Construction and Performance of a Fast-Track Concrete Pavement in Kansas

MUSTAQUE HOSSAIN AND JOHN WOJAKOWSKI

The fast-track or high early strength concrete offers the opportunity of taking advantage of higher early strength gain in a smaller time for construction or rehabilitation of high volume roads and city streets serving businesses. The Kansas Department of Transportation and the city of Manhattan, Kansas, built a section of fast-track concrete pavement in an urban setting in Manhattan, Kansas, in 1989 and 1990. The mixture design was developed using a special Type-III cement and three different types of locally available aggregates. Strength gain of this mix in the field was satisfactory except on a few occasions when the daily low temperature dropped below −0°C (32°F). Two mixes with different water-cement ratios performed equally in terms of strength gain. The maturity data collected in the slabs and field beams indicate that the maturity of companion field beams lagged that of the slab bottom or top. However, the maturity number was well correlated with the 24-hr flexural strength of the beams when the beam strengths were corrected for temperature of testing. The field beams appeared to mature earlier than the laboratory beams and thus showed higher strengths at the same age. Multiple surveys of this fast-track pavement during the past few years did not reveal any major distress. Visual survey conducted in 1993 indicates that the longitudinal surface texture of the pavement is showing wear. This might happen because of the grinding action of the sand particles on the pavement surface applied during the winter months under the traffic load. Overall, the performance of this pavement is excellent.

The time window available for construction or rehabilitation of high volume roads and city streets serving businesses is an important consideration. The fast-track or high early strength concrete offers the opportunity of taking advantage of higher early strength gain in a smaller time window for pavement construction or rehabilitation. Thus, the main objective of using this concrete is to increase the rate of strength gain of concrete pavements without any reduction in the ultimate concrete strength and durability, so that the pavement can be opened to traffic in a matter of hours or days.

The Kansas Department of Transportation (KDOT) and the City of Manhattan, Kansas, built a section of fast-track concrete pavement in Manhattan, Kansas, in 1989 and 1990. The project was closely monitored and some research quality data on the concrete maturity (i.e., indication of strength gain) and strength were gathered. The project was surveyed in 1991 and 1993. The design, construction, and performance of this project to date is discussed.

PROJECT DESCRIPTION

Location and Layout

The fast-track pavement, part of the KDOT project 81 U-1122-01, is in Manhattan, Kansas, about 90 km (56 mi) northwest of Topeka. The project consisted of grading, widening, surfacing, and bridge construction from Station 54 + 00 to Station 239 + 038 on Anderson Avenue, a major arterial connecting the suburban west side with the old east side of the town. The fast-track pavement extends from Station 49 + 00 to Station 179 + 00 and includes three intersections and fifteen driveways serving various businesses between Seth Childs Road and Wreath Avenue (Figure 1). The roadway is a four-lane undivided facility with a dual left-turn lane in the middle. In this paper "the project" means only the fast-track part of the KDOT project 81 U-1122-01.

M. Hossain, Department of Civil Engineering, Kansas State University, Manhattan, Kan. 66506. J. Wojakowski, Kansas Department of Transportation, Materials and Research Center, 2300 Van Buren, Topeka, Kan. 66611.

Soils, Climate, and Drainage

The soils in the project area are mostly silty clay (Unified CL or AASHTO A-6) with low shrink-swell potential. Approximately 70 to 90 percent pass U.S. number 200 sieve. The climate in this region is moderately extreme with hot, humid summers (temperatures exceeding 35°C [100°F]) and cold (below −20°C [0°F]) wet winters. Figure 2 shows the monthly low and high temperatures in the project area since 1989. The 30-year annual precipitation is around 91 mm (32 in.). The average number of frost-free days is 176. The referenced meteorological data were recorded at the National Weather Services station in Manhattan. Drainage on the project was provided by the side slopes, curb and gutter, and intermittent inlets to the storm sewers.

Traffic History

The project was designed for 1986 ADT of 16,300. The projected ADT for 2006 is 36,430. The percentage of trucks was 5 percent in 1986 and currently consists of some heavy delivery vehicles and tankers serving the adjoining supermarket, automobile dealership, and gas stations. This mix of traffic led to the city's decision to use the fast-track concrete on this project so that vehicular access would not be denied to any business for more than 48 hr.

Pavement Section

The mainline pavement section consists of 229 mm (9 in.) of plain concrete (PCCP) placed directly over the compacted subgrade. The business entrances and turnaround areas are 178 mm (7 in.) thick. The pavement is a jointed PCCP with joints at a uniform spacing of 4.6 m (15 ft).

