early hydration stages. In this regard, Soroka (*1*) elaborates by stating that: "It can be realized that this problem of thermal cracking is further aggravated by the accelerating effect of temperature on the rate of hydration. This effect results in a higher rate of heat evolution which, in turn, brings about a higher rise in concrete temperature."

The magnitude of thermal stresses that develop in a restrained concrete pavement is directly proportional to the change in temperature it is subjected to during it design life. The higher the development of concrete temperatures during hydration, the higher the magnitude of thermal stress that develops. The concrete temperature at placement, therefore, significantly influences the magnitude of the thermal stress the pavement is subjected to. This is confirmed by the SHRP-C-321 study (*2*), which reported that the effects of temperature and moisture early in the life of concrete strongly influence early strength development and long-term durability. Other research findings also concluded that the concrete temperature development during the first 24 to 72 hours after placement has a major impact on long-term pavement performance (*3*, *4*).

Objectives

The primary objectives of this paper are to investigate the effects of high concrete temperatures on long-term concrete pavement performance, and to discuss the different reasons why high concrete temperatures during placement are of concern. Secondary objectives of this paper are to review current approaches to mitigate the effects of high concrete temperatures, and to present a conceptual method to produce longer lasting concrete pavements even if paved during hot weather conditions.

Scope

This paper will first discuss the range of problems that could be experienced during concrete placement in hot weather conditions. Next, more background on the development of thermal stresses and concrete temperatures are provided. Thereafter, long-term performance data from the Texas rigid pavement database will be evaluate to determine the effect of high concrete temperatures at placement on continuously reinforced concrete (CRC) pavement performance. Finally, current and proposed techniques to mitigate the detrimental effects of high concrete temperatures are discussed.

PROBLEMS ASSOCIATED WITH HIGH INITIAL CONCRETE TEMPERATURES

This section contains some review of literature related to the problems associated with high concrete temperatures. As redundant as this may seem, the repetition is necessary to emphasize the various effects of high concrete temperatures on concrete pavement performance. The problems with high concrete temperatures are nationally recognized, and it is reported by ACI committee 305 (*5*) that problems in hot weather conditions could be experienced in both the fresh and hardened concrete. In the fresh state, problems with the use of chemical admixtures have also been reported, as some chemicals become incompatible and are less effective at higher temperatures. ACI 305 (*5*) further comments that, "Potential problems in fresh concrete are likely to include:

- Increased water demand;
- Increased rate of slump loss and corresponding tendency to add water at the job site;
- Increased rate of setting, resulting in greater difficulty with handling, compacting, and finishing, and a greater risk of cold joints;
- Increased tendency for plastic shrinkage cracking; and
- Increased difficulty in controlling the entrained air content."

ACI 305 (*5*) also comments that, "Potential problems in hardened concrete are likely to include:

- Decreased 28-day and later strengths resulting from either higher water demand, higher concrete temperature, or both at time of placement or during the first several days;
- Increased tendency for drying shrinkage and differential thermal cracking from either cooling of the overall structure, or from temperature differentials within the cross section of the member;
- Decreased durability resulting from cracking;
- Increased potential for reinforcement corrosion – making possible the ingress of corrosive solutions;
- Increased permeability as a result of high water content, inadequate curing, carbonation, lightweight aggregates, or improper matrix-aggregate proportions."

Two aspects caused by high concrete temperatures at placement that may have a significant impact on the behavior and long-term performance of concrete pavements are an increased rate of hydration; and a decreased 28-day or long-term concrete strength. Due to their importance, both these issues will now be discussed in more detail.

Increased rate of hydration at high temperatures

In 1975, Samarai, Popovics and Malhotra (*6*) reported that elevated temperatures (in reference to hot climates) cause rapid setting. "The higher the curing temperature is, the faster are the reactions between cement and water, and consequently the shorter becomes the setting time." Figure 1 is presented in this paper, and one of the inherent problems associated with concrete placement under high temperature conditions is clearly identifiable. The heat of hydration increases rapidly above curing temperatures of around 25 to 30°C. It should be emphasized that this graph was developed through the studying of the hydration of C_3S, which is the largest compound found in cement. For typical Type I cements in the United States, C_3S contributes about 54% of the cement particle composition (*7*).

Concrete mixture proportions currently used in highway construction may contain mineral and/or chemical admixtures, which could significantly change the rate of the hydration and heat development. The effect of adding fly ash to a mixture can be seen in Figure 2, which shows the rate of heat development for two different mixes tested by isothermal calorimetry (*8*). The vertical axis of Figure 2 shows the rate of heat evolution in terms of milliwatts per gram (mW/gram). Note that the mixture with Type I cement (Figure 2a) reaches a rate of heat evolution of around 20 mW/gram at a mixing temperature of 55°C (131°F). The mixture with 17% Type F Fly Ash replacement (Figure 2b) only reaches a rate of heat evolution of around 13 mW/gram, which indicates for this mixture that the use of fly ash would significantly reduce the development of concrete temperatures.

