Comparative Study of Manganese-Treated and Conventional Asphalt Concrete Mixtures and Pavements

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A typical rehabilitation alternative of roadways that have reached their serviceability level is the construction of asphalt concrete (AC) overlays on either rigid or flexible pavements. However, overlays constructed with conventional AC tend to reflect the cracking and jointing patterns of existing pavements a short time after their placement. Other typical distresses observed in conventional AC mixtures are fatigue cracking, stripping, and moisture damage. A manganese-based AC additive (CTI-101, Chemkrete) has been claimed to minimize some of these problems. The Ohio Chemkrete test section was built at a location subjected to average climatic and traffic conditions. Whether the additive led to any beneficial performance gains or, at least, to equal performance for the same cost of conventional AC overlays was studied. The study compared condition surveys (consisting of pavement condition rating and crack surveys), Dynaflect deflection measurements, and laboratory testing of field-procured specimens that obtained values of resilient modulus, Marshall stability, indirect tensile strength, fracture toughness, creep compliance, and fatigue. Results of laboratory tests performed on field-procured cores indicated better performance by conventional AC specimens than by the Chemkrete-treated specimens. On the basis of results of core testing, VESYS III computer model rut depth calculations predicted that rut depths would be approximately twice the magnitude along the Chemkrete-treated section than along the control section. Dynaflect deflection measurements indicated a slightly better performance on the control section than on the Chemkrete-treated section. No significant gains in the engineering properties of AC mixtures are obtained with the addition of Chemkrete.

Prolonging the service life of pavements has been a subject of major concern for highway and materials engineers. As the expansion of the highway network reached its apparent limit in the United States, and with the increased amount of traffic on most of these roads, attention has been directed towards maintenance and rehabilitation.

A typical rehabilitation alternative is the construction of asphalt concrete (AC) overlays on either rigid or flexible pavements that have reached their minimum acceptable serviceability level. However, a short time after their placement overlays constructed with conventional AC tend to reflect the cracking and jointing patterns of the existing pavements. Other typical distresses observed in conventional AC mixtures are fatigue cracking, stripping, and moisture damage. Some of these problems may be minimized with the use of additives in the AC. These additives are claimed to affect the properties of the AC by producing mixtures in which softer asphalts can be used without impairing the high-temperature stability of the mixture, while not becoming as brittle at low temperatures (*1*).

A manganese-based AC additive (CTI-101) developed by Chemkrete Technologies, Inc., has been claimed to produce these beneficial effects (*1,2*). The apparent success in improving desirable properties in the laboratory, reported by several authors, has encouraged state highway officials to set up experimental pavement sections containing this additive to determine whether or not pavement performance improvements result under actual working conditions (*1,3–6*).

Several test sections containing CTI-101 (Chemkrete) as an additive, as well as adjacent control sections containing conventional AC, have been built in several states, with mixed performance results. The Ohio Chemkrete test section was built at a location subjected to average climatic and traffic conditions. The objective of the study was to determine whether the additive led to any beneficial performance gains or, at least, equal performance for the same cost of AC overlays.

PREVIOUS LABORATORY EXPERIENCE

Extensive laboratory testing of Chemkrete-modified and conventional AC specimens was undertaken by several researchers to determine if the addition of Chemkrete produced any significant improvement in the physical and engineering properties of asphalt concrete mixtures (*1,4,6*).

Chemkrete-modified AC mixtures had a more desirable behavior than conventional AC mixtures when tested in the laboratory. However, a significant amount of curing time was required before these beneficial properties materialized. This result may have some implications on placement conditions as well as on the length of time before allowing traffic on a new construction project. The most important gains, in some cases, were a reduction in the temperature susceptibility, as indicated by a flatter temperature-viscosity relationship and the possibility of using marginal-quality aggregates in the preparation of AC mixtures.

PREVIOUS FIELD EXPERIENCE

Experimental pavement sections using Chemkrete have been built in several states with various degrees of success (*7–10*). Moulthrop and Higgins (*3*) also reported a total of 44 projects

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containing Chemkrete-modified asphalts built in a variety of climates in the United States between January 1980 and August 1984.

In previous studies, it was expected that the addition of Chemkrete to AC mixtures would result in a reduction of their temperature susceptibility leading to less rutting or shoving at high temperatures and less thermal distress at low temperatures. Other benefits would include (a) a longer pavement life because of greater load-carrying capacity as a result of resilient modulus and indirect tensile strength increases at high temperature, (b) lower cost because of reduced section thickness for equal performance, and (c) the possibility of using less costly aggregates. These studies indicated that Chemkrete-modified AC yielded more desirable properties than conventional AC when subjected to adequate curing in the laboratory. Conventional AC pavement sections, however, performed substantially better than Chemkrete-modified AC pavement sections when subjected to identical curing, climatic, and traffic conditions.

PROJECT DESCRIPTION

The Ohio Chemkrete test section is located on US-23 near the Delaware-Marion county line. At that location, US-23 is a 4-lane, divided highway carrying an average daily traffic of 18,425 vehicles, with a direction distribution factor of 50 percent, and 23 percent of the traffic consisting of trucks.

