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ABSTRACT

Open-graded friction courses (OGFCs) are special purpose mixes used to improve friction, minimize hydroplaning, reduce splash and spray, improve night visibility, and lower pavement noise levels. OGFCs typically utilize a gap-grading for aggregates and a low percentage of filler. Asphalt contents for OGFCs are generally slightly higher than for dense-graded mixes.

The combination of uniform-grading, low filler, and normal OGFC asphalt contents can lead to the asphalt binder draining from a mix during transportation and laydown procedures (typically called draindown). States that use OGFC typically utilize fibers to help prevent draindown. Generally, these states have specified mineral fibers over organic fibers because of the fear that organic fibers (cellulose) would absorb water and lead to moisture problems in the field.

This study was conducted to evaluate the use of cellulose fibers in OGFC mixes. The study entailed both a field and laboratory phase. Field work entailed conducting a visual distress survey of six experimental OGFC pavements placed in Georgia during 1992. These pavements contained six different combinations of binder polymer and additives. Laboratory work entailed preparing OGFC mixes with both cellulose and mineral fibers and performing numerous moisture sensitivity tests. Results indicated that cellulose fibers performed as well as mineral fibers in OGFC mixes.

Key Words: Open-Graded Friction Course, OGFC, Cellulose, Fibers

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INTRODUCTION

Open-graded friction courses (OGFCs) are special purpose mixes used to improve surface frictional resistance, minimize hydroplaning, reduce splash and spray, improve night visibility, and lower pavement noise levels (*1*, *2*). These functions are achieved primarily by removing water from pavement surfaces during periods of rain. OGFC is a hot mix asphalt (HMA) that is designed to have a high percentage of internal air voids through which water can be removed from a pavement surface.

In order to achieve the high percentage of internal air voids, OGFCs typically utilize a uniform-grading for aggregates. Uniform-grading indicates that the aggregate gradation is comprised of mostly a single aggregate size. Typically, 50 to 60 percent of the aggregate particles are approximately the same size. To also ensure high percentages of internal voids, OGFCs typically have a low filler (material passing 0.075 mm) content (2 to 5 percent). Asphalt contents for OGFCs are generally slightly higher than for dense-graded mixes.

The combination of a uniformly graded aggregate and low filler content can lead to the asphalt binder draining from the mixture, by gravity, during transportation and laydown procedures. This phenomenon is typically called draindown. To combat the draining of asphalt binder from the mixture, fibers are sometimes added to stabilize the binder during mixing and placement. An additional benefit of using fibers is that fibers have been shown to allow increased asphalt binder contents and thus increase film thicknesses thereby increasing durability.

A recent survey of states that use OGFC (*3*) indicated that 19 percent (4 out of 21 states that use additives) use some form of fiber. Most of these states specify mineral fibers because of a concern that organic fibers (cellulose) may absorb water leading to premature moisture problems in the field. However, no research has been conducted to evaluate this potential problem with current cellulose fibers.

Objective

The objective of this study was to evaluate the use of cellulose fibers within OGFC mixtures.

Scope

This study was accomplished by comparing cellulose and mineral fibers both in the field and laboratory. The field portion of this study entailed a visual distress survey performed on six experimental OGFC sections located on I-75 in Georgia. These test sections included OGFC sections with both cellulose and mineral fibers as well as other additives.

Since the major concern with cellulose fibers in OGFC is the potential to absorb water, the primary distress type evaluated in the laboratory was moisture susceptibility. Testing included determining the amount of water absorbed by lab compacted OGFC samples, tensile strength ratios using different freeze-thaw cycles, the “boil” test, and rut testing with the Asphalt Pavement Analyzer in a submerged state.

RESEARCH APPROACH

The objective of this study was accomplished by two main parts: a field evaluation and laboratory evaluation. Figure 1 illustrates how these main parts were conducted. A description of each part follows.

