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16. Abstract

Laboratory experiments were conducted to determine the feasibility and effects of applying a coating of portland cement paste to marginal aggregates and curing prior to use in hot mixed asphalt concrete. Aggregates ranging in size from fine sand to one-inch rock were separately coated with cement, cured, and then blended to produce the desired mixture design. Laboratory specimens were prepared and tested. Tests included Hveem and Marshall stability, resilient modulus as a function of temperature, indirect tension, moisture susceptibility, creep, and permanent deformation.

Laboratory test results showed that asphalt mixtures made using coated aggregate exhibited higher Hveem stability and lower creep compliance than similar uncoated mixtures. This is indicative that the cement coating process will decrease the rutting potential of asphalt mixtures made with marginal aggregates. No other mixture properties were consistently improved. Abrasion during mixing and compaction of the laboratory specimens removed a significant portion of the cement coating.

Full-scale cement coating tests were successfully performed in the field. Test pavements using similar uncoated and coated aggregates were constructed. It was determined that approximately 95 percent of the cement coating was removed from the aggregates during routine handling of the aggregates and plant mixing operations.

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CEMENT COATING MARGINAL AGGREGATES FOR USE IN ASPHALT PAVEMENTS

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Research Report 1253-1F

Submitted by

Texas Transportation Institute
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Sponsored by

Texas Department of Transportation

November, 1992

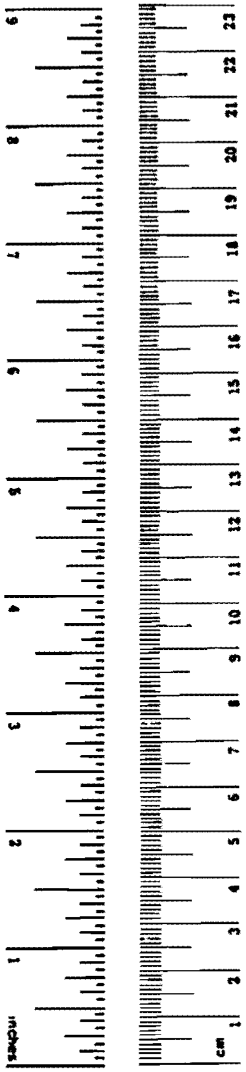
METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	2.54	centimetres	cm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in²	square inches	645.2	centimetres squared	cm ²
ft²	square feet	0.0929	metres squared	m²
yd²	square yards	0.836	metres squared	m²
mi²	square miles	2.59	kilometres squared	km²
ac	acres	0.395	hectares	ha
	MASS (weight)			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft³	cubic feet	0.0328	metres cubed	m³
yd³	cubic yards	0.0765	metres cubed	m³

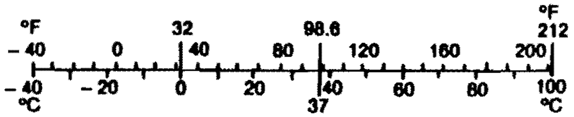
NOTE: Volumes greater than 1000 L shall be shown in m³.

	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm²	millimetres squared	0.0016	square inches	in²
m²	metres squared	10.764	square feet	ft²
km²	kilometres squared	0.39	square miles	mi²
ha	hectares (10 000 m²)	2.53	acres	ac
	MASS (weight)			
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m³	metres cubed	35.315	cubic feet	ft³
m³	metres cubed	1.308	cubic yards	yd³
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

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* SI is the symbol for the International System of Measurements

SUMMARY

Recent developments of a technique for cement coating of gravel type aggregates prior to use in hot mix asphalt concrete showed promising results in the laboratory. The basic principle of this process is to create a rough-textured surface on the aggregate particles in order to promote adhesion between asphalt binder and the aggregate particles and significantly increase the interparticle friction of a paving mixture, which improves the shear strength of the mix and thus increases the load bearing capacity of the aggregate-binder mixture.

The primary objectives of this study was to establish practical field operations for the aggregate coating process and for utilization of the modified aggregates in hot mixed asphalt concrete and to examine the economic feasibility of the overall process. Laboratory and field experiments were conducted to determine the effects of applying a coating of portland cement paste to marginal aggregates and curing prior to use in hot mixed asphalt concrete. Aggregates ranging in size from fine sand to one-inch rock were separately coated with cement, cured, and then blended to produce the desired mixture design. Laboratory specimens were prepared and tested. Tests included Hveem and Marshall stability, resilient modulus as a function of temperature, indirect tension, moisture susceptibility, creep, and permanent deformation.

Laboratory test results showed that asphalt mixtures made using coated aggregate exhibited higher Hveem stability and lower creep compliance than similar uncoated mixtures. This is indicative that the cement coating process will decrease the rutting potential of asphalt mixtures made with marginal aggregates. No other mixture properties were consistently improved. Abrasion during mixing and compaction of the laboratory specimens removed a significant portion of the cement coating.

Full-scale cement coating tests were successfully performed in the field. Test pavements using similar uncoated and coated aggregates were constructed. It was determined that approximately 95 percent of the cement coating was removed from the aggregates during routine handling of the aggregates and plant mixing operations. The process is not recommended for implementation.

IMPLEMENTATION STATEMENT

Laboratory and field evaluations of a process to coat marginal aggregates with portland cement prior to use in hot mixed asphalt concrete were performed. Laboratory test results indicated the coating process will improve shear strength of asphalt paving mixtures which is indicative of improved pavement rutting resistance. However, in the field, standard aggregate handling and mixing procedures abraded away about 95 percent of the cement coating. Therefore, the cement coating process is not recommended for implementation at this time.

Texas DOT specification Items 300, 292, and 340 and standard mixture design procedures can be used successfully when cement coated aggregates are employed. Design guidelines for using the cement coating process are provided herein.

Asphalt mix plant operations require significant modifications. A pug mill or other suitable mixing equipment must be available and capable of metering in portland cement and water and mixing them with the aggregates. These treated aggregates must be stockpiled and allowed to cure for a minimum of two days. Then the treated aggregates are used in the normal fashion to produce, place, and compact hot mix asphalt.

If an aggregate is unsuitable for use in a pavement surface course because of potentially poor surface friction, the cement coating process cannot be used to upgrade the aggregate such that it will provide adequate skid resistance. The cement coating will be quickly be worn away by the action of traffic.

A coating process for upgrading marginal aggregate for use in hot mixed asphalt concrete has the potential to save transportation construction and/or rehabilitation funds at selected locations where it is necessary to haul suitable quality aggregates for long distances. A successful coating process could qualify normally unsuitable aggregates from many local sources thus conserving higher quality aggregates, reducing transportation costs, and ultimately saving substantial public funds. When comparing the cost of HMAC containing high quality aggregate with that of HMAC containing cement coated local aggregate, it is estimated that a maximum savings approaching 10 percent can be realized when the haul distance for the high quality aggregate is the maximum required in Texas.

The only problem observed in this study was the lack of toughness or abrasion resistance of the cement coating. Research is needed to develop a more abrasion resistant and yet cost effective coating.

DISCLAIMER

This report is not intended to constitute a standard, specification or regulation and does not necessarily represent the views or policy of the FHWA or Texas Department of Transportation. Additionally, this report is not intended for construction, bidding, or permit purposes.

ACKNOWLEDGEMENTS

Mr. Paul Krugler of the Texas DOT Materials and Tests Division (D-9) served as chairman of the Technical Panel for this research project. His assistance in obtaining aggregates for testing in the study and in the prosecution of the work is hereby gratefully acknowledged.

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Laboratory testing at TTI was performed by Messrs. Mark Simmons, Sidney Greer, Eric Isbell, and Gene Schlieker.

Assistance in preparing this manuscript was received from Mmes. Lupe Fattorini, Cathy Bryan, and Bea Cullen.