Two Chemkrete test sections were placed in July 1984; a 2-mi-long section in the travel lane of the northbound direction, and a 1-mi-long section, also in the travel lane, of the southbound direction. The original plans called for the passing lanes in both directions to be used as control sections; however, because of the difference in the number and composition of traffic this procedure was changed to select the control sections on the travel lanes (northbound and southbound), following the Chemkrete-modified sections.

The existing pavement consisted of 9 in. of badly cracked portland cement concrete pavement on 6 in. of granular subbase, placed on a gently rolling terminal moraine deposit. The project called for the placement of a 3-in.-thick overlay consisting of a 1¼-in.-thick wearing course (Ohio Department of Transportation Type 404) on a 1¾-in.-thick leveling course (Type 402). Approximately 25 percent of the joints were full-depth repaired before overlay.

Mixture and Placement Characteristics

Limestone aggregate was mixed with AC–5 asphalt cement treated with 4 percent of Chemkrete (CTI–101) for the Chemkrete test section, whereas AC–20 asphalt cement was mixed with the same aggregate for the control section. A laboratory analysis of the AC–5 asphalt cement treated with 4 percent of Chemkrete yielded a dynamic viscosity equal to 250 poises. The test was conducted at 140°F following AASHTO T202 specifications.

The grain size distribution for the aggregate used in the AC for the wearing course met Ohio 848, Type I, specifications. The grain size distribution for the aggregate used in the AC for the leveling course met Ohio 848, Type II, specifications. The maximum-sized aggregate was limited to 1 in. for the leveling course and to ½ in. for the wearing course.

Mixture design, by the Marshall method, indicated required AC contents of 5.9 percent by weight for the wearing course and 5.1 percent by weight for the leveling course. A recommended 4 percent Chemkrete dosage by weight of binder yielded an average 0.089 percent manganese content by weight of binder (after testing representative samples), as compared to a target of a 0.08 percent content. Tested samples ranged from 0.082 to 0.104 percent in manganese content by weight of binder.

Construction Procedure

The construction procedure for Chemkrete-modified AC pavements is similar to that of conventional AC pavements. The only variation is the addition of Chemkrete to the AC before blending it with the aggregate. The Chemkrete AC blending may be done in a heated storage tank that requires prolonged mixing or at the nozzle before spraying the AC on the heated aggregate.

The AC used in the construction of the test section was prepared with the specified proportions at a mixing plant and transported to the site where it was compacted with a pneumatic breakdown roller, followed by a vibratory intermediate, and a heavy, tandem finish roller.

Temperature during placement ranged between 255°F and 275°F. Minor cracking was noticed in the northbound Chemkrete section after rolling; however, overnight traffic knitted the pavement together. The southbound section showed heavy segregation and low AC content, leading to raveling when traffic was permitted onto this section. The section was immediately removed and repaved (*2*).

Initial Performance Observations

Initial performance observations obtained 5 months after overlay placement are presented in Table 1 (*2*). Before the first winter, the conventional AC pavement section was performing better than the Chemkrete-treated AC pavement section. No apparent drainage-associated distress was observed at either the Chemkrete or the control sections. Although some of the most distressed joints were full-depth repaired along both the Chemkrete and the control sections, reflection cracking still occurred at these joints, showing not one but two reflected cracks.

TESTING PROGRAM AND ANALYSIS

The investigation of Chemkrete-modified AC pavements included the comparison of their performance with that of conventional AC pavements. The comparison included PCR and crack condition surveys, Dynaflect deflection measurements, and the laboratory testing of field-procured specimens to obtain pertinent physical and engineering properties.

The following discussions will be limited to the presentation of test results and the identification of any noticeable and consistent behavioral trends of field-obtained, Chemkrete-

TABLE 1 INITIAL PERFORMANCE OBSERVATIONS

	Control Section	Chemkrete Section
Texture	Good	Good
Edge Cracking	None	None
Reflective Cracking	Many Joints	Almost every Joint
Average Crack Spacing Spacing (ft)	98.3	58.9*

*Approximate Joint Spacing

modified and conventional AC specimens, as well as of the actual field test sections.

Condition Survey

The field condition survey included periodic PCR determinations and crack surveys to ascertain the pavement overlay performance with time and an increased number of vehicles, for both Chemkrete-treated and untreated pavement sections.

Reflection cracking surveys were conducted in December 1984, in May and October 1985, and in April 1986, leading to the results presented in Table 2. Pavement condition surveys were also performed on May 17, 1985, and April 7, 1986 (see Table 3).

Comparisons can be made between the PCR obtained on the Chemkrete and the control sections. Results of the earlier PCR determination indicated that the Chemkrete-treated section was performing slightly better than the control section. The second and more detailed (on a joint by joint basis) PCR determination, obtained approximately 1 year later, indicated slightly better performance on the control section than on the Chemkrete section.

Dynaflect Deflection Measurements

Dynaflect deflection measurements, provided by ODOT, were used as an added method to measure the relative performance of Chemkrete-treated AC pavements with respect to the performance of conventional AC pavements. Existing data, however, do not distinguish between deflection measurements obtained at the joint on the approach or leave slab or at midslab, making it difficult to draw any conclusions regarding pavement performance with respect to time or seasonal variations.