Field Evaluation

The Georgia Department of Transportation (GDOT) has a series of OGFC experimental test sections on Interstate 75 south of Atlanta, Georgia. These sections were constructed in 1992 and consist of OGFC mixtures with different types/combinations of asphalt modifiers/polymers. Included are OGFC sections that contain no modifiers/fibers, cellulose fibers, mineral fibers, polymer and cellulose fibers, polymer, and crumb-rubber modified asphalt. A visual distress survey was performed by NCAT in November and December of 1998 to evaluate the performance of each section. Additionally rut depth measurements were obtained from each

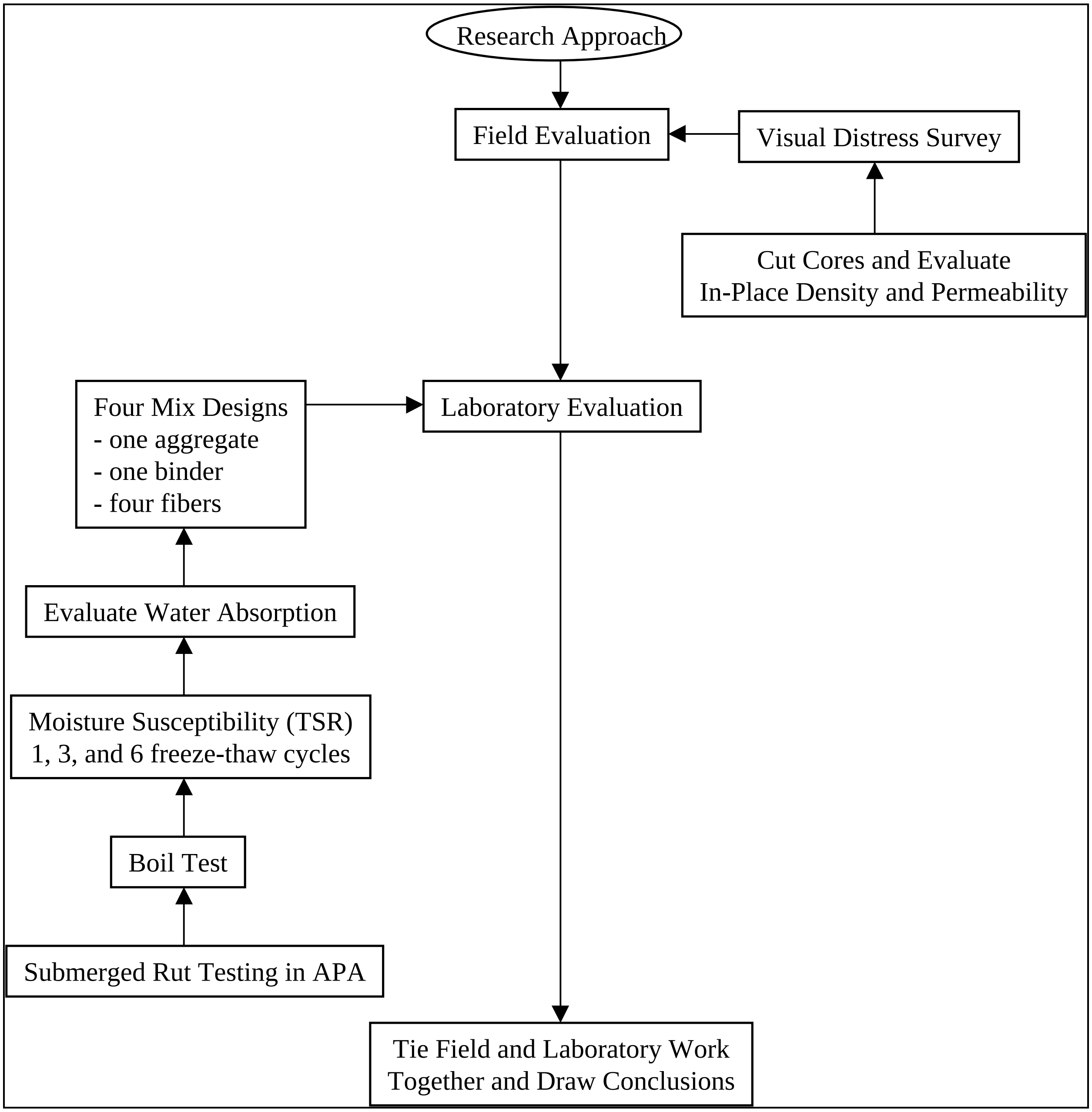

Figure 1. Research Approach

section using a stringline. Cores were obtained from each of the six test sections from which in-place density and laboratory permeability were determined.

