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Stem Cured Concrete: Varying the Rate of Temperature Rise

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STEAM CURED CONCRETE: VARYING THE RATE OF TEMPERATURE RISE

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ABSTRACT

The precast concrete industry uses steam curing procedures to quickly produce structural members. The rate of temperature rise in the steam chamber is critical to the steam curing process. This investigation examines the effect of varying rates of rise on the compressive strength of the concrete.

A 6000 psi mix design was used to test three separate rates of temperature rise. The specimens were fabricated in standard 6 x 12 in. molds, and each batch was tested at 24 hours, 3 days, and 28 days.

The control (moist cured) specimens, the 40°F/hr rise specimens, and the 50°F/hr rise specimens had comparable strengths at all ages. Similar early age strengths for all rise rates cause the batches to appear equal initially. However, the 60°F/hr rise specimens showed a considerably lower 28-day strength than the moist specimens. Higher rates of temperature rise were found to be detrimental to the development of 28 day compressive strength values.

1. INTRODUCTION

The recent growth in the use of precast, prestressed concrete members throughout the construction industry has placed a tremendous demand on production facilities. To meet this demand, the prestressing plants are forced to expedite the curing of concrete and mass produce the members. Steam curing has become a popular method of accelerating the gain of compressive strength in precast concrete members. This process minimizes plant cycle time and maximizes output by reducing the time that the concrete must remain in the forms.

A typical plant cycle includes casting, initial set, steam curing, stripping the forms, and cleaning the forms (Hanson, 1963). The concrete is first placed in reusable forms and then allowed to begin its initial set. A few hours later, the members are subjected to steam at atmospheric pressure for a specified length of time. When the concrete develops sufficient strength, the forms are removed and cleaned.

A critical factor in the success of the steam curing procedure is the rate at which the temperature in the curing chamber is increased from room temperature to a specified maximum temperature. This study examines the relationship between three practical rates of rise (40° F/hr, 50° F/hr, and 60° F/hr) and the compressive strengths of the concrete.

2. EXPERIMENT PROCEDURE

The experiment procedure consisted of fabricating the specimens, curing the specimens, and testing the specimens.

2.1 Fabrication of Specimens

Three batches were cast to test the three separate rates of rise. All batches were laboratory mixes prepared in a 7.5 ft^3 mixer. The test specimens were fabricated using a mix designed to produce an approximate 28-day strength of 6000 psi. Standard 6 x 12 in. molds were used in compliance with ASTM C470, and the specimens were molded by methods described in ASTM C31. The coarse aggregate used was ASTM Number 67, and the fine aggregate was crushed limestone. The mix design for one c.y. is as follows:

Type I Portland Cement:	752 lb.
Coarse Aggregate:	1,730 lb.
Fine Aggregate:	1,242 lb.
Water:	≈ 292 lb.

(Oluokum, 1990). The water content varied ±1% because the slump for each batch was held constant at 2-3/4 inches.

2.2 Curing of Specimens

Each batch consisted of six moist and six steam-cured

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2.2 Curing of Specimens

Each batch consisted of six moist and six steam-cured specimens. The twelve cylinders for each batch were cast at the same time and allowed an initial set period of five hours. Next, six of the specimens were placed in the steam chamber. The temperature was increased at a particular rate to the maximum temperature of 160 °F in the steam chamber (See Figure 1). Each batch of concrete remained in the steam chamber for a total of 16 hours. The three different rise rates are demonstrated in Figure 2.

After the total curing time had elapsed, the specimens were removed. At the age of 24 hours, the samples were stripped and placed in the moist room where curing continued at 73°F in compliance with ASTM C192.

2.3 Testing of Specimens

Four specimens from each batch, two steam cured and two moist cured, were tested for compressive strength values at the ages of 24 hours, 3 days, and 28 days. Prior to testing, the specimens were capped with a sulfur compound (ASTM C617). The tests were conducted in uniaxial compression until failure. A total of 36 cylinders were tested.