Dynaflect deflection measurements were obtained on two different occasions: September 27, 1984, and December 4, 1985. Figures 1 and 2 show the deflection measured with the first sensor (W1), and the spreadability (SPR%) defined by the equation

$$SPR\% = \frac{W1 + W2 + W3 + W4 + W5}{5\,W1} \times 100 \qquad (1)$$

where $W1$, $W2$, $W3$, $W4$, and $W5$ are the deflections measured with the first, second, third, fourth, and fifth sensors, respectively.

Measurements at the two different times have been presented to determine whether there are any significant changes

TABLE 3 AVERAGE PAVEMENT CONDITION RATINGS

	MAY 1985	APRIL 1986
CHEMKRETE (Northbound)		
20.0 - 20.5 (DEL)	93.0	84.0
20.5 - 21.0 (DEL)	90.0	89.0
21.0 - 21.5 (DEL)	91.0	82.0
00.0 - 0.5 (MAR)	90.0	89.0
CONTROL (Pass-Northbound)		
0.5 - 1.0 (MAR)	89.0	87.0
1.0 - 1.5 (MAR)	89.0	89.0

DEL = Refers to Delaware County Log Mile on US-23

MAR = Refers to Marion County Log Mile on US-23

TABLE 2 REFLECTION CRACKING SURVEY

DATE	CHEMKRETE	CONTROL
December, 1984	Low	Very Low
May, 1985	Low-Medium and Extensive	Medium and Extensive
October, 1985	Medium and Extensive	Medium and Extensive
April, 1986	Medium and Extensive	Medium and Extensive

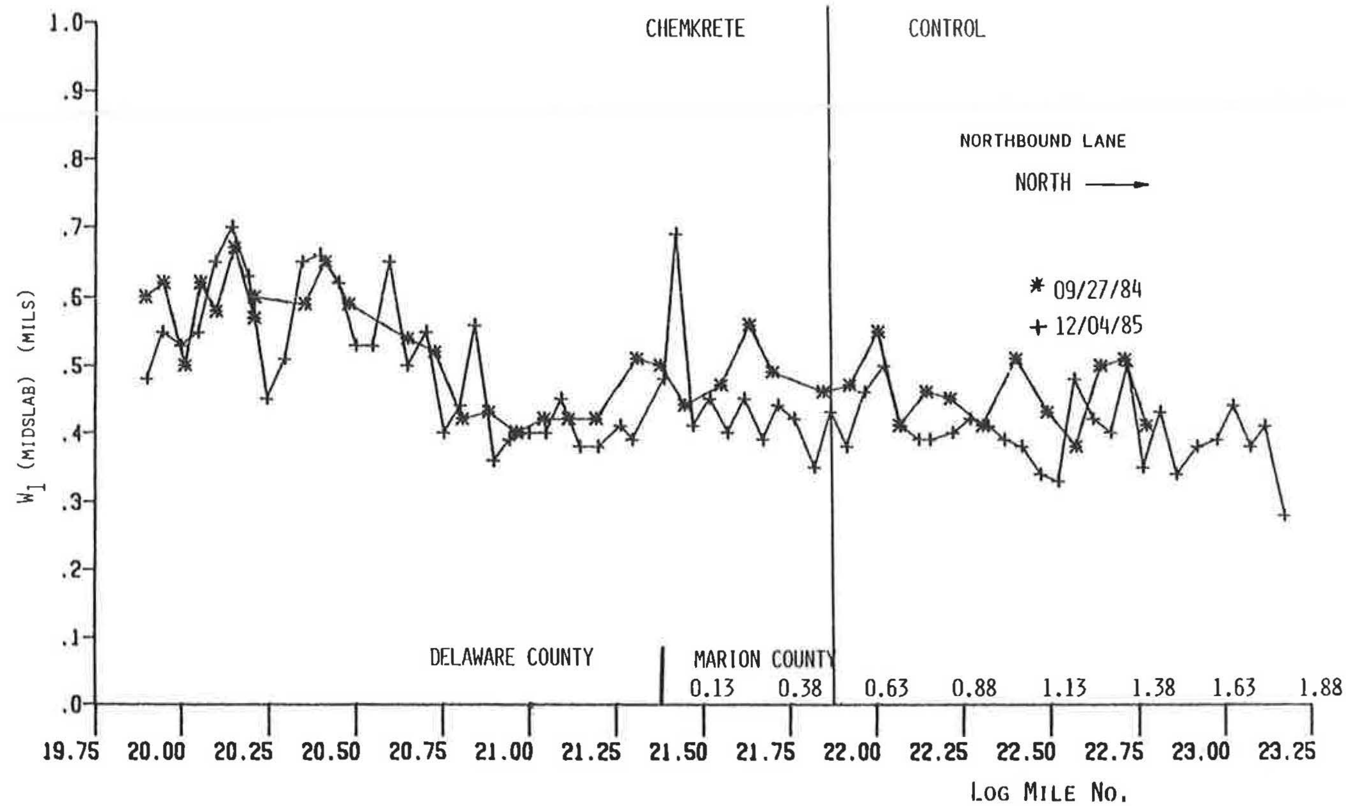


FIGURE 1 First sensor Dynaflect deflections along the Chemkrete and control sections.