Laboratory Evaluation

Laboratory testing was accomplished to study differences between cellulose and mineral fibers in laboratory compacted OGFC specimens. The first step in this task was to perform mix designs using the GDOT procedure for designing OGFC mixtures (4). This procedure involves compacting OGFC mixtures with 25 blows per face of a Marshall hammer at varying asphalt contents. Optimum asphalt content is defined as the asphalt content that produces the lowest voids in mineral aggregate (VMA). Four mix designs were conducted and included one aggregate source, one asphalt binder, and four forms of fiber. The gradation for these mixtures were identical and met a GDOT 12.5 mm OGFC gradation. A granite aggregate was selected for the study. The source was suggested by the GDOT because of its potential for stripping. Of the four fiber types used, three were cellulose while the fourth was a slag wool (mineral fiber). The three forms of cellulose included a loose fiber, a 66/34 pelletized fiber (66 percent cellulose fiber and 34 percent asphalt), and an 80/20 pelletized fiber. The cellulose fibers were added to the OGFC mixtures at a dosage rate of 0.3 percent based upon total mixture mass while the mineral fiber was introduced at a dosage rate of 0.4 percent of total mixture mass. The difference in dosage rate between the two fiber types is a result of differences in specific gravity. The dosage rates represent approximately equal volumes of fiber in the mix. These rates are also recommended for SMA. For all of the mixtures a PG 76-22 asphalt binder obtained from Amoco at Gwinett County, Georgia was used. This binder was modified with an styrene butadiene styrene (SBS) polymer.

Four types of laboratory tests were conducted. First, a test was used to quantify the amount of water absorbed into OGFC mixtures containing the four fiber types. This test was conducted by allowing compacted OGFC mixtures to soak in a 60°C (140°F) water bath for three days (72 hours). After soaking, the specimens were allowed to dry at room temperature. Mass measurements were obtained at 1, 2, 4, 21, 24, 48, and 72 hours to determine mass loss. Any mass loss should be water flowing or evaporating from the specimens. This test methodology was selected to evaluate how long water would be retained by OGFC samples containing the various fiber types. Three replicates of each mixture were tested.

The second laboratory test conducted was GDT-66 (5), “Method of Test for Evaluating the Moisture Susceptibility of Bituminous Mixtures by Diametral Tensile Splitting.” This procedure is similar to the modified Lottman procedure. Testing was conducted to evaluate the sensitivity to moisture induced damage for mixtures containing the various fibers. The four mixtures were evaluated after 1, 3, and 6 freeze-thaw cycles.

The third laboratory test also evaluated the sensitivity of the different mixtures to moisture induced damage. This testing was conducted in accordance with GDOT-56 (6), “Test Method for Heat Stable Anti-Strip Additive.” For this test, loose OGFC mixture was placed into boiling water for ten minutes (hence, the test has been called the “boil” test). A visual inspection was then performed to determine the approximate percentage of aggregate particles in which the asphalt binder was totally or partially removed. This testing was also conducted for each mixture.

The final laboratory test was conducted with the Asphalt Pavement Analyzer (APA). Three beam samples of OGFC were fabricated using the loose cellulose and mineral fibers. These beams were fabricated and tested in accordance with GDT-115 (7), “Method of Test for Determining Rutting Susceptibility Using the Loaded Wheel Tester,” while submerged in water at 60°C.