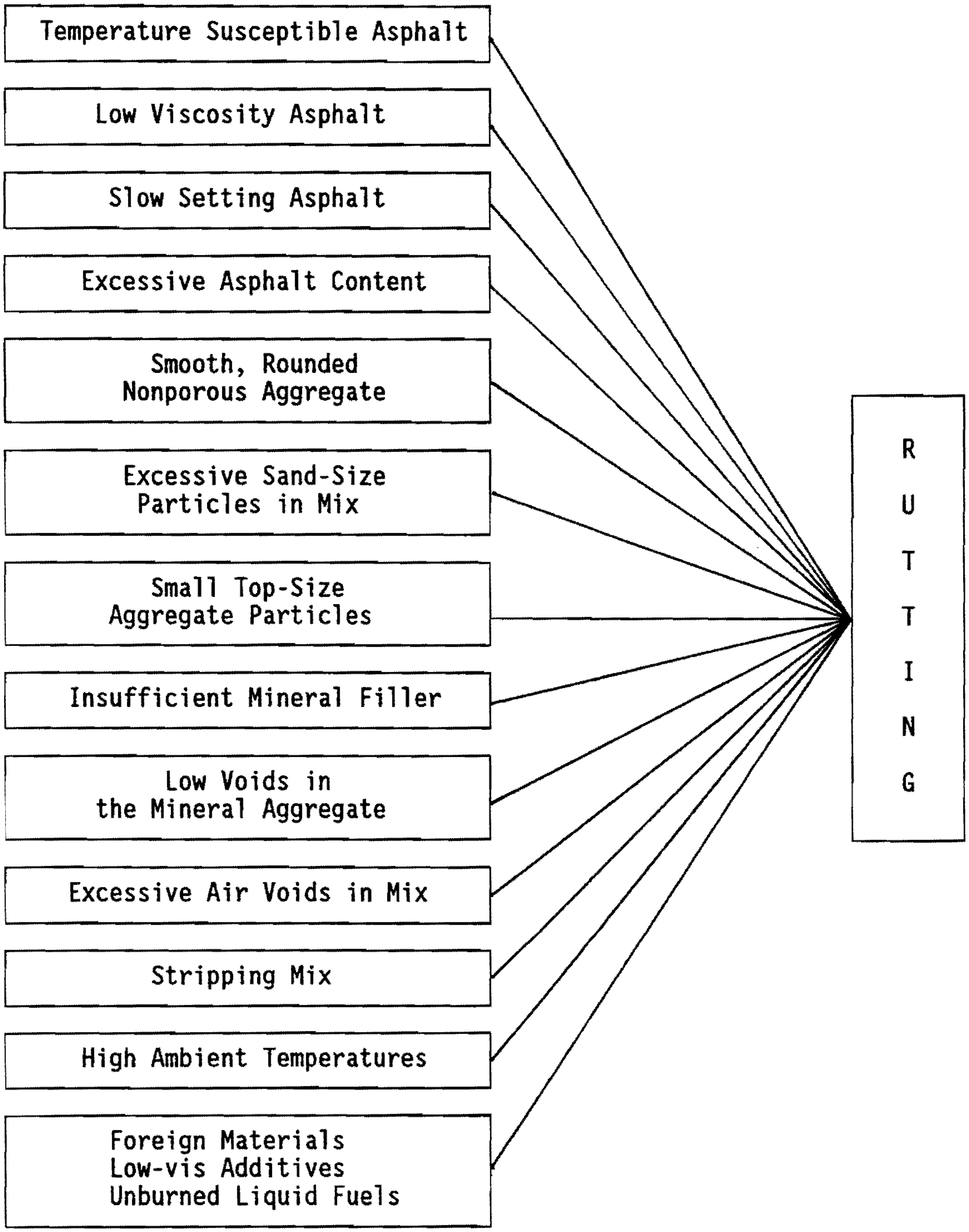

Figure 1. Factors Contributing to Rutting.

For finer aggregates (less than 0.2 inches in diameter) and sands, 7 percent cement by weight of aggregate was seen to be an adequate quantity for producing well coated non-sticking particles.

Water Content

The water content required for an optimum coating is the sum of the amount of water needed to bring the aggregate to saturated surface dry condition and the amount of water needed for cement hydration (1). The amount of water added was shown to be critical. An excessive amount of water resulted in non-uniform coating while an inadequate amount resulted in very weak cement coating (cement not completely hydrated) which was subject to loss by abrasion. The amount of water added was calculated using (1):

$$W = 0.2C + (W_a - W_n) * \text{Aggregate weight}$$

where

W_a = water absorption of the aggregate and
W_n = natural water content of the aggregate.

Hydration Time

A two day time period is reported by Bayomy et al.(1) to be the minimum required to allow for cement hydration and to ensure permanent adhesion of the cement film on particle surfaces. This was verified by testing in this study.

ASPHALT MIXTURE DESIGN

The optimum asphalt content (one which produces compacted specimens of approximately 4 percent air voids with Hveem stabilities of at least 35) was determined for each mix. The Texas gyratory compactor was used to prepare the specimens and the compaction procedures conformed to the specifications of TEX-206-F. Mixture design was performed in accordance with TxDOT Construction Bulletin C-14.

SAMPLE PREPARATION

After selecting the proper aggregates, they were batched according to the required gradation and dried overnight at 140°F (60°C). The aggregates were then cooled, and the prescribed amounts of cement and water were added. The blend was then mixed thoroughly in a Hobart mixer for about 90 seconds and then stored in covered pans for 48 hours to cure. The pans were covered to minimize evaporation before the cement completely hydrated. The cement coating was visually inspected to determine if the aggregates tended to lump or stick together. If the coated and cured aggregate was suitably friable, it was used to prepare asphalt mixtures.

Each aggregate size used in a given blend to produce the asphalt mixtures was treated separately with the prescribed quantity of portland cement. The aggregates were then blended in accordance with the design for the different mixture types (i.e., Lab Standard, District 21, District 5, and District 17) to produce the asphalt mixtures. Throughout the study, the TxDOT method of mix design was adopted.

Two different sizes of specimens, two inch and eight inch, were prepared for the experimental work. Two-inch height by four-inch diameter specimens were prepared using the Texas gyratory compactor for the basic stability, stiffness, strength, and water susceptibility tests.

Eight-inch height by four-inch diameter specimens were prepared for the creep tests. Asphalt mixtures were compacted to the desired dimensions in three lifts with a different number of blows in each lift. A specially formulated compaction procedure was employed to ensure isotropy in the axial direction. These specimens were compacted at 275°F using the California kneading compactor. The desired air void content was four percent plus or minus one percent, however, this could not always be obtained with this compactor. Nevertheless, specimens containing similar uncoated and coated materials were compacted to approximately the same air void level. The creep samples were then sulfur capped at both ends to ensure a flat loaded surface perpendicular to the sample axis.

All specimens were left undisturbed at room temperature for a minimum of three days prior to testing to allow relief of any residual internal stresses from the compaction process. They were transferred to the proper temperature environment for about four hours prior to testing.

DESCRIPTION OF LABORATORY TESTS

Durability of Cement Coating

It was noticed during sample preparation that a significant amount of the cured cement coating on the aggregate was abraded away. Therefore, the condition of the cement coating before and after mixing was carefully scrutinized using the scanning electron microscope. Three treatments were examined: 1) uncoated aggregate, 2) aggregate freshly coated with portland cement, and 3) coated aggregate that had been heated, mixed with asphalt, compacted in the laboratory, and extracted with solvent.

Polish Value

Standard polish value testing was performed by the TxDOT on uncoated and coated aggregate to aid in determining the suitability of treated aggregate for use in pavement surface courses. Friction values were measured on the original aggregates as received and after the standard polishing procedure prescribed in Tex-438-A. Values before and after polishing were compared to determine the durability of the cement coating and assess the contribution to pavement surface friction.

Resilient Modulus

Resilient modulus is a measure of the ability of a material to absorb energy when deformed elastically and recover when unloaded. The resilient modulus test (17) is described in detail in ASTM Method D 4123-82. It is a nondestructive test which measures mixture stiffness of cylindrical specimens two inches in height and four inches in diameter at a given temperature. It was determined using the Mark III Resilient Modulus Device developed by Schmidt. A diametrical load approximately 72 pounds was applied for a duration of 0.1 second while monitoring the diametrical deformation perpendicular to the plane of loading. The load is normally reduced to about 20 pounds for tests performed at 100°F or higher to prevent damage to the specimen. Resilient modulus was determined over a range of temperatures (from 0°F to 104°F), to account for relative temperature susceptibility of the paving mixtures (18, 19, 20).

Stability Tests

Hveem and Marshall stability tests were conducted at 140°F in accordance with Tex-208-F and ASTM D1560, respectively. The samples were prepared using the Texas gyratory compactor and the compaction effort was varied in order to obtain samples with similar air void contents for both the uncoated and coated aggregates.

Indirect Tension Test

The indirect tension test (Tex-226-F) employs an indirect method of measuring mixture tensile properties. The two inch tall and four inch diameter cylindrical specimens were loaded diametrally at a constant rate of deformation until complete failure occurred. Diametral deformation perpendicular to the loaded plane was monitored in order to examine mixture toughness. These tests were conducted at a temperature of 77°F and a rate of deformation of two inches per minute.

