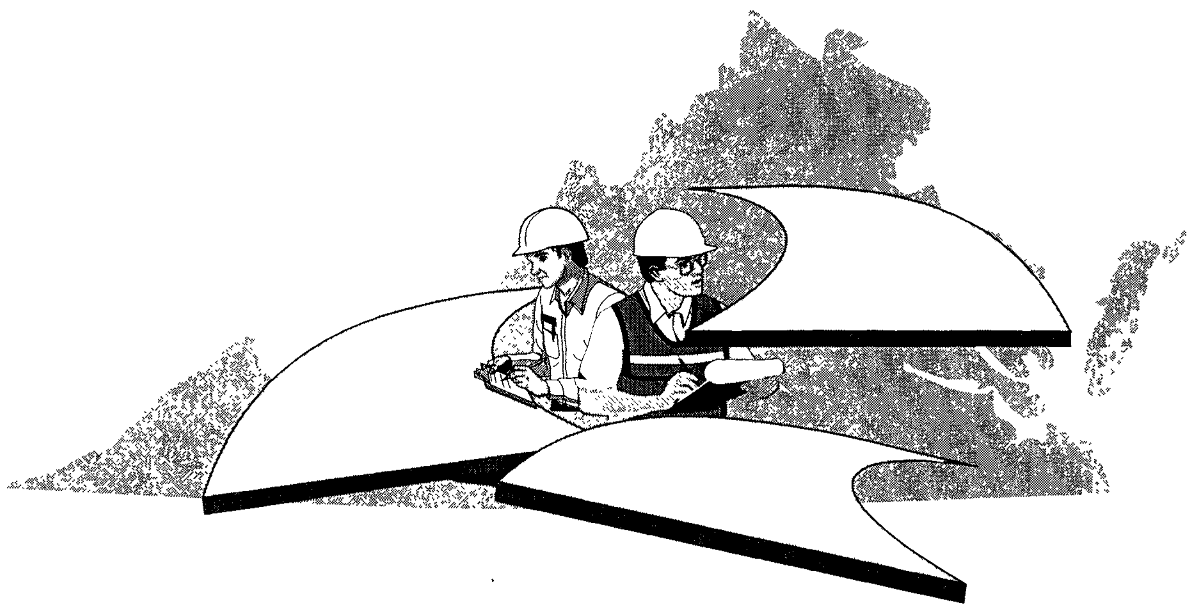
INTERIM REPORT

EVALUATION OF THE INSTALLATION AND INITIAL CONDITION OF HYDRAULIC CEMENT CONCRETE OVERLAYS PLACED ON THREE PAVEMENTS IN VIRGINIA



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16. Abstract

Hydraulic cement concrete pavement overlays were placed in the summer of 1995 at the following locations in Virginia:

- I-295 near Richmond
- I-85 near Petersburg
- Rt. 29 near Charlottesville.

Overlays were placed on I-295 SBL (near mile marker 29) and I-85 SBL (near mile marker 51) in Virginia to prevent spalling caused by a shy cover over the reinforcement and to enhance the structural integrity. Both locations are continuously reinforced concrete pavement. An overlay was also placed on Rt. 29 NBL (1.6 km south of Charlottesville) in Virginia to correct a rutted asphalt pavement.

The construction was funded with 20 percent Virginia Department of Transportation maintenance funds and 80 percent special ISTEA Section 6005 federal funds specifically allocated to demonstrate overlay technologies. ISTEA funds were also used to evaluate the installation and initial conditions of the overlays and to prepare the report. The variables in this study were concrete mix design, overlay thickness, and base material. Mineral admixtures and steel and plastic fibers were used to improve the mechanical properties and durability of the overlay concrete. Overlay thickness and base material were varied to determine their effect on overlay performance.

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INTERIM REPORT

EVALUATION OF THE INSTALLATION AND INITIAL CONDITION OF HYDRAULIC CEMENT CONCRETE OVERLAYS PLACED ON THREE PAVEMENTS IN VIRGINIA

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In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

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1. Project Introduction

1.1 Summary

Hydraulic cement concrete (HCC) pavement overlays were placed in the summer of 1995 at the following locations in Virginia:

- I-295 near Richmond
- I-85 near Petersburg
- Rte. 29 near Charlottesville.

Overlays were placed on the I-295 southbound lane (SBL) (near mile marker 29) and the I-85 SBL (near mile marker 51) to prevent spalling caused by a shy cover over the reinforcement and to enhance the structural integrity. Both locations are continuously reinforced concrete pavement. An overlay was also placed on the Rte. 29 northbound land (NBL) (1.6 km south of Charlottesville) to correct a rutted asphalt pavement.

The construction was funded with 20 percent Virginia Department of Transportation (VDOT) maintenance funds and 80 percent special ISTEA Section 6005 federal funds specifically allocated to demonstrate overlay technologies. ISTEA funds were also used to evaluate the installation and initial conditions of the overlays and to prepare the report.

The variables in this study were concrete mix design, overlay thickness, and base material. Mineral admixtures and steel and plastic fibers were used to improve the mechanical properties and durability of the overlay concretes. Overlay thickness and base material were varied to determine their effect on overlay performance. A summary of these variables is presented in Table 1.1.

Project	I-295	I-85	Rte. 29
Mineral Admixture	Fly Ash	Fly Ash	Slag
Type of Fiber Used	Hooked-end Steel	Hooked-end Steel	Hooked-end Steel
	Fibrillated Polypropylene	Monofilament Polypropylene	Monofilament Polypropylene
	Polyolefin	---	Polyolefin
Overlay Thickness (mm)	51	102	51/76/102
Base Material	Continuously Reinforced Concrete Pavement	Continuously Reinforced Concrete Pavement	Asphalt Pavement

Table 1.1. Summary of project variables

Site location maps for the three overlay projects are shown in Figures 1.1, 1.2, and 1.3.