DESIGN DESCRIPTION

Material Characteristics

The mix design and materials were specified by the KDOT *Standard Specifications for State Road and Bridge Construction*, 1980 and 1990 editions, and *special provisions* for the project (*1*).

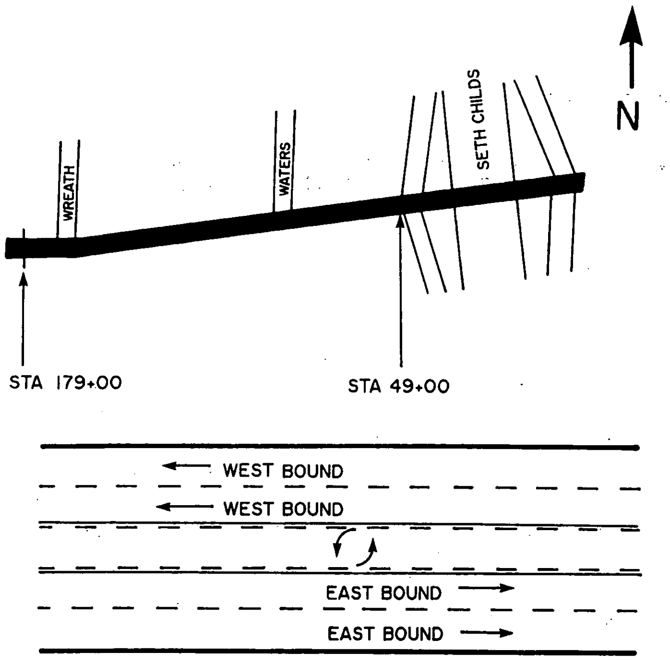

FIGURE 1 Location and layout of fast-track test section.

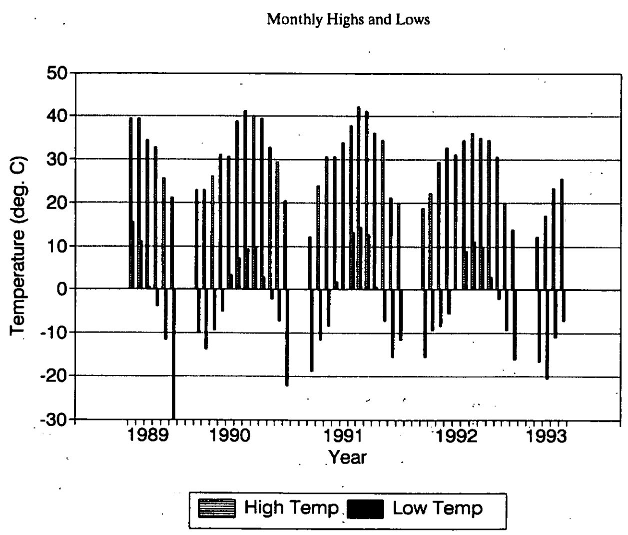

FIGURE 2 Monthly high and low temperatures for 1989, 1990, 1991, 1992, and 1993.

Cement

A special Type III portland cement was specified for this project to meet the required minimum compressive strength of 8,966 kPa (1,300 psi) at 12 hr when 51-mm^3 (2-in.^{3}) mortar specimens were tested according to the ASTM C109 (*2*). However, this cement also met the 1980 KDOT standard specifications for Type-III cement. The general properties of the cement used on this project were

- Initial setting time (Gilmore): 145 min,
- Final setting time (Gilmore): 285 min,
- Autoclave expansion: 0.100 percent,
- Blaine fineness: 560 m^2/kg.

Chemical composition of this cement is shown in the following table:

Constituents	*Percent Present*
Silicon Oxide	20.34
Aluminum Oxide	4.09
Ferric Oxide	3.23
Calcium Oxide	62.79
Magnesium Oxide	3.72
Sulfur Trioxide	3.37
Sodium Oxide	0.16
Potassium Oxide	0.48
Loss on ignition	1.71
TriCalcium Silicate	59.3
TriCalcium Aluminate	5.4

Average compressive strength of 51-mm (2-in.) standard mortar cube specimens tested according to the ASTM C106 were 3,517, 21,586, and 32,828 kPa (510, 3130, and 4760 psi) for 8 hr, 1 day, and 3 days, respectively.

Aggregates

Three different types of locally available aggregates, coarse (crushed limestone), intermediate (river gravel), and fine (river sand), were used in the design of the mix. The coarse aggregate was a KDOT Class-1 durable (freeze-thaw resistant) aggregate. The required gradations for these aggregates are shown in Table 1. The proportions specified in the concrete mixture were as follows:

- Coarse aggregate: 43 to 52 percent,
- Intermediate aggregate: 20 to 29 percent,
- Fine aggregate: 25 to 31 percent.