Experimental results have shown that a change in initial mixture temperature significantly affects the rate of heat development (*9*). The higher the fresh concrete temperature, the higher and more rapid the rate of hydration. In fact, Komonen and Penttala (*9*) concluded that, "…mixing temperature was the most significant variable. The higher the mixing temperature was the earlier the heat gain took place."

Concrete strength as affected by high curing temperatures

Concretes mixed, placed, and cured at elevated temperatures normally develop higher early strengths than concrete produced and cured at lower temperatures, but strengths are generally lower at 28 days and later ages (*10*, *11*, *12*, *13*). Data are available that show that low placement temperatures followed by normal curing will lead to higher concrete strengths as compared to concrete placed at high temperatures (*12*,*13*). It has also been shown that high curing temperatures will lead to a reduced later-age concrete strength, as compared to samples cured at lower temperatures (*10*, *12*).

Verbeck and Helmuth (*13*) presented an explanation for the reduced long-term strength for concretes cured at high temperatures. They suggested that a higher initial temperature results in more than a proportional increase in the initial rate of hydration. Therefore, during the early stage of curing, when there is rapid strength development, the strength of concrete cured at the high temperature is greater than that of concrete cured at lower temperature. However, with rapid hydration, hydration products do not have time to become uniformly distributed within the pores of the hardening paste. In addition, "shells" made up of low permeability hydration products build up around the cement grains. The non-uniform distribution of hydration products leads to more large pores, which reduce strength, and the shell impedes hydration of the unreacted portion of the grains at later ages. This theory was later validated by means of backscattered electron imaging, which provides a direct means of examining the uniformity of distribution of hydration products (*14*). It was found that "… the sample hydrated at 50°C had dense hydration shells surrounding the cement grains …", and that an increased curing temperature also resulted in an increased porosity.

Irrespective of the cause of the strength loss associated with concrete placed at high temperatures, this strength loss will directly affect long-term pavement performance. Concrete pavements are designed for fatigue failures, by ensuring that enough pavement depth is provided to keep the stress to strength ratio to an acceptable level. When the long-term strength of the concrete is reduced, the capacity of the pavement to withstand the intended fatigue life is reduced and the pavements performance is decreased.

If one combines the effect of the increased thermal stress development associated with the high set temperature (outlined in the following section), and the lower long-term strength, one can easily understand why some sections constructed during hot weather conditions may exhibit poor performance.

DEVELOPMENT OF CONCRETE TEMPERATURES AND THERMAL STRESSES

The development of thermal stresses (σ_T) can be calculated by the simplified expression presented in Equation 1. The magnitude of the thermal stress is directly proportional to the magnitude of the temperature change that the pavement is exposed to. For an accurate estimate of the thermal stress, creep effects during early-ages and over the pavement life should be accounted for in Equation 1 (*11*).

$$\textbf{Thermal Stress} = s_T = DT \cdot a_t \cdot E_c \cdot K_r \qquad \text{. . . . . (}\textit{Equation 1}\text{)}$$

Where, DT = Temperature Change = $T_{\text{zero-stress}} - T_{\min}$ (°C),
a_t = Coefficient of Thermal Expansion (strain/°C),
E_c = Creep adjusted Modulus of Elasticity (Pa),
K_r = Degree of restrain factor,
$T_{zero\text{-}stress}$ = Concrete zero-stress temperature (°C), and
T_{min} = Minimum concrete temperature on a cold winter night (°C).

Figure 3 presents an illustration of the development of thermal stresses over time for freshly placed concrete. In terms of stress development, the final-set temperature is the temperature at which the concrete begins to resist stresses induced by drying shrinkage or temperature changes. In Figure 3, it can be seen that for summer casting conditions, the concrete temperature increases beyond the setting temperature, line (A). As the expansion of the concrete caused by the temperature rise is restrained, the concrete will be in compression when the peak temperature, line (B), is reached. During this phase the hydrating paste is still developing structure, the strength is low, and high amounts of early-age relaxation may occur when the concrete is subjected to high compression loads (*11*). When a decline in concrete temperature starts to occur, the compressive stress will be relieved until the concrete temperature drops below the zero-stress temperature, where the stress condition changes from compression to tension, line (C). Note that due to the effects of relaxation, the zero-stress temperature may be significantly higher than the final-set temperature (11). If tensile stresses, caused by a further temperature drop, exceed the tensile strength of the concrete cracking will occur, line (D).