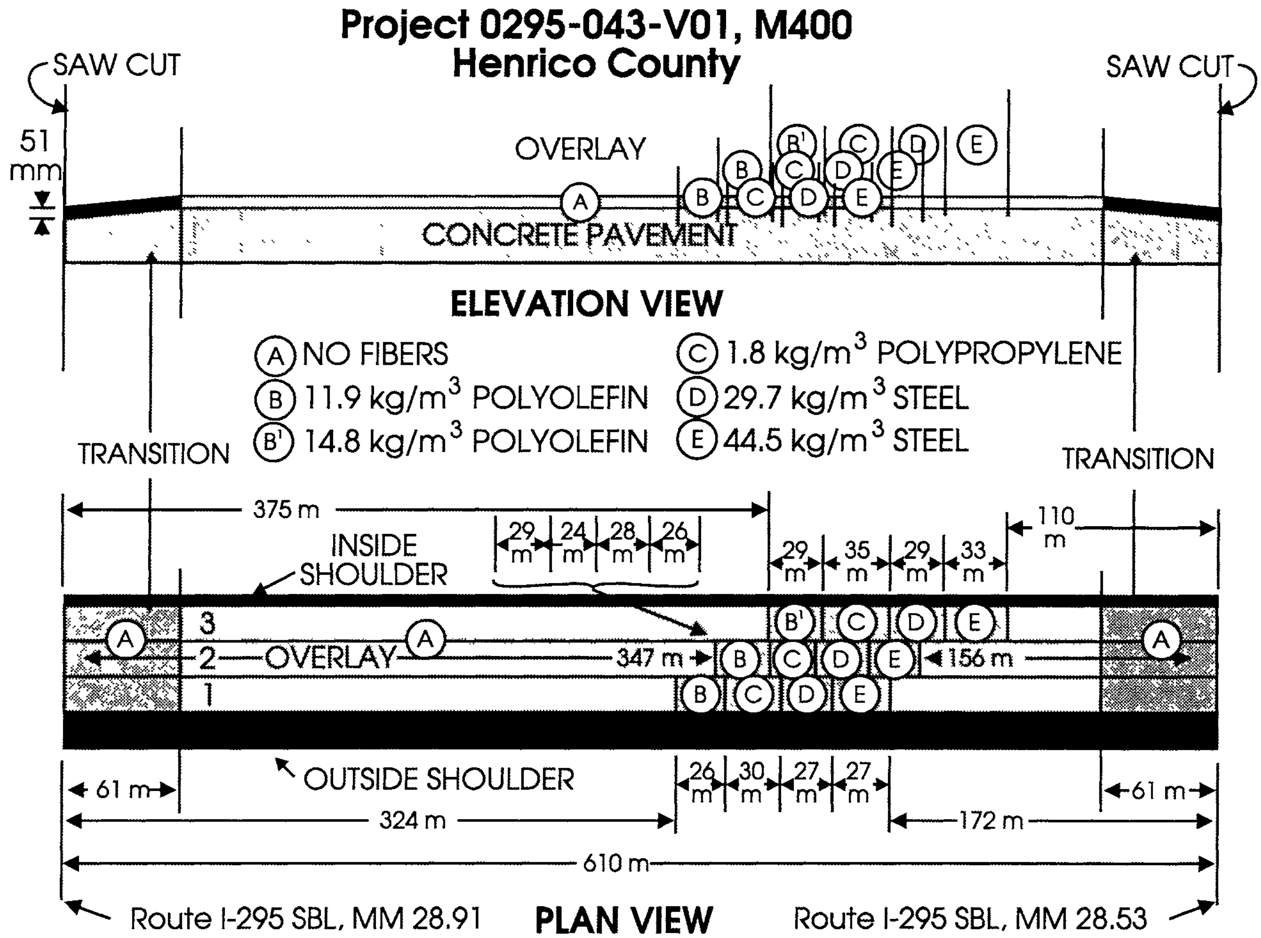

Figure 1.1. Site map for I-295

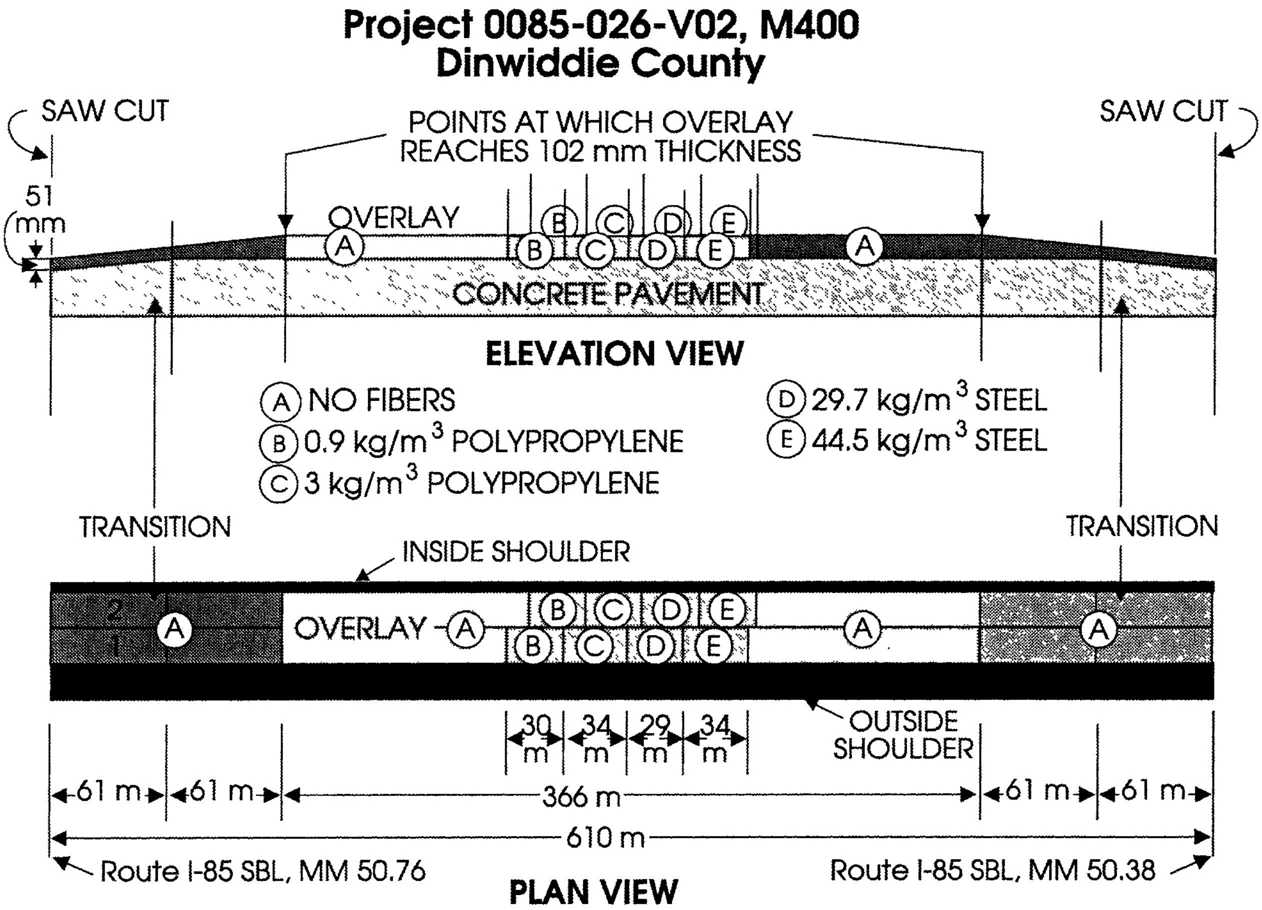

Figure 1.2. Site map for I-85

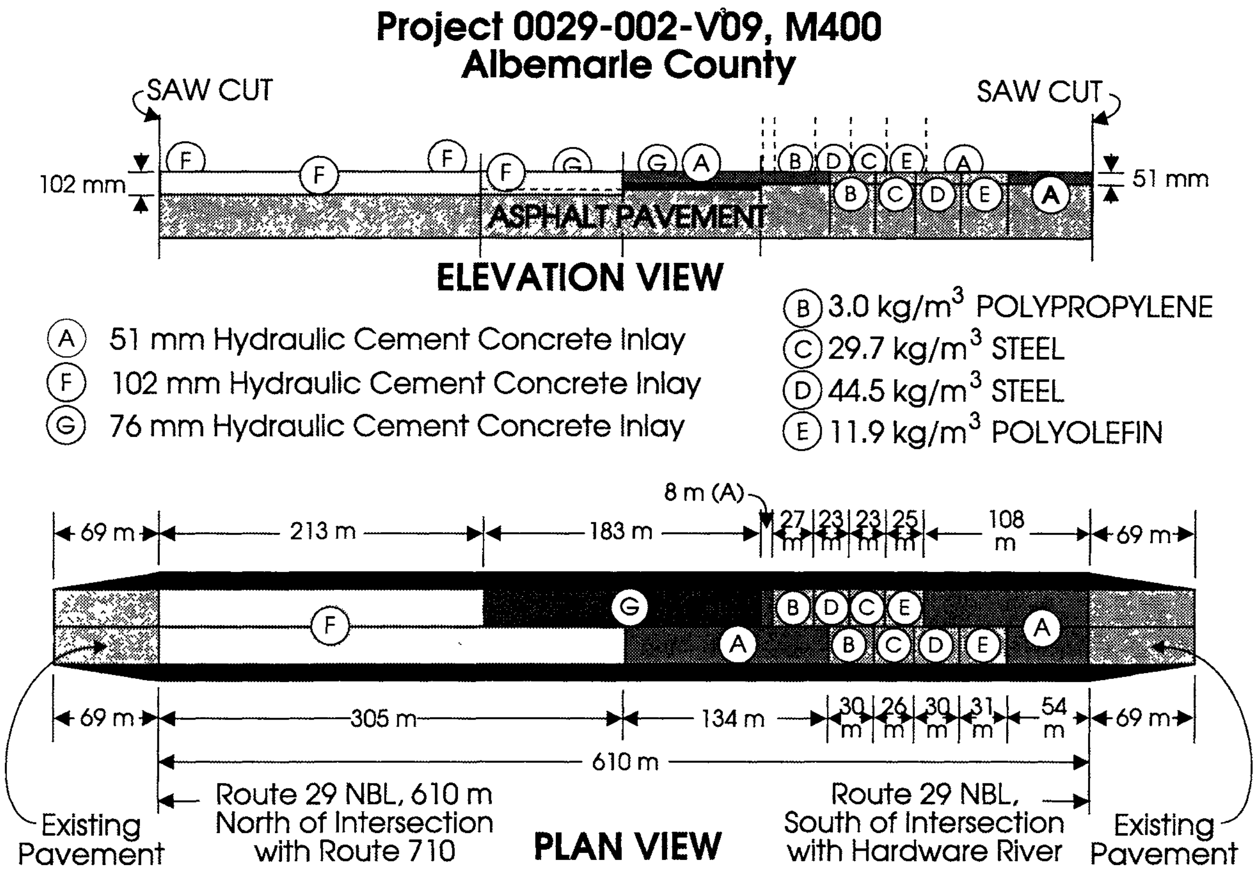

Figure 1.3. Site map for Rte. 29

1.2 Objective

The objective of this research is to evaluate HCC pavement overlays with pozzolans and slag and with and without fibers constructed using ISTEA Section 6005 funds. The overlays were placed to correct for shy cover over the reinforcement or rutting and to enhance the structural integrity of the pavements.

1.3 Methodology

The objective is to be accomplished by completing the following tasks:

- Task 1: Evaluate conditions of each pavement before overlay is placed.
- Task 2: Document the specifications used for each installation.
- Task 3: Record results of quality assurance testing for each overlay.
- Task 4: Evaluate initial conditions of each installation.
- Task 5: Evaluate the condition of each installation annually.
- Task 6: Evaluate final condition of installation in 1999.
- Task 7: Submit draft and final report to the Federal Highway Administration (FHWA).

Tasks 1 through 5 are discussed in this report.

2. Evaluation of Conditions Prior to Installation

2.1 Map of Cracks and Patches

Maps of cracks and patches from a preinstallation survey are on file.

2.2 Permeability to Chloride Ion (AASHTO T 277)

Prior to placement of the overlays on I-295 and I-85, eight cores 102 mm (4 in) in diameter were taken from the HCC pavement at each site. No cores were taken from the asphalt pavement on Rt. 29.

Slice 51 mm (2 in) thick were cut from the top 51 mm and the next 51 mm of each core. The slices were tested for permeability to chloride ion (AASHTO T 277). The results were as follows:

I-295 top 51 mm, 1489 coulombs
I-295 next 51 mm, 4463 coulombs
I-85 top 51 mm, 1781 coulombs
I-85 next 51 mm, 6473 coulombs.

The top part of both pavements had a low permeability and the next part a high permeability. The permeability is considered to be typical for pavements constructed without pozzolans or slag.

2.3 Falling Weight Deflectometer (ASTM D 4694)

See Section 5.2 for plots of composite stiffness vs. distance. These plots compare the composite stiffness of the pavement before and after the overlays were placed.

2.4 Preinstallation Photographic Record

A video of preplacement conditions is available.

3. Specifications for Installation

3.1 Site Preparation and Preoverlay Repairs

No patching was required on I-295 and Rte. 29. A small area on I-85 was patched prior to placement of the overlay. The first and last 61 m of the I-295 and I-85 placements were milled to provide for a 51-mm minimum thickness overlay at the beginning and end of each installation. Milling was used throughout the 610-m installation to remove the asphalt necessary to provide the required overlay (inlay) thickness.

3.2 Surface Preparation

The continuously reinforced concrete pavements were shotblasted to remove the top 3 mm, and the asphalt pavement was broomed to remove milling dust prior to placement of the overlays. A water truck was used to flood the prepared surfaces and to maintain a saturated surface-dry condition as the overlays were placed.

3.3 Overlay Technology

Several overlay technologies were explored in this project. An evaluation of different concretes modified with mineral admixtures was conducted by varying the amount of fly ash and slag in the concretes. Different fiber types and amounts were added to each of the three overlay concretes, allowing for comparison of the performance of concrete overlays with and without fibers. The overlay thickness was varied to compare cracking tendencies and patterns and pavement stiffness as determined by a falling weight deflectometer (See Section 5.2).

3.4 Fiber-Reinforced Concrete Symbolic Designations

The symbols in Table 3.1 will be used throughout the report to designate the types of fiber-reinforced concrete (FRC) used in this project.

Symbol	Fiber Amount, kg/m^3	Description
PO-1	11.9	25 mm polyolefin fiber
PO-2	14.8	51 mm polyolefin fiber
FP	1.8	fibrillated polypropylene fiber
MP-1	0.9, 3.0	monofilament polypropylene fiber, Brand I
MP-2	3.0	monofilament polypropylene fiber, Brand II
ST	29.7, 44.5	30/50 hooked end steel fiber

Table 3.1. Symbolic designation of overlay FRCs

3.5 Overlay Design Life

All overlays were designed to have a service life of 20 years or more.

3.6 Mixture Design

Approved mixture proportions and ingredients are shown in Tables 3.2, 3.3, and 3.4. Cement was partially replaced with fly ash or slag in the three projects to improve the durability of the concretes. Class F fly ash was used in the I-295 and I-85 projects and slag in the Rte. 29 project. The water-cementitious material ratio (w/cm) was increased for the FRC in the I-295 project but not for the other projects. Two control mixtures were prepared for the Rte. 29 project because of differences in maximum aggregate size. The maximum coarse aggregate size in the 51 mm thick overlay was 13 mm and in the 76 mm and 102 mm-thick sections was 25 mm.

The concretes were proportioned using the volumetric method. However, the fiber volumes were not included as was recommended by the manufacturer and is an accepted practice.