3. TEST RESULTS AND DISCUSSION

From the basic test data (Table 1), average values were obtained representing each data point (Table 2). The moist-cure values represent the overall averages of the moist cured specimens.

The first graphic data display (Figure 3) shows the average strength values for each data point (psi) versus age of the concrete (days). In this graphic, the values used to represent the moist cure samples are the averages of all three batches. As expected, the strengths of the moist-cured specimens are significantly lower than the strengths of the steam-cured specimens at early ages. Thus, steam curing is needed to develop the compressive strength required to remove the forms promptly without damaging the concrete.

However, the actual strength of the steam-cured concrete may be shadowed by the early strength. The three groups of steam-cured specimens representing the different rates of rise have essentially the same strength at early ages (Figure 3). This property may be desirable to precast plant operators, but the similar early strengths may actually give the impression that the three batches have equal strengths regardless of the rise rate. Thus, the similar early strengths impair quality control because the various rise rate conditions are undetectable at early ages.

The compressive strengths of the batches at 28 days are not as comparable as the early age strengths (Figure 3). The 40°F rise and 50°F rise batches have practically the same strength, and all are above the design strength of 6000 psi. However, the compressive strength of the 60°F rise rate at 28 days is below the design strength of 6000 psi. This noticeable decrease is perhaps caused by the formation of microcracks in the concrete when it is subjected to higher rise rates in the steam chamber.

Plotting the strengths (psi) versus the rise rates with three data points on one vertical line representing one batch vividly reveals the degradation of the 28-day strength of the 60°F rise batch (Figure 4). The one-day and three-day compressive strengths of all steam-cured specimens are essentially the same. On the other hand, the 28-day curve vividly reveals degradation over time in the development of ultimate strength capacity. Although the moist, 40°F rise, and 50° rise values are consistent, the 60°F rise value is considerably lower and is below the design strength of 6000 psi.

4. CONCLUSIONS

The results discussed in the preceding section show that high rise rates of temperature in the steam curing chamber may cause microcracking in the concrete. This phenomenon noticeably reduces the rate of development of ultimate strength in steam cured concrete members. For the rate of rise of 60°F/hr, the 28-day compressive strength is below the 6000 psi design strength.

Furthermore, the effect of the high rise rates does not become evident until the concrete has aged. For many precast members, this flaw may not be easily detected. In order to avoid this situation, plant operators must give more attention to controlling the rate of temperature rise in the steam chamber. The rise must be closely monitored to produce precast members that possess the necessary design strength.

REFERENCES

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TABLE 1:
BASIC TEST DATA

40 F/HR RISE

	24 HR	3 DAY	28 DAY
Moist	1. 2740 psi 2. 2600 psi	1. 4860 psi 2. 4930 psi	1. 6650 psi 2. 6930 psi
Steam	1. 5840 psi 2. 5270 psi	1. 5870 psi 2. 5570 psi	1. 6580 psi 2. 6930 psi

50 F/HR RISE

	24 HR	3 DAY	28 DAY
Moist	1. 3150 psi 2. 3060 psi	1. 4490 psi 2. 4704 psi	1. 6500 psi 2. 6260 psi
Steam	1. 5550 psi 2. 5290 psi	1. 5730 psi 2. 5750 psi	1. 6190 psi 2. 6680 psi

60 F/HR RISE

	24 HR	3 DAY	28 DAY
Moist	1. 3130 psi 2. 3160 psi	1. 4810 psi 2. 5000 psi	1. 6330 psi 2. 6580 psi
Steam	1. 5290 psi 2. 5590 psi	1. 5660 psi 2. 5480 psi	1. 6010 psi 2. 5730 psi