The behavior of the temperature development after placement is a complex problem. It is mainly affected by the temperature of the concrete at placement, the curing temperature, the type and quantity of the cementitions materials, the solar radiation intensity, and the boundary conditions of the pavement. Figure 4 summarizes temperatures measured on two different CRC paving projects in Dallas, Texas. Figure 4a shows the steep rise in temperature for a section that was placed in hot weather conditions, as the average air temperature during the day of placement was above 30°C. This mixture design used 5 sacks of Type I cement with no mineral admixtures. The concrete was placed at a temperature of 32°C (90°F) and maximum temperature of 62°C (144°F) occurred only 7.0 hours after placement. Figure 4b shows the temperature rise for a section that was placed in weather conditions that is not considered to be hot weather placement conditions, as the average air temperature during the day of placement was only 20°C (68°F). This mixture design used 5.5 sacks of a Type I cement with a 20 percent by volume replacement with class F fly ash. The concrete was placed at a temperature of 22°C (72°F) and maximum temperature of 39°C (102°F) occurred 9.5 hours after placement. The difference in the peak temperature is approximately 23°C

(42°F). It should be noted that some of the difference is due to the use of class F fly ash, but the predominant factor is due to the difference in curing temperature as shown in Figure 2.

The difference in temperature histories of the two CRC pavements, shown in Figure 4, will have a direct impact on the amount of thermal stress the pavement will experience. The zero-stress temperature for the section placed under the hot weather conditions (Figure 4a) will be much higher than for the section cast under normal paving temperatures (Figure 4b). To produce improved performance of concrete pavement placed all year around, sections constructed under high air temperature conditions require mitigation techniques to reduce the heat development in the concrete. The following section will evaluate the effect of high concrete temperatures based on long-term CRC pavement performance data.

EVALUATION OF THE EFFECT OF AIR TEMPERATURES AT PLACEMENT ON LONG-TERM CRC PAVEMENT PERFORMANCE

CRC pavement data from the Texas Rigid Pavement (TRP) database (*15*) will be used to evaluate the effect of concrete temperatures on long-term CRC pavement performance. The TRP database contains performance data for sections located across the state, with some of the sections constructed in the early 1960s. The analysis of the TRP database considered all non-overlaid sections that were older than 5 years. The thicknesses of the sections vary between eight and thirteen inches. The age of the non-overlayed sections is from 11 years to 36 years old, with the average age at around 23 years.

As the TRP does not contain the concrete temperature at placement, the average maximum daily air temperature during the month of placement was determined from historical climatic data. The maximum air temperature was selected, as concrete placement in general occurs during the daytime during which the maximum daily temperature occurs. This approach was deemed appropriate for this comparative study, as the initial concrete temperature is correlated to the air temperature that prevailed during construction. Failures were defined as severe punchouts, plus asphalt or portland cement concrete patches. In this analysis the air temperature during placement (T_a) was grouped into the following five bins:

$10.0°C \leq T_a < 15.5°C$ $(50°F \leq T_a < 60°F)$
$15.5°C \leq T_a < 21.0°C$ $(60°F \leq T_a < 70°F)$
$21.0°C \leq T_a < 26.5°C$ $(70°F \leq T_a < 80°F)$
$26.5°C \leq T_a < 32.0°C$ $(80°F \leq T_a < 90°F)$
$32.0°C \leq T_a < 37.5°C$ $(90°F \leq T_a < 100°F)$

For each of the five bins listed above, the median number of failures per 305m (1,000 foot) section was calculated. The mean was chosen because there is a great deal of variability in the data that is collected by means of visual condition surveys. The number of failures in each bin will be normalized with respect to the total number of failures that occurred in all the sections, as this will provide a comparative indication of the effect of air temperature at placement.

Figure 5(a) provides an overall summary of the 337 CRC pavement sections analyzed. From this figure it may be seen that there is an increased number of failures as the air temperature at placement increases. More than 36% of all failures occurred in the sections that were placed under conditions where the air temperature at placement exceeded 32.0°C (90°F). Around 26% of the failures occurred when the sections were constructed at air temperature between 26.5°C and 32°C. The result for the 10.0°C to 15.5°C bin is against the trend that can be found for the other bins, and the cause for this is not known. It might be speculated that the increase in failures at the very low temperatures might be related to cold weather concreting problems. The data exhibits a linear trend, with a coefficient of correlation (r^2–value) of 0.87.