3.6.1 I-295

Fiber Type	Control	PO-2	PO-1	FP	ST	
Fiber length, mm	--	51	25	19	32	32
Fiber amount, kg/m^3	--	14.8	11.9	1.8	29.7	44.5
Cement, kg/m^3	320	320	320	320	320	320
Fly Ash, kg/m^3	75	75	75	75	75	75
Coarse aggregate, kg/m^3	908	908	908	908	908	908
Fine aggregate, kg/m^3	745	728	728	728	728	728
Water, L/m^3	153	178	178	178	178	178
Air entraining, L/ m^3	0.232	0.155	0.155	0.155	0.155	0.155
Water Reducer, L/ m^3	0.77-3.9	0.77-3.9	0.77-3.9	0.77-3.9	0.77-3.9	0.77-3.9
Air, %	6	6	6	6	6	6
Slump, mm	51	51	51	51	51	51
w/cm	0.39	0.45	0.45	0.45	0.45	0.45

Table 3.2. Mix proportions for the I-295 project

3.6.2 I-85

Overlay Type	Control	MP-1		ST	
Fiber length, mm	--	19	19	32	32
Fiber amount, kg/m^3	--	0.9	3	29.7	44.5
Cement, kg/m^3	344	344	344	344	344
Fly Ash, kg/m^3	81	81	81	81	81
Coarse aggregate, kg/m^3	1036	1036	1036	1036	1036
Fine aggregate, kg/m^3	632	632	632	632	632
Water, L/m^3	178	178	178	178	178
Air entraining, L/ m^3	0.232	0.232	0.232	0.232	0.232
WR + R , L/ m^3	0.83	0.83	0.83	0.83	0.83
Air, %	6	6	6	6	6
Slump, mm	51	51	51	51	51
w/cm	0.42	0.42	0.42	0.42	0.42

Note: WR + R = Water reducing and retarding admixture

Table 3.3. Mix proportions for I-85 project.

3.6.3 Rte. 29

Overlay Type	Control, 51 mm	Control, 102 mm	PO-1	MP-2	ST	
Fiber length, mm	--	--	25	19	32	32
Fiber amount, kg/m^3	--	--	11.8	3.0	29.7	44.5
Cement, kg/m^3	251	226	251	251	251	251
Slag, kg/m^3	167	151	167	167	167	167
Coarse aggregate, kg/m^3	880	1051	880	880	880	880
Fine aggregate, kg/m^3	792	758	792	792	792	792
Water, L/m^3	188	153	187	187	187	187
Air entraining, L/ m^3	0.4	0.4	0.4	0.4	0.4	0.4
WR + R, L/ m^3	0.77	0.77	0.77	0.77	0.77	0.77
Air, %	6	6	6	6	6	6
Slump, mm	76	51	51	51	51	51
w/cm	0.45	0.41	0.45	0.45	0.45	0.45

Note: WR + R = Water reducing and retarding admixture

Table 3.4. Mix proportions for Rte. 29 project.

3.7 Aggregate Grading Specification

Table 3.5 describes the grading of the coarse and fine aggregates used in the three projects as specified by VDOT.

Type of Aggregate	38 mm (1.5 in)	25 mm (1 in)	19 mm (3/4 in)	13 mm (1/2 in)	10 mm (3/8 in)	No. 4	No. 8	No. 16	No.30	No. 50	No.100
CA-no.57	Min. 100	95±5	--	43±17	--	Max. 7	Max. 3	--	--	--	--
CA-no.7	--	--	Min. 100	95±5	57±17	Max. 15	Max. 5	--	--	--	--
FA-Grade A	--	--	--	--	Min. 100	97±3	90±10	67±18	42±17	17±9	Max. 10

Table 3.5. Aggregate Grading (VDOT *Road and Bridge Specifications,* January 1994).

3.8 Characteristics of Ingredients

The concretes were obtained from different suppliers because the projects were at different locations. Therefore, the properties of the concrete ingredients shown in Tables 3.6 through 3.8 were slightly different for the three overlays. Tables 3.6, 3.7, and 3.8 summarize the material properties of the concrete ingredients. In general, a Type I/II cement was used with a siliceous natural fine aggregate and granite gneiss coarse aggregate. Moisture contents of the aggregates varied throughout the projects but were compensated for during batching. An air-entraining admixture was used in all concretes. A water reducer was used in the I-295 project, and a water reducer plus retarder was used in the other two projects.

The properties of the fibers used are summarized in Table 3.9. Steel fibers have a much higher elastic modulus than polypropylene or polyolefin fibers. The lengths of the fibers varied from 19 to 51 mm. Steel and polyolefin fibers had similar aspect ratios ranging from 40 to 60, and the polypropylene fibers had a much larger aspect ratio of 35,620.

The shape of the fibers also varied. The steel fibers had hooked ends. The hooked ends improve the post-crack energy-absorbing capacity of the FRC by improving the pullout resistance of the fibers. Two types of polypropylene fibers were used in the projects: monofilament and fibrillated fibers.

3.8.1 I-295

Material	Type	Source	Specific Gravity	Absorption	Fineness Modulus
Cement	Type II	Roanoke Cement Co.	3.15	---	---
Fly Ash	Class F	Monex Resources	2.93	---	---
CA	granite gneiss	Tarmac	2.64	0.6	---
FA	manufactured siliceous	Tarmac	2.57	0.5	2.80
Air entraining	Micro Air	Master Builders	---	---	---
Water Reducer	Pozzolith 220-N	Master Builders	---	---	---
Fiber	Polyolefin	3M	0.91	---	---
Fiber	Fibrillated Polypropylene	Fibermesh	0.91	---	---
Fiber	Hooked-end Steel 30/50	Bekeart	7.87	---	---

Table 3.6. Characteristics of ingredients used for I-295 overlay.

3.8.2 I-85

Material	Type	Source	Specific Gravity	Absorption	Fineness Modulus
Cement	Type II	Lehigh Cement Co.	3.15	---	---
Fly Ash	Class F	Ash Management	2.21	---	---
CA	granite gneiss	C&D Materials	2.74	0.6	---
FA	manufactured siliceous	Luck Stone Corp.	2.63	0.5	2.6
Air entraining	AEA 15	Sika	---	---	---
Water Reducer and Retarder	Plastiment	Sika	---	---	---
Superplasticizer	10ESL	Sika	---	---	---
Fiber	Monofilament Polypropylene	Sika	0.91	---	---
Fiber	Hooked-end Steel 30/50	Bekeart	7.87	---	---

Table 3.7. Characteristics of ingredients used for I-85 overlay.

3.8.3 Rte. 29

Material	Type	Source	Specific Gravity	Absorption	Fineness Modulus
Cement	Type II	Roanoke Cement Co.	3.15	---	---
Slag	granulated blast furnace	Blue Circle Atlantic	2.93	---	---
CA	granite gneiss	Martin Marietta	2.80	0.6	---
FA	manufactured siliceous	Tarmac	2.63	0.9	2.76
Air entraining	Daravair-1000	W.R. Grace	---	---	---
Water Reducer and Retarder	Daratard	W.R. Grace	---	---	---
Superplasticizer	WRDA-19	W.R. Grace	---	---	---
Fiber	Polyolefin	3M	0.91	---	---
Fiber	Fibrillated Polypropylene	Fibermesh	0.91	---	---
Fiber	Monofilament Polypropylene	W. R. Grace	0.91	---	---
Fiber	Hooked-end Steel 30/50	Bekeart	7.87	---	---

Table 3.8. Characteristics of ingredients used for I-29 overlay.

3.8.4 Fiber Characteristics

Fiber	Length (mm)	Diameter (mm)	Aspect Ratio (l/d)	Yield Strength (MPa)	Elastic Modulus (MPa)	Specific Gravity
Steel Fibers (30/50)	30	0.5	60	1170	200000	7.87
Polypropylene (fibrillated)	19	N/A	N/A	550-750	3450	0.91
Polypropylene (monofilament)	19	5.33E-4	35620	550-750	3450	0.91
Polyolefin	25	0.40/0.57*	51-77	275	2650	0.91
Polyolefin	51	0.66/1.0*	44-63	275	2650	0.91

*Fibers have elliptical cross section (diameter 1/diameter 2).

Table 3.9. Material properties of fibers used in Projects A and B.

3.9 Curing Method and Time

A white pigmented liquid membrane curing material was sprayed onto the surface of the concrete following the tining operation for each project. Traffic was placed on the overlays after 6 days of cure.

3.10 Bond Strength (VTM-92)

There was no standard specification for tensile bond strength.

3.11 Compressive Strength (ASTM C 39)

A minimum 28-day design compressive strength of 27.6 MPa (4000 psi) was required for the concretes used in this project. This is higher than the 20.7 MPa (3000 psi) required for regular paving concrete.

3.12 Grout

For each pavement overlay, the mortar fraction of the overlay concrete was broomed onto the base asphalt or HCC. The coarse aggregate fraction was discarded.

4. Results of Quality Assurance Testing

4.1 Overlay Construction Dates

Table 4.1 lists the construction dates for the three overlays.

Lane	I-295	I-85	Rte. 29
IL (passing)	6/7/95-6/8/95	6/13/95-6/14/95	7/20/95-7/21/95
ML	6/15/95	N/A	N/A
OL (travel)	6/26/95	6/23/95	7/6/95-7/7/95

Table 4.1. Placement dates for overlays.

4.2 Actual Mixture Proportioning

Tables 4.2, 4.3, and 4.4 show the actual mixture proportions for the three projects. All concrete was truck mixed in accordance with ASTM C 94.

4.2.1 I-295

Overlay Type	Control	PO-2	PO-1	FP	ST	
Fiber length, mm	--	51	25	19	32	32
Fiber amount, kg/m^3	--	15	12	1.8	29.7	44.5
Cement, kg/m^3	320	320	320	320	320	320
Fly Ash, kg/m^3	75	75	75	75	75	75
Coarse aggregate, kg/m^3	908	908	908	908	908	908
Fine aggregate, kg/m^3	745	728	728	728	728	728
Water, L/m^3	166	178	174	174-178	178	174
Air entraining, L/ m^3	0.21-0.23	0.15	0.15	0.15	0.15	0.15
Water Reducer, L/ m^3	0.51	0	1.81	0.0-0.33	0.0-3.1	0.77-3.9
Air, %	4.5-6.4	6.5	6.1-6.3	6.5-7.2	6.3-7.1	5.9-6.3
Slump, mm	34-114	64	51-121	38-95	76-108	44-102
w/cm	0.42	0.45	0.44	0.44-0.45	0.45	0.44

Table 4.2. Actual mix proportioning for the I-295 installation.

4.2.2 I-85

Overlay Type	Control	MP-1		ST	
Fiber length, mm	--	19	19	32	32
Fiber amount, kg/m^3	---	0.9	3	29.7	44.5
Cement, kg/m^3	344	344	344	344	344
Fly Ash, kg/m^3	81	81	81	81	81
Coarse aggregate, kg/m^3	893-1084	1078 -1084	1078-1084	1078-1084	1078-1084
Fine aggregate, kg/m^3	627-847	627-637	627-637	627-637	627-637
Water, L/m^3	137.6-148	141-148	141-144	176-179	171-179
Air entraining, L/ m^3	0.14-.35	0.14-0.31	0.14-0.31	0.14-0.31	0.14-0.31
WR + R, L/ m^3	0.55-0.88	0.69-0.88	0.69-0.88	0.69-0.88	0.69-0.88
Air, %	4.2-7.5	5.4-6.9	4.2-7.3	4.8-7.3	5.4-7.5
Slump, mm	32-83	51-83	44-76	44-76	51-76
w/cm	0.40-0.43	0.41-0.43	0.41 -0.42	0.41-0.42	0.41-0.42

Note: WR + R = Water-reducing and retarding admixture

Table 4.3. Actual mix proportioning for the I-85 installation.