TEST RESULTS AND ANALYSIS

Distress Survey and Laboratory Testing on OGFC Test Sections

On October 29 and December 7, 1998, representatives of NCAT performed a visual distress survey for six experimental OGFC pavement sections located on Interstate 75 south of Atlanta, Georgia. This location is in a wet-no-freeze region with average high ambient temperature of approximately 35°C (95°F). Each of the six OGFC mixtures were designed to meet the 1992 GDOT specification for OGFC (4). Mixtures used in this field study are shown below.

Mix Code	Mix Description
D	Coarse OGFC
D16R	Coarse OGFC with 16% crumb rubber
DM	Coarse OGFC with mineral fibers
DC	Coarse OGFC with cellulose fibers
DP	Coarse OGFC with styrene-butadiene (SB) polymer
DCP	Coarse OGFC with SB and cellulose fibers

For the above mixes, the D, DM, and DC mixtures utilized an AC-20 binder. The DP and DCP used an AC-20 binder modified with styrelf, while the D16R mix had an AC-20 modified with 16 percent of a minus 80 sieve rubber. The rubber was blended into the virgin AC-20 by high speed mixing (8). Properties of these binders are provided in Table 1.

Table 1. Asphalt Binder Properties Used on Field Test Sections (*8*)

Test	AC-20s	AC-20s with Styrelf	AC-20s + 16% Rubber
Viscosity @ 140°F (poises)	1793	9,739	17,648
Viscosity at 275°F (cSt)	352	1,095	10,195
Penetration @ 77°F, 100 g, 5 sec (dmm)	68	55	40
Softening point, ring and ball (°F)	122	138	138
Elastic recovery from 10 cm, 5 cm/min, 77°F (%)	18	77	57
Force ductility @ 10-cm ext., 5 cm/min, 77°F (lb.)	0.04	0.18	0.43
Thin-film Oven Residue			
Viscosity @ 140°F (poises)	4569	29,665	70,794
Force ductility @ 10-cm ext., 5 cm/min, 39°F (lb.)	3.87	11.5	15.3
Ductility, 5 cm/min., 39°F (cm)	12	31	20

The visual distress survey consisted of evaluating each experimental section for surface texture, rutting, cracking, and raveling. Results of the visual distress survey are presented in the following sections.

Distress Survey

Surface Texture

All six sections appeared to have some coarse aggregate pop-out. The D16R section appeared to have the most coarse aggregate pop-out while the DC, DM, and DP sections appeared to have the lowest amount. Another surface texture item was the existence of small "fat spots." Each of the six sections had these fat spots and ranged in diameter from approximately 8 cm (3 in) to 20 cm (8 in). The D and DCP section appeared to have the most fat spots but these were not significant. All sections also showed scarring which was most likely caused by vehicles with flat tires. The scarring was not a mix related problem.

Rutting

Rut depth measurements were made in each experimental section with a stringline. Table 2 presents the average rut depth for each section along with the number of measurements conducted.

Table 2. Rut Depth Measurements

Section	Avg. Rut Depth, mm	No. Observations
D	2.4	4
D16R	2.4	6
DM	2.8	4
DC	4.1	7
DP	0.0	5
DCP	1.3	5

Table 2 shows that the DP section had the lowest average rut depth at 0.0 mm. However, traffic on this entire section was downhill. The DC section had the highest amount of rutting at 4.1 mm. The amount of rutting in all sections was insignificant.

Cracking

The primary cracking on all six experimental sections was reflective from a Portland cement concrete underlying each section. All six sections exhibited reflective cracking. Table 3 presents descriptions and percentages of reflective cracks for each section. Percentage of reflective cracks was determined by counting the number of reflective cracks visible at the pavement surface.

Table 3. Severity and Percentage of Reflective Cracks

Section	Description	% Cracks Showing
D	Low to medium severity	75
D16R	Low to high severity	87
DM	Low severity	55
DC	Low severity	45
DP	Low to medium severity	61
DCP	Low to medium severity	65

The information in Table 3 only refers to reflective cracks occurring transversely across the pavement. Reflective longitudinal cracks were observed on five sections: D, DC, DCP, D16R, and DP. Longitudinal reflective cracking was very low severity in the DC and DP sections. For the D and D16R sections some of the longitudinal cracks had opened.