TABLE 2:
AVERAGE TEST DATA

40 F/HR RISE

	24 HR	3 DAY	28 DAY
Moist	1. 2670 psi	1. 4900 psi	1. 6790 psi
Steam	1. 5550 psi	1. 5720 psi	1. 6750 psi

50 F/HR RISE

	24 HR	3 DAY	28 DAY
Moist	1. 3100 psi	1. 4600 psi	1. 6380 psi
Steam	1. 5420 psi	1. 5740 psi	1. 6440 psi

60 F/HR RISE

	24 HR	3 DAY	28 DAY
Moist	1. 3150 psi	1. 4910 psi	1. 6450 psi
Steam	2. 5440 psi	2. 5570 psi	2. 5870 psi

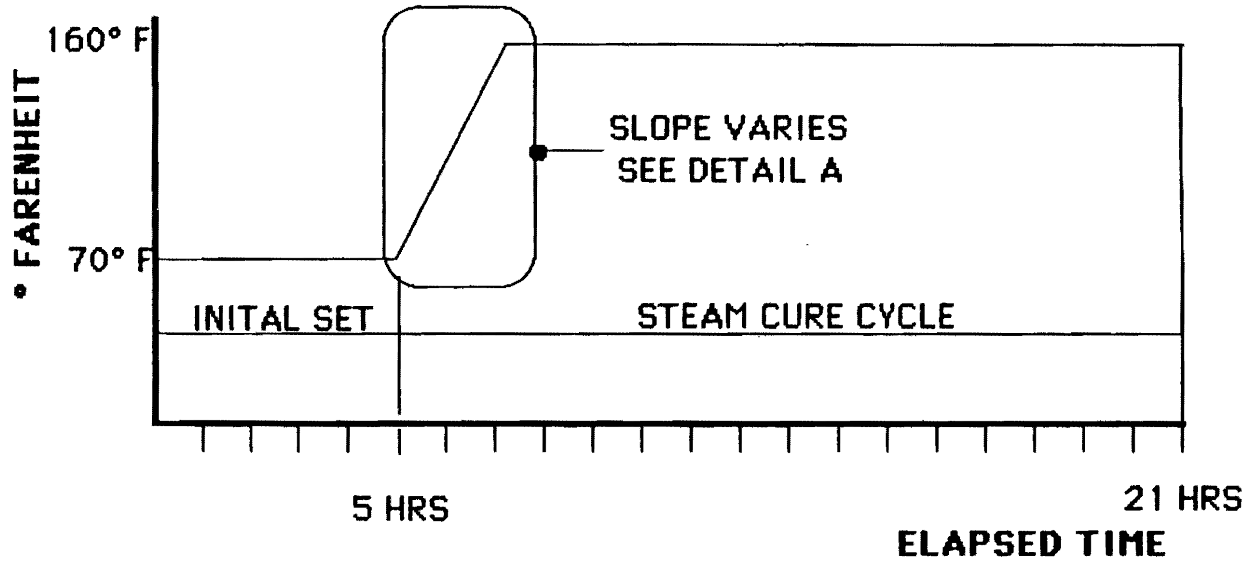

FIGURE 1: TYPICAL THERMAL EXPOSURE OF STEAM CURED SPECIMENS