4.2.3 Rte. 29

Overlay Type	Control, 51 mm	Control, 102 mm	PO-1	MP-2	ST	
Fiber length, mm	--	--	25	19	32	32
Fiber amount, kg/m^3	--	--	12	3	29.7	44.5
Cement, kg/m^3	251	226	251	251	251	251
Slag, kg/m^3	167	151	167	167	167	167
Coarse aggregate, kg/m^3	922	1051	922	922	922	922
Fine aggregate, kg/m^3	752	745-758	752	752	752	752
Water, L/m^3	167-192	143-181	180	180-184	176-179	171-179
Air entraining, L/ m^3	0.3	0.3	0.48	0.44-0.48	0.48	0.48
WR + R, L/ m^3	0.77-1.08	0.77-0.97	0.85-1.08	0.85-1.08	0.85-1.08	0.85-1.08
Air, %	4.3-8.0	4.0-6.0	5.6-7.4	6.6-6.8	5.6-10.3	4.4-6.0
Slump, mm	44-95	44-83	44	38.1-44	83-114.3	51-76.2
W/cm	0.40-0.46	0.38-0.48	0.43	0.43-0.44	0.42-0.43	0.41-0.43

Note: WR + R = Water reducing and retarding admixture

Table 4.4. Actual mix proportioning for Rte. 29 installation.

4.3 Aggregate Moisture Content

The fine and coarse aggregate moisture contents are shown in Table 4.5. Aggregates had surface moisture except for the coarse aggregate used in the concrete on I-295, which was completely dry.

Aggregate Type	I-295			I-85		Rte.29	
	IL	ML	OL	IL	OL	IL	OL
Coarse aggregate	0	0	0	1.1-1.6	1.0-1.3	0.3-1.0	0.5-1.8
Fine aggregate	4.0-8.0	4.0-7.0	5.0-7.0	6.6-8.3	5.0	5.6-6.2	3.7-5.0

Table 4.5. Moisture content of coarse and fine aggregate.

4.4 Comparison of Actual Mix Properties to Design Specifications

In most cases, the actual mix proportions and properties corresponded well to the design specifications. Deviations from the design did occur for the water-cementitious material ratio (w/cm), fine aggregate content, and coarse aggregate content in the three projects. These deviations were small and in compliance with VDOT specifications and are not expected to adversely affect the quality of the concrete.

4.5 Summary of Placement Conditions

The placement conditions for the three overlays are shown in Table 4.6. For the placement of overlays on bridges special precautions should be taken when the evaporation rate exceeds 0.25 $kg/m^2/h$ (VDOT Widening, Repairing and Reconstructing Existing Structures, Section 412.03). The evaporation rate for each placement day was taken from a nomograph. All rates were less than the recommended maximum value.

Road	Lane	Date	Climatic Conditions	Rate of Evaporation $kg/m^2/h$	Concrete Temp °C	Air °C	Relative Humidity %	Avg. Gusts km/h
I295	IL	6/7/95	Day, hot	0.10	23-27	24-36	66-75	< 0.25
		6/8/95	Day, hot	0.10	23-28	29-38	67-77	< 0.25
	ML	6/15/95	Day, cool	0.05	20-27	20-29	70-78	< 0.25
	OL	6/26/95	Day, hot	0.05	23-39	23-36	64-76	< 0.25
I85	IL	6/13/95	Day, cool	0.05	23-27	20-27	74-86	< 0.25
		6/14/95	Morning, cool	0.10	23-25	16-25	74-91	< 0.25
	OL	6/23/95	Day	0.07	26-32	23-32	65-93	< 0.25
29S	OL	7/6/95	Day, hot	0.10	28-32	24-36	65-93	< 0.25
		7/7/95	Day, hot, rain (10 min)	0.10	28-32	20-38	63-96	< 0.25
	IL	7/20/95	Morning	0.10	27-29	24-33	67-71	< 0.25
		7/21/95	Morning, humid	0.07	28-32	23-36	72-100	< 0.25

Table 4.6. Placement conditions during overlay placement.

4.6 Thermal Coefficients of Deck and Overlay Concrete

Results of the thermal coefficient of expansion (TCOE) test on saturated and dry concretes are shown in Figures 4.1, 4.2, and 4.3. These tests indicate the volumetric changes attributable to temperature change in concretes free to move.

TCOEs for all concretes were within the normal range of 0.11 to 0.16 mm/mm per deg C x 10^{-6}. The addition of fibers to the concrete caused little change in thermal expansion, but the thermal expansion in the concretes on I-85 was lower than that of the concrete on I-295 and Rte. 29. This can be explained by the variation in material properties of the cement and coarse and fine aggregates.

Assuming a thermal coefficient for the base concrete on I-295 and I-85 of 10.3 x 10^{-6} mm/mm per deg C x 10^{-6} and a modulus of elasticity for the concretes of 28.9 GPa theoretical shear stresses at the bond interface for a 40°C temperature change would range from a low of 0 for sections of I-85 to a high of 1.8 MPa (268 psi) on I-295.[1] These low stress levels suggest that thermal stress should not cause delaminations of the overlays.

4.6.1 I-295

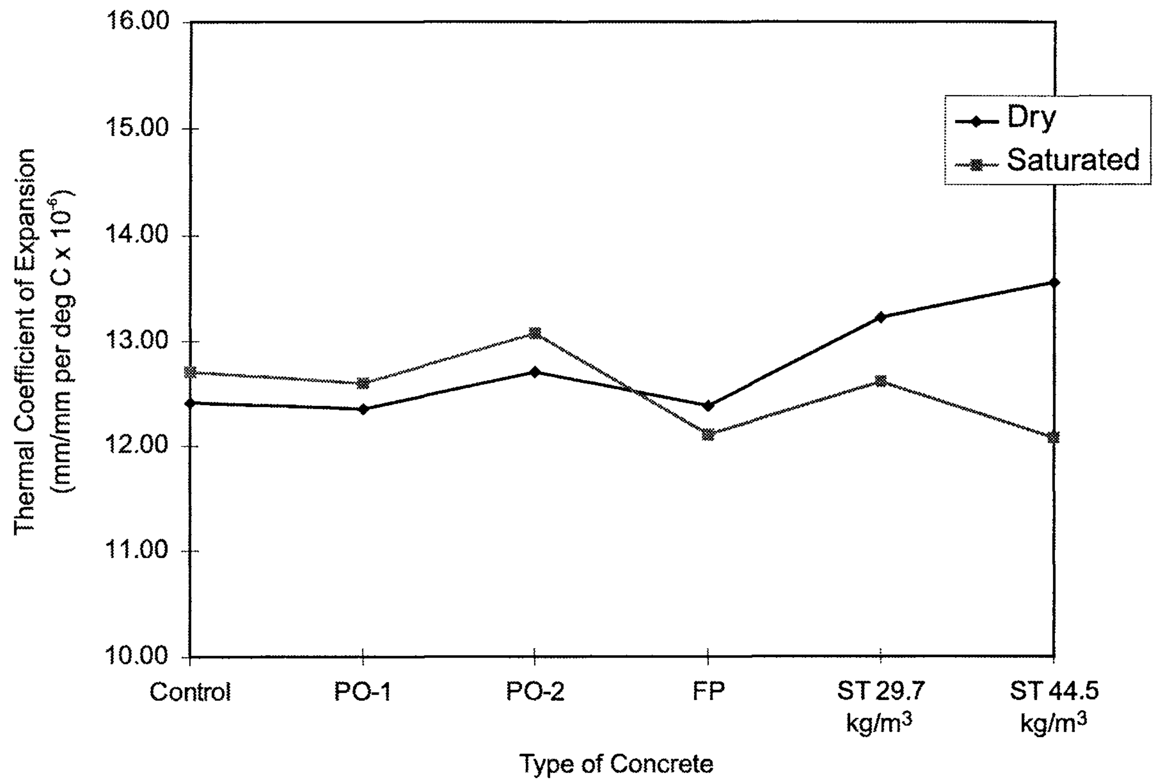

Figure 4.1. Saturated and dry thermal coefficient of expansion versus type of concrete placed on I-295.

4.6.2 I-85

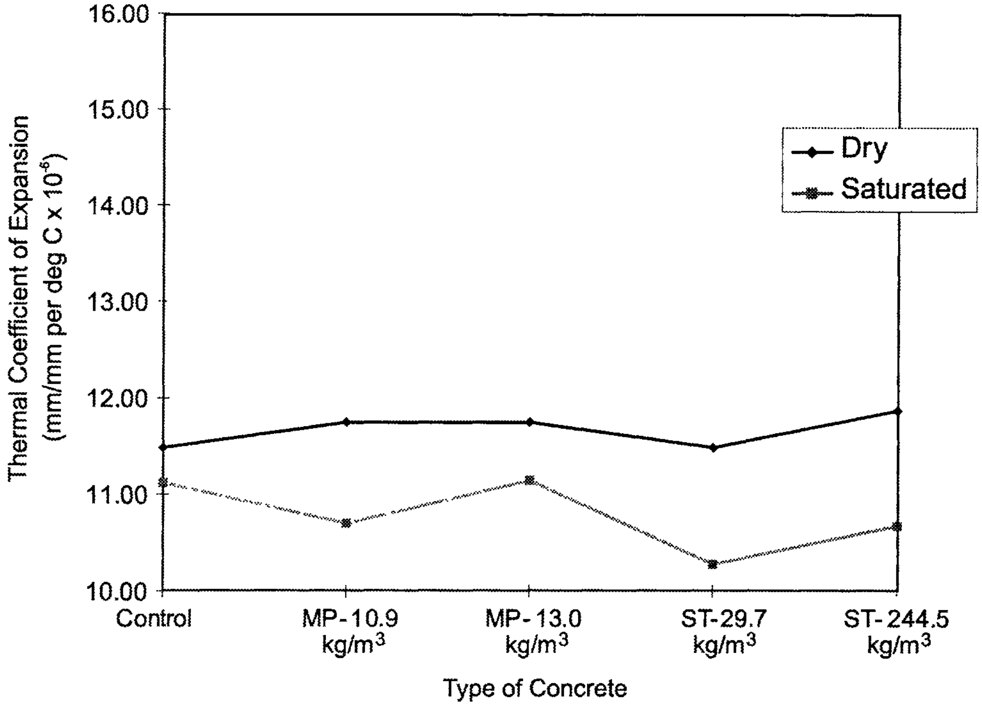

Figure 4.2. Saturated and dry TCOE versus type of overlay concrete placed on I-85.