Trial Concrete Mix Design

Trial concrete mixture design was submitted by the cement supplier, Ash Grove Cement Company of Overland Park, Kansas. This mix design was evaluated by the Shilstone method (*3*). Table 2 shows the mix design information. Both water-reducing and air-entraining admixtures were used, and the resulting mix had about 5 percent air content.

Cylinder and beam specimens were prepared with this mix and cured under a thermal blanket. The compressive strengths were 25,172 and 27,517 kPa (3650 and 3990 psi) at 18 and 24 hr, respectively. The corresponding flexural strength values were 2,897 and 3,759 kPa (420 and 545 psi), respectively. Ultimately, all specifications for the materials and mix were developed.

The following proportioning in mix design was specified:

- kg of cement per m^3, minimum 386 (710);
- kg of water per kg of cement, maximum, 0.44;
- percent of air by volume, 6 ± 2 [as determined by Kansas test method KT-19 (Rollameter)].

The mix was required to meet the following minimum strength requirements when specimens made with the mix were cured 18 hr under a specified insulating blanket (with an R value of at least 0.5):

TABLE 1 Specified Gradations for Aggregates for Fast-Track Concrete

Aggregate	% Retained on sieve size									
	25 mm	19 mm	13 mm	6mm	#4	#8	#16	#30	#50	#100
Coarse aggregate (CA)	0	0-6	26-38	60-72	91-95	96-100				
Intermediate aggregate (SG)			0	0-5	10-20	42-70	75-98	91-100	96-100	97-100
Fine aggregate (FA)				0	0-6	9-17	28-38	55-65	86-96	94-100

Note: 1 in = 25.4 mm

TABLE 2 Trial Mix Design Information

Mix component	weight per sack (saturated, surface dry)
Cement, Type-III, kg	42.68
FA, Kaw River Sand, kg	42.25
SG, Blue River, kg	38.39
CA, Limestone, kg	86.94
Water, kg	17.07
Air Entrainment, %	5.0
Hycol, Water reducer, ml/m^3	789
Daravair, air entrainer, ml/m^3	371
Water-cement ratio (kg/kg)	0.40
Slump, mm.	63.5
Concrete unit weight, kg/m^3	2238

Note: 1 in = 25.4 mm
1 lb = 0.454 kg
1 cu. yd. = 0.765 cu. m.
1 oz = 28.35 g

Test	*kPa (psi)*	*Test Method*
Compressive strength	20,670 (3,000)	KT-22 & AASHTO-T22
Flexural strength	2,412 (350)*	KT-231

* *as determined from third point loading.*

PROJECT CONSTRUCTION

Concrete Mix

Two transit mixes with design water-cement ratios of 0.40 and 0.44 were used on this job. Detailed properties of these mixes are shown in Table 3. A water-reducing admixture meeting the ASTM standard C494 and an air-entraining admixture were used. The mix with 0.44 water-cement ratio had higher air content and slump than the mix with 0.40 water-cement ratio. This mix was used on most of the project.

Layout

Concrete was placed in the mainline pavement by using a slip-form paver. However, the turn-outs and other places were poured manually using fixed forms. In 1989, paving was done in July, October, November, and December (2 days only). In 1990, paving continued from April through October. Time of placement varied from as early as 6:00 a.m. to as late as 8:00 p.m.

TABLE 3 As-Batched Mix Design Information

Ingredient	Mix with 0.40 water-cement ratio	Mix with 0.44 water-cement ratio
	weight per sack (SSD)	weight per sack (SSD)
Cement, Type-III, kg	42.68	42.68
FA, Kaw River Sand, kg	41.39	40.32
SG, Blue River, kg	38.08	37.08
CA, Limestone, kg	86.10	83.84
Water, kg	17.07	18.73
Concrete unit wt., kg/m^3	2353	2290
Ent. Air, %, (Rollameter)	3.5	5.6
Hycol, Water reducer, ml/m^3	1052	1052
Daravair, air entrainer, ml/m^3	148	148
Water-cement ratio (kg/kg)	0.40	0.44
Slump, mm	38.1	76.2

Note: 1 in = 25.4 mm
1 lb = 0.454 kg
1 cu. yd. = 0.765 cu. m.
1 oz = 28.35 g

Consolidation

The pavement was required to be consolidated so that the density of the concrete should not be less than 98 percent of the rodded unit weight. Density was measured by a nuclear gauge. The 98 percent density requirement was waived on miscellaneous areas such as entrance pavement and so forth.