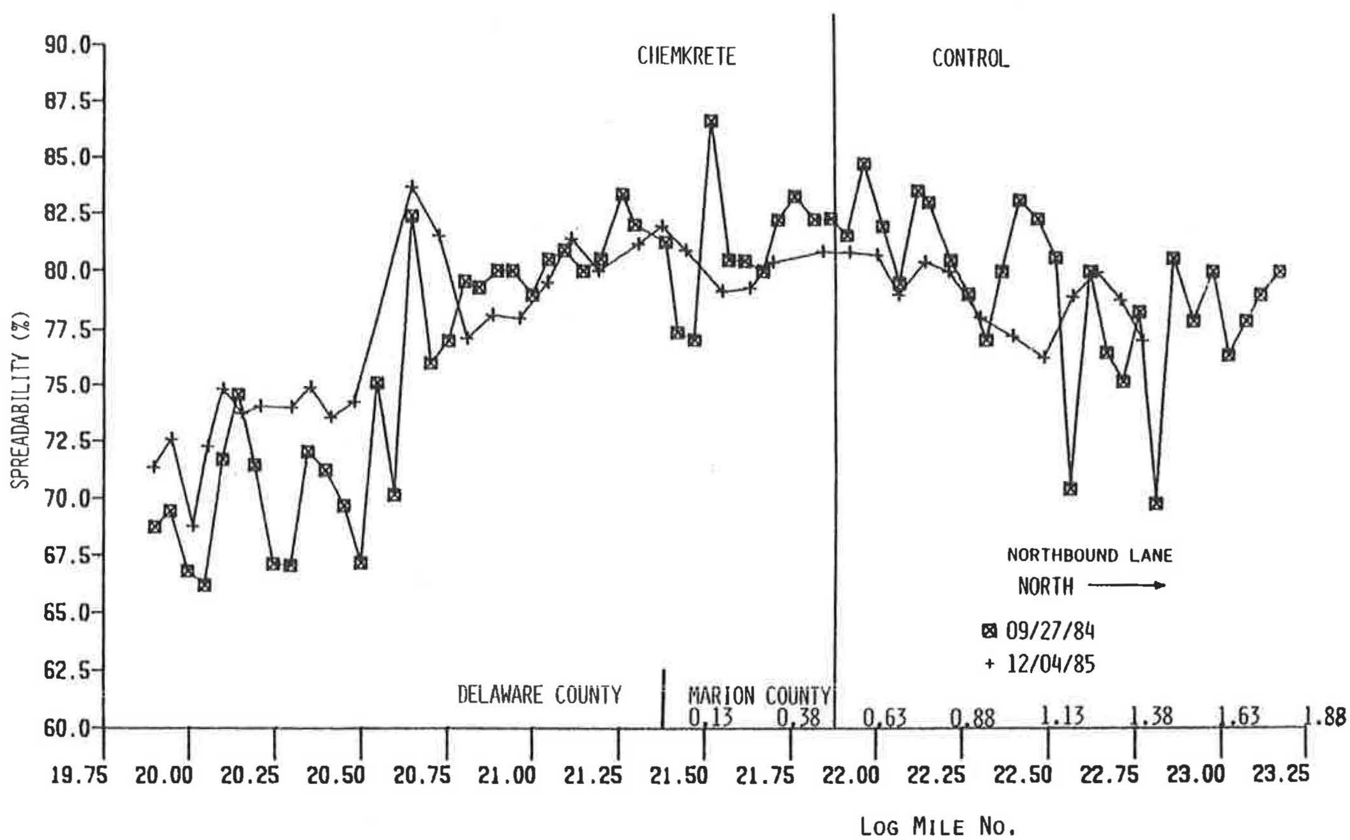


FIGURE 2 Spreadability (from Dynaflect measurements) along the Chemkrete and control sections.

in the relative performance of the Chemkrete and control sections with time and additional traffic.

The observation of the deflection measurements obtained with the first sensor, *W*1 (see Figure 1), generally indicated that higher deflections (less favorable) were obtained on the Chemkrete-treated section than on the control section. Near the boundary between the Chemkrete and control sections, the variations in *W*1 and spreadability were less than at stations farther apart. This result may indicate the influence of subgrade variability on the Dynaflect deflection measurements. Spreadability values were, in general, lower on the Chemkrete section (also less favorable) than on the control section as shown in Figure 2. Dynaflect testing results indicate slightly more favorable values on the conventional AC than on the Chemkrete-treated section.

Laboratory Testing of Field Cores

Field-extracted cores from both the Chemkrete-modified and control sections were subjected to resilient modulus, Marshall stability, indirect tensile strength, fracture toughness, creep compliance, and fatigue tests. All extracted cores were 4 in. in diameter and extended through both the wearing and leveling courses. In some cases, it was difficult to drill through the leveling course because some of the cores crumbled during extraction, probably from lack of adequate compaction during construction or lack of adequate curing. Wearing course specimens, in some cases, were also thinner than 1 in., which presented difficulties in the testing of the disc-shaped specimens.