4.6.3 Rte. 29

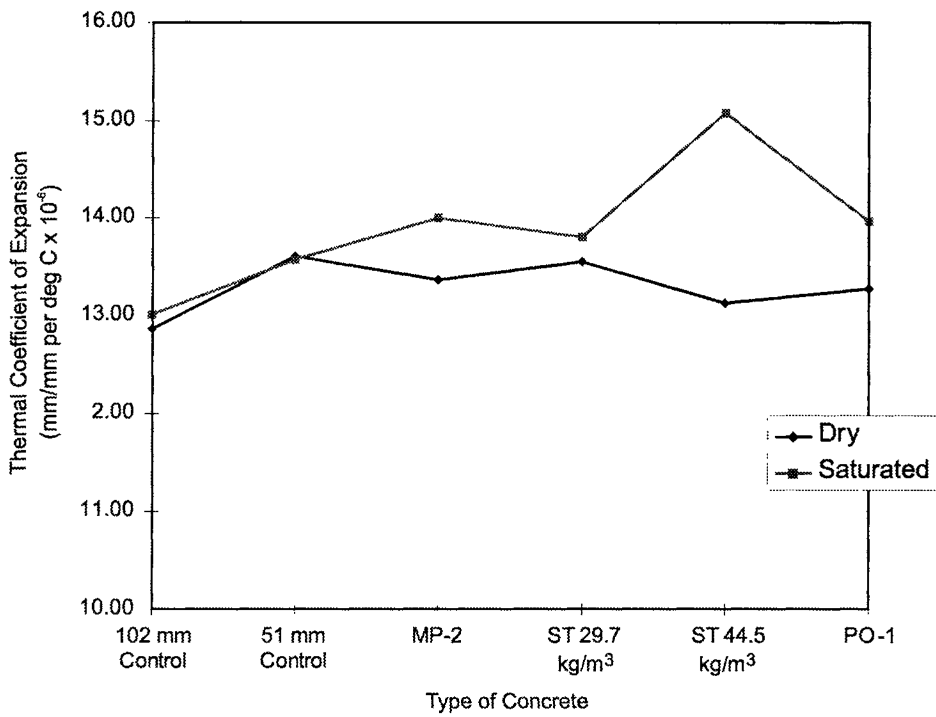

Figure 4.3. Saturated and dry TCOE versus type of overlay concrete placed on Rte. 29.

4.7 Drying Shrinkage of Overlay Concrete

Results of the shrinkage tests are shown in Figures 4.4, 4.5, and 4.6. In all projects, concrete shrinkage had normal trends and magnitudes. The highest shrinkage on I-295 occurred in the concrete with the 51-mm-long polyolefin FRC, and the lowest shrinkage occurred in the control concrete. The highest shrinkage on I-85 occurred in the concrete with the smaller dosage of polypropylene FRC, and the lowest shrinkage occurred in the concrete with the larger dosage of polypropylene FRC. The highest shrinkage on Rte. 29 occurred in the concrete with the 25-mm-long polyolefin fibers and the polypropylene fibers, and the lowest shrinkage occurred in the concrete with the 102-mm-thick control concrete. Variations in water content between batches of concrete in different projects contributed to the variations in drying shrinkage.

4.7.1 I-295

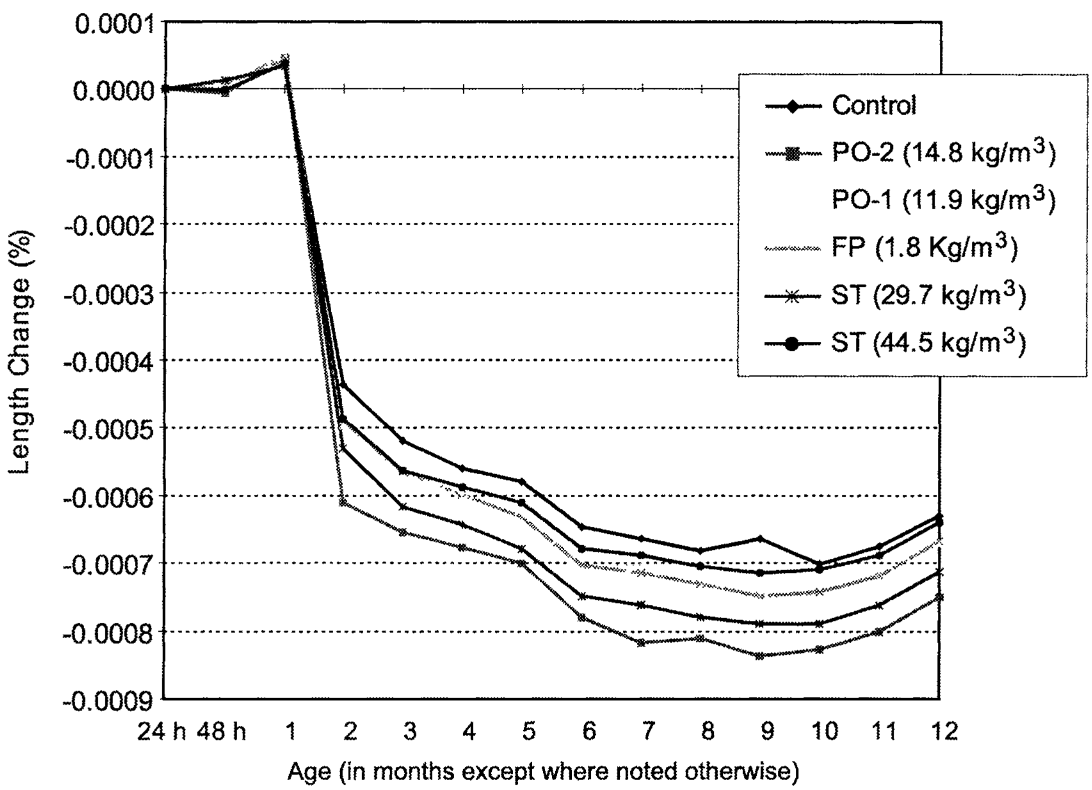

Figure 4.4. Drying shrinkage versus age for overlay concrete placed on I-295.

4.7.2 I-85

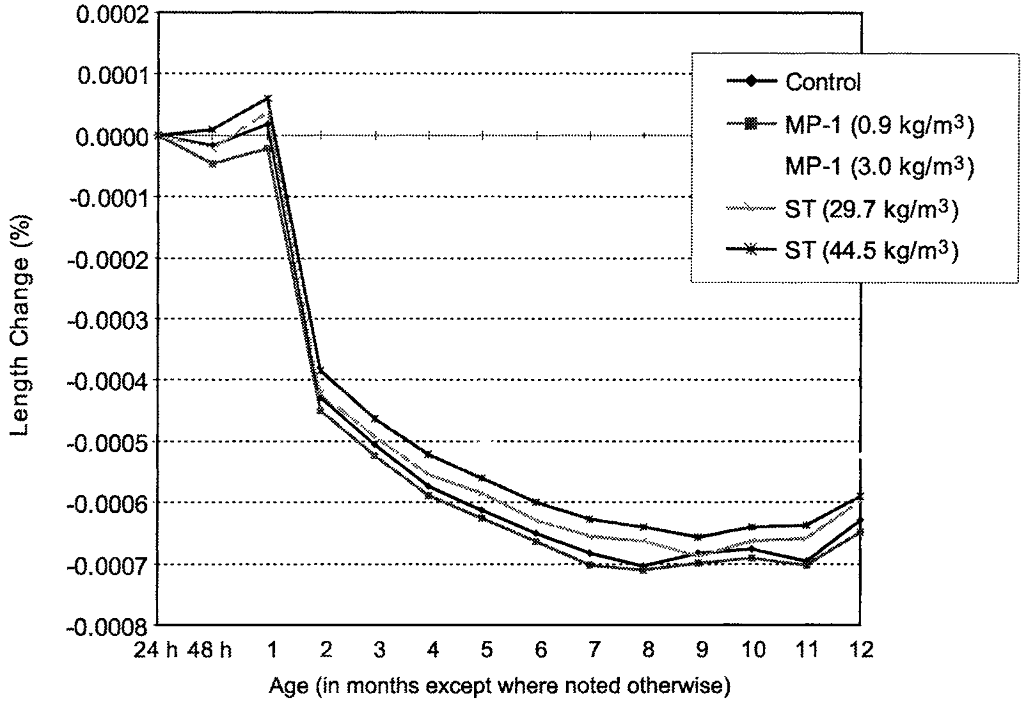

Figure 4.5. Drying shrinkage versus age for overlay concrete placed on I-85.

4.7.3 Rte. 29

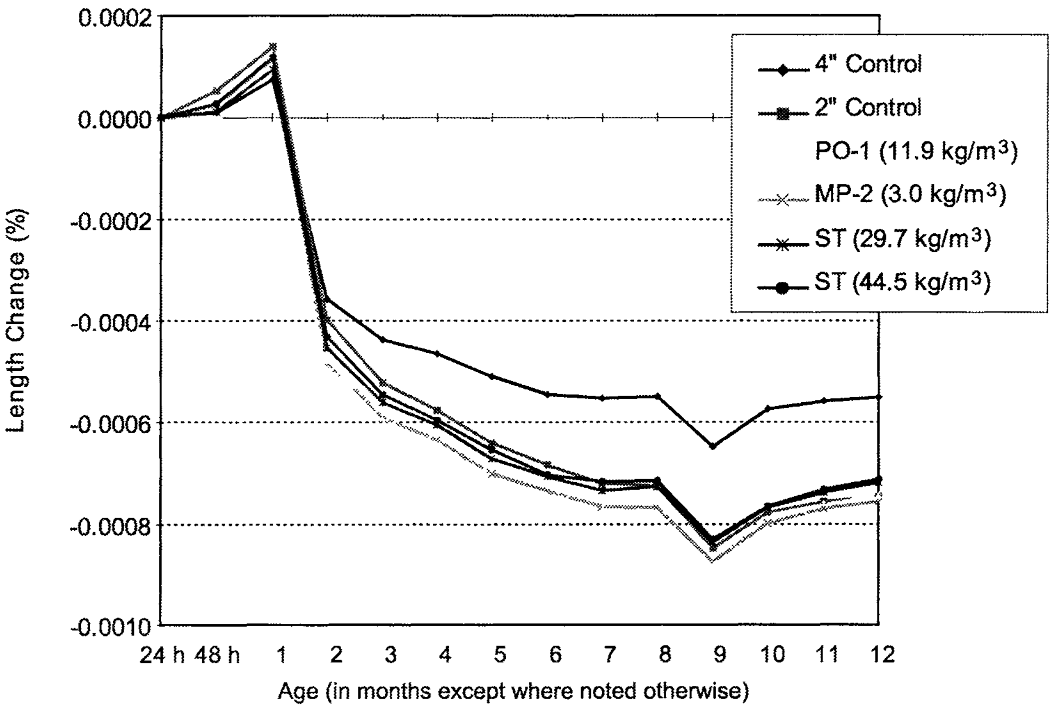

Figure 4.6. Drying shrinkage versus age for overlay concrete placed on Rte. 29.