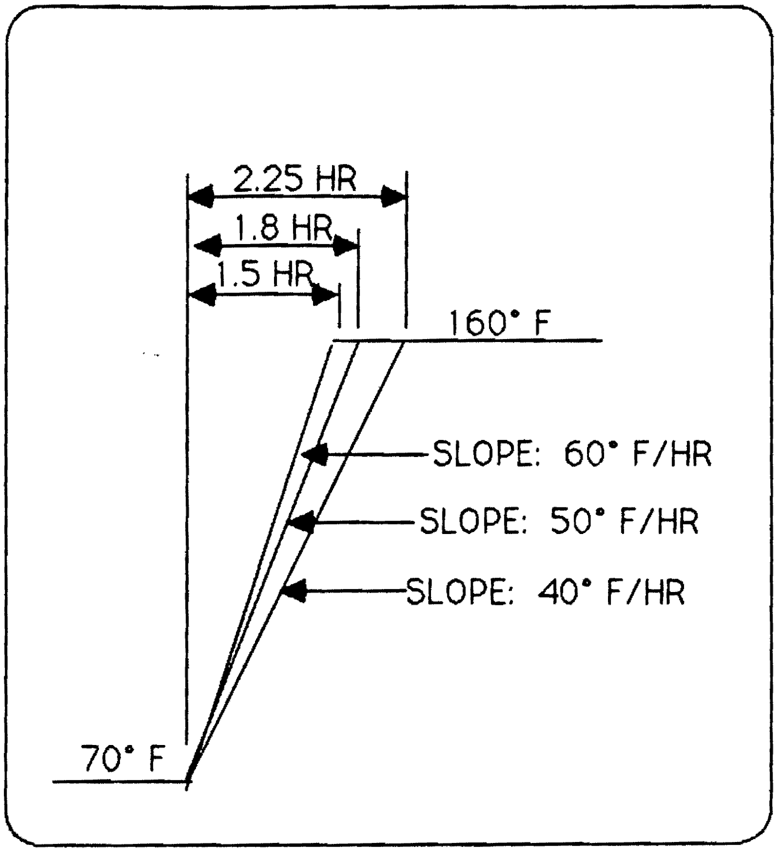

FIGURE 2: DETAIL A

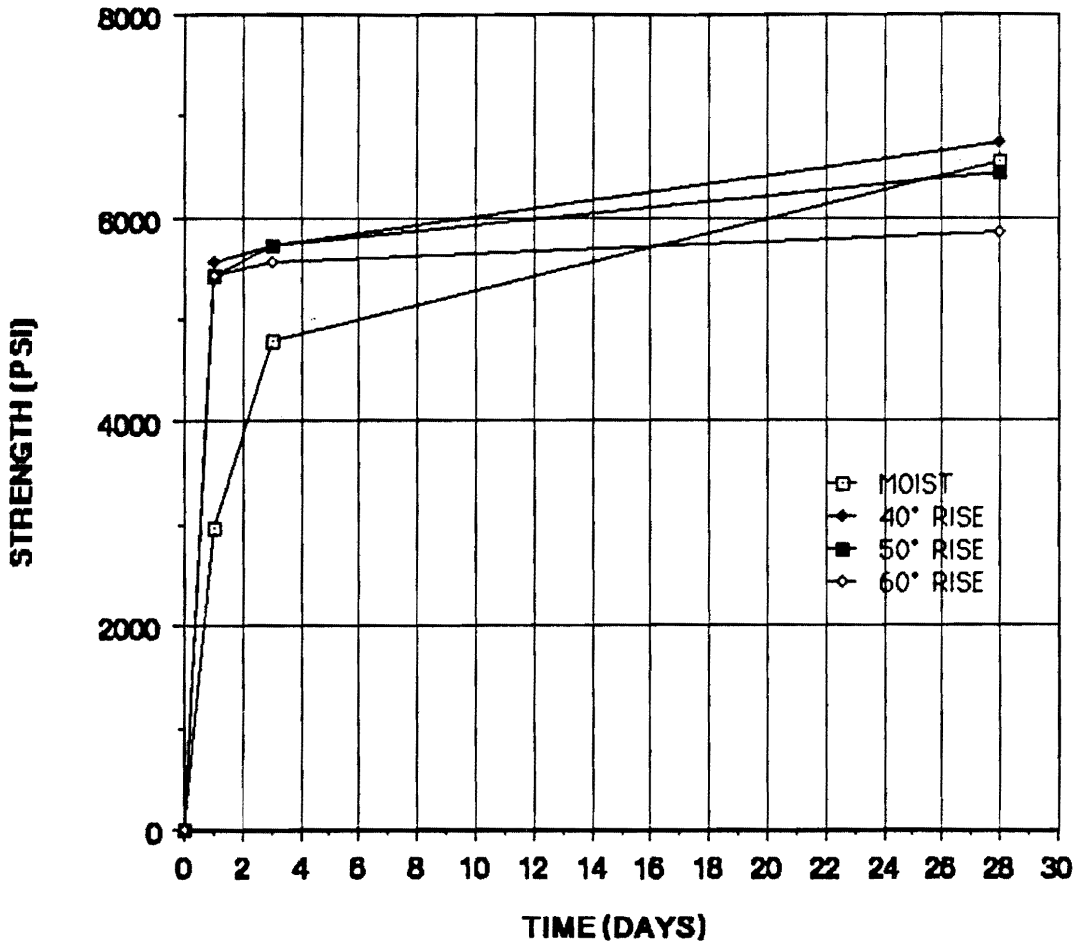

FIGURE 3: STRENGTH V. TIME

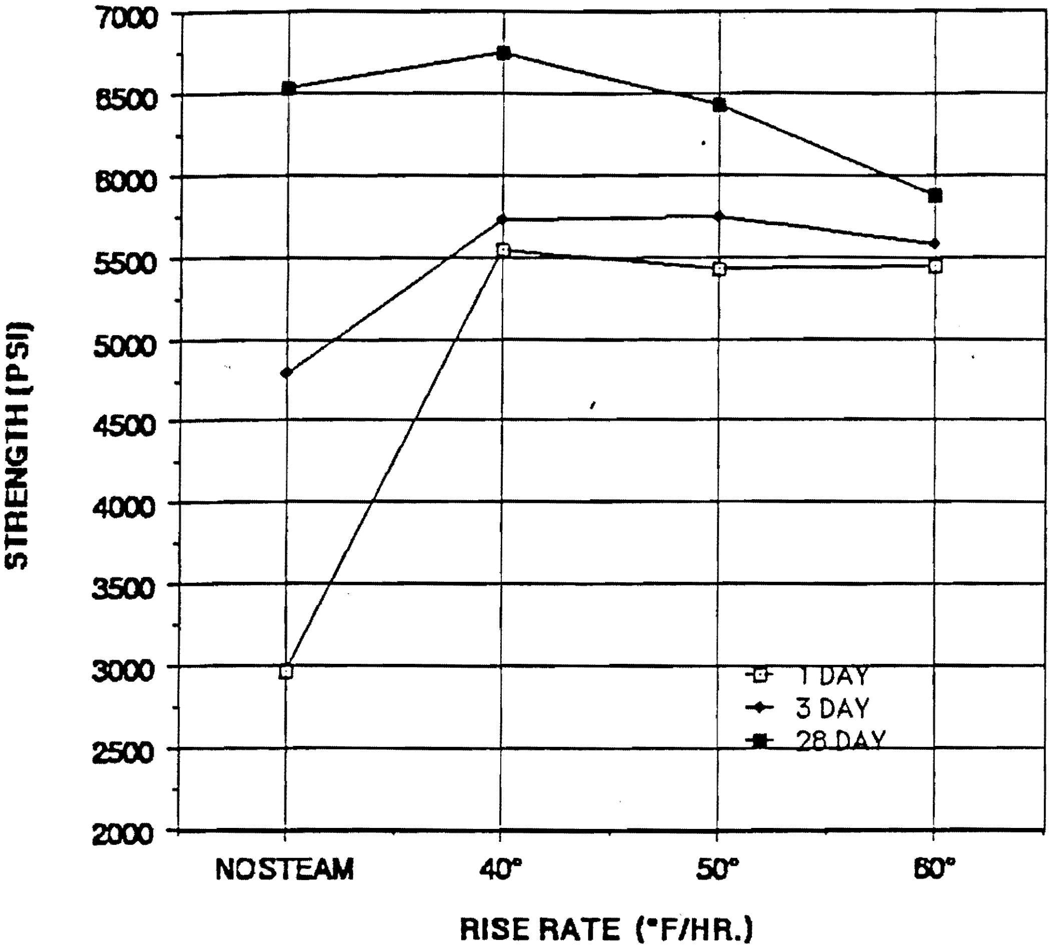

FIGURE 4: STRENGTH V. RISE RATE