Early Strengths of Class F, C, and B Portland Cement Concrete

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Early Strengths of Class F, C, and B

Portland Cement Concrete

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DISCLAIMER

ABSTRACT

Fast track concrete has proven to be successful in obtaining high early strengths. This benefit does not come without cost. Type III cement and insulation blankets to accelerate the cure add to its expense when compared to conventional paving. This research was intended to determine the increase in time required to obtain opening strength when a fast track mix utilized conventional Type I cement and also used a conventional cure. Standard concrete mixes also were tested to determine the acceleration of strength gain when cured with insulation blankets. The goal was to determine mixes and procedures which would result in a range of opening times. This would allow the most economical design for a particular project and tailor it to that projects time restraint.

Three mixes were tested: Class F, Class C, and Class B. Each mix was tested with one section being cured with insulation blankets and another section without. All used Type I cement.

Iowa Department of Transportation specifications required 500 psi of flexural strength before a pavement can be opened to traffic. The Class F mix with Type I cement and using insulation blankets reached that strength in approximately 36 hours, the Class C mix using the blankets in approximately 48 hours, and the Class F mix without covers in about 60 hours. (Note: Class F concrete pavement is opened at 400 psi minimum and Class F bonded overlay pavement at 350 psi.)

The results showed a significant improvement in early strength gain by the use of insulation blankets. The Type I cement could be used in mixes intended for early opening with sacrifices in time when compared to fast track but are still much sooner than conventional pavement. It appears a range of design alternatives is possible using Type I cement both with and without insulating blankets.

INTRODUCTION

In 1987 several p.c. paving projects were constructed using the fast track mix and procedures developed in Iowa. This alternative to conventional paving resulted in opening strengths in less than twenty-four hours. These projects have established that fast track can produce the high early strengths for which it was designed.

Two aspects of fast track which normally are not seen in conventional paving include the use of a special Type III cement and the placement of insulating blankets over the finished pavement. The Type III cement is used to accelerate the hydration process and the blankets are used to trap that heat. The Type III cement is not a widely used product. Most ready mix plants do not keep this on hand and many do not have the storage facilities to accommodate more than one cement. The insulation blankets are a costly item in terms of initial cost and the labor-intensive procedure to install them. Both add to the expense of the fast track procedure. If either or both could be eliminated but still achieve an acceptable time of opening, significant savings could be realized.

Not all projects need to obtain opening strengths in less than twenty-four hours. Yet, some roadways may need to be open to traffic in less than the five to fourteen days that are required for conventional paving. This research was intended to determine the strength gain over time for various mixes, each being cured with and without insulation blankets. The goal was to determine what effect the type of mix and insulation had on the strength gain. This information will be helpful in determining the most economical design for a project with a given time table for opening the facility to traffic.

SCOPE

The research examined two standard Iowa Department of Transportation concrete mix classes and a modified fast track class. Each mix was divided into two sections with insulating blankets being used to cover one of them and conventional curing being used on the other. This resulted in six test sections. Test beams were taken from each section and tested at particular ages. These tests, when plotted, show the relationship of strength gain over time for each section.

Standard Class B and Class C mixes were used. Since insulating blankets are normally not used with these mixes, this project will show the benefit in early strength by the use of such blankets. These mixes have the least amount of cement and thereby are less expensive.

The Class F mix is the fast track design. Each of the two test sections differ from the standard fast track procedure. The Class F mix used in this research used Type I cement instead of Type III. The uncovered section deviated further by not using the insulation blankets.

Temperatures were also monitored. Checks were made of the pavement temperature and the temperature of the test beams. Comparing the two will give an indication of how well the curing of the pavement is being duplicated by the beams. To find a significant variance may indicate that the strength of the beams is not completely representative of the strength in the pavement.

Cores were taken from the pavement test sections at 28 days. They were used to determine the effect of high early opening strength on ultimate strength as represented by these cores. Also a relationship between the same classes of mix with and without the insulated blankets was examined.

OBJECTIVES

The objective of this research was to establish a range of alternative designs that produce opening strengths at various times. These designs will fall between fast track and our standard Class B and C mixes in terms of curing time to obtain early opening strength and also cost. By establishing this range, engineers can choose a mix and curing procedure that will give the strengths they need in the appropriate time, particularly suited for each project, and at the most economical cost.