Moisture Susceptibility

For pavements utilizing low quality aggregates, moisture susceptibility is often a serious problem. This is due to the fact that smooth rounded aggregates tend to form very weak mechanical bonds with the binder. The two modes of failure leading to moisture induced damage, have been identified as adhesive failure and cohesive failure (21). Adhesive failure occurs as a complete or a partial separation of the asphalt film from the aggregate surface in the presence of moisture; whereas, cohesive failure is a cleavage within the asphalt or mastic.

Cohesive failure potential is normally reduced by increasing the asphalt content in the mix. Adhesive failure potential is normally reduced by increasing the roughness of the aggregate surface (surface texture) to facilitate improved mechanical bonding. In addition, the cement coating should change the surface chemistry of the aggregate particles making them more lipophilic, thus giving preference to asphalt instead of water. Based on these definitions, cement coating of aggregates should improve both cohesive and adhesive strength of resulting asphalt mixtures.

A ratio of tensile strength before and after exposure to moisture is a measure of the asphalt mixture's resistance to moisture damage (22, 23). Moisture sensitivity of the specimens was evaluated in accordance with Tex-531-C.

Creep/Permanent Deformation Tests

Rutting, characterized by permanent deformation in the wheelpath of the upper layers of a flexible pavement, is of primary concern in the design of flexible pavements which are subjected to heavy and/or frequent traffic loads and high pavement temperatures. Rutting potential in particular receives a lot of consideration when the pavement is constructed with low quality aggregates which are not capable of producing an adequate interlock and thus shear strength. The major parameters that influence rut depth are:

i) Material properties of the asphalt mixture,
ii) Maximum applied load,
iii) Frequency of loading,
iv) Asphalt mixture temperature, and
v) Compaction density

To accurately predict rut depth in a pavement it is necessary to consider all the above factors. In this study, however, the evaluation of rutting potential was limited to a comparative study of the material properties of laboratory compacted asphalt mixtures containing uncoated and coated aggregate. It can be assumed that all other ambient conditions would exhibit similar relationships between asphalt mixtures made using untreated and treated aggregates.

Time dependent deformation behavior of the uncoated and cement coated aggregate in asphalt concrete samples was evaluated by conducting a series of laboratory tests on four-inch diameter by eight-inch tall specimens. Dynamic testing, carried out to simulate moving traffic, consisted of repeated axial haversine loading. The test involved a loading pulse with a frequency of one Hertz applied 10,000 times then followed by a rest period when the load is zero for 1000 seconds. The loading pulse consisted of a 0.05 second load linearly increasing to a predetermined maximum normal stress, a 0.05 second load linearly decreasing to zero psi and a 0.9 second recovery period.

Two to three specimens each of four different aggregates were tested at three different levels of stress. Careful attention was given to controlling air voids of the specimens tested so that the only variable would be the condition of the aggregate surface.

EXPERIMENTAL RESULTS

Laboratory tests were performed on asphalt mixtures containing uncoated and coated aggregates from three different locations in Texas. Cement coating of aggregates was performed in accordance with the instructions in the previous section.

Two field trials were constructed and the materials used in these field trials were tested in the laboratory. A detailed description of the test pavements and their construction is given in the next section. Laboratory tests were conducted on two types of field samples: plant mixed-laboratory compacted and pavement cores.

TESTS ON AGGREGATES

Gradation

Three or more aggregates were blended to produce the four job mix formulas used for evaluating the asphalt concrete mixture designs. When the aggregates were blended in accordance with the job mix formulas, the resulting gradings were as shown in Figures A1 through A4 in Appendix A.

Early in the study, there was concern that cement coating of fine grained materials might create irreversible agglomerations and thus significantly change the aggregate grading. Therefore, an aggregate composed of river gravel, sand, and silt was coated with cement. Each size range was coated separately with the prescribed quantity of cement and allowed to cure. After mixing uncoated and coated aggregate with asphalt cement and compacting specimens in the laboratory, the asphalt was extracted using solvent, and the gradations of the aggregates were determined (Figure A5). Results show a slight reduction in the material passing the sieves smaller than a No. four sieve but no significant change in the aggregate grading due to the cement coating process. It was concluded that the mixing and compaction processes broke apart the cemented particles such that the design gradation was not seriously altered.

Durability of Cement Coating

It was noticed that a major portion of the cement coating was worn off the aggregate surfaces during preparation of laboratory specimens of asphalt concrete. This loss of cement coating occurred with the aggregates from all three sources used in the laboratory study. It was concluded that the vast majority of the loss occurred from abrasion during the highly kinetic asphalt mixing process and that possibly a little more subsequently occurred during compaction.

The scanning electron microscope (SEM) was used to carefully inspect aggregate surfaces of uncoated aggregate, coated aggregate, and aggregate that had been coated, mixed with asphalt, compacted, and extracted with solvent. It is estimated that 50 to 75 percent of the cement coating was removed from the plus No. four sieve size aggregate during routine laboratory mixing and compaction. Three different aggregate sizes were examined which included the following standard sieve sizes: 1) 1/2 inch to 3/8 inch, 2) No. 30 to No. 50, and 3) minus No. 200; these were coated with 4.3 percent, seven percent, and seven percent cement, respectively. The sand-size particles appeared to retain the cement coating slightly better than the larger aggregate. It was often difficult to distinguish between the minus No. 200 aggregate particles and the cement particles in the electron microscope, therefore, the examination of coating loss for these small sizes was inconclusive. Selected photomicrographs from the SEM study are presented in Figures 6 through 11.

An experiment was devised to study the effects of water-cement ratio on durability of the cement coating. Pea gravel (about 3/8-inch) aggregate was coated with four percent cement in the recommended fashion using two water-cement ratios lower and two higher than the recommended value of 0.2. A sample of each treated aggregate was placed in a small rock polisher and tumbled for various periods of time from zero to 15 minutes. Then the aggregate was washed over a No. 10 sieve to remove any fines created by the tumbling action and dried. The findings indicated that higher water-cement ratios provided tougher coatings of portland cement (Figure 12). Although the aggregates were covered during the curing period (hydration of the cement), evaporative loss of water from these small samples may have resulted in effective water-cement ratios lower than those reported.

During field mixing operations, with the Type B (one-inch maximum size) aggregate, much more abrasion loss of the cement coating occurred than in the laboratory. Based on microscopic examination, it was estimated that about 95

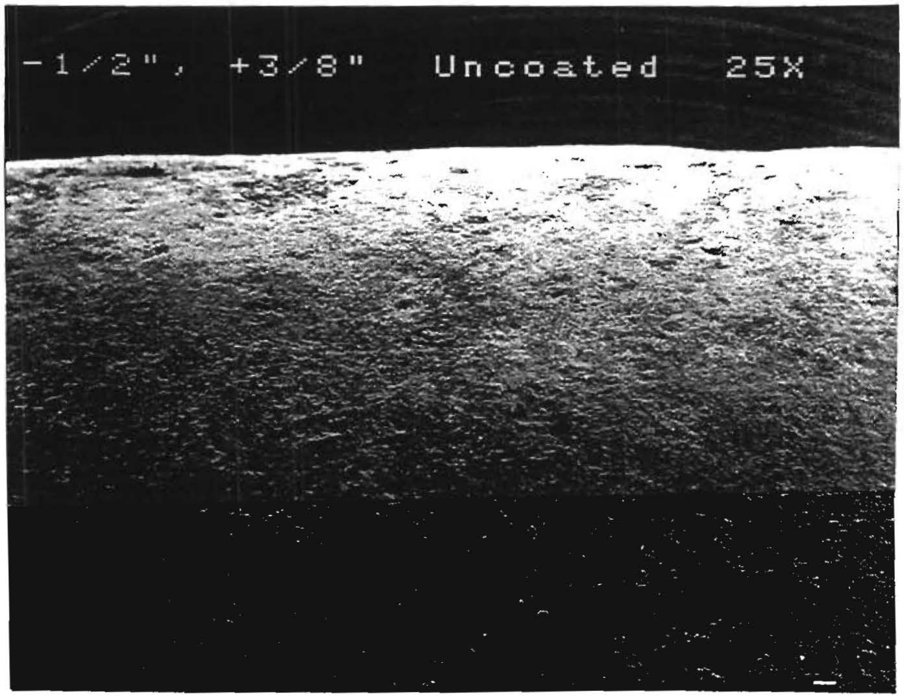

Figure 6. Photomicrograph of Uncoated River Gravel Aggregate Surface - Magnified 25 Times.