The diametrical modulus of resilience is commonly applied to asphaltic mixtures. A dynamic load of known duration and magnitude (below the indirect tensile strength of the sample) is applied across the vertical diameter of a Marshall-sized specimen, and the elastic deformation across the horizontal diameter is measured with displacement transducers. The resilient modulus M_r is calculated using the equation

$$M_r = \frac{P\,(\mu + 0.2734)}{\Delta t} \quad (2)$$

where

P = magnitude of dynamic load,
μ = Poisson's ratio,
t = specimen thickness, and
Δ = total deformation.

The ultimate strength of asphaltic mixtures under an indirect tensile stress field is obtained after diametrically applying a vertical load, at a rate of advance of the load piston of 0.065 in./min, until the maximum load (yield strength) that the specimen is able to withstand is reached. The indirect tensile strength σ_y is calculated using the equation

$$\sigma_y = \frac{2P}{\pi D t} \quad (3)$$

where

P = maximum load (lb),
D = specimen diameter (in.), and
t = specimen thickness (in.).

Both resilient modulus and indirect tensile strength tests were conducted at 40°F, 70°F, and 100°F to account for temperature influences expected during the life of the pavement. Some of the specimens tested for resilient modulus and indirect tensile strength were subjected to Lottman's accelerated moisture damage system to determine their durability under freezing and thawing. The procedure consists of the vacuum saturation of Marshall-sized specimens after which they are subjected to freezing at 0°F for 15 hr while the specimens are wrapped, followed by their submersion in a 140°F distilled water bath for 24 hr.

The Ohio State University procedure was used to determine the fracture toughness K_{1c} of Marshall-sized specimens. The method consists of cutting a right-angled wedge into a Marshall-sized specimen and initiating a crack (usually 0.25 in. long) at the apex of the notch. The specimen is set on a base with the notch pointing upwards, and a vertical load is applied to it through a three-piece set-up consisting of two plates (placed against the sides of the wedge) and a semicircular rod placed between the two plates to transmit the load by wedging to the sides of the notch. The results of tests conducted at room temperature allowed the calculation of K_{1c} from the equation

$$K_{1c} = \frac{P}{t}\,(0.92 + 0.284c + 0.552_c^{\,2}) \quad (4)$$

where

P = maximum applied load (lb),
t = specimen thickness (in.), and
c = initial crack length (in.).

The fracture toughness test provides pavement engineers with an additional parameter for evaluating cracking potential (one of the controlling asphalt pavement design criteria). K_{1c} is a material constant independent of crack geometry, loading conditions, or other physical variables (*11*).

The creep compliance and permanent deformation tests have been developed to determine the long-term effects of static and dynamic loads on the behavior of asphaltic mixtures. The contribution of asphaltic layers to rutting is measured in the laboratory by testing cylinders in dynamic compression or static creep, as specified in the VESYS II User's Manual (*12*). The procedure includes an incremental static-dynamic test in which specimens measuring 4 in. in diameter by 8 in. in height are used to determine the primary response, expressed as the creep compliance function, and the permanent deformation properties of asphaltic mixtures.

The permanent deformation properties are derived from incremental static-dynamic compression tests to define the fraction of the predicted total strain that is permanent, as a function of load cycles. The permanent strain, measured during the test, is plotted versus the number of load repetitions on a log-log scale, and a straight line is drawn to approximate the permanent strain within the expected range of loading. The permanent deformation properties are characterized by the parameters μ and α, defined as

$$\alpha = 1 - s \quad (5)$$

$$\mu = \frac{Is}{\varepsilon_{200}} \quad (6)$$

where

s = slope of the drawn line,
I = intercept at one load repetition, and
ε_{200} = resilient strain at the 200th load repetition.

The standard-sized specimen designated by the VESYS II procedure (cylindrical specimens, 4 in. in diameter by 8 in. in height) has been modified to accommodate field cores using specimens 4 in. in diameter by 1¼ to 1¾ in. in height. Values obtained from creep compliance and permanent deformation tests are used in conjunction with the VESYS III computer model to predict the amount of rutting in the treated and untreated pavements after a defined period of time.

Fatigue tests are useful in developing damage functions for the design of AC pavements when pavement failure by fatigue is identified as the design control factor. Results of fatigue testing were statistically analyzed to develop regression equations for damage functions of the form

$$N_f = K(1/\sigma)^n \quad (7)$$

where

N_f = number of load applications to failure,
σ = applied stress, and
K, n = regression constants.

Three sets of cores each were obtained at the Chemkrete and control sections to determine changes in engineering properties with time and traffic. The cores were obtained in September 1984, October 1985, and October 1986. It was particularly difficult to obtain enough intact cores in September 1984, because they crumbled during extraction. As previously indicated, this behavior probably results from insufficient curing of the mixture. Tables 4 and 5 present the results of laboratory testing of cores obtained in October 1985. These tables represent typical behavior observed at different sampling periods. A complete summary of all testing conducted at each sampling period has been provided by ODOT (*13*).

Test results indicate that specimens obtained from the control section yield, in general, slightly more desirable results than specimens obtained from the Chemkrete-treated section.