PROCEDURES

The research project was located in Boone County, just east of Boone. The test sections were on E41 (Old Highway 30), a short distance west of the east line of Section 26, Township 84N, Range 26W. This section of roadway was being reconstructed with a new 24' pavement, 9" thick, utilizing a Class B p.c.c. pavement mix. The portion of the construction project where this research took place was 1.36 miles long.

Eight test beams were taken from each of the six test sections. Two beams were tested from each section at each of the following times: 18 hours, 24 hours, 3 days and 7 days.

The sections were constructed on September 25, 1987, on a clear day with the temperature in the mid 70's and a slight breeze. The first section was placed at approximately 2:20 p.m. with the last section being finished at 3:25 p.m. The locations and concrete tests were as follows:

	Location Station	Location Station	Slump in.	Air %
Class F with blankets	1076+60	1077+00	2	7.2
Class F without blankets	1077+00	1077+40	2 1/4	7.5
Class C with blankets	1075+95	1076+30	1 3/4	7.8
Class C without blankets	1076+30	1076+60	2 1/4	7.8
Class B with blankets	1078+90	1078+20	1 1/2	6.5
Class B without blankets	1078+20	1078+50	3/4	6.0

The three mix proportions used in this research are shown below:

Approximate Quantity of Material per Cubic Yard

Mix No.	Cement-Type I (lbs.)	Fine Aggregate (lbs.)	Coarse Aggregate (lbs.)
F-4	710	1402	1402
C-4	624	1478	1482
B-6	524	1804	1206

The sand and gravel were from Hallett's at the Jenkins-Sturtz pit. The brand of cement used was Ash Grove.

Eight beams were taken from each section. After the curing cart passed the test sections, the beams were placed adjacent to the edge of the slab. All sections and beams were sprayed with curing compound at the normal specified rate. The blankets were then spread over both the slab and beams on those sections being cured in that manner. The blankets were placed at approximately 5:00 p.m.

RESULTS

The results of the tests of the 48 beams are listed in Table 1. This data is shown in Figure 1 as modulus of rupture strength versus time curves. With both the Class F and Class C mixes, a significant gain in additional strength during the first twenty-four hours resulted from the use of the insulating blankets. The blankets were removed at twenty-four hours and the strengths began to converge after that.

The tests show that some gain in extra strength occurred when the blankets were used with the Class B mix, but only in the initial curing period. By twenty-four hours, both sections exhibited the same strength. The extra strength gained before that time may not be of great importance since the actual flexural strength at that time is still very low.

Table 2 shows the temperatures that were recorded during the research. A measurement was taken in a test beam and also in the pavement itself at each of the test sections. Figures 2 and 3 are plots of this data with the former showing the temperatures in the pavement and the later representing the temperatures in the test beams.

The insulating blankets significantly affected the pavement temperatures by reducing the effect of ambient air temperature. In all three classes of concrete, the sections with the insulation blankets gained some temperature during the cool night. On the other hand, the uncovered B and C mixes dipped in temperature as the air cooled, but the F mix, without blankets, exhibited a small temperature gain. The heat trapped by the blankets resulted in additional temperature (at the time of the coolest air temperature) of 21^{o}, 13^{o},and 9^{o} for the Class F, C, and B mixes respectively.

Figure 3 shows the temperatures of the beams. All the beams gained in temperature initially, during the sunny afternoon. But, the uncovered beams closely paralleled the air temperature during the night. The next day those uncovered beams completed the hydration process and achieved higher temperatures than the covered beams. The temperature difference between maximum and minimum for the uncovered beams was as much as 36^{o}. The covered beams were able to maintain a more constant temperature but still dropped from 7^{o} to 11^{o} below the maximum temperature. The warm ambient temperature and the heat from the sun actually warmed the beams more than the benefit derived from the blankets. It may also be true that the covered beams achieved more hydration earlier and over a longer period of time so that a much smaller portion of the process was left to take place during the heat of the afternoon.

The 28 day core compressive strengths are shown below.