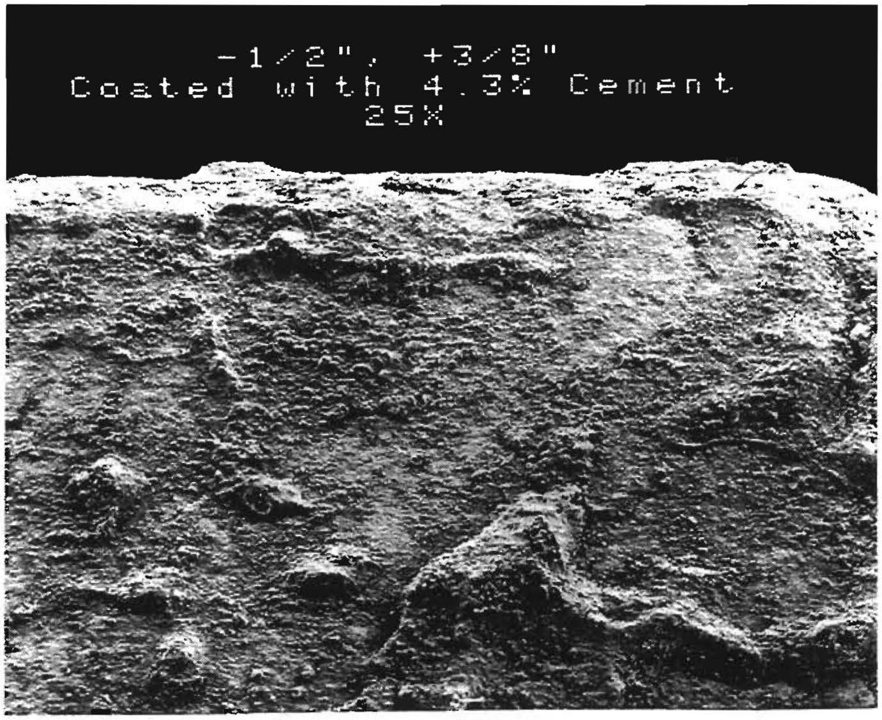

Figure 7. Photomicrograph of Cement Coated River Gravel Aggregate Surface - Magnified 25 Times.

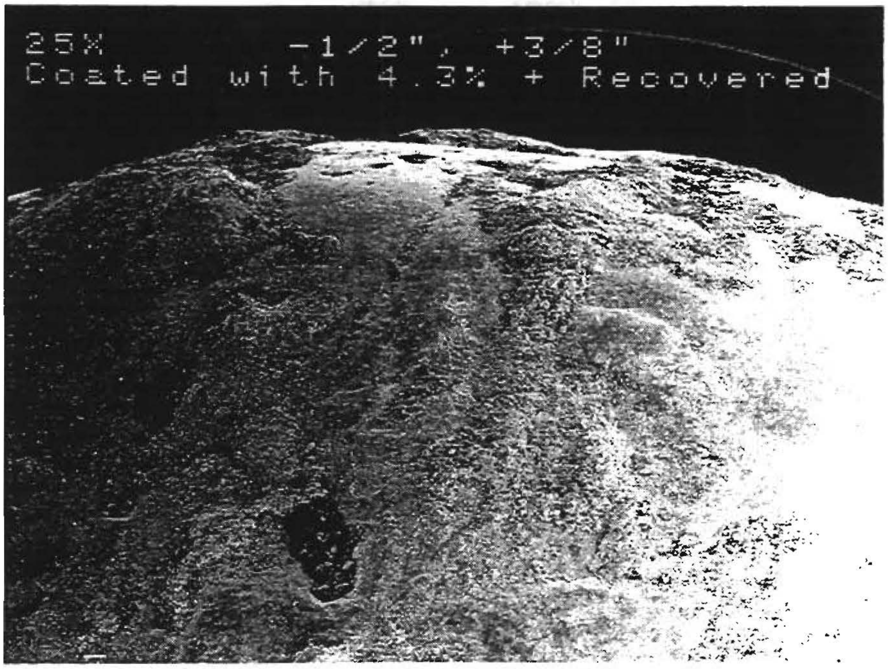

Figure 8. Photomicrograph of Cement Coated River Gravel After Laboratory Mixing, Compaction and Solvent Extraction - Magnified 25 Times.

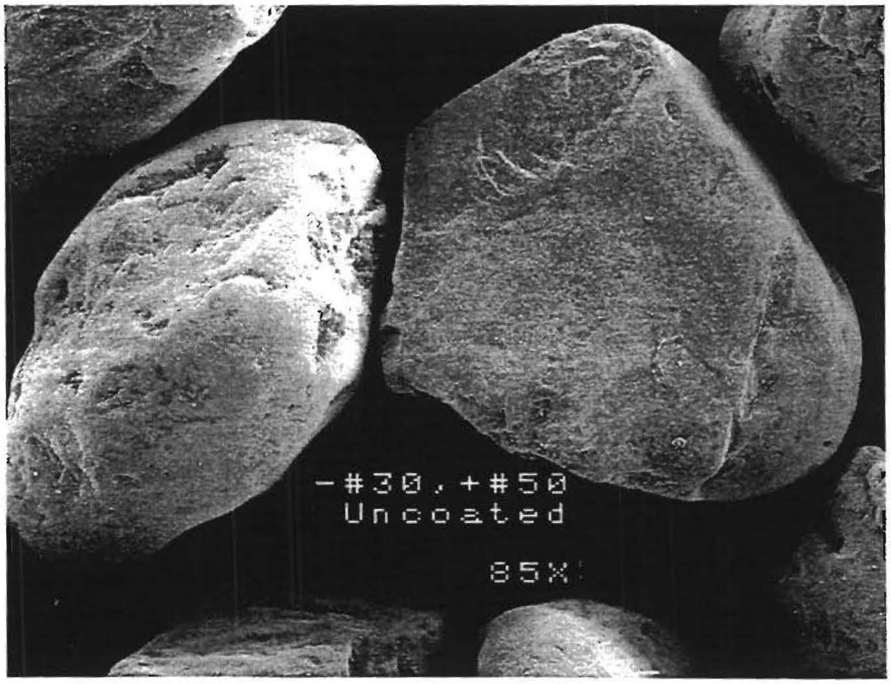

Figure 9. Photomicrographs of Uncoated Natural Sand Particles - Magnified 85 Times.

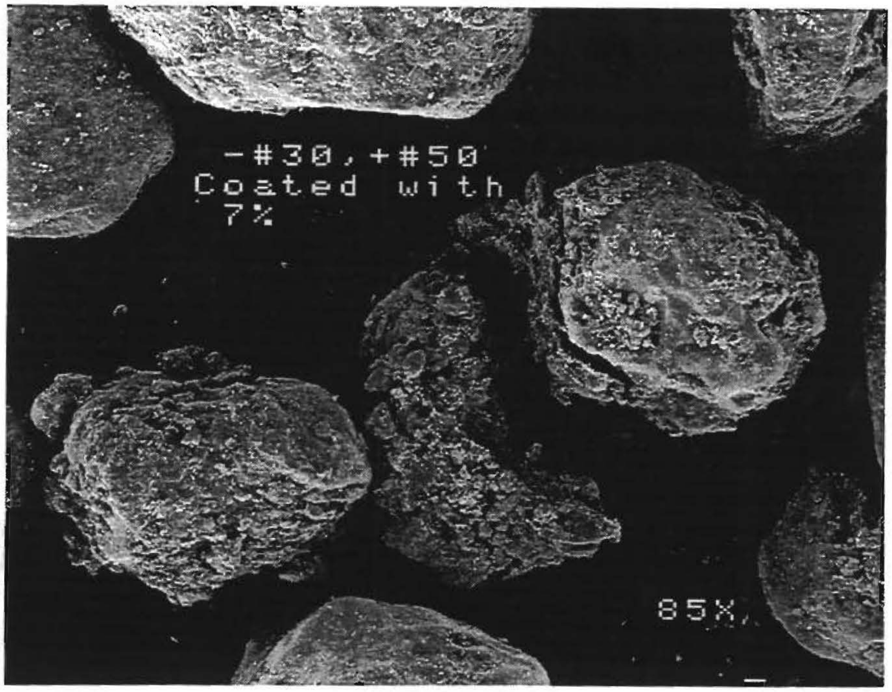

Figure 10. Photomicrograph of Cement Coated Natural Sand Particles - Magnified 85 Times.

Figure 11. Photomicrograph of Coated Sand Particles After Laboratory Mixing, Compaction, and Solvent Extraction - Magnified 85 Times.