Besides reflective cracking, only the D16R section showed any other type of cracking. Within the D16R section, secondary cracking around some reflective cracks had occurred.

Raveling

All six experimental sections showed some signs of raveling. However, all were minimal except for the D16R section. Within this section, some medium severity raveling had occurred next to cracks.

Permeability Testing Conducted on Cores

As stated previously, 150 mm cores were obtained from each of the six sections for which the distress surveys were conducted. Three cores per section were tested in the laboratory to determine permeability. The laboratory permeameter used for this study is commercially sold and measures permeability utilizing the falling head approach.

Table 4 presents the average laboratory permeability values from each of the six sections. Statistically, no significant differences occurred in the permeability values of the six sections. However, the DC and DCP sections showed the highest mean permeability values and the DP showed the least.

Also included in Table 4 are average in-place air void contents for each of the six test sections. The volume of samples tested for bulk specific gravity was determined by measuring the core dimensions and calculating the sample volume. In-place air void contents generally ranged from 15 to 19 percent. As would be expected, the in-place air voids and permeability data tended to show increased permeability with increasing air voids for each section.

Table 4. Average Permeability and In-Place Air Void Contents for the Six Test Sections

Section	Individual Permeability Test Results x 10^{-5}, cm/sec			Avg. Permeability x 10^{-5}, cm/sec	Avg. In-Place Air Voids, %
D	852	998	4358	2069	16.7
D16R	5349	538	10620	5502	15.8
DM	8402	948	257	3202	19.9
DC	10056	15249	350	8552	16.2
DP	874	1005	3525	1801	13.9
DCP	687	5093	18582	8121	19.2

LABORATORY STUDY

A single gradation was used for all four mix designs. Table 5 and Figure 2 present this gradation. The gradation meets a GDOT 12.5 mm OGFC gradation band (4). One percent lime by total aggregate mass was included in the gradation.

Results of the mix designs are presented in Table 6. Based upon the designs, all four mixes had similar volumetric properties at respective optimum asphalt contents. The mix containing loose cellulose fibers (CF) did have a slightly lower optimum asphalt content.

Table 5. Study Gradation

Sieve, mm	Gradation, % Passing	Gradation Band
25.0	100	---
19.0	99.9	100
12.5	88.6	85-100
9.5	63.7	55-75
4.75	18.5	12-25
2.36	8.0	5-10
1.18	4.5	---
0.6	4.3	---
0.3	4.0	---
0.15	3.3	---
0.075	3.2	2-4