	28-day Compressive Strength (psi)
Class F w/Insulation	4945 and 3820
Class F Std. Cure	5065 and 3945
Class C w/Insulation	3500 and 3630
Class C Std. Cure	4610 and 4295
Class B w/Insulation	3450 and 3545
Class B Std. Cure	3130 and 2960

CONCLUSIONS

It is interesting to note the effect of the insulating blankets on the three mixes. The F mix showed a 42 percent increase in strength with the blankets at 18 hours and a 27 percent increase at 24 hours. The C mix gave a 13 percent increase at 18 hours and a 27 percent increase at 24 hours. The B mix had a 31 percent increase at 18 hours but no difference at 24 hours. The insulating blankets do have a significant effect on high early strength. It would appear that the additional strength gain is realized at different times with different mixes, though. Overall the F mix had the largest gain in strength with the use of blankets and the additional gain was evident over the longest period of time.

When the temperature plot is compared with the figure showing the strengths, it appears that the uniformity in temperature contributes to the higher gain in strength. Even if the maximum temperature is not as high, the consistent temperature has a significantly favorable effect.

A comparison of the pavement temperatures and the beam temperatures reveals a rather unsettling situation. The beam temperatures were roughly 20 degrees cooler than the pavement temperatures at 14 hours. The beams generally followed the air temperature; whereas the pavement temperatures were somewhat constant. This raises the question as to how well the strengths obtained from testing the beams actually represent the strengths existing in the pavement. Fortunately, the error will likely be such that the pavement is actually stronger than what the beams would show.

An objective of this research was to identify a range of procedures and mixes where cost and performance would fall between conventional practices and the new accelerated fast track design. Both F mix sections and the covered C mix section produced strengths within that range and also were significantly different from one another.

One of the F mix sections was covered and thereby differed from fast track only in the use of Type I cement instead of Type III. The other section differed in a second aspect by not being cured using the insulation blankets. From field experience in 1987, flexural strengths of fast track mix can be expected to average around 550 psi in 18 hours. This research would show that the substitution of Type I cement would sacrifice approximately 125 psi (to 418); and to also use a standard cure (no blankets), a sacrifice of another 125 psi (to 294) could be expected. The C mix with the insulating blankets exhibited eight hour strengths (318 psi) quite similar to the uncovered F mix, although somewhat higher.

The Standard Specifications, Section 2301.36, require a strength of 500 psi before opening to traffic, in addition to a minimum age. Based on this strength the three sections mentioned above differ in terms of time required to reach that strength. The difference between the mixes are rather similar. The covered F mix reached 500 psi in approximately 36 hours, the covered C mix in about 48 hours, and the noncovered F mix in about 60 hours. As a comparison, the fast track mixes normally reached that strength in 18 hours.

It should be noted that fast track pavement is normally opened when it has reached a strength of 400 psi. This lower value is used because of the very controlled curing conditions and the continued strength gain after the blankets are removed. The opening strength used for mixes and cure methods other than fast track will need due consideration and may vary by project.

Table 1

MODULUS OF RUPTURE (PSI)
(center point loading)

Section	18-hr	24-hr	3-day	7-day
Class F w/Insulation	418	462	619	744
Class F Std. Cure	294	363	550	677
Class C w/Insulation	318	406	606	712
Class C Std. Cure	282	319	538	669
Class B w/Insulation	200	282	506	650
Class B Std. Cure	153	282	506	638

Note: Insulation removed after 1 day of cure

Table 2

TEMPERATURE (^{o}F)

Section		Mix	1.5-2 hr*	7-hr	14-hr	24-hr**	3-day**
Class F	Pavement	77	80	97	105	103	74
w/Insulation	Beam		83	92	83	87	77
Class F	Pavement	77	79	83	84	97	75
Std. Cure	Beam		81	71	59	95	73
Class C	Pavement	77	83	92	93	94	74
w/Insulation	Beam		85	75	74	81	68
Class C	Pavement	75	79	78	80	95	73
Std. Cure	Beam		88	71	62	93	72
Class B	Pavement	78	76	83	84	90	71
w/Insulation	Beam		82	82	75	80	73
Class B	Pavement	76	76	79	75	91	71
Std. Cure	Beam		77	69	59	91	74
Ambient Air		80	80	64	54	82	68

*Temperature taken when beams were moved next to slab and insulation was placed on the slab.