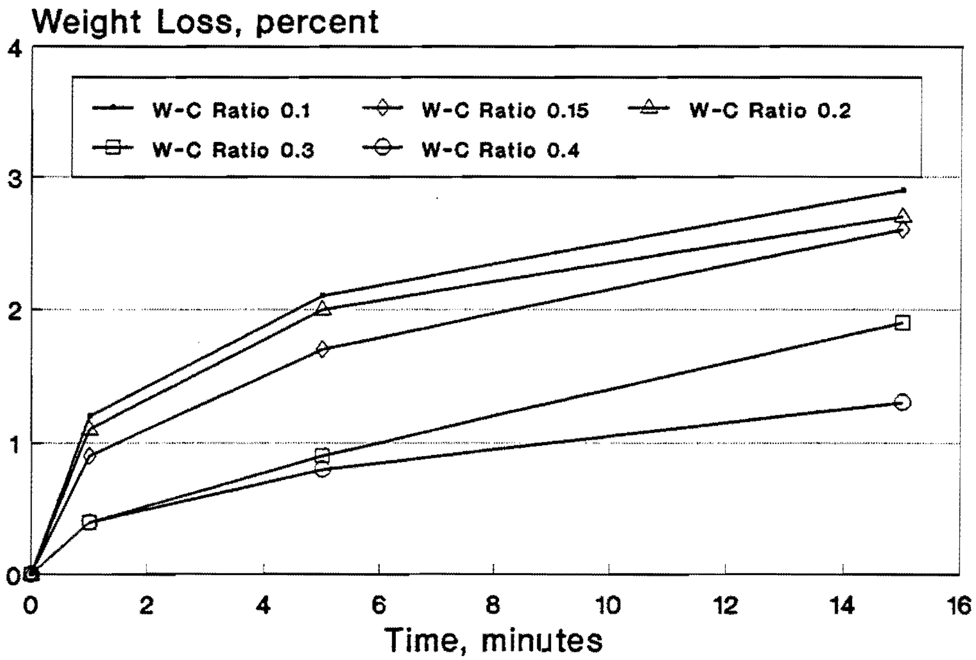

Figure 12. Weight Loss of Cement Coated Pea Gravel versus Tumbling Time in a Rock Polisher at Five Different Water-Cement (W-C) Ratios.

percent of the cement coating was removed from the aggregate surfaces by routine aggregate handling procedures and plant mixing operations. This coating loss occurred in the field even with water-cement ratios significantly greater than 0.2. Water-cement ratios in the field ranged from 0.35 to 0.6 for the different aggregates. It appears that the abrasive forces during plant mixing are much more severe than mixing using a Hobart mixer in the laboratory. Apparently, one-inch aggregate tumbling in a drum mix plant provides an effective ball mill.

Polish Value

Selected uncoated and cement coated aggregates were sent to the Materials and Tests Division of TxDOT for standard polish value testing (Tex 438-A). Coupons were prepared using aggregates between the 1/2-inch and 3/8-inch sieve sizes. The British Portable Tester was used to measure surface friction of the coupons before and after artificially "polishing" the surface to simulate wear by traffic. The friction values measured before and after polishing were reported as initial and final values (Figure 13). Each friction value was derived from an average of four measurements on seven different coupons or a total of 28 measurements.

Initially, the coated aggregate yielded consistently higher friction values than their uncoated counterparts. However, after the polishing procedure, the coated aggregates most often yielded lower friction values than the corresponding uncoated materials. This indicates the fine-grained cement filled the microtexture in most of the aggregates tested and thus adversely affected friction value after polishing.

It was concluded that aggregates needing cement coating for acceptable use in asphalt concrete should not normally be used in construction of pavement surface courses.

ASPHALT CEMENT PROPERTIES

Properties of the Texaco AC-20 asphalt cement used in the laboratory mixture study are provided in Table 1.

Properties of the original Exxon AC-20 and asphalts extracted and recovered from pavement cores obtained from the test pavements at College Station are shown in Table 2. Extracted asphalt content is also given.

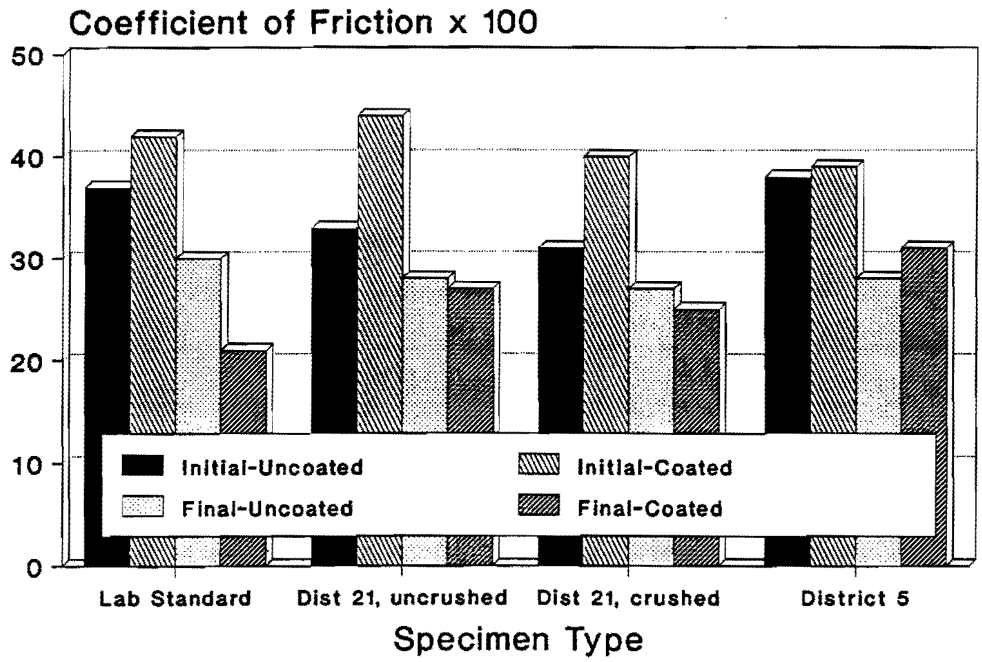

Figure 13. Coefficient of Friction of Uncoated and Coated Aggregates Before and After Polishing.

Table 1. Properties of the Asphalt Cement Used in Laboratory Mixture Study.

Asphalt Source Grade	Texaco AC-20
Viscosity at 140°F, P	2293
Viscosity at 275°F, cSt	478
Penetration at 77°F, 100 g, 5s, dmm	74
Penetration at 39.2°F, 100g, 5s, dmm	26
Softening Point, °F	119
Softening Point, °C	48
Temperature Susceptibility[1], 140°F to 275°F	-3.34
PVN[3]	-0.30
PVN[*3]	-0.37
P.I.[4] from penetration at 77°F and softening point	-0.76
Penetration ratio	35
After Rolling Thin Film Over Test	
Viscosity at 140°F, P	3515
Viscosity at 275°F, cSt	722
Penetration at 77°F, 100g, 5s, dmm	46
Penetration at 39.2°F, 100g, 5s, dmm	19
Ductility, cm	120+

[1] Temperature susceptibility = $(\log \log \eta_2 - \log \log \eta_1) / (\log T_2 - \log T_1)$, where η= viscosity in poises, T = absolute temperature.

[2] PVN = $[(4.258 - 0.7967 \log P - \log X) / (0.7951 - 0.1858 \log P)] (11.5)$, where P = penetration at 77°F, dmm and X = viscosity at 275°F, centistokes.

[3] PVN* = $[(6.489 - 1.590 \log P - \log X^1) / (1.050 - 0.2234 \log P)] (-1.5)$, where P = penetration at 77°F, dmm and X^1 = viscosity at 140°F, poise.

[4] P.I. = $(20 - 500\alpha) / (1 + 50\alpha)$
$\alpha = [\log 800 - \log (\text{pen}_{25°C})] / (T_{SP} - 25)$, where T = temperature, °C.

Table 2. Binder Data for District 17 Test Pavements.

Test	Original Asphalt		Extracted Asphalt			
			Uncoated Mix		Coated Mix	
	Fall '91	Spring '92	Fall '91	Spring '92	Fall '91	Spring '92
Pen @ 77°F	55	58	41	48	49	44
Vis @ 140°F	2130	2010	3070	2520	2930	2990
Vis @ 255°F	370	371	-	-	-	-
Asphalt Content	-	-	4.6	5.0	4.7	5.0

ASPHALT MIXTURE DESIGN

Mixture design was accomplished using the TxDOT method as presented in Construction Bulletin C-14. This procedure for determining the optimum asphalt content was repeated for both uncoated and coated mixes. A summary of findings is listed in Table 3. It is clear from the table that the optimum asphalt content increases by about 0.5 to 1.5 percent when the aggregates in a mix are coated with cement.