Texturing

Texturing with the metal comb was not required on this project. Final finish was applied by a longitudinal burlap-drag.

Curing

A white curing compound and insulated blankets were used on this project. The insulating blanket cover intended for curing was specified to have a layer of closed cell polystyrene foam protected by at least one layer of plastic film with an R-value of at least 0.5. The thermal blanket was left on until the concrete had attained a minimum strength of 1,723 kPa (250 psi) modulus of rupture (third-point loading method). The curing compound was used during early morning hours and under cloud covers. However, the test results reported in this report for the maturity of the concrete in the slab were collected during curing with insulated blankets.

Sawing and Sealing

Primary saw-cuts of 3-mm (1/8 in.) width and full-joint depth were done as soon as the concrete hardened, and no ravelling or spalling due to the saw cuts occurred. These cuts were made satisfactorily throughout the project before any cracking occurred. However, on one slab, cracking occurred before the primary cut. In secondary cuts, the joints were widened to a width of 9 mm (3/8 in.) to form the sealant reservoir when concrete had attained at least 1,723 kPa (250 psi) modulus of rupture. The joints were cleaned by sandblasting, followed by compressed air blast. After installing the backer rod, a hot-poured, single component joint sealant manufactured by Koch Materials, Inc., and meeting ASTM D-1190 was used.

Opening to Traffic

The project was opened to traffic after the concrete had attained a minimum strength of 3,100 kPa (450 psi), and all joints were sealed. No business was denied vehicular access for more than 48 hr, and this fulfilled the city's objective of using fast-track concrete on the project.

STUDY OF FAST-TRACK CONCRETE

As mentioned earlier, some research quality data were gathered on this project to study the relationships among different concrete mix design parameters. The parameters studied include 24-hr flexural strength of concrete (from third-point beam test), concrete temperature (at the time of placement), concrete maturity, daily highest and lowest air temperatures, air content, and slump of the concrete mix. The following section describes the results of this analysis.

Relationship of Flexural Strength and Concrete Temperature, Daily Highest Air Temperature, Air Content, and Slump

Table 4 shows the summary statistics of 24-hr flexural strength, concrete temperature, daily highest air temperature, air content, and

TABLE 4 Summary of Statistics of Fast-Track Concrete Parameters

Water-Cement Ratio	Statistic	24-hr Flexural Strength (kPa)	Concrete Temp. (deg.C)	Daily High Temp. (deg. C)	Air Content (%)	Slump (mm)
0.40	Mean	90.19	25	25.89	4.9	40.64
	Std. Dev.	11.31	-12.78	-10.67	0.57	12.7
	C.V. (%)	13	12	16	12	762
	Range	77 - 103	17.78 - 32.78	16.11 - 36.11	4 - 5.5	25.4- 66
	Sample Size	7	7	7	7	7
0.44	Mean	91	25.33	29.78	5.5	55.88
	Std. Dev.	21.61	-14.22	-9.44	1.1	9.14
	C.V. (%)	24	8	18	21	17
	Range	42.63 - 115	19.44 - 30.56	13.89 - 41.67	4 - 9	38.1 - 66
	Sample Size	19	19	19	19	19

Note: 1 in = 25.4 mm
1 psi = 6.89 kPa
C.V. = coefficient of variation

slump of the concrete mix collected during construction of this project. The beams were cast in the field and cured under the curing blanket. The number of observations for concrete mixes with water cement ratios of 0.40 and 0.44 were 7 and 19, respectively. The variability of flexural strength for the mix with 0.44 water-cement ratio is very high. This happened because of low flexural strength attainment due to very low daily temperatures for 3 days in November and December 1989. Daily low temperatures of −5°, −12°, and −6°C (23°, 11°, and 21°F) were recorded on these days, and the mix failed to reach the required flexural strength of 2,412 kPa (350 psi) in 18 hr.

Students *t*-tests were conducted between the means of 24-hr flexural strengths of field beams cast with these two mixes. The results did not show any significant difference in strength at 5 percent level of significance. There was somewhat higher variability of air content for the mix with 0.44 water-cement ratio.