TABLE 4 PHYSICAL AND ENGINEERING PROPERTIES OF FIELD CORES AND WEARING COURSE CORES OBTAINED OCTOBER 1985

PARAMETER	UNTREATED	CHEMKRETE TREATED
	Average Value	Average Value
Thickness (in)	1.36 NB	1.36 NB
	1.08 SB	1.35 SB
Unit Weight (pcf)	142.1 NB	142.3 NB
	141.4 SB	143.9 SB
MR @ 40^oF ($x10^6$psi)	2.19	1.32
MR @ 70^oF ($x10^6$psi)	1.39	0.76
MR @ 70^oF ($x10^6$psi) (a)	1.31	0.75
MR @ 70^oF ($x10^6$psi) (b)	0.69	0.38
MR @ 100^oF ($x10^6$psi)	0.26	0.14
σ_y @ 70^oF (psi)	193	96
σ_y @ 70^oF (psi) (a)	208	109
σy @ 70^oF (psi) (b)	117	60
K_{1c} (psi $\sqrt{in}$)	917	419

(a) Vacuum Saturation Only

(b) Freeze and Thaw (Lottman's Procedure)

NB = Northbound Lane Specimens

SB = Southbound Lane Specimens

TABLE 5 PHYSICAL AND ENGINEERING PROPERTIES OF FIELD CORES AND LEVELING COURSE CORES OBTAINED OCTOBER 1985

PARAMETER	UNTREATED	CHEMKRETE TREATED
	Average Value	Average Value
Thickness (in)	1.81 NB	1.82 NB
	2.37 SB	
Unit Weight (pcf)	143.1 NB	145.7 NB
MR @ 40^{o}F ($x10^{6}$psi)	1.84	1.87
MR @ 70^{o}F ($x10^{6}$psi)	1.10	0.90
MR @ 70^{o}F ($x10^{6}$psi) (a)	0.91	1.01
MR @ 70^{o}F ($x10^{6}$psi) (b)	0.76	0.60
MR @ 100^{o}F ($x10^{6}$psi)	0.28	0.15
σ_y @ 70^{o}F (psi)	171	121
σ_y @ 70^{o}F (psi) (a)	190	171
σy @ 70^{o}F (psi) (b)	114	70
K_{1c} (psi $\sqrt{}$in)	600	418

(a) Vacuum Saturation Only

(b) Freeze and Thaw (Lottman's Procedure)

NB = Northbound Lane Specimens

SB = Southbound Lane Specimens

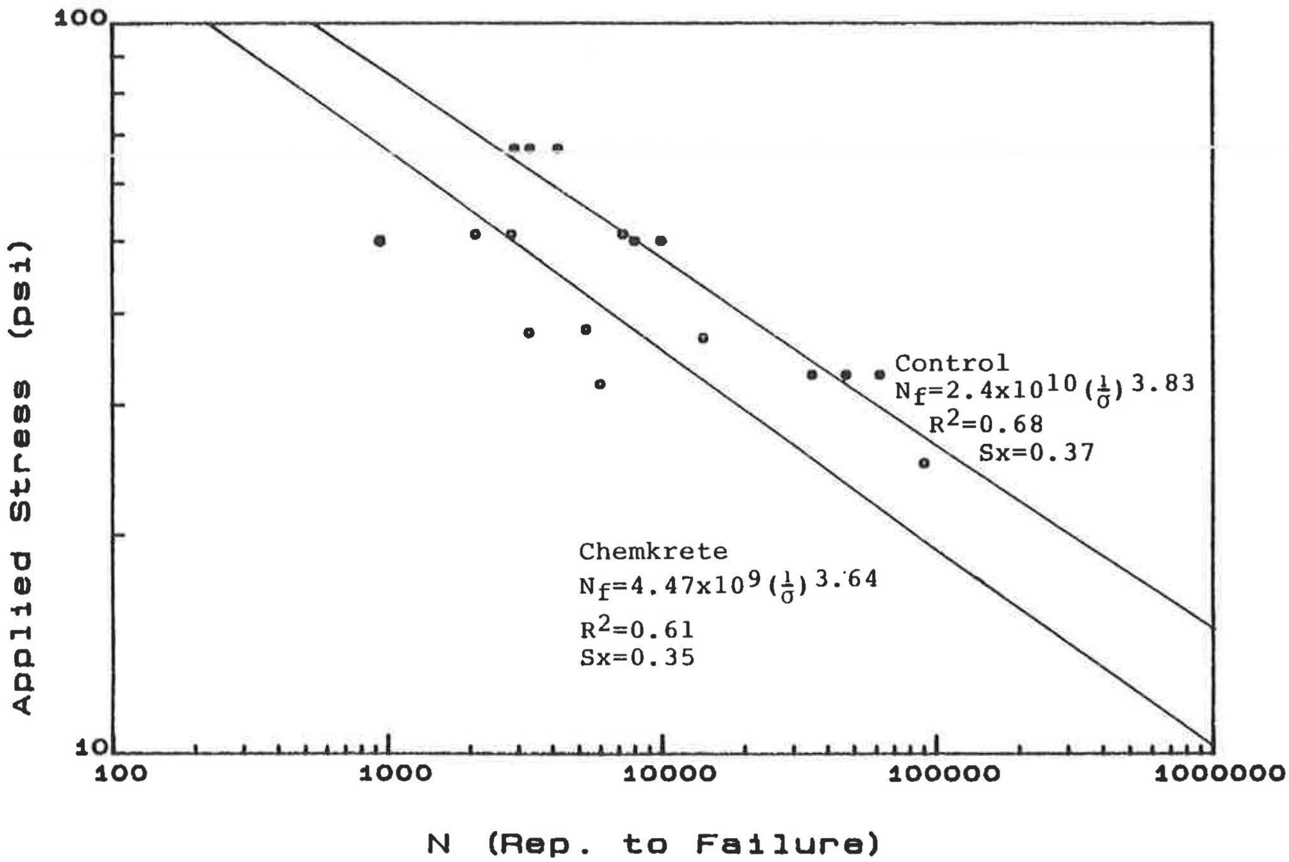
This conclusion is based on the comparison of test results of resilient modulus, indirect tensile strength, fracture toughness, and Marshall stability.

