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Project Summary Report 0-4392-S
Project 0-4392: Use of Fibers in Concrete Pavement
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PROJECT SUMMARY REPORT

Fibers in Continuously Reinforced Concrete Pavements: A Summary

Continuously reinforced concrete pavement (CRCP) is the major type of highway pavement used for the expressways in the urban parts of Texas because of its increased ride quality, minimal maintenance, and extended service life afforded from CRCP. However, CRCP may sometimes experience early failure of ride quality owing to surface spalling adjacent to full depth cracks when certain siliceous river gravels are used (see Figure 1). This problem has been most commonly encountered in the Houston area, resulting in the need to repair or apply an overlay to a number of damaged sections. Significant effort has been made through various research projects to improve the performance of these gravel sources to achieve an acceptable level of performance, but to date these efforts have not resulted in a practical solution.

Project 0-4392 investigated whether fiber-reinforced concrete may solve problems associated with siliceous river gravel, particularly spalling. Both synthetic and steel fibers were used in a comprehensive laboratory program and two full-scale field trials. This research summary report briefly outlines the main findings from the laboratory and field testing programs; for more detailed information, please refer to the comprehensive project report.

Figure 1 – Severe Spalling of CRCP (Won, 2001)

What We Did...

Research Objectives

The main objectives of this project were the following:

1. Conduct a comprehensive literature review in order to determine the current state of the art regarding CRCP design and behavior, as well as the role that fiber reinforcement may play in improving its performance
2. Perform field investigations to verify constructability and workability of fibers in CRCP construction
3. Perform frequent monitoring to evaluate the effect of fibers on crack spacing, crack width, and spalling development
4. Perform laboratory testing that validates the effect of fibers on typical concrete paving mixes
5. Provide the Texas Department of Transportation (TxDOT) with recommendations for possible changes in the construction and design specifications of CRCP, which could serve to reduce or prevent spalling.

Fiber-Reinforced Concrete – An Overview

Plain portland cement concrete is an inherently brittle material with low tensile strength and strain capacity. While the traditional means of overcoming these inherent flaws has been to add steel reinforcing bars at specified locations in the matrix, during the past century there have been developments in using randomly oriented, discrete fibers (steel or synthetic) to remedy these weaknesses. This type of material is known as fiber-reinforced concrete (FRC). The use of steel fibers can improve some of the mechanical properties of concrete, such as tensile or flexural strength and fatigue performance, but the most important improvement imparted by steel and synthetic fibers is the ability to control crack widths and carry significant stresses after the initial cracking of the concrete. This improvement in post-cracking behavior gives the concrete a pseudo-ductility that is known as toughness.

FRC has gained in popularity in recent years, with applications aimed at preventing plastic and drying shrinkage cracking, improving abrasion and impact resistance, increasing tensile strength and strain capacity, and reducing the amount of conventional steel in certain applications. Prior to this project, there was very little, if any, work done on using FRC in full-depth CRCP, and this project sought to evaluate the feasibility of using fibers in CRCP specifically to address the spalling problems plaguing the state of Texas, especially in the Houston area.

What We Found...

Laboratory Evaluation

In order to implement fiber reinforcement in continuously reinforced concrete pavement (CRCP) design, it is important to understand how fibers improve the inherent properties of typical CRCP mixtures. The goal of this research was to quantify these effects by performing a comprehensive evaluation of the various fresh and hardened concrete properties relevant to fiber reinforcement and pavement construction, behavior, and design. A variety of fiber materials, geometries, and dosages were used to determine the most effective means of improving the various properties being investigated. Because pavement construction is driven by material costs and the relative cost of fiber reinforcement is high, only low dosages of fibers were tested.

Table 1 – Fiber Used in Laboratory Study

Fiber Designation	Description	Length (in)	Aspect Ratio
SF1	Steel - Collated Hooked-End	2.36	65
SF2	Steel – Corrugated	1.97	44
SnF1	Synthetic - Monofilament	1.57	90
SnF2	Synthetic – Collated-Fibrillated	< 1.18*	NA*

*The SnF2 fiber is graded and does not conform to a specific length or aspect ratio.

Both crushed limestone and siliceous river gravel were used in this project to provide insight into why limestone typically provides better long-term spalling performance than siliceous river gravel.

Typical materials and mixture proportions used in CRCP were evaluated in this research. The various types of steel and synthetic fibers used in the laboratory phase are shown in Table 1, and the mixture proportions are shown in Table 2.

The results of the laboratory testing showed that fibers can have a significant effect on decreasing the workability and increasing the flexural toughness, but for most parameters they provide little or no significant difference when compared to concrete containing no fibers. The mixtures containing higher dosages of synthetic fibers had a significant effect on decreasing workability, but this effect was offset by using a water-reducing admixture and increasing the coarse aggregate/fine aggregate ratio.