To study the interrelationships among the parameters mentioned, a correlation analysis was done. Table 5 shows the correlation ratios among these parameters. The following observations can be made on the basis of the results of Table 5 and general trends for these parameters as related to the fast-track concrete:

- There are significant relationships between the 24-hr flexural strength and daily high temperature, concrete temperature, and air content. It can be generally observed that the 24-hr flexural strengths were higher when the daily high temperature exceeded 24°C (75°F) for both mixes (Figure 3). Figure 4 shows that the fast-track concrete mixture failed to achieve the desired flexural strength in 24 hr when the daily high temperature fell below 0°C (32°F). On the other hand, flexural strength was the highest when the concrete temperature was between 27° and 29°C (80 and 85°F), as shown in Figure 5.
- As can be expected, the flexural strength tended to decrease as the air content increased, as evidenced by the negative coefficient of correlation and trend in Figure 6. Air entrainment was also significantly affected by the daily high temperature.
- Air entrainment significantly increased slump of the fast-track concrete mix. However, the slump was not a direct factor in determining the strength gain of the concrete as long as it was between 25 and 76 mm (1 and 3 in.) (Figure 7).

TABLE 5 Correlation Among Fast-Track Concrete Mix Parameters

Water-Cement Ratio	Parameter	24-hr Flexural Strength	Concrete Temp.	Daily High Temp.	Air Content	Slump
0.40	24-hr Flexural Strength	1.0	0.19	0.48	-0.37	-0.33
	Concrete Temp.	0.19	1.0	0.79*	0.14	0.72*
	Daily High Temp.	0.48	0.79*	1.0	-0.20	0.55**
	Air Content	-0.37	0.14	-0.20	1.0	0.34
	Slump	-0.33	0.72*	0.55	0.34	1.0
0.44	24-hr Flexural Strength	1.0	0.46*	0.79*	-0.53*	-0.21
	Concrete Temp.	0.46*	1.0	0.69*	-0.33	-0.26
	Daily High Temp.	0.79*	0.69*	1.0	-0.41**	-0.26
	Air Content	-0.53*	-0.33	-0.41**	1.0	0.52*
	Slump	-0.21	-0.26	-0.14	0.52*	1.0

* significant at 5% level of significance.
** significant at 10% level of significance.

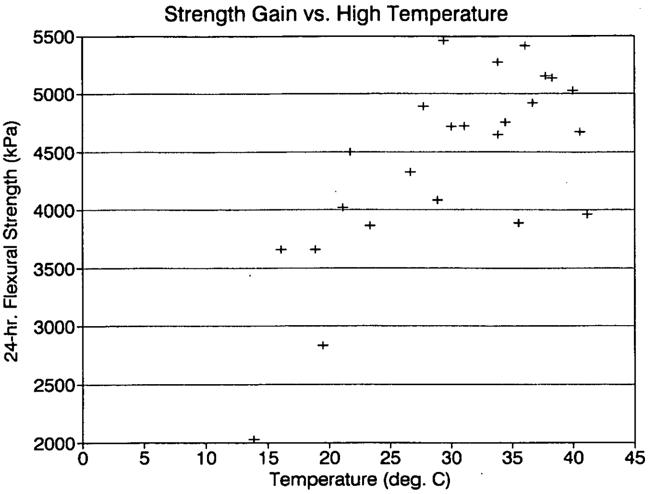

FIGURE 3 Strength gain of fast-track concrete versus daily high temperature.

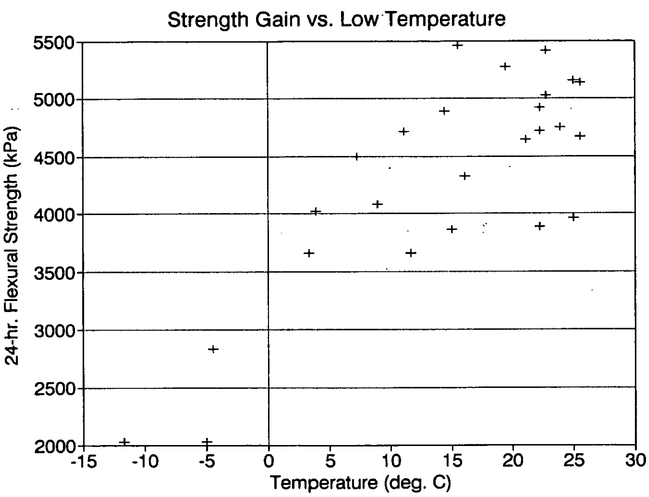

FIGURE 4 Strength gain of fast-track concrete versus daily low temperature.