Table 3. Mixture Design Data.

Mix Type	Condition of Aggregate	Optimum Asphalt Content (%)
Lab Standard	Uncoated	4.7
	Coated	5.6
District 21	Uncoated	5.6
	Coated	6.4
District 5	Uncoated	4.5
	Coated	6.0
District 17	Uncoated	4.6
	Coated	5.1

The fact that uncoated aggregates require less asphalt cement to reach the same optimum design criteria as coated aggregates is further illustrated by Figures 14 through 17. For both the Laboratory Standard (Figure 14) and District 17 mixtures (Figure 16), cement coated samples are shown to require about 0.5 to 1.0 percent more asphalt than the corresponding uncoated mixtures to reach the same level of density. Figures 15 and 17 show that the mixtures containing coated aggregates are more able to tolerate asphalt in excess of optimum than their uncoated counterparts. That is, as asphalt content is increased above optimum, Hveem stability decreases faster for the uncoated materials than for the coated materials. As an example, the TxDOT specification permits the asphalt content to vary by ±5 percent of optimum. If this tolerance is permitted using the mixture shown in Figure 17, Hveem stability decreases by six percent for the uncoated aggregate but only three percent for the coated aggregate.

TEST SPECIMEN PREPARATION

Aggregate coated with cement and cured in accordance with the recommendations of Bayomy (1) were normally friable and suitable for use in standard sample preparation procedures. Soon after curing an undisturbed container of cement coated aggregate, some materials initially appeared to be rather solidly cemented together. However, upon mild impact with the heel of the hand or mixing tools, the materials were usually easily broken apart.

All two-inch high by four-inch diameter specimens were prepared using the Texas gyratory shear compactor. The eight-inch high by four-inch diameter creep specimens were prepared using the California kneading compactor.

MIXTURE TESTS

Results of tests on individual compacted two-inch by four-inch specimens are tabulated in Appendix B. These data are summarized in Tables 4 and 5. Plots of representative samples of dynamic creep data are given in Appendix C.

Resilient Modulus

Resilient modulus tests were performed at five different temperatures

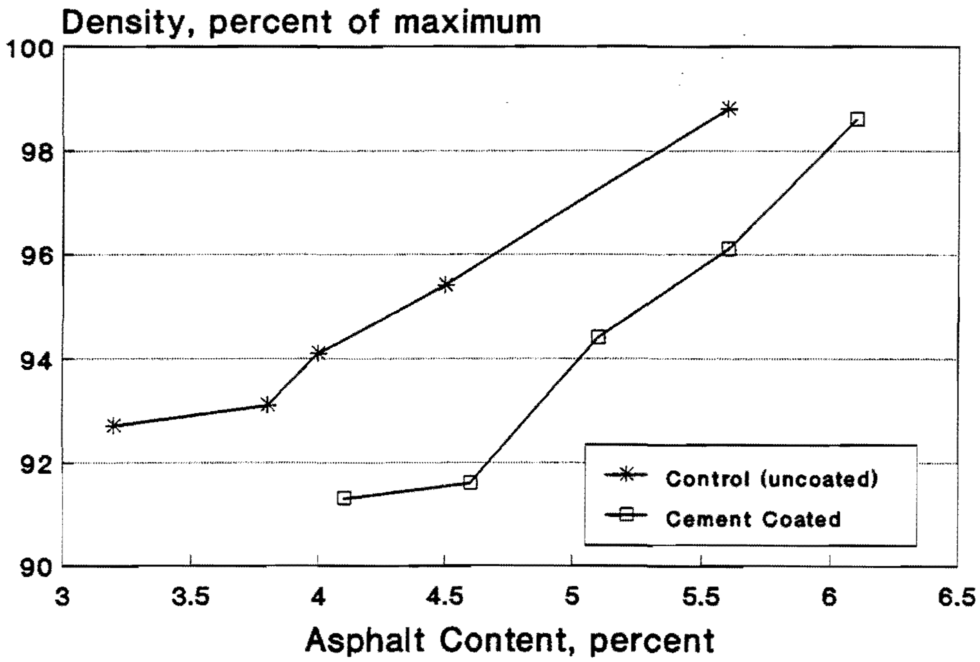

Figure 14. Density of Lab Compacted Mixture vs. Asphalt Content for Laboratory Standard Aggregate.

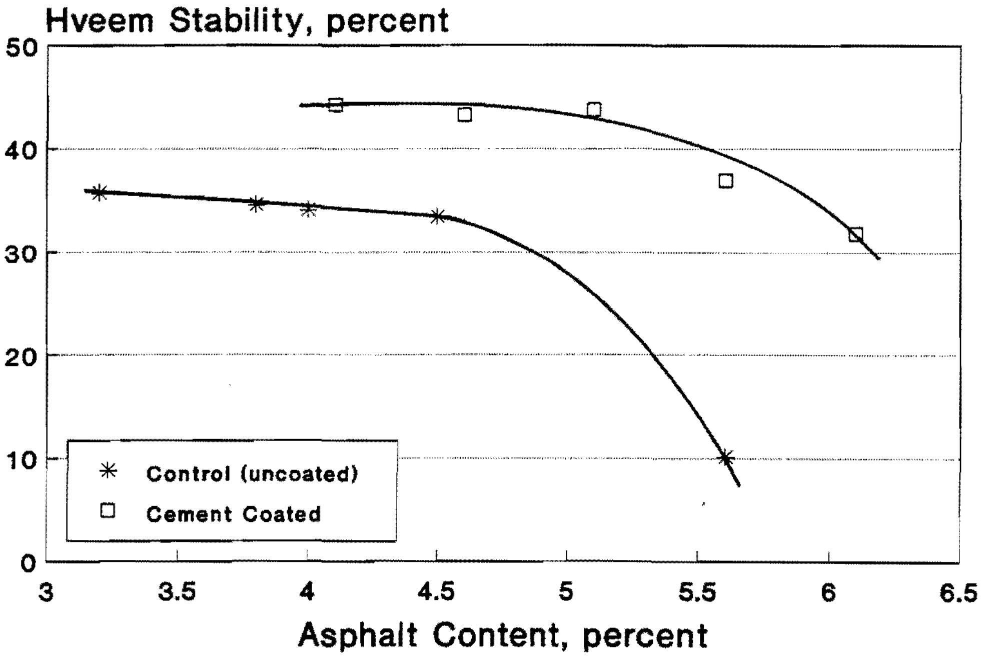

Figure 15. Hveem Stability of Lab Compacted Mixture vs. Asphalt Content for Laboratory Standard Aggregate.

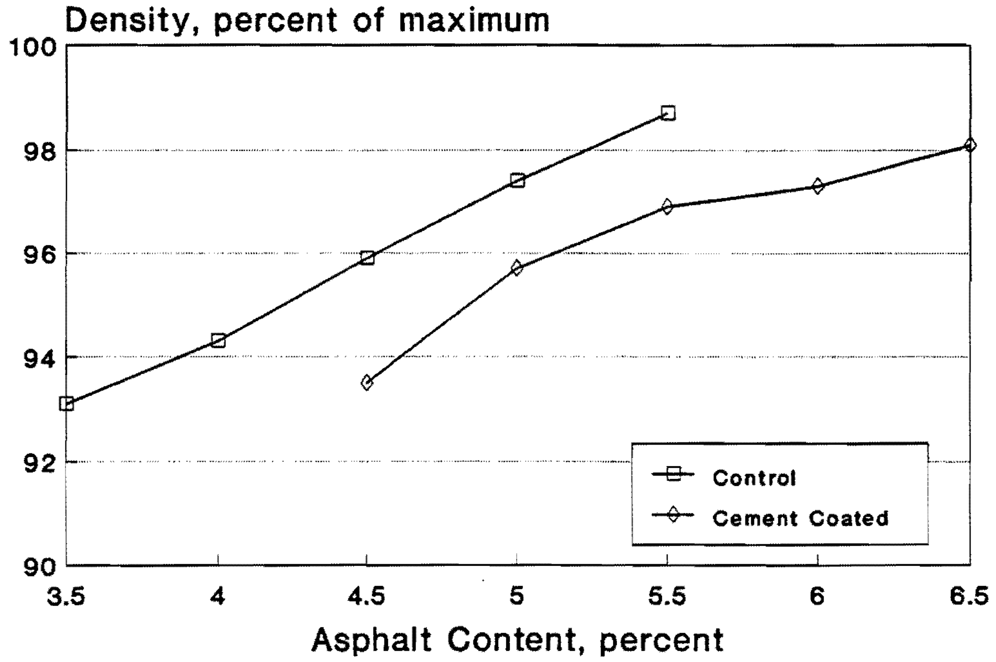

Figure 16. Density of Lab Compacted Field Mixture vs. Asphalt Content for District 17 Mix.