**Insulation removed after 1 day of cure

FIGURE 1
Flexural Strengths(PSI) VS Time(HRS)

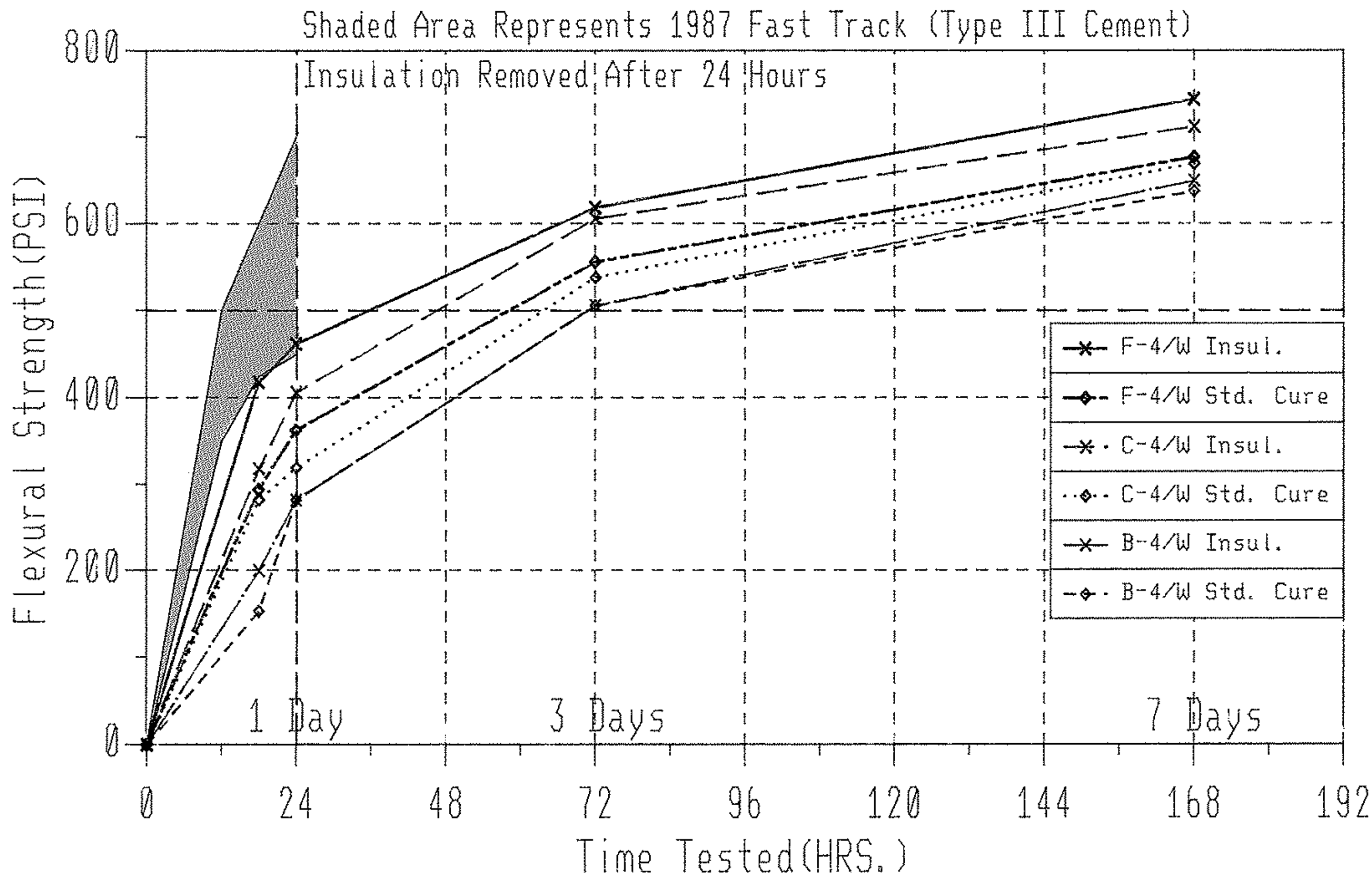

Figure 2
Pavement Temperature(F) VS Time(HRS)