In addition to testing, field-obtained cores were subjected to fatigue testing to compare the relative performance of the Chemkrete-treated and conventional AC pavement sections. Fatigue testing was performed on leveling and wearing course cores and the results are shown in Figures 3 and 4 for cores obtained in October 1986. Similar trends were observed on the fatigue testing of cores obtained in October 1985, and the corresponding results have also been provided by ODOT (*13*). No fatigue testing was performed on cores obtained in September 1984 because of the difficulty in obtaining sufficient intact specimens. Regression equations following the form of Equation 7, their coefficient of determination R^2, and their standard error of estimate Sx are shown next to the corresponding curves, when appropriate. These curves indicate that cores from the control sections performed substantially better than cores from the Chemkrete-treated sections. These cores already had some accumulated fatigue damage from the applied traffic between the time of construction and the time of testing.

Pavement deformation characteristics of field-compacted, Chemkrete-treated, and conventional (control) AC were investigated through creep compliance and permanent deformation tests, as previously described. The average results of three specimens tested for each type of mixture are presented in Table 6. These results were used in conjunction with the VESYS III computer model to obtain expected rut depths versus time along the Chemkrete-treated and control sections. Layer properties used in the VESYS III analyses are presented in Table 7. The control section generally exhibited more desirable permanent deformation characteristics than the Chemkrete-treated section. The calculated rut depths (through VESYS III analyses and shown in Figure 5) along the Chemkrete-treated section are approximately double the magnitude of those of the control section.

SUMMARY AND CONCLUSION

Results of laboratory tests performed on field-procured cores indicated better performance of the control specimens than that of the Chemkrete-treated specimens. Properties such as