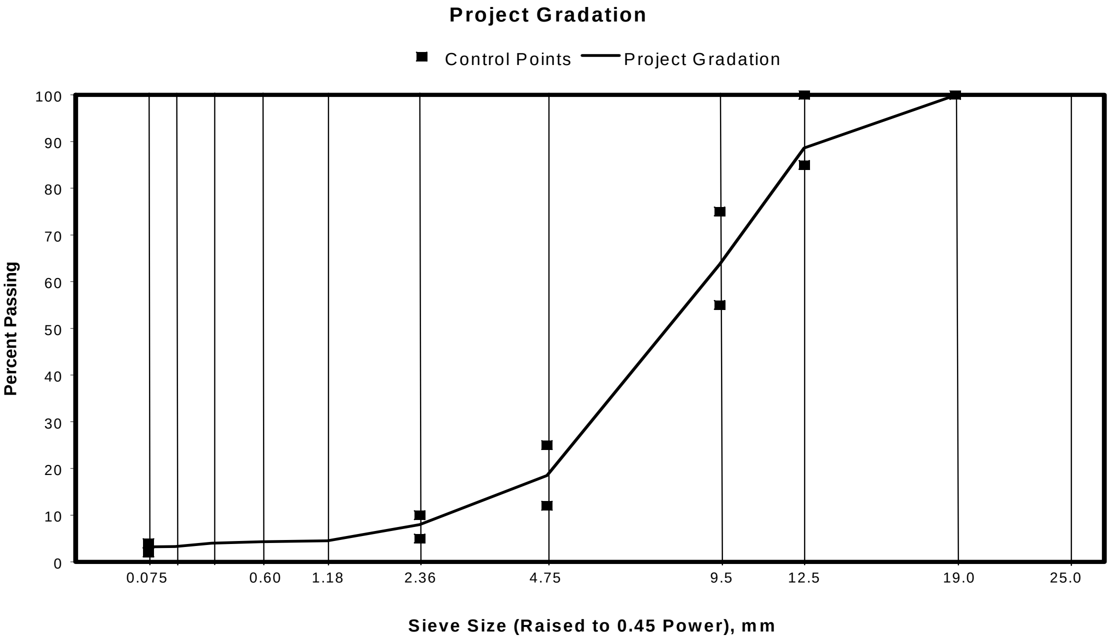

Figure 2. Project Gradation

Table 6. Mix Design Information

Mix Designation	Opt. Asphalt Content	% Air Voids	% VMA	% VFA
Mineral Fiber	6.2	17.5	29.0	39.6
Cellulose - Loose	5.8	17.1	28.3	39.7
Cellulose Pellets - 80/20	6.3	17.3	28.9	40.2
Cellulose Pellets - 66/34	6.2	17.5	29.0	39.7

At optimum asphalt content, fifteen specimens of each mix were compacted using 25 blows per face of a Marshall hammer. Three specimens per mixture were used to evaluate water absorption. The remaining twelve specimens were used to evaluate moisture susceptibility using GDT-66. Three samples were tested as unconditioned, three samples subjected to one freeze-thaw cycle, three samples subjected to three freeze-thaw cycles, and three samples subjected to six freeze-thaw cycles.

Table 7 provides results of the water absorption testing. This table shows the average water content (expressed as percentage) of specimens after drying at room temperature for various times. The amount of water in a sample was determined by subtracting the mass of a sample prior to any conditioning from the mass of the same sample after conditioning and drying at room temperature for the various times. The percent water at any time was then calculated as the amount of water in the sample at that time divided by the original mass of that sample (prior to conditioning) and expressing as a percentage. Figure 3 presents the data graphically.

Figure 3 shows that all four mixtures had approximately the same rate of water loss. However, the amount of water loss did vary. The mix containing loose cellulose had the highest amount of water left in the samples followed by the 80/20, 66/34, and mineral fiber mixes, respectively. Because the test method employed is not a standard method, it is unclear whether the differences in water contents is significant. However, after one hour the highest water content was approximately 1.4 percent for the loose cellulose mix which is not a large difference from the approximately 1.0 percent for the mineral fiber mix. After 72 hours, the percent water ranged from 0.11 to 0.24, which again does not appear to be significant.

Table 8 provides the tensile strength ratios (TSR) for each mixture after 1, 3, and 6 freeze thaw cycles. It should be noted that for the 66/34 cellulose unconditioned subset, one tensile strength appeared to be significantly lower than the other two. Values in Table 7 for the 66/34 cellulose data within parentheses provide the TSR values after the one low tensile strength is removed.