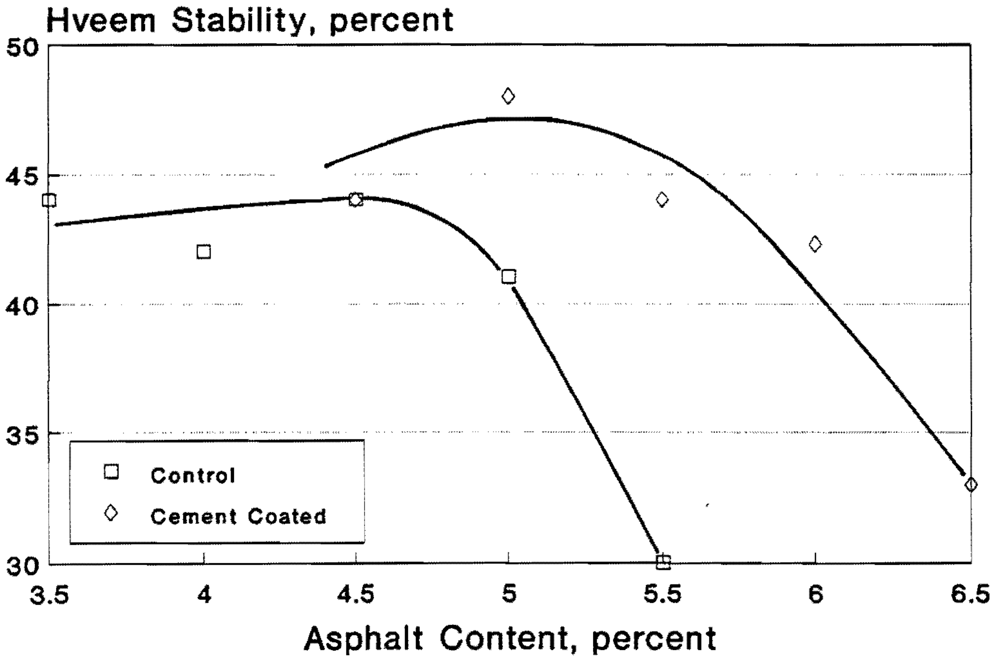

Figure 17. Hveem Stability of Lab Compacted Field Mixture vs. Asphalt Content for District 17 Mix.

Table 4. Summary of Resilient Modulus, Hvieem and Marshall Stability of Test Specimens[1].

Type Mixture	Air Void Content[2], percent	Resilient Modulus, psi x 10^3					Hveem Stability[2]	Marshall Test	
		0°F	36°F	50°F	77°F	104°F		Stability, lbs.	Flow, 0.01"
Lab Standard									
Uncoated	2.9 (3.3)	1960	1790	1450	268	73	26	940	14
Coated	3.7 (6.4)	1850	1830	950	213	54	38	1030	16
District 21									
Uncoated	3.1 (4.1)	1850	1190	609	114	16	31	780	16
Coated	3.2 (4.8)	1740	1050	586	109	24	38	780	16
District 5									
Uncoated	3.0 (4.0)	1630	1620	914	228	49	41	990	18
Coated	5.0 (5.0)	1420	1310	824	263	43	49	1380	20
District 17 (Field mixed-lab compacted - Fall 1991)									
Uncoated	4.3 (4.2)	1890	1730	601	323	33	32	710	13
Coated	4.7 (4.5)	2000	1720	582	321	32	34	600	13
District 17 (Field mixed-lab compacted - Spring 1992)									
Uncoated	3.2 (3.2)	-	2430[3]	1290[4]	409	65	40	1330	13
Coated	3.3 (3.3)	-	2300[3]	1090[4]	363	59	43	1520	13
District 17 (Pavement cores - Fall 1991)									
Uncoated	3.4 (3.4)	-	2200[3]	1040[4]	214	30	23	1190	13
Coated	2.5 (2.4)	-	2370[3]	860[4]	173	25	33	1060	13
District 17 (Pavement cores - Spring 1992)									
Uncoated	3.9 (4.4)	-	2080[3]	909[4]	183	19	23	632	12
Coated	3.8 (3.6)	-	2400[3]	851[4]	202	25	33	1050	13

---

[1] Average of tests on three different specimens.
[2] Numbers in parenthesis are average air voids for Hveem and Marshall specimens only.
[3] Samples tested at 30°F.
[4] Samples tested at 59°F.

Table 5. Summary of Properties of Test Specimens Before and After Accelerated Lottman Freeze-Thaw Procedure[1].

	Before Moisture Treatment			After Moisture Treatment		
		Tensile Properties[2,3]		Tensile Properties[2,3]		
Type Mixture	Air Void Content, percent	Tensile Strength, psi	Strain @ Failure, in/in	Tensile Strength, psi	Strain @ Failure, in/in	Tensile Strength Ratio
Lab Standard						
Uncoated	7.0	88	N/A	24	N/A	27
Coated	7.3	66	N/A	48	N/A	73
District 21						
Uncoated	7.9	82	0.1330	51	0.1250	62
Coated	7.3	125	0.1230	57	0.1320	46
Distict 5						
Uncoated	5.3	98	0.1180	44	0.1250	45
Coated	6.0	114	0.1100	70	0.1210	61
District 17 (Field mixed-lalb compacted - Fall 1991)						
Uncoated	6.5	110	0.1080	93	0.1430	85
Coated	7.9	85	0.0980	81	0.1680	95
District 17 (Field mixed-lab compacted - Spring 1991)						
Uncoated	6.9	93	0.1070	72	0.1730	77
Coated	6.9	92	0.1070	47	0.1200	51
District 17 (Pavement cores - Fall 1991)						
Uncoated	3.2	144	0.1170	-	-	-
Coated	2.7	144	0.1130	-	-	-
District 17 (Pavement cores - Spring 1992)						
Uncoated	3.6	104	0.1170	-	-	-
Coated	4.0	102	0.1130	-	-	-

[1] Average of three different specimens.

[2] Average of four different specimens.

[3] Indirect tension tests were performed at 77°F and 2"/minute before and after moisture treatment.

ranging from 0°F to 104°F (Table 4). Variations of resilient moduli with temperature are plotted in Figures 18 through 22. Resilient modulus remains almost constant from 0°F to about 40°F. Above 40°F, the values of resilient moduli decrease as the temperature increases. There are no appreciable or consistent differences in resilient modulus values between the uncoated and coated specimens.

Any stiffness increase in these mixtures anticipated by the addition of cement was offset by the higher optimum binder content of the coated mixtures.

Hveem Stability

Hveem stability was consistently increased when cement coated aggregate was used in the asphalt mixtures (Table 4 and Figure 23). These results support the theory that cement coating improves the surface texture of the aggregates thereby improving the internal friction and thus enhancing the Hveem stability of the mixture.

Marshall Stability

Marshall stability values for coated specimens are higher than those for uncoated specimens for the Laboratory Standard and District 5 mixtures, equivalent for District 21 mixture, and lower for the District 17 mixture (Table 4 and Figure 24). Although Marshall flow varied significantly between the different mixtures, there was no significant difference in flow attributable to the cement coating.

Tensile Properties

Indirect tension tests were performed at 77°F and two inches per minute. For the Laboratory Standard and District 17 mixtures, tensile strength was lower for coated specimens than for the corresponding uncoated specimens, while for the District 21 and District 5 mixtures, tensile strength was higher for the coated specimens (Table 5 and Figure 25). Strain at failure was not appreciably affected by the cement coating.