The results of the toughness testing (following the American Society for Testing and Materials [ASTM] C 1018) showed that the choice of fiber type and dosage has a significant effect on the post-cracking behavior of concrete. Figures 2 and 3 show the typical load-deflection curves for the various mixtures. Steel fibers typically provide greater improvements in toughness and residual strength than synthetic fibers, and both parameters are proportional to dosage rate for any fiber used. Toughness and residual strength could potentially be good indicators of improved spalling performance of CRCP, but long-term monitoring of CRCP containing fibers will be critical for verifying this hypothesized correlation. Once an adequate database of the long-term performance of fiber-reinforced CRCP has been collected, trends can be formulated relating toughness and residual strength to various CRCP performance parameters including crack width, crack spacing, and spalling performance.

After an evaluation of a range of FRC mixtures in the laboratory and optimization of these mixtures for workability, plans were then focused on implementing selected mixtures in full-depth CRCP trials in the Houston area.

Field Trials Using Fiber-Reinforced Concrete in CRCP

Recognizing that the mechanisms underlying spalling are not fully understood and that laboratory testing may not directly evaluate the true effects of fibers on spalling, researchers conducted two full-scale field tests using a variety of FRC mixtures in CRCP. The full details of these field tests are provided in the comprehensive report, 0-4392-4, and only a brief summary is provided in this report (0-4392-S).

The goals of these field tests were to determine the feasibility of using FRC in full-depth paving, specifically to observe the impact on workability, paving, finishing, and tining, and to study the long-term efficacy of fibers in reducing spalling. Because this was merely a two-year project, and spalling often takes several years to manifest itself in CRCP, only preliminary results are presented in this report. Long-term monitoring of these test sections is essential to determine if fibers are a viable means of preventing spalling and improving long-term performance.

A frontage road was selected for the preliminary field study so that the fibers could be tested on a small scale, using a roller screed (not a slipform paver), before subjecting a main lane slip-form paving job to potential difficulties. The site is located on the northbound frontage road on the inside lane of the Kirkwood Drive Exit on Highway 59, just southwest of Houston. This location was selected because of the relatively high truck traffic and the fact that there are times of relatively lower traffic flow, which could allow for flexibility with monitoring. A local source of river gravel was used that had a history of spalling in CRCP. Mixture proportions fairly similar to the laboratory evaluations were used in this field study, and three different fibers were used (SF1 at 25 and 40 pcy, SnF1 at 4 and 6 pcy, and SnF2 at 1.5 pcy). A variety of tests were performed on concrete sampled from the site, including air content, slump, unit weight, temperature, compressive strength, tensile strength, flexural strength, and flexural toughness. The results were consistent with those of the previous laboratory testing.

The concrete was cast in a central-mix plant and was transported to the site in 10-yd^3 dump trucks. In general, the mixtures were easy to place and finish, with the exception of the mixture containing 6 pcy of SnF1, which was quite stiff. The finishing process produced a hairy surface throughout the section, which is shown in Figure 4. The roller screed was unable to embed the fibers into the concrete, but the carpet drag seemed to help somewhat. The problem was exacerbated by the straight edge and tining operation. It should be noted that the exposed fibers do not pose a hazard to motorists but do diminish the pavement's appearance. Because of the difficulties in placing this section, the length of the SnF1 test section was reduced.

After the test sections were placed,

Table 2 – Mixture Proportions Used in Laboratory Testing Program

Mix #	Mixture Designation*	Water (pcy)	Type A/D Reducer/ Retarder (oz/cy)	Type I/II Cement (pcy)	Class C Fly Ash (pcy)	Fine Aggregate (pcy)	Coarse Aggregate**		Fiber Reinforcement	
							Type	Amount (pcy)	Type	Amount (pcy)
1	SRG-Control	225	6.6	429	120	1,341	SRG	1,905	-	-
2	SRG-SF1-25	225	10.0	429	120	1,341	SRG	1,905	SF1	25
3	SRG-SF1-40	225	13.3	429	120	1,341	SRG	1,905	SF1	40
4	SRG-SF2-27.5	225	19.9	429	120	1,341	SRG	1,905	SF2	27.5
5	SRG-SnF1-4	225	18.3	429	120	1,341	SRG	1,905	SnF1	4
6	SRG-SnF1-6	225	24.9	429	120	1,341	SRG	1,905	SnF1	6
7	SRG-SnF2-1.5	225	10.0	429	120	1,341	SRG	1,905	SnF2	1.5
8	LS-Control	225	13.3	429	120	1,341	LS	1,913	-	-
9	LS-SF1-25	225	24.9	429	120	1,341	LS	1,913	SF1	25
10	LS-SF1-40	225	33.2	429	120	1,341	LS	1,913	SF1	40
11	LS-SF2-27.5	225	19.9	429	120	1,341	LS	1,913	SF2	27.5
12	LS-SnF1-4	225	24.9	429	120	1,341	LS	1,913	SnF1	4
13	LS-SnF1-6	225	41.5	429	120	1,341	LS	1,913	SnF1	6
14	LS-SnF2-1.5	225	24.9	429	120	1,341	LS	1,913	SnF2	1.5

* Mixture Designation reported as follows: Aggregate type – Fiber Type – Fiber Dosage (pcy)