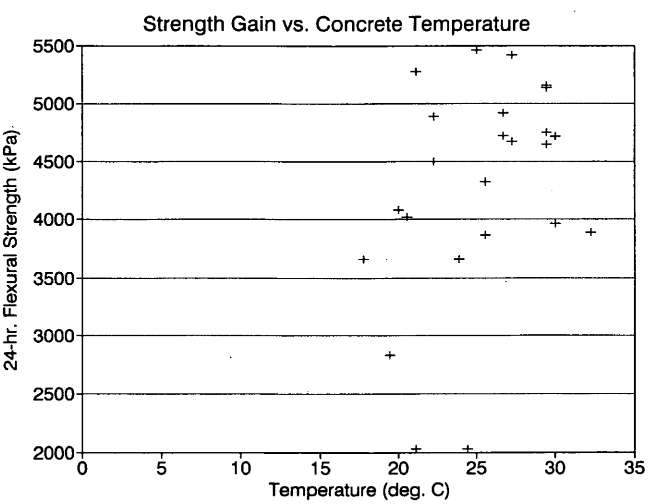

FIGURE 5 Strength gain of fast-track concrete versus concrete temperature.

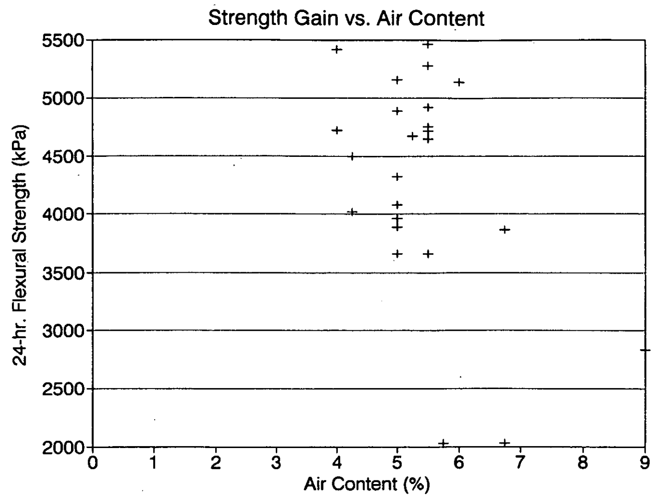

FIGURE 6 Strength gain of fast-track concrete versus air content.

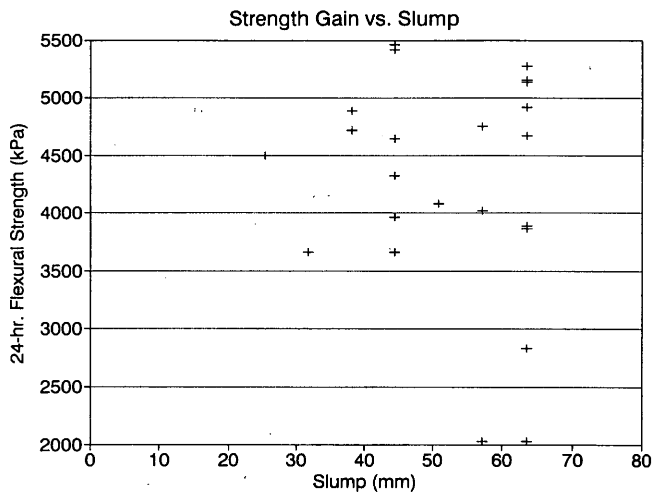

FIGURE 7 Strength gain of fast-track concrete versus slump.

Another general observation indicates that the time of day of concrete pour had little direct impact on the early strength gain other than affecting the concrete temperature slightly.

Fast-Track Concrete Maturity

The maturity of fast-track concrete was evaluated by collecting time and temperature data using a maturity meter manufactured by James Instruments. Thermocouple wires were inserted at the following locations in the slab: 13 mm (1/2 in.) from the top, center, and 13 mm (1/2 in.) from the bottom. Temperature was also monitored in the field beam where thermocouple wires were buried 76 mm (3 in.) into the beam around 152 mm (6 in.) from one end. Air temperature was also monitored. The slabs and beams were cured using blanket insulation during data collection. Maturity data were collected for 24 hr. Figure 8 shows the plot of temperature versus time for October 4 and 5, 1989. It is obvious that the maturity of a fast-track concrete slab can not be directly monitored by a companion beam.