As the type of aggregate used during construction could influence the results, this analysis was repeated for the two major coarse aggregate types used in Texas: limestone and siliceous river gravel. For this analysis a total of 134 river gravel, and 203 limestone sections were considered. Figure 5(b) shows the influence of aggregate type on the long-term performance of CRC pavements as a function of the air temperature at placement. A similar trend as discussed for Figure 5(a) can be found, as the percentage of failures increase with an increase in air temperature at placement. Although not the topic of this paper, it may also be seen from this figure that significantly more failures occur in the siliceous river gravel section as compared to the limestone sections. The increased number of failures in the river gravel section can be attributed to its higher coefficient of thermal expansion and poorer bond characteristics.

The analysis presented in this section emphasizes the importance of air temperature on long-term performance of CRC pavements. The results were not unexpected, as an increase in air temperature at placement will produce an accompanied increase in concrete temperature, which will relate to higher thermal stresses. In the following section, techniques to mitigate the detrimental effects of high concrete temperatures will be discussed.

TECHNIQUES TO MITIGATE THE DETRIMENTAL EFFECTS OF HIGH CONCRETE TEMPERATURES

This section will provide a summary of current construction practices to mitigate the detrimental effects of high concrete temperatures. To produce longer lasting concrete pavements, a conceptual method to minimize the occurrence of excessive thermal stresses will also be introduced.

Current practices

One possible measure to minimize the potential problems associated with hot weather concreting can be to control the concrete mixture temperature (*5, 6, 8,* and *16*). Under hot weather placement conditions, an effort should be made to keep the concrete temperature as low as economically feasible. By controlling the temperature of the ingredients, the temperature of the fresh concrete can be regulated (*5*).

In 1998 the American Concrete Paving Association (ACPA) compiled a database of current state practices from surveys of State departments of transportations (DOTs) (*17*). When using the data, one has to keep in mind that the data was obtained by survey and that the data are those in most general use in the State. Table 1 presents a summary of the practices of different State DOTs with regards to the specified limit of the concrete temperature at placement. Note that it is not clear whether the States that do not show a maximum concrete placement temperature, do not specify one, or did not respond to the survey. Note that 50% of the concrete producing States place a limit of 90 °F on the concrete placement temperature. At the time of the survey, the State of Texas had no limit on the concrete placement temperature. This table reveals a national recognition of problems associated with concrete placement under high temperature conditions.

There are a number of mitigation measures that can be used to minimize the potential of experiencing problems associated with hot weather concreting, of which the following are only a few examples (*5, 12*):

- The use of concrete materials and proportions with satisfactory performance in place under hot weather conditions;
- Use cooled concrete, which can be achieved by using chilled mixing water, ice in the mixture, the use of liquid nitrogen to cool the mixing water or the concrete mixture, or the cooling of the coarse aggregate.
- The use of a concrete consistency that allows rapid placement and effective consolidation at high temperatures;
- Schedule placement activities during the times of the day or night when the weather conditions are favorable;
- Minimize the time to transport, place, consolidate, and finish the concrete; and
- Protect the concrete from moisture loss at all times during placement and during its curing period.

Proposed method

ACI 305 (*5*) states that in general types of construction in hot weather, "… it is impractical to recommend a maximum limiting ambient or concrete temperature because the humidity and wind speed may be low, permitting higher ambient and concrete temperatures. A maximum ambient or concrete temperature that will serve a specific case might be unsatisfactory in others." ACI committee 305 further recommends that, "…at some temperature between about 75 F and 100 F (24 and 38 C) there is a limit that will be found to be most favorable for best results in each hot weather operation, and such a limit should be determined for the work."

In modern paving operations the use of mineral admixtures has become common practice, and under certain conditions, these admixtures could mitigate some of the problems associated with hot weather placement. The specification of a limiting concrete temperature at placement might be applicable to some conditions, but unnecessary in others. The limits selected by most States were chosen based on mixture designs that contain no mineral or chemical admixtures that may be effective in reducing the rate of heat evolution. The limits also do not account for the use of mineral admixtures, and the same limit applies to cement with or without mineral admixtures. It has been well documented that the use of mineral admixtures such as fly ash or ground granulated blast furnace (GGBF) slag can significantly slow down the rate of heat evolution (*8, 16*). The current practice is thus prohibitive and does not encourage the use of mineral admixtures during hot weather applications. In order to encourage the use of mineral admixtures, specifications should differentiate between mixtures that have different heat evolution rates.