4.8 Compressive Strength

The 24-hour compressive strengths (Tables 4.7, 4.8, and 4.9) are similar for all projects. At 28 days, the values were about 30 MPa and higher, and at 1 year, the values exceeded 40 MPa. Compressive strengths in these projects were much higher than those of conventional paving concrete where the minimum 28-day design compressive strength is 21 MPa. At 6 days to 1 year, the slag concrete used in the Rte. 29 project had compressive strengths 5 to 10 MPa higher than that of the fly ash concretes of I-295 and I-85.

4.8.1 I-295

Fiber Type	Amount kg/m^3	Time after Placement	Compressive Strength (MPa)
Control (51 mm)	0	24 hours	11.9
		6 days	22.5
		28 days	30.5
		1 year	40.1
PO-1	11.9	24 hours	10.9
		6 days	21.6
		28 days	29.3
		1 year	39.0
PO-2	14.8	24 hours	8.5
		6 days	15.2
		28 days	21.7
		1 year	30.2
FP	1.8	24 hours	12.2
		6 days	22.5
		28 days	29.5
		1 year	38.5
ST	29.7	24 hours	10.9
		6 days	22.5
		28 days	29.8
		1 year	41.7
ST	44.5	24 hours	11.2
		6 days	24.1
		28 days	32.0
		1 year	45.0

Table 4.7. Compressive strength of overlay concrete with fly ash placed on I-295.

4.8.2 I-85

Fiber Type	Amount kg/m^3	Time after Placement	Compressive Strength (MPa)
Control (102 mm)	0	24 hours	9.4
		6 days	18.7
		28 days	28.6
		1 year	43.9
MP-1	0.9	24 hours	11.5
		6 days	23.8
		28 days	33.5
		1 year	49.9
MP-1	3	24 hours	13.4
		6 days	26.9
		28 days	38.3
		1 year	57.5
ST	29.7	24 hours	8.3
		6 days	19.7
		28 days	32.3
		1 year	47.4
ST	44.5	24 hours	9.6
		6 days	20.8
		28 days	32.4
		1 year	52.1

Table 4.8. Compressive strength of overlay concrete with fly ash placed on I-85.

4.8.3 Rte. 29

Fiber Type	Amount kg/m^3	Time after Placement	Compressive Strength (MPa)
Control (51 mm)	0	24 hours	9.1
		6 days	25.5
		28 days	40.3
		1 year	49.3
Control (102 mm)	0	24 hours	9.9
		6 days	27.5
		28 days	41.9
		1 year	51.3
PO-1	11.9	24 hours	9.3
		6 days	27.5
		28 days	38.2
		1 year	46.9
MP-2	3	24 hours	6.9
		6 days	22.5
		28 days	36.3
		1 year	45.7
ST	29.7	24 hours	9.0
		6 days	25.3
		28 days	40.0
		1 year	49.1
ST	44.5	24 hours	10.4
		6 days	26.8
		28 days	41.2
		1 year	53.0

Table 4.9. Compressive strength of overlay concrete with slag placed on Rte. 29.

4.9 Impact Test Results

At 28 days, the impact resistance of the concretes was determined by the drop weight test as an average of five specimens from each batch. All testing was performed using an automated impact testing machine manufactured by 3M in Minneapolis, Minnesota, in accordance with ACI 544.2R. The levels of distress investigated were first crack and ultimate failure. Ultimate failure is defined as the opening of cracks in the specimen to a point at which pieces of concrete are touching three of the four positioning lugs on the base plate. The results of the impact tests are given in Table 4.10.

The results indicate that the number of blows to first crack and ultimate failure increases with increasing fiber volume and length. This effect is more pronounced in the FRC with polyolefin and steel fibers. Both fibrillated and monofilament polypropylene FRC had low impact resistance compared to steel and polyolefin FRC. The highest impact endurance was obtained in the 51-mm-long polyolefin FRC used in the I-295 project.

Job	Fiber Type	Amount kg/m^3	First Crack	Failure
I-295	Control	0	17	23
	PO-1	11.9	15	59
	PO-2	14.8	10	88
	FP	1.8	17	30
	ST	29.7	18	54
	ST	44.5	25	67
I-85	Control	0	9	15
	MP-1	0.9	8	17
	MP-1	3	24	35
	ST	29.7	18	50
	ST	44.5	32	72
Rt-29	4" Control	0	50	55
	2" Control	0	36	45
	PO-1	11.9	50	173
	MP-2	3	24	34
	ST	29.7	64	117
	ST	44.5	58	100

Table 4.10. Impact test results from overlay concrete.

4.10 Flexural Toughness Results

The flexural strength and toughness results are given in Tables 4.11, 4.12, and 4.13. The first crack strength and toughness values were determined in accordance with ASTM C 1018. To eliminate the effects of settlement of the supports and crushing at the load points, a Japanese yoke was used. Loads were applied with a closed loop, servo-controlled universal testing machine. The first crack strength, toughness parameters, and toughness results using the Japanese Standard Method SF-4 are given as an average of four beams. *Toughness* is defined as a measure of the concrete's ability to absorb energy during fracture. Toughness is measured by a series of indices that are determined from the area under the load-deflection curve. The indices are computed by dividing the total area under the load-deflection curve up to a specific deflection by the area under the curve up to first crack. Toughness indices I_5, I_{10}, and I_{20} are calculated at 3, 5.5, and 10.5 times the first crack deflection, respectively. In Japanese Standard SF-4, *toughness* is defined as the area under the load-deflection curve up to a deflection of span/150 or 2 mm for a span length of 300 mm.

The first crack strength of the plain concrete was 3.65 MPa in the I-295 project, 3.76 MPa in the I-85 project, and 4.94 MPa in the Rte. 29 project. Results from the I-295 project showed decreases in first crack strength over the control with the addition of fibers. In the I-85 samples, increases over the control in first crack strength were obtained. In the Rte. 29 samples, decreases in first crack strength in all fiber types except steel were determined. In general, the changes in first crack strengths were small and it is established that at these fiber additions, changes in first crack strength are not expected.

Beyond first crack, FRCs do not lose their load-carrying capability but instead transfer the load to the fibers spanning the cracked region. In general, steel fibers provided the highest toughness values, followed closely by polyolefin fibers and then polypropylene fibers. In addition to the toughness indices, ASTM C 1018 requires residual strength factors to be reported. ASTM C 1018 states that the residual strength factors characterize the level of strength retained after first crack by expressing the average post-crack load over a specific deflection interval as a percentage of the load at first crack. Thus, $R_{5,10}$ is the average percentage of first crack strength over the interval from 3 to 5.5 times the first crack deflection. Since plain concrete fails at first crack, it has no residual strength. The highest residual strength values were obtained with steel fibers, followed by polyolefin fibers and then polypropylene fibers.

Toughness indices and residual strength factors are both highly dependent on the first crack strength. If first crack strengths vary greatly, comparison between the indices and strength factors becomes difficult or invalid. The concretes tested in this investigation had first crack strengths close to each other, with the majority of results within a 15 percent variation of the control and none greater than 25 percent.

The flexural toughness, residual strength factors, and Japanese toughness were calculated by an Excel spreadsheet specifically created for this study. The spreadsheet senses any drop in load signifying first crack and then calculates the area under the curve using numerical integration.

4.10.1 I-295

Fiber Type	Amount kg/m^3	First Crack MPa	I5	I10	I20	R5,10	R10,20	Japan.
Control (51 mm)	0	3.76	1	1	1	0	0	------
PO-1	11.9	3.41	3.97	7.19	13.38	64.5	61.8	116
PO-2	14.8	3.27	4.42	7.68	14.05	65.1	63.5	57
FP	1.8	3.55	2.91	4.79	7.69	37.6	29.1	55
ST	29.7	3.64	4.29	7.82	15.09	70.7	72.7	157
ST	44.5	4.02	4.77	9.37	18.88	91.9	95.1	193

Table 4.11. Flexural toughness results from overlay concrete placed on I-295.

4.10.2 I-85

Fiber Type	Amount kg/m^3	First Crack MPa	I5	I10	I20	R5,10	R10,20	Japan.
Control (102 mm)		3.65	1	1	1	0	0	------
MP-1	0.9	4.05	1.61	2.26	3.54	12.9	12.8	20
MP-1	3.0	4.53	2.36	3.64	5.84	25.4	21.7	39
ST	29.7	3.87	3.62	6.63	12.2	60.2	55.8	128
ST	44.5	4.34	4.23	7.85	14.96	72.3	71.1	182

Table 4.12. Flexural toughness results from overlay concrete placed on I-85.

4.10.3 Rte. 29

Fiber Type	Amount kg/m^3	First Crack MPa	I5	I10	I20	R5,10	R10,20	Japan.
Control (2")		4.94	1	1	1	0	0	------
Control (4")		4.67	1	1	1	0	0	------
PO-1	11.9	4.86	3.38	6.14	11.64	55.2	56.1	160
MP-2	3.0	4.83	1.65	2.45	3.88	16.1	14.4	35
ST	29.7	5.12	3.44	6.37	12.31	58.5	59.4	186
ST	44.5	5.50	3.99	7.66	15.72	73.5	80.6	262

Table 4.13. Flexural toughness results from overlay concrete placed on Rte. 29.

4.11 Shear Bond Strength

Shear bond specimens were prepared by placing a 51-mm-thick slice of a 102-mm-diameter cylinder of hardened concrete in the bottom of a 102-mm-diameter mold and placing a 51-mm-thick overlay on the sawn surface of the base concrete. The cured specimens were placed in a guillotine shear jig, and the overlays sheared from the base concrete to provide a shear bond strength value. The location of the failure plane was determined. The failure could happen in the base concrete, bonded surface, or the overlay. The shear bond strengths are provided in Tables 4.14, 4.15, and 4.16.

Shear bond strengths were satisfactory in all projects and typical of well-bonded overlays. On I-295, the 51-mm-long polyolefin FRC had the lowest shear bond strength. All FRCs on I-85 had shear bond strengths similar to the control concrete. The Rte. 29 project had lower shear bond values because of the relative weakness of the concrete-asphalt interface as compared to a concrete-concrete interface.

4.11.1 I-295

Fiber Type	Amount kg/m^3	Time after Placement	Avg. Bond Strength (kPa)	Overlay Failure Area (%)		
				Base	Bond	Overlay
Control (51 mm)	0	6 days	3210	8	88	4
		28 days	4170	19	65	16
		1 year	5960	18	68	14
PO-1	11.9	6 days	3340	21	76	3
		28 days	4070	35	64	1
		1 year	5210	38	46	16
PO-2	14.8	6 days	2280	3	97	0
		28 days	4070	18	82	0
		1 year	4070	75	22	3
FP	1.8	6 days	3240	12	88	0
		28 days	4520	15	81	4
		1 year	5270	33	52	15
ST	29.7	6 days	3520	22	77	1
		28 days	4520	37	61	2
		1 year	5790	42	41	17
ST	44.5	6 days	3450	13	86	1
		28 days	4450	18	73	9
		1 year	6340	33	58	9

Table 4.14. Shear bond test results from overlay concrete placed on I-295.