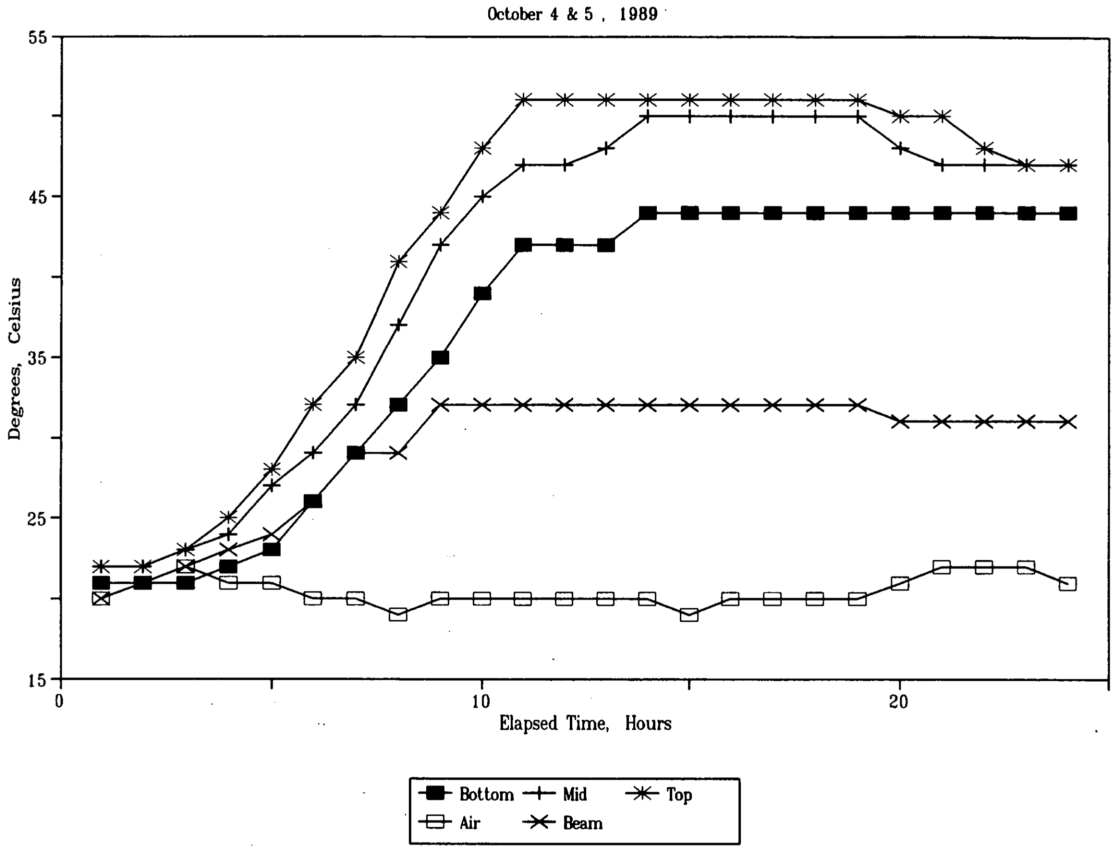

FIGURE 8 Typical time-temperature relationship for fast-track concrete.

This is expected because of the greatly different masses of concrete (and heat losses) of the slabs and the beams. Moreover, it is also the reason that the maturity concept is needed.

Correlation between Fast-Track Concrete Maturity and Strength

Figure 9 shows the maturity numbers measured in the slabs and field beams after 24 hr for the mix, with a water-cement ratio of 0.44 on three different days in 1989 and 1990. The maturity numbers of beams always lagged behind those of the slab top and bottom. The strength gain of fast-track concrete can be monitored by using the lesser of the maturity numbers at the top and bottom of the slab. To correlate the 24-hr flexural strength with the maturity number, data were collected for the mix with 0.44 water-cement ratio on 3 different days. The flexural strength data were corrected for test temperature using the correction factors suggested by Neville (*4*). Figure 10 shows the plot of these data. It is apparent that the 24-hr flexural strength has a linear relationship with the maturity number. From the extrapolation of these data, it was found that this fast-track mix had a maturity number of approximately 3,600 when it reached the 24-hr flexural strength of 3,100 kPa (450 psi).

PAVEMENT PERFORMANCE

The project was surveyed for visual distresses in April 1991 and July 1993. The 1991 survey revealed only one diagonal crack. No scaling was observed. Some areas adjacent to the joints had been ground. Some spalling was observed in a few joints. In 1993, the project was surveyed using the APWA PAVER methodology developed by the U.S. Army Corps of Engineers (*5*). A total of 120 slabs (approximately 3.7 m × 4.6 m (12 ft × 15 ft) size), which represents 30 percent of the project area, was randomly sampled and surveyed for 19 different distresses. Low severity joint seal damage was observed over the whole area. Popouts were recorded on approximately 9 percent of the slabs surveyed. Minor joint and corner spalling was also observed. No polished aggregates except in the ground areas were evident. But the longitudinal surface texture formed during construction appeared to be showing wear. This