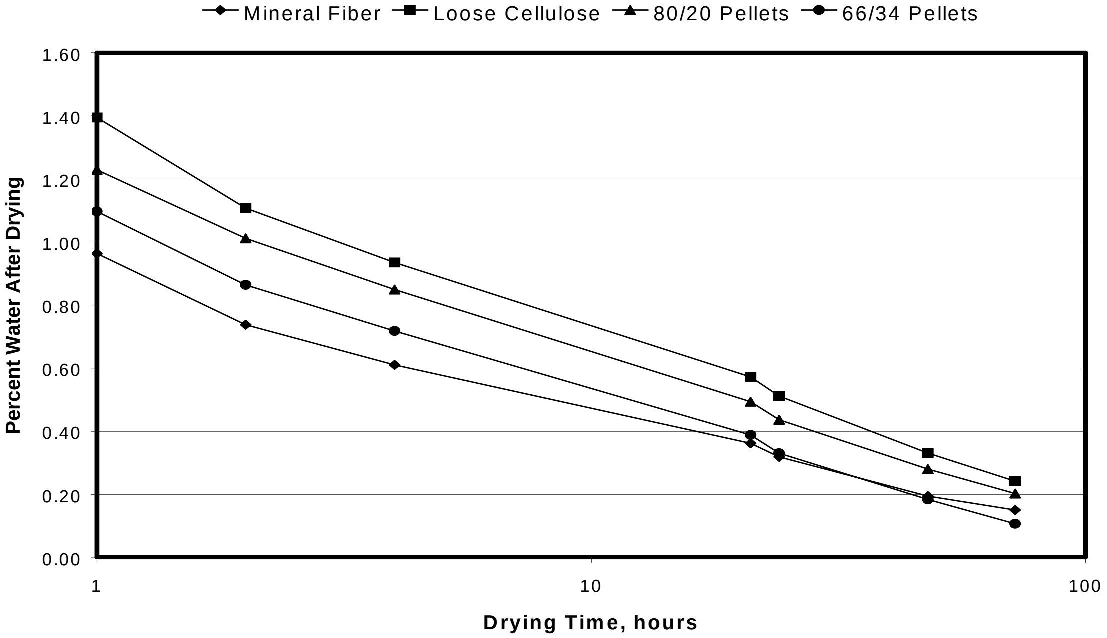

Figure 3. Results of Water Absorption Testing

Table 7. Water Absorption Experiment

Mixture	Mineral Fiber				Cellulose-Loose				Cellulose-80/20				Cellulose-66/34			
Replicate	1	2	3	Avg	1	2	3	Avg	1	2	3	Avg	1	2	3	Avg
% Water After 1 hr.	0.85	1.11	0.93	0.96	1.46	1.32	1.40	1.39	1.18	1.29	1.22	1.23	1.05	1.05	1.19	1.10
% Water After 2 hrs.	0.65	0.87	0.70	0.74	1.16	1.03	1.13	1.11	0.94	1.13	0.97	1.01	0.84	0.82	0.93	0.86
% Water After 4 hrs.	0.54	0.73	0.57	0.61	0.99	0.86	0.95	0.93	0.77	0.98	0.80	0.85	0.69	0.69	0.77	0.72
% Water After 16 hrs.	0.34	0.45	0.30	0.36	0.66	0.53	0.52	0.57	0.42	0.62	0.43	0.49	0.38	0.39	0.40	0.39
% Water After 24 hrs.	0.30	0.40	0.25	0.32	0.59	0.48	0.46	0.51	0.36	0.56	0.39	0.44	0.33	0.33	0.33	0.33
% Water After 48 hrs.	0.20	0.24	0.14	0.19	0.40	0.32	0.28	0.33	0.22	0.38	0.24	0.28	0.19	0.21	0.16	0.18
% Water After 72 hrs.	0.18	0.16	0.10	0.15	0.30	0.24	0.18	0.24	0.15	0.28	0.17	0.20	0.11	0.14	0.07	0.11

Table 8. Results of GDT-66 Moisture Susceptibility Testing

Mixture	Mineral Fiber				Cellulose-Loose				Cellulose-80/20				Cellulose-66/34			
Replicate	1	2	3	Avg	1	2	3	Avg	1	2	3	Avg	1	2	3	Avg
Uncond.Tensile Str., kPa	503	411	475	463	495	478	474	482	467	415	422	435	477	341	453	424
Tensile Str. ~ 1 F/T Cycle, kPa	334	357	309	333	431	454	400	428	310	387	334	343	410	464	426	434
Tensile Str. ~ 3 F/T Cycles, kPa	417	306	346	356	307	357	367	344	291	330	342	321	382	447	448	426
Tensile Str. ~ 6 F/T Cycles, kPa	237	222	207	222	253	345	263	287	196	194	226	205	294	156	264	238
TSR @ 1 F/T Cycle, %	71.9				88.7				79.0				102.3 (93.2) *			
TSR @ 3 F/T Cycles, %	76.7				71.2				73.8				100.3 (91.4) *			
TSR @ 6 F/T Cycles, %	47.6				59.5				47.3				56.3 (51.2) *			

* Values in parentheses reflect TSR values excluding Replicate No. 2 from the unconditioned subset that appeared to be an outlier.