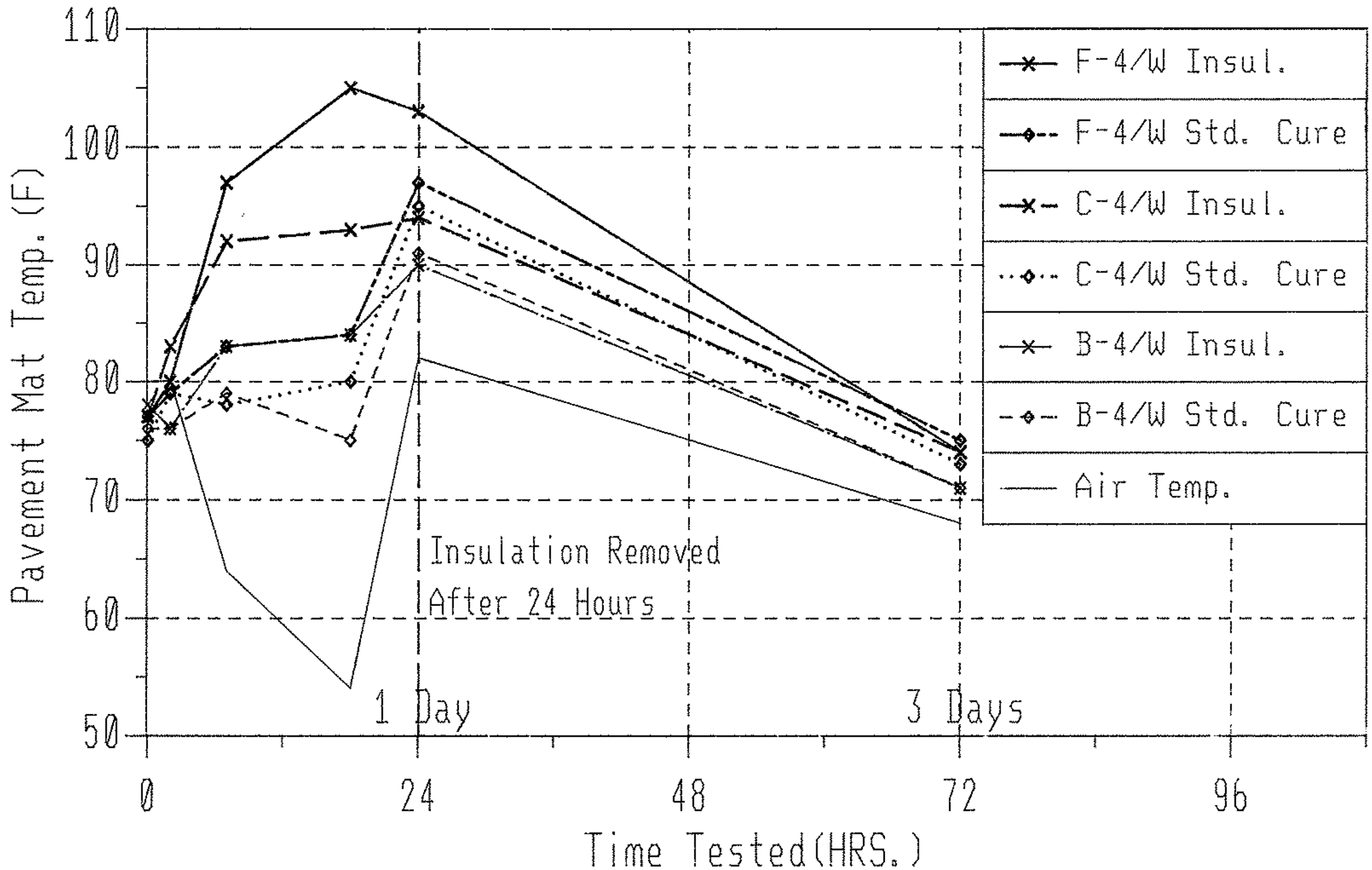

Figure 3
Flextural Beam Temperatures(F) VS Time (HRS)