To mitigate against potential problems due to concrete paving in hot weather applications, it is proposed that the following two steps be implemented:

- Redesign of CRC pavement reinforcement standards
- Develop end-result specification that limit the maximum in place concrete temperature during hydration

Redesign of CRC pavement reinforcement standards

Currently most States utilize a reinforcement design standard that is not a function of the in place concrete temperature, but rather one that provides uniform reinforcement requirements all year round. As it would be to costly to design for the worst case design scenario all year round, it is proposed that the CRC pavement reinforcement standards be re-designed to provide steel quantities that consider the concrete temperature at placement. In the summer months a different reinforcement design could thus be required.

Develop end-result specification that limit the maximum in place concrete temperature during hydration

It is recommended that an end-result type specification be used, as it would allow the most contractor innovation during the selection of the mixture constituents and their proportions. It is recommended to limit the maximum in-place concrete temperature of the hydrating concrete. The specified values should be based on the amount of reinforcement provided in the section, the project location, and the type of coarse aggregate used in the concrete mixture. This practice would thus link the design conditions to the actual construction conditions experience on site. This would allow the contractor to consider and optimize the cost of cooling the mixture versus the use of mineral and/or chemical admixtures during hot weather placement conditions. The contractor is also in the position to schedule the paving activity at different times of the day, as this could also impact the concrete temperature development.

Initially small trial slabs could be used to evaluate the effect of high curing and concrete placement temperatures on the heat development of a specific mixture, and to determine whether the proposed mixture design hydrates slow enough and as to not exceed the specified maximum temperature limit. Alternatively, computerized algorithms could be used to evaluate the temperature development of a mixture prior to placement. If the most feasible option requires cooling of the concrete mixture, then the choice was based on the job-specific concrete mixture proportion and conditions. This approach would encourage the use of mineral admixtures, which has been shown to minimize the problems associated with hot weather paving. The fact that the maturity method is being used more common is also beneficial as many contractors are becoming more familiar with the concrete temperature development of their in-place pavements.

Due to the advances in modern technology, inexpensive devices are currently available to monitor the temperature of the in-place concrete. It is recommended that the use of such devices, installed at specified intervals, be investigated for quality control purposes in a concrete temperature control specification.

CONCLUSIONS AND RECOMMENDATIONS

Based on the information presented in this document, it is shown that the development of high concrete temperatures could cause a number of effects that have been shown to be detrimental to long-term concrete performance. High concrete temperatures increase the rate of hydration, thermal stresses, the tendency for drying shrinkage cracking, permeability, and decrease long-term concrete strengths, and durability as a result of cracking.

CRC pavement data from the Texas Rigid Pavement (TRP) database was used to evaluate the effect of concrete temperatures on long-term CRC pavement performance. It was shown for both major aggregate types that there are an increased number of failures as the air temperature at placement increases. More than 36% of all failures occurred in the sections that were placed under conditions where the air temperature at placement exceeded 32.0°C (90°F). Around 26% of the failures occurred when the sections were constructed at air temperature between 26.5°C and 32°C. The result of this analysis emphasizes the importance of concrete temperature control during concrete pavement construction in hot weather conditions.

Most States specify a maximum concrete temperature at placement, and the limit remains the same irrespective of the type of mineral or chemical admixtures used. In modern paving operations the use of mineral admixtures has become common practice, and under certain conditions, these admixtures could mitigate some of the problems associated with hot weather placement. The specification of a placement temperature limit to prevent these problems might be applicable to some conditions, but unnecessary in others.

In order to produce specifications that encourage contractor innovation and the use of improved materials, modern specifications should account for these materials in order to ensure improved concrete performance under all paving conditions. To provide improved performance for section paved under hot weather conditions, it is proposed that the CRC pavement reinforcement standards be re-designed to provide steel quantities for specific use during hot weather conditions, and that an end-result specification that limits the maximum concrete temperature during hydration be implemented.

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  (b) Pavement failures for all section and for the two most common aggregate types used in Texas

TABLE 1 Maximum concrete temperature at placement limits for all States

State	Maximum Concrete Temperature at Placement (° F)	State	Maximum Concrete Temperature at Placement (° F)
Alabama		Montana	
Alaska		Nebraska	90
Arizona	90	Nevada	
Arkansas	90	New Hampshire	85
California		New Jersey	
Colorado		New Mexico	
Connecticut	90	New York	90
Delaware	90	North Carolina	95
Florida	85	North Dakota	90
Georgia	90	Ohio	90
Hawaii	90	Oklahoma	90
Idaho	80	Oregon	
Illinois	90	Pennsylvania	90
Indiana		Rhode Island	
Iowa		South Carolina	90
Kansas	90	South Dakota	
Kentucky	90	Tennessee	
Louisiana	95	Texas	
Maine		Utah	90
Maryland	90	Vermont	
Massachusetts		Virginia	
Michigan	90	Washington	
Minnesota	90	West Virginia	90
Mississippi	95	Wisconsin	
Missouri		Wyoming	