4.11.2 I-85

Fiber Type	Amount kg/m³	Time after Placement	Avg. Bond Strength (kPa)	Overlay Failure Area (%) Base	Bond	Overlay
Control (102 mm)	0	6 days	2380	5	95	0
		28 days	3450	6	90	4
		1 year	4720	11	84	5
MP-1	0.9	6 days	2380	3	97	0
		28 days	3690	10	89	1
		1 year	5760	23	67	10
MP-1	3	6 days	4550	12	85	3
		28 days	4550	16	74	10
		1 year	5790	24	61	15
ST	29.7	6 days	2930	14	86	0
		28 days	5030	18	82	0
		1 year	6030	19	61	20
ST	44.5	6 days	3000	34	66	0
		28 days	4790	24	70	6
		1 year	5900	18	62	20

Table 4.15. Shear bond test results from overlay concrete placed on I-85.

4.11.3 Rte. 29

Fiber Type	Amount kg/m³	Time after Placement	Avg. Bond Strength (kPa)	Overlay Failure Area (%) Base	Bond	Overlay
Control (2")	0	6 days	1720	5	95	0
		28 days	1070	0	95	5
		1 year	2070	1	87	12
Control (4")	0	6 days	1520	3	94	3
		28 days	1520	1	90	9
		1 year	2930	7	84	9
PO-1	11.9	6 days	1340	1	99	0
		28 days	1930	4	87	9
		1 year	2790	6	86	8
MP-2	3	6 days	1410	1	99	0
		28 days	2000	5	90	5
		1 year	2340	5	79	16
ST	29.7	6 days	1550	4	96	0
		28 days	1340	1	93	6
		1 year	1410	1	68	31
ST	44.5	6 days	1450	3	96	1
		28 days	1650	0	95	5
		1 year	2210	1	88	11

Table 4.16. Shear bond test results from overlay concrete placed on Rte. 29.

4.12 Permeability to Chloride Ion (AASHTO T277)

The results of the permeability tests are given in Table 4.17. This test measures the amount of electrical charge that passes through a concrete sample during a 6-hour period. Steel FRC was not tested for permeability because of the significant increase in conductivity of the concrete by the metal. At 28 days, the FRCs from all the overlays had high permeability values. However, at 1 year, the permeability values of all concretes containing either class F fly ash or slag were low to very low. This demonstrates the effectiveness of pozzolan or slag in reducing permeability of concretes. In conventional paving concretes without a pozzolan or slag at 28 days, high permeability values are expected, which reduce to a moderate range with time.

Job	Fiber Type	Amount	Permeability (Coulombs)		
		(kg/m^3)	28 Day	3 Months	12 Months
I-295	None	0	6151	2643	1082
	PO-1	11.9	7465	3258	1515
	PO-2	14.8	9822	3984	1368
	FP	1.8	7126	3435	1899
I-85	None	0	5017	3736	954
	MP-1	0.9	6566	2840	1007
	MP-1	3.0	4544	1820	594
Rt-29	None (102 mm)	0	1776	1204	1027
	None (51 mm)	0	2820	1590	1407
	PO-1	11.9	3408	1732	1394
	MP-2	3.0	4219	2181	1358

Note : Steel fiber specimens not tested for rapid permeability.

Table 4.17. Permeability of specimens made from overlay concrete.

4.13 Resistance to Freezing and Thawing (ASTM C 666)

Freezing and thawing test results are shown in Table 4.18. The results indicated acceptable resistance to cycles of freezing and thawing for all specimens. VDOT specifies that for satisfactory resistance to freezing and thawing, there must be less than 7 percent weight loss at 300 cycles, greater than a 60 durability, and a surface scaling rating of less than 3. In general, concretes had better resistance to freezing and thawing on I-295 and I-85 than on Rte. 29, with the fiber amounts and types having a minimal effect on the results. Highest scaling was in the Rte. 29 slag concretes with the small maximum size aggregate.

Job	Fiber Type	Amount (kg/m^3)	Weight Loss (%)	Durability Level	Surface Scaling
I-295	None	0	1.56	103	1.16
	PO-1	11.9	2.74	106	1.13
	PO-2	14.8	1.59	107	1.55
	FP	1.8	0.49	104	0.80
	ST	29.7	0.38	108	0.70
	ST	44.5	0.35	108	0.70
I-85	None	0	0.72	112	1.00
	MP-1	0.9	0.64	112	0.75
	MP-1	3.0	0.26	110	0.60
	ST	29.7	0.77	111	0.72
	ST	44.5	0.49	111	0.68
Rt-29	None (102 mm)	0	1.5	111	1.2
	None (51 mm)	0	3.1	104	2.1
	PO-1	11.9	2.7	104	1.8
	MP-2	3.0	1.4	102	1.1
	ST	29.7	2.2	106	1.6
	ST	44.5	6.2	88	2.3

Note: All values for condition after 300 cycles.

Table 4.18. Freeze-thaw resistance of overlay concrete.

5. Evaluation of Conditions after Installation

5.1 Location of Delaminations

No delaminations were found based on a chain drag of the overlays approximately 1 month after they were constructed.

5.2 Falling Weight Deflectometer

The stiffness of the pavements was determined by a falling weight deflectometer (FWD) before and after the placement of the overlays. An FWD imparts a series of impact loads transversely across a lane of pavement at 300-mm longitudinal intervals and measures the deflection at each impact point. An average deflection is obtained for each 300-mm interval, and the composite stiffness at each interval is then calculated from pavement deflection equations. The composite stiffness of the pavements for the projects is provided in Figures 5.1, 5.2, and 5.3. Stiffness of the pavement was improved with the placement of an overlay in all projects. However, the overall stiffness of the Rte. 29 pavement with asphalt and concrete was low because of the presence of the asphalt layer.

5.2.1 I-295

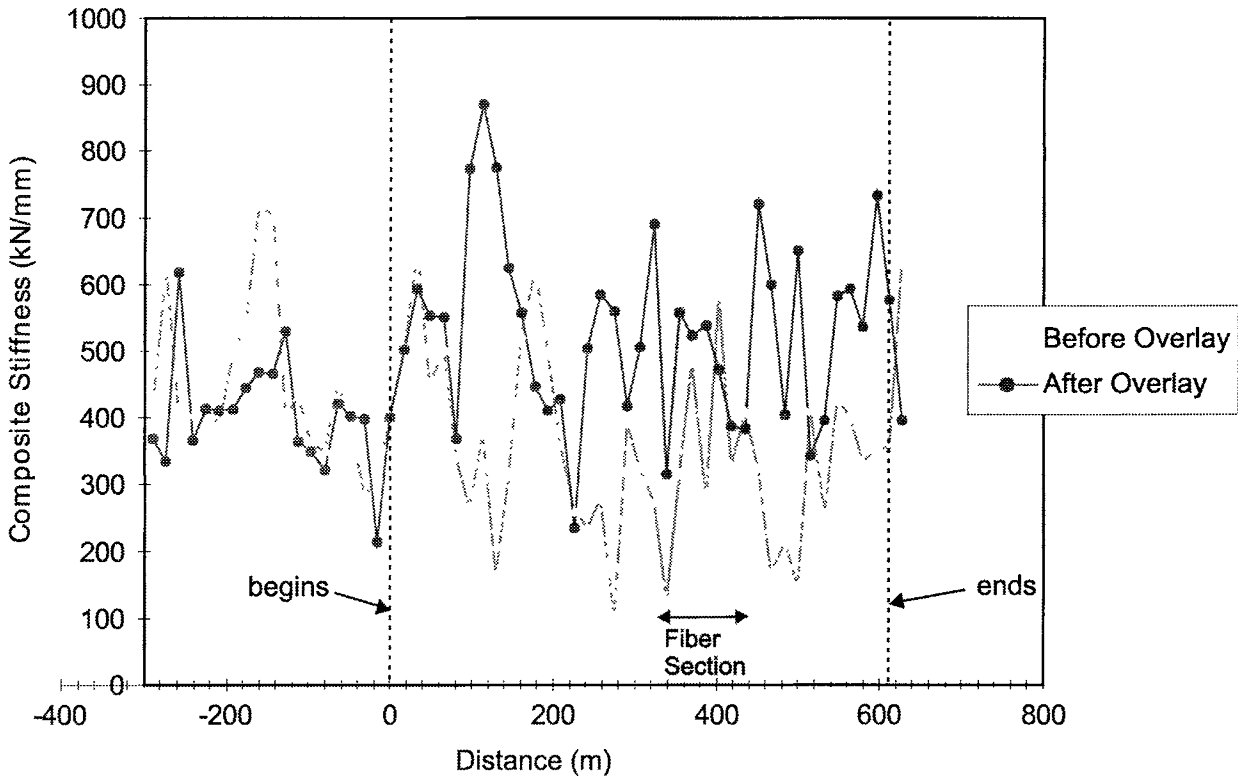

Figure 5.1. FWD data before and after placement of overlay on I-295 outside lane.

5.2.2 I-85

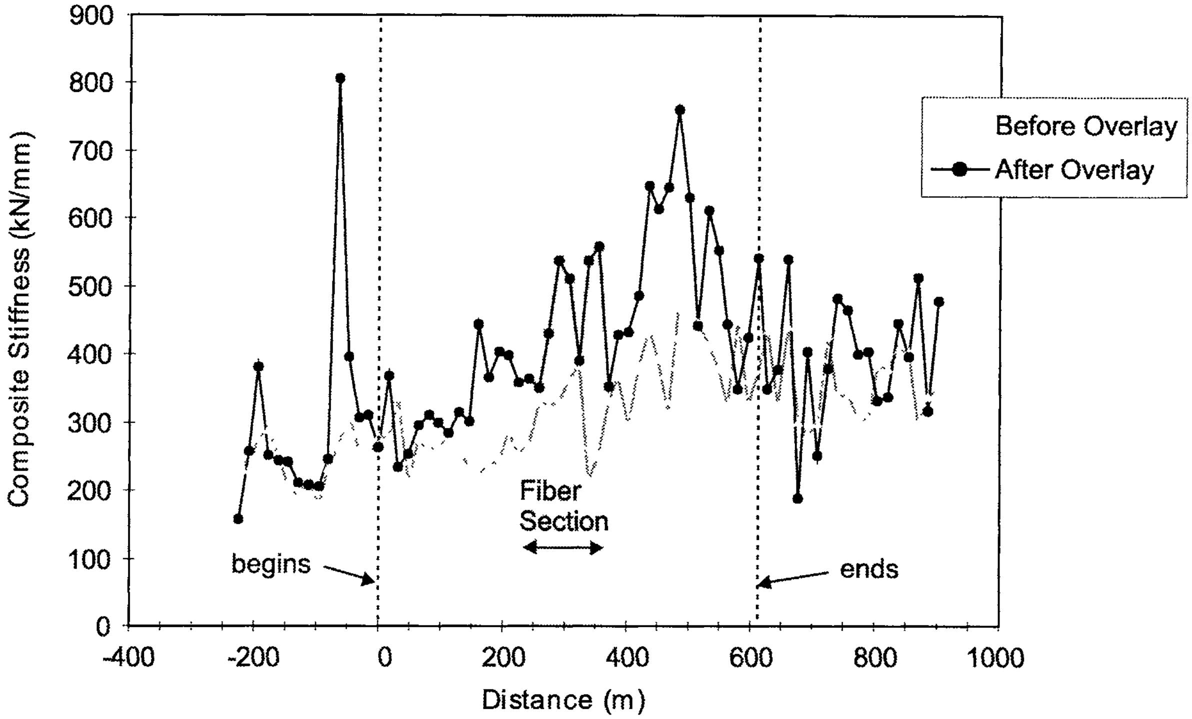

Figure 5.2. FWD data before and after placement of overlay on I-85 outside lane.