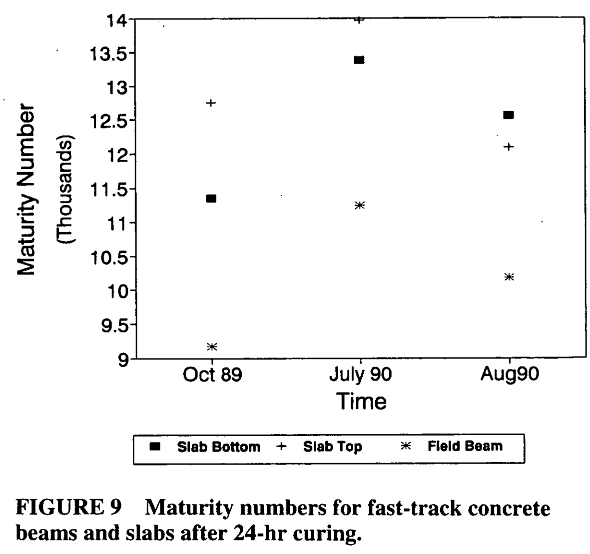

FIGURE 9 Maturity numbers for fast-track concrete beams and slabs after 24-hr curing.

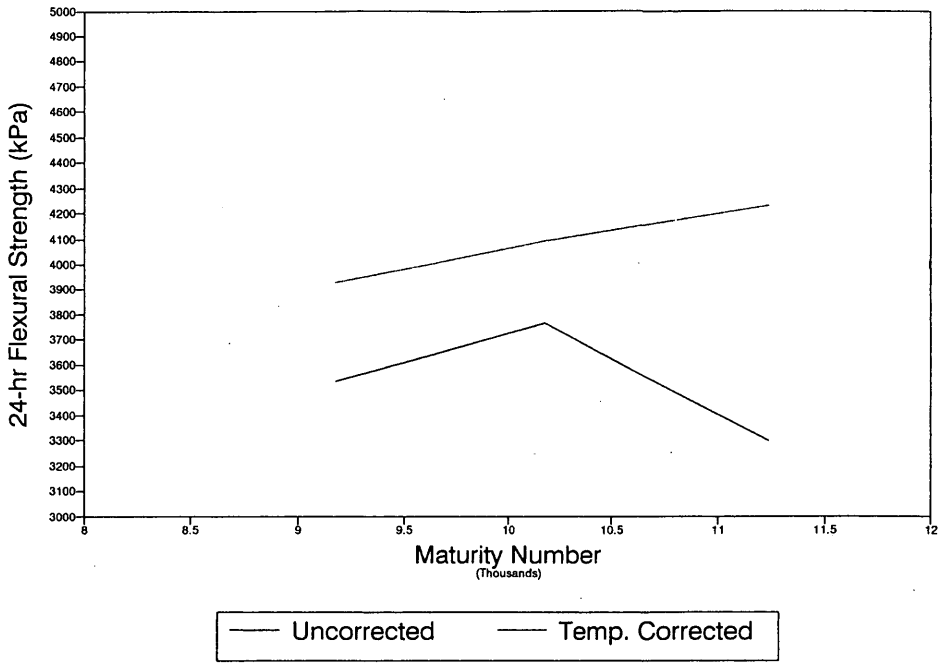

FIGURE 10 Relationship between maturity number and flexural strength of fast-track concrete beams after 24-hr curing.

might happen because of the grinding action of the sand particles on the pavement surface applied in winter under the traffic load. However, in view of the fact that the posted speed limit on this facility is 48 km/hr (30 mph), this condition should not create any friction-related problem. On the basis of the results of the PAVER survey, the pavement condition index of this pavement was calculated to be 96, which is a rating of "excellent."

CONCLUSIONS

The fast-track concrete pavement in Manhattan, Kansas, was successfully constructed using a high early strength or fast-track concrete mixture. No business in the surrounding area was denied vehicular access for more than 48 hr. The mixture was designed using a special Type-III cement and three different types of locally available aggregates. Strength gain of this mixture in the field was satisfactory except on a few days when the daily low temperature dropped below 0°C (32°F). Two mixes with different water-cement ratios performed equally in terms of strength gain. The maturity data collected in the slabs and field beams indicate that the maturity of companion field beams lagged that of the slab bottom or top. However, the maturity number has an excellent correlation with the 24-hr flexural strength of the beams when the beam strength values were corrected for temperature of testing. The field beams appeared to mature earlier than the laboratory beams and showed higher strength at the same age. Surveys of the fast-track pavements during the past few years did not reveal any major distresses. A survey conducted in 1993 indicates that the longitudinal surface texture of the pavement is showing wear. This might happen because of the grinding action of the sand particles on the pavement surface applied during winter under the traffic load. Overall, the performance of this project is excellent.

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