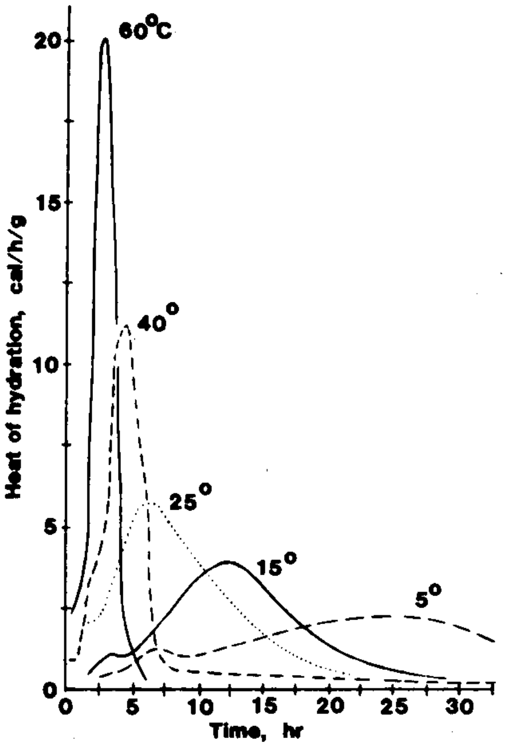

FIGURE 1 Heat of hydration for Tricalcium Silicate (C_3S) under different curing temperatures (*6*)

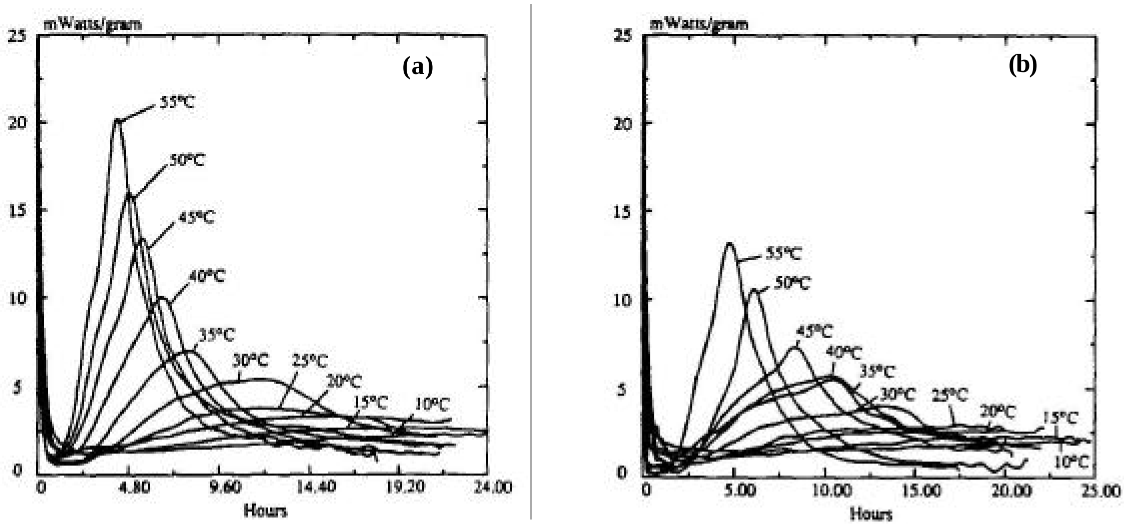

FIGURE 2 Heat of hydration: (a) Type I Cement, (b) Type I Cement with 17% Class F Fly Ash (*8*)

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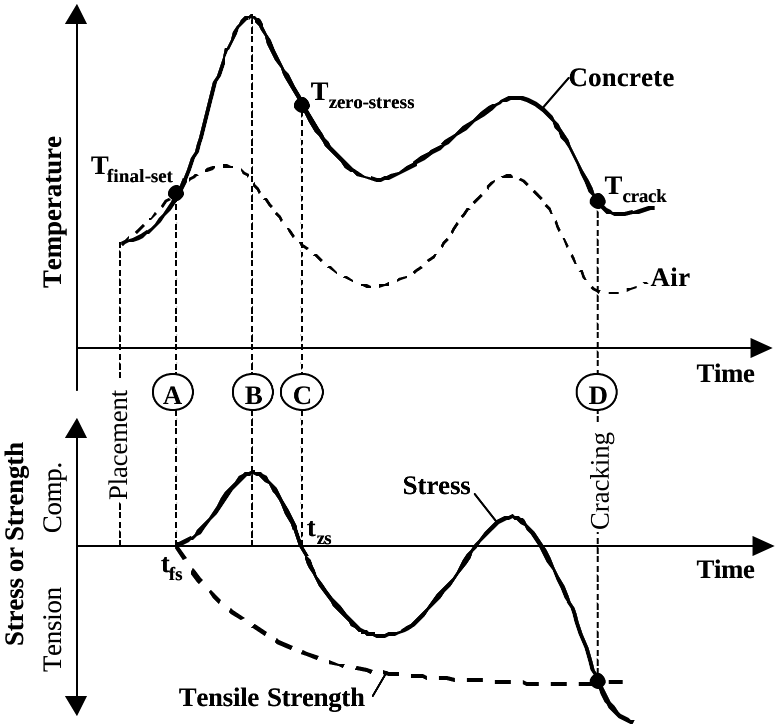