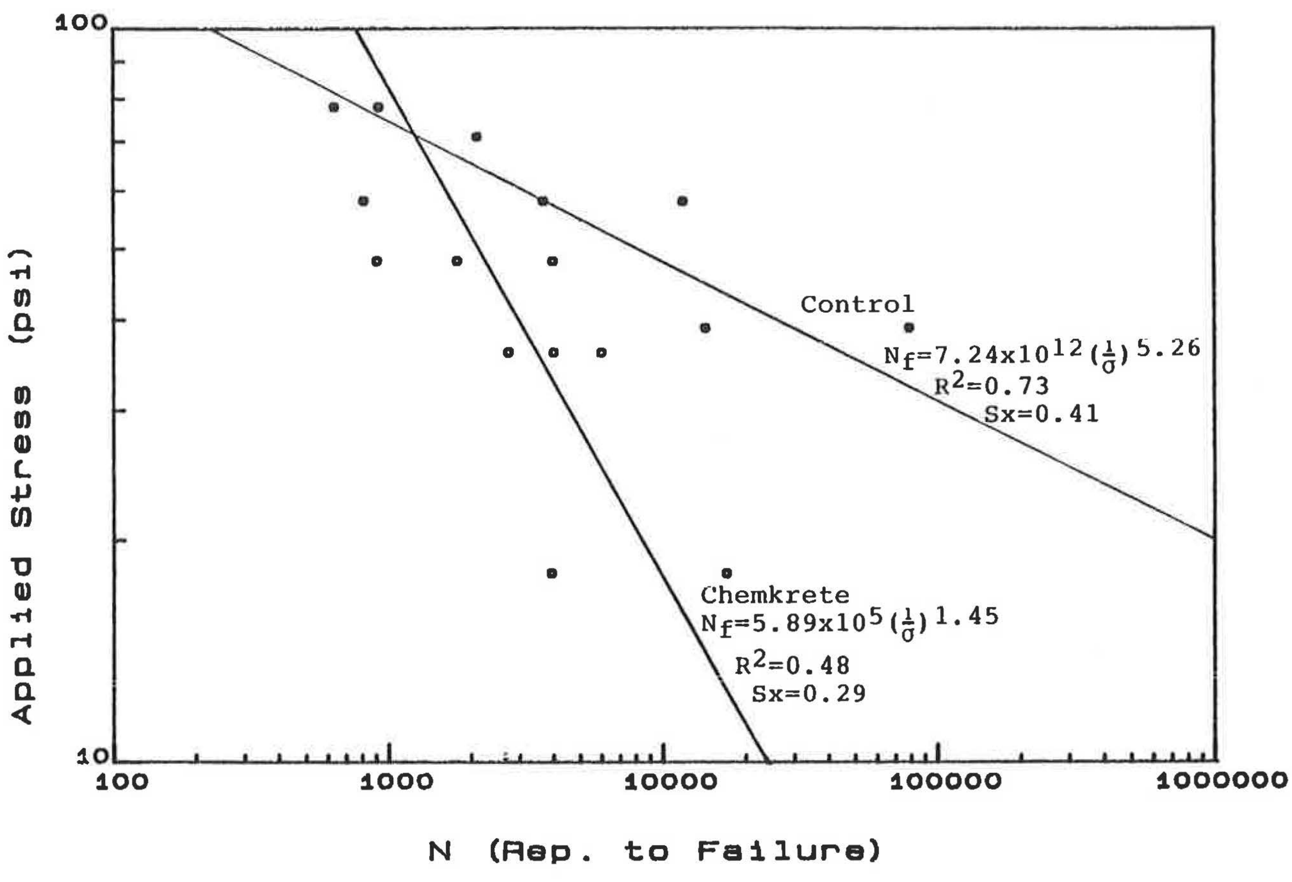


FIGURE 4 Fatigue curves (leveling course cores obtained October 1986).

TABLE 6 CREEP COMPLIANCE TEST RESULTS

Course	Section	I *10^{-6}	s	ϵ_{200} *10^{-6}	μ	α
Wearing	Chemkrete	3.47	0.49	3.95	0.43	0.51
	Control	0.91	0.56	2.32	0.22	0.44
Levelling	Chemkrete	4.17	0.47	4.32	0.45	0.53
	Control	1.23	0.31	2.30	0.17	0.69

* Refer to Equations 5 and 6 for Symbol Equivalencies.

TABLE 7 MATERIAL PROPERTIES FOR VESYS III ANALYSES

Layer		Thickness (in)	Mr *10^6 (psi)	μ	α
ODOT 404	Chemkrete	1.25	1.06	0.43	0.51
	Control	1.25	1.27	0.22	0.44
ODOT 402	Chemkrete	1.75	0.63	0.45	0.53
	Control	1.75	0.99	0.17	0.69
PCC		9.00	3.60	0.10	0.95
Gravel Base		6.00	0.07	0.05	0.60
Subgrade		Semi- Infinite	0.02	0.0075	0.85

* Refer to Equations 5 and 6 for Symbol Equivalencies

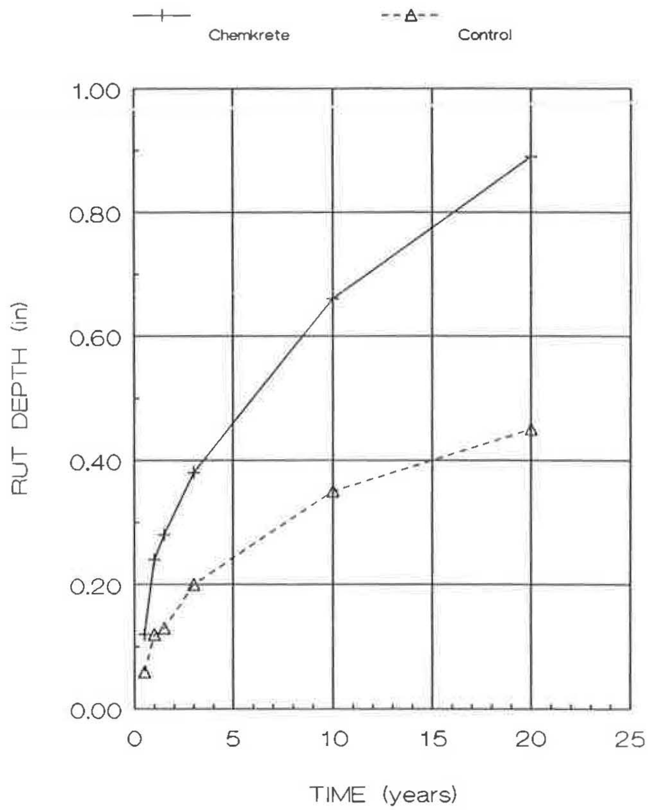


FIGURE 5 Predicted rut depth (VESYS III analyses).

modulus of resilience, indirect tensile strength, and fracture toughness were consistently higher on the control specimens than on the Chemkrete-treated specimens. Control section cores also exhibited longer fatigue life and more desirable creep and permanent deformation characteristics than Chemkrete-treated section cores. VESYS III computer model rut depth calculations also indicated predicted rut depths of approximately twice the magnitude along the Chemkrete-treated section than along the control section.

Dynaflect deflection measurements also indicated a slightly better performance on the control section than on the Chemkrete-treated section. The difference, however, was almost imperceptible in measurements obtained near the boundary of the two sections. Subjective field observations (PCR) also indicated a slightly better performance of the control section than that of the Chemkrete-treated section. Because both Chemkrete-treated and control sections had the same overlay thickness, no apparent beneficial gains are obtained in the performance of AC mixtures with the addition of Chemkrete to the AC.

No significant gains in the engineering properties of AC mixtures are obtained with the addition of Chemkrete, consistent with experience in other states, as previously discussed. Laboratory testing of field-obtained cores subjected to similar climatic and traffic conditions indicates that Chemkrete appears to adversely affect the engineering properties of AC. This behavior may be attributed to the lack of proper curing within a reasonable period of time before the road is opened to traffic.

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