The TSR data seems to indicate that all four mixes performed similarly. After three freeze-thaw cycles all four mixes had TSR values above 70 percent. It should be stated that the GDOT requirement for TSRs after one freeze-thaw cycle is 80 percent retained strength. However, TSR values were significantly reduced after six freeze-thaw cycles. TSR values ranged from 47 to 60 percent after six cycles. Based upon this moisture susceptibility testing, the mixtures containing cellulose fiber performed similarly to the mixture containing mineral fiber.

Results of the GDT-56, "Test Method for Heat Stable Anti-Strip Additive," showed no visual stripping in any of the four mixtures.

The final laboratory test was rut testing in the APA while the samples were submerged in water (60°C). This testing was conducted for only the loose cellulose and mineral fiber mixtures at optimum asphalt content. Prior to testing, samples were conditioned in a 60°C water bath overnight. Results of this testing are provided in Table 9. This table shows that the loose cellulose mixture had a lower rut depth after 8000 cycles than did the mineral fiber mix, though enough replicates were not tested to determine if the differences were significant.

Table 9. Results of Submerged Rut Testing

Mixture	Rut Depth at 8000 Cycles, mm
Loose Cellulose	5.2
Mineral Fiber	7.6

DISCUSSION

This was a very interesting study in that both laboratory and field data was obtained to accomplish the objective of evaluating cellulose fibers in OGFC mixes. Field work entailed a visual distress survey of six OGFC test sections and permeability testing conducted on cores from the six OGFC test sections.

The visual distress survey indicated that the OGFC section containing cellulose fiber and no asphalt binder modifier (DC) has performed as well, if not better, than the other five sections. The DC section had a relatively low amount of coarse aggregate pop-out, the lowest amount of reflective cracking, and very minor raveling. However, the DC section did have the highest rut depth at 4.1 mm (0.12 in) but is not deemed significant after six years of traffic.

Permeability testing on cores obtained from each section indicated that the DC section also had the highest amount of permeability. Interestingly, the DCP section had the second highest permeability value.

Laboratory work in this study consisted of performing four mix designs, conducting water absorption testing, TSR testing (GDT-66), the boil test (GDT-56), and submerged rut testing. The four mixes used in the laboratory study were identical in components except for the fiber additives and respective optimum asphalt contents. Results of the mix designs showed that all four mixes had similar volumetric properties at optimum asphalt content. However, the loose cellulose fiber mix did have a slightly lower optimum asphalt content.

Results of the water absorption testing indicated that all four mixes had approximately the same rate of water loss. The data also suggested that the magnitude of water contents at all times were similar. TSR testing and the boil test also indicated that the cellulose fibers are comparable to the mineral fiber with respect to resisting moisture damage. TSR tests after three freeze-thaw cycles were satisfactory (above 70 percent retained strength) for all four mixes.

Results of the submerged rut tests also indicated that the cellulose fiber mix was comparable to the mineral fiber mix with respect to rut resistance.

The data from this study is very interesting because the field data and laboratory data appear to provide the same indications. The field section containing cellulose (without asphalt modifiers) performed as well as the section containing mineral fiber. This also was shown in the laboratory.

CONCLUSIONS

The primary function of an OGFC is to remove water from a pavement's surface. Therefore, during and immediately after a rain event OGFC can contain water. In the past, concerns have been expressed that cellulose fibers may absorb water during a rain event and lead to premature failures due to moisture damage. Therefore, many states have required mineral fibers as mineral fibers do not absorb water. Based upon the findings in this study, cellulose fibers performed comparably to mineral fibers both in the field and laboratory.

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