FIGURE 3 A graphical representation of the development of thermal stresses

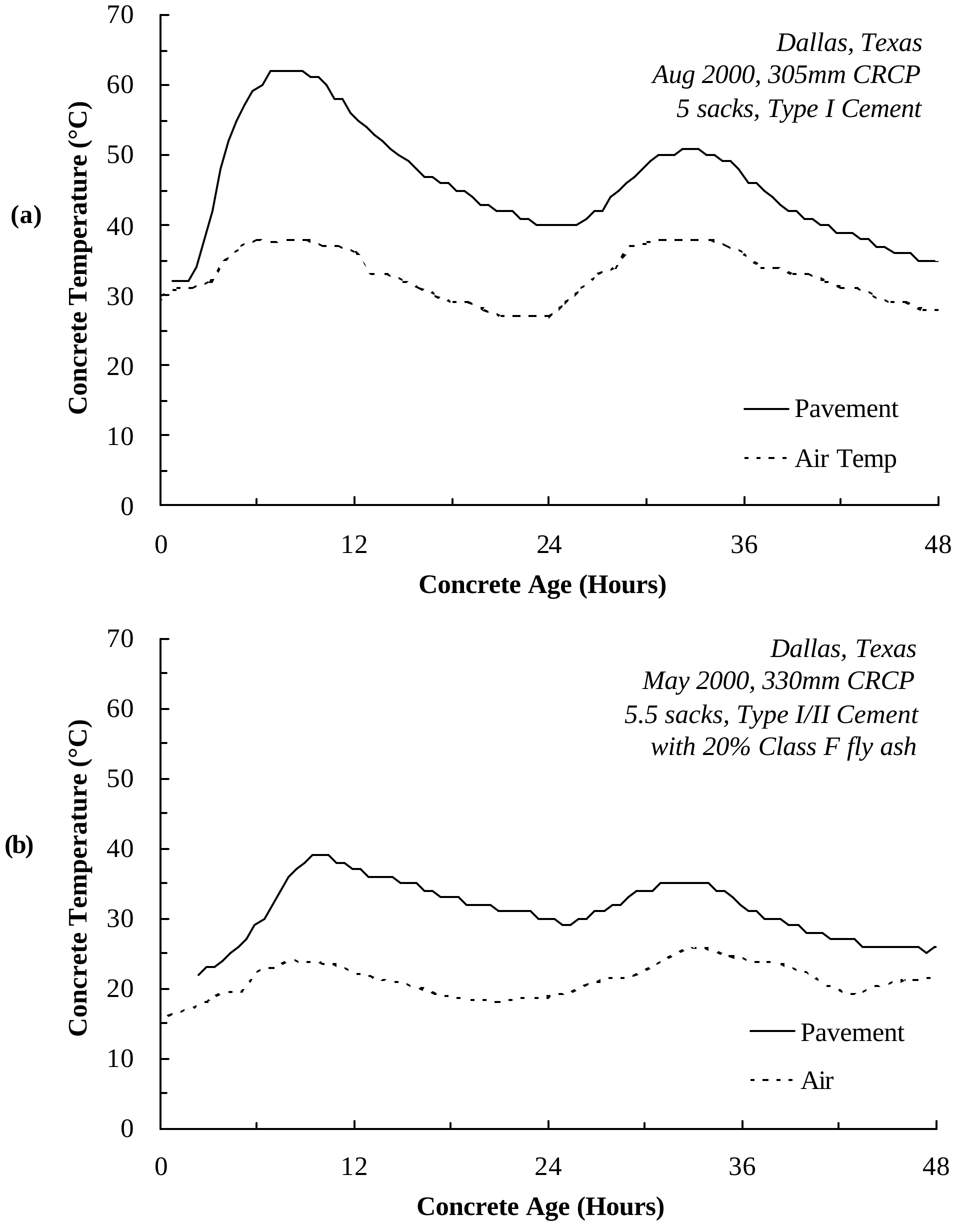

FIGURE 4 The development of concrete temperatures under different air temperature conditions:

(a) Hot temperature placement conditions (Air Temperature > 30°C)
(b) Normal temperature placement conditions (Air Temperature < 25°C)

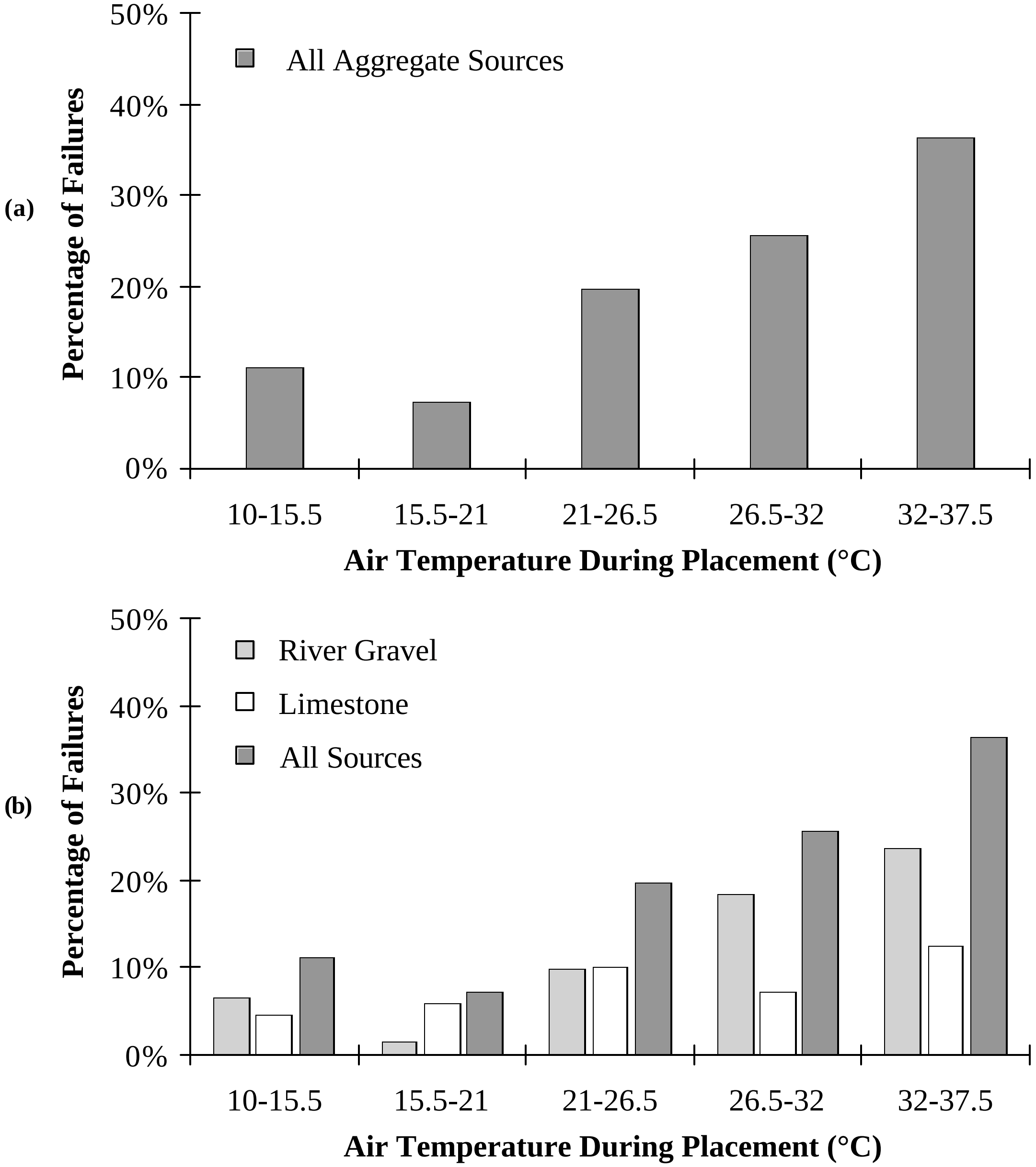

FIGURE 5 The effect of air temperature during placement on long-term CRCP performance:

(a) Pavement failures for all aggregate types (Total of 337 sections)

(b) Pavement failures for all section and for the two most common aggregate types used in Texas (134 river gravel sections, and 203 limestone sections)