5.2.3 Rte. 29

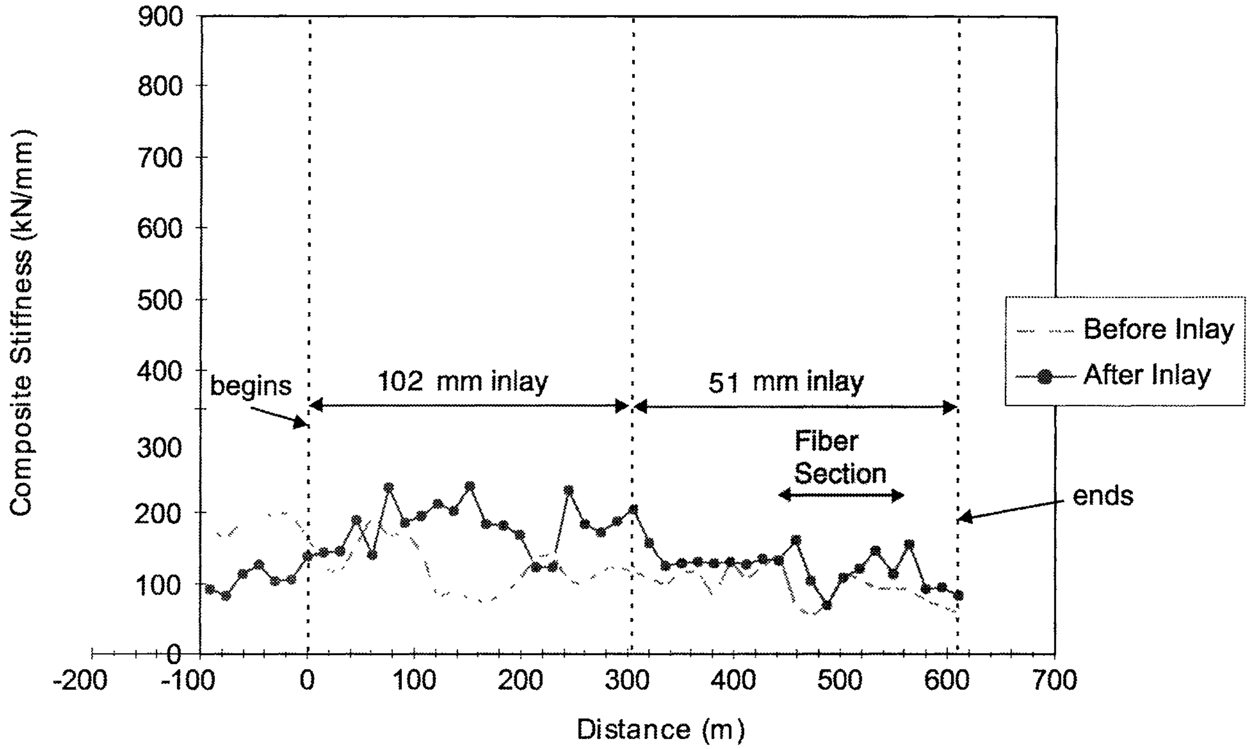

Figure 5.3. FWD data before and after placement of overlay on Rte. 29.

5.3 Skid Tests

The bald tire skid numbers at 3 months are provided in Table 5.1. This test uses a skid trailer that travels at a constant speed. VDOT considers skid numbers to be satisfactory when they are above 40, and values for all projects were above 40. Placement of the I-85 overlay led to large improvements in skid numbers as shown in Table 5.1; the road previously had skid numbers in the 20 to 40 range. I-295 had high skid numbers prior to placement of the overlay, and the high numbers were maintained with the placement of the overlay. The overlay on Rte. 29 had higher numbers than the 20 to 40s that are typical for asphalt.

Job	Lane	Before Test Section	Test Section	After Test Section
I-295	IL	58.0	48.6	50.9
	ML	52.2	48.4	45.6
	OL	51.6	53.2	48.6
I-85	IL	34.7	53.7	40.6
	OL	22.3	48.4	28.6
Rte. 29	IL	---	52.4	---
	OL	---	42.4	---

Note: Bald tire test was used for all lanes.

Table 5.1. Skid test results from overlay placements.

5.4 Tensile Adhesion Test Results

Three cores, 57 mm in diameter and 102 to 152 mm long, were taken from each overlay test section approximately 1 month after the overlay was placed. The cores were saw-cut parallel, 25 mm above and below the bond line, and metal caps were epoxied onto the sawn surfaces. The specimens were pulled in direct tension to provide an indication of tensile bond strength and failure mode. The tensile bond strengths are given in Table 5.2.

The results for tensile bond strength are excellent for I-295 and I-85 and similar to those obtained in the shear bond strength test.[2,3] The lower values for Rte. 29 are caused by the lower strength of the asphalt base relative to the concrete bases. Failures are predominately in the base on all three pavements, indicating that surface preparation prior to placement of the overlays was excellent.

Job	Fiber Type	Amount kg/m³	Overlay Thickness (cm)	Bond Strength (kPa)	Failure Area (%) Overlay	Bond	Base
I-295	Control (51 mm)	0	6.05	1731	19	2	79
	PO-1	11.9	5.95	2162	88	2	10
	PO-2	14.8	5.72	1029	7	5	88
	FP	1.8	5.83	1765	50	1	49
	ST	29.7	5.81	2017	60	2	38
	ST	44.5	5.69	1834	39	1	60
I-85	Control (102 mm)	0	10.48	1646	0	0	100
	MP-1	0.9	10.68	1573	17	0	83
	MP-1	3	10.99	1909	17	0	83
	ST	29.7	10.72	1479	0	0	100
	ST	44.5	10.68	1847	0	0	100
Rte. 29	Control (51 mm)	0	6.03	794	15	0	85
	Control (102 mm)	0	10.24	744	13	5	82
	PO-1	11.9	5.89	657	28	40	32
	MP-2	3	5.79	798	13	15	72
	ST	29.7	5.77	815	14	25	61
	ST	44.5	5.72	531	20	36	44

Table 5.2. Tensile adhesion test results from overlay placements.

5.5 Permeability Test Results

Cores 102 mm in diameter were taken through the overlays approximately 1 month after the overlays were placed. The top 51 mm was tested for permeability to chloride ion (AASHTO T 277). The results are shown in Table 5.3. The results indicate that after 6 weeks of cure, permeability ranges from medium to high. It is expected that when tests are done at a later age when the pozzolans and slag are more completely cured, the permeability will be in the low range.[4-9]

Fiber Type	Amount (kg/m³)	Job I-295	I-85	Rt-29
Control	0	2051	4462	3136
PO-2	14.8	-	-	-
PO-1	11.9	2847	-	3328
FP	1.8	5115	-	-
MP-1	0.9	-	4481	-
MP-1	3.0	-	2609	-
MP-2	3.0	-	-	4067

Table 5.3. Permeability of cores taken after overlay installation.

5.6 Post-Installation Photographic Record

A video of post-placement conditions is available.

5.7 Crack, Patch, and Test Location Map

Sketches of the cracks and patches before and after placement of the overlays are on file.

5.8 Cost of Overlay

Table 5.4 provides the cost for the placement of the concrete overlays for the projects. I-295 costs are less those for I-85 because the overlay placed in I-295 was 51 mm thick and required less material than the 102-mm overlay placed in I-85. In this study, steel FRC was more expensive than polypropylene or polyolefin FRC. However, the cost does not reflect the market price of polyolefin FRC. Because of bidding and contractual stipulations, polyolefin fiber was acquired at the cost of polypropylene fiber. The actual order of the cost from highest to lowest was polyolefin FRC followed by steel FRC and then polypropylene FRC. Therefore, the actual cost of the polyolefin FRC would be higher than what was shown in Table 5.4.

The cost data show that a 102-mm overlay can be a much better buy than a 51-mm overlay. Especially for "white topping" as represented by Rte. 29, the cost of the 102-mm overlay is only 8 percent more than that of the 51-mm overlay, but the thickness is double and the modulus is four times greater.

An asphalt overlay 51 mm thick would cost approximately $\$3/m^2$. A 51-mm concrete overlay would have to last 10 times longer than a 51-mm asphalt overlay to be competitive. Consequently, white topping would not typically be economical compared to placing asphalt on asphalt. Use of white topping could be justified at selected locations such as intersections where rutting of asphalt is severe and the asphalt requires frequent replacement that results in severe disruption of traffic.

Similarly, the use of HCC overlays on continuously reinforced concrete pavements would not typically be economical compared to the use of asphalt, but it might be justified in special situations.

	Control, 51 mm, $/m²$	Control,102 mm, $/m²$	PPM, $/m²$		ST, $/m²$		Mobilization, $/m²$	Traffic Control and Misc., $/m²$
Fiber Amount, kg/m³	0	0	0.9	3.0	29.7	44.5		
I-295	21.53	---	25.48	27.15	29.07	31.28	3.81	10.26
I-85	28.41	---	32.06	34.51	43.24	49.34	3.81	8.42
Rte. 29	24.64	26.56	25.90	27.87	33.73	38.10	5.38	26.85

Table 5.4. Comparison of cost per m^2 for FRC versus regular concrete overlays.

6. Conclusions

The high performance concrete overlays were successfully placed on continuously reinforced concrete and on asphalt pavements. The installation data and the 1-year evaluation of concretes and the overlays indicate that:

1. Strong and low permeability concretes were obtained.

2. Addition of fibers increased the toughness index of the concretes. In the overlays the presence of fibers appeared to control the widening of cracks.

3. Resistances to cycles of freezing and thawing of air-entrained concretes were satisfactory.

4. Stiffness of the pavements was increased with the addition of the overlays.

5. Satisfactory skid numbers were achieved in all test sections.

6. The 51 mm thick overlays placed on asphalt cracked badly as soon as traffic was applied and are not likely to last long.

7. Compared to asphalt, HCC overlays will not typically be economical.

8. Because of the high cost of fibers, their use would not typically be economical.

7. Recommendations

1. HCC overlays 51 to 102 mm thick should be used to increase the cover over reinforcement, improve ride quality, and increase the stiffness of continuously reinforced concrete pavements when these benefits justify the cost.

2. HCC overlays 76 to 102 mm thick should be placed on asphalt to prevent rutting when economically justified.

3. HCC overlays 51 mm thick should not be used on asphalt.

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