** SRG = Siliceous River Gravel, LS = Crushed Limestone

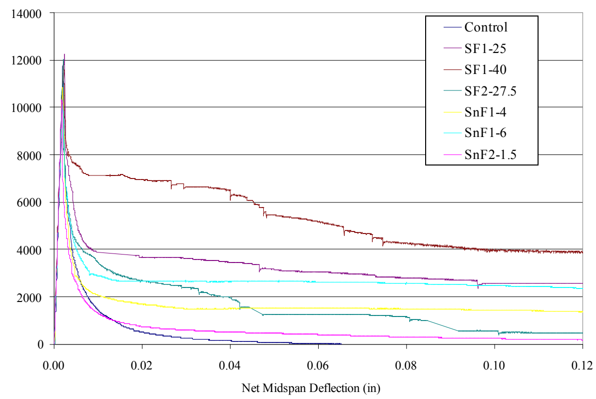

Figure 2 – Flexural Toughness (ASTM C 1012) for Mixtures Containing Siliceous River Gravel as Coarse Aggregate

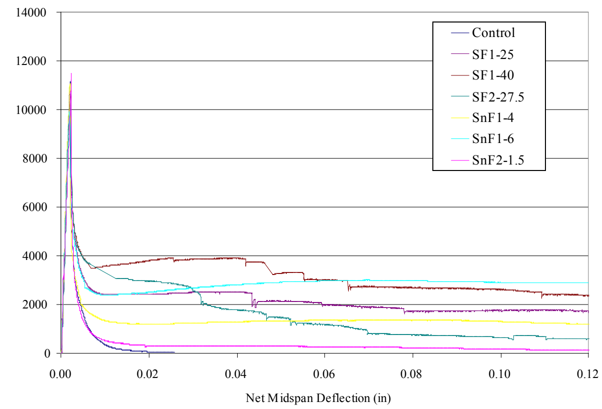

Figure 3 – Flexural Toughness (ASTM C 1012) for Mixtures Containing Limestone as Coarse Aggregate

monitoring was performed over the next 8 months, including crack mapping, crack width measurements, and crack spacing measurements. Interestingly, there was already evidence of spalling in each control section of the test pavement 235 days after construction. As shown in Figure 5, the spalling present in these sections is minor and does not pose much of a problem at this point. However, as the pavement is opened to traffic, the repeated heavy truck loading could exacerbate the severity of the spall and require expensive repairs. No pavement sections containing fibers had shown any signs of spalling up to 235 days after construction, which is quite encouraging. Long-term monitoring is essential to determine if fibers are effective in preventing spalling.

A second, more extensive field study was conducted to supplement the findings of the preliminary field evaluation. This test was also meant to be constructed under colder conditions than the preliminary field test. Extensive research has shown that pavements constructed in the winter develop far fewer cracks with a better distribution. The concrete placed in the initial field study was constructed in August and experienced severe ambient conditions. Although the second field study was constructed in April, the ambient conditions present during construction closely resembled the conditions that might be experienced in the winter and offered a nice comparison to the previous study. Another key difference between the two field studies is the method of construction. This field study was constructed with a slipform paving machine, making the effect of fibers on workability completely different than the previous study, which was constructed with a roller screed. A testing program similar to that of the first field trial was incorporated into this trial, including a complete characterization of fresh and hardened concrete properties. Also, monitoring of pavement performance was included, but only limited field data were generated because of this field trial's timing, occurring as it did near the end of the project.

Figure 4 – Hairy Texture of Pavement Section Containing 6 pcy of SnF1

In general, the slipform paving using FRC went quite smoothly, with the only difficulties being in placing SnF1. Similar problems were observed in the first field test, and based on these results, if future paving were to be performed with this fiber, lower dosages would be recommended. As stated above, the time to monitor these test sections was quite limited, and for this reason, no conclusions can be made on the impact of FRC on spalling for this second field test.

The Researchers Recommend…

It has been shown from both laboratory and field specimen testing that fiber reinforcement has the potential to impart improvements on CRCP performance. While most hardened properties are not changed, the increases in toughness that fibers provide are likely to decrease crack widths, improve load transfer across cracks, and lead to improved long-term spalling resistance. Toughness was found to be highly dependent on fiber type and/or dosage. Steel fibers were also found to typically provide greater improvements in toughness for the same volume replacement, compared to synthetic fibers. However, determination of the degree to which fibers will improve long-term pavement performance is still preliminary because of the lack of allotted time for this research project.

Spalling, even in poor-performing pavements, takes time to appear, and the field sections will need to experience more traffic loads and temperature cycles before real conclusions can be formulated. A more significant amount of time must pass before better correlations between toughness and CRCP performance are possible.

Figure 5 – Evidence of Spalling in Control Sections after 235 days (note that no spalling has been observed in any of the FRC sections)

For More Details...

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The research is documented in the following reports:

0-4392-4 *Fiber in CRCP Pavements*

To obtain copies of a report: CTR Library, Center for Transportation Research,
(512) 232-3126, email: ctrlib@uts.cc.utexas.edu

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Disclaimer

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