Based on these tests, tensile strength of asphalt mixtures is not consistently affected by the cement coating the aggregate. The inconsistent behavior and wide variability in tensile strength of these specimens is

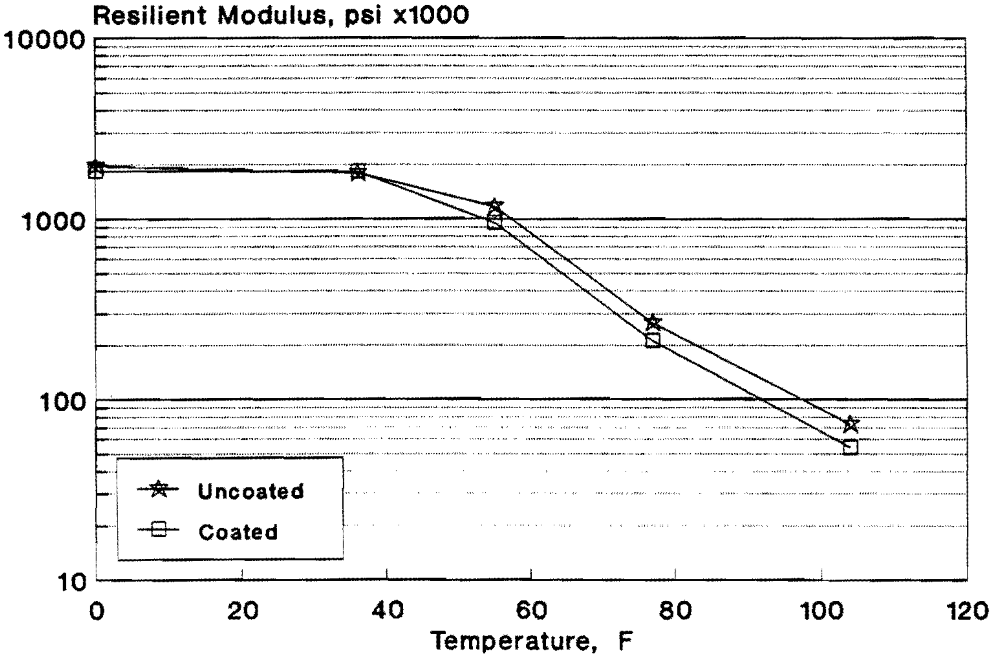

Figure 18. Resilient Modulus vs. Temperature for Asphalt Mixtures Containing Laboratory Standard Aggregate.

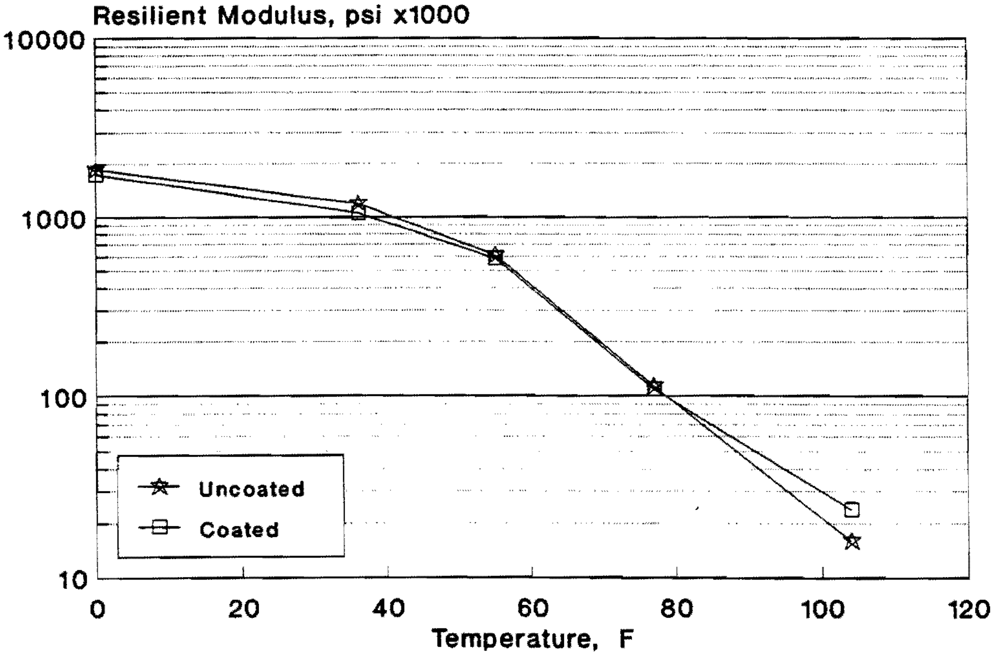

Figure 19. Resilient Modulus vs. Temperature for Asphalt Mixtures Containing District 21 Aggregate.

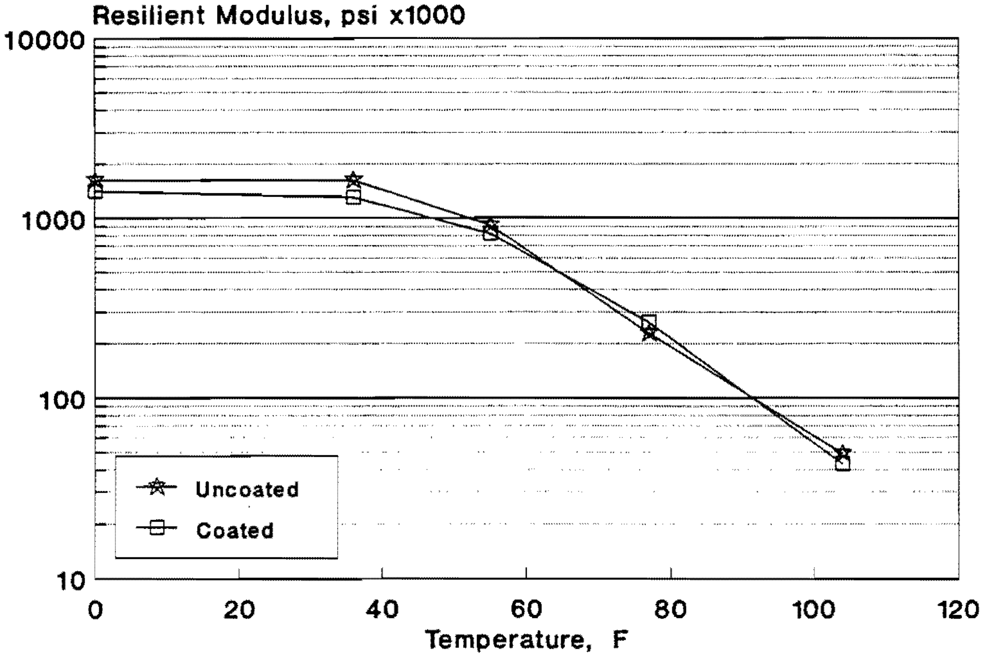

Figure 20. Resilient Modulus vs. Temperature for Asphalt Mixtures Containing District 5 Aggregate.

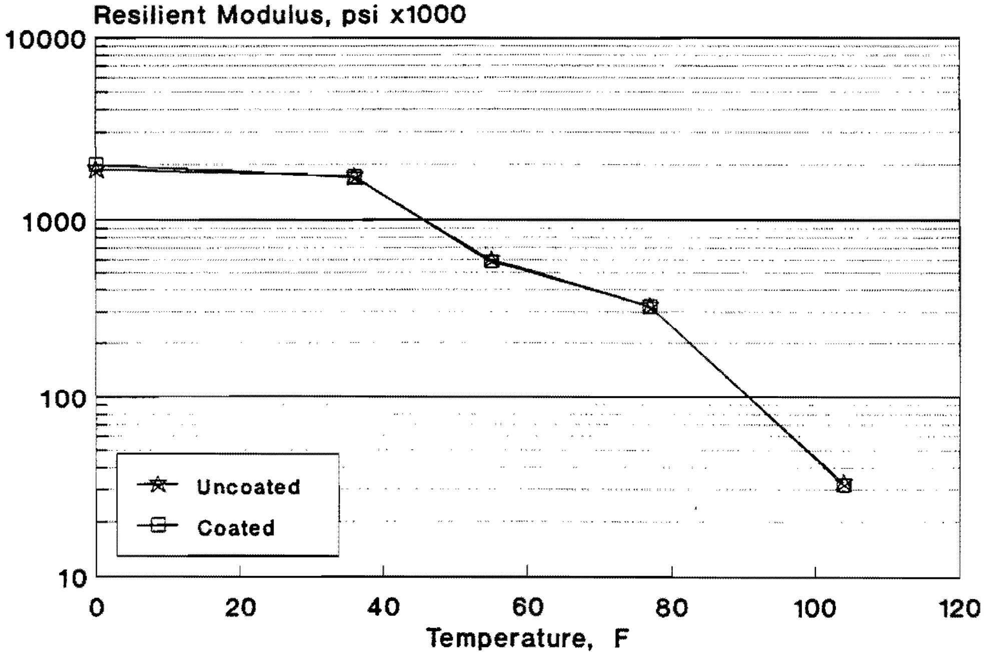

Figure 21. Resilient Modulus vs. Temperature for Asphalt Mixtures Containing District 17 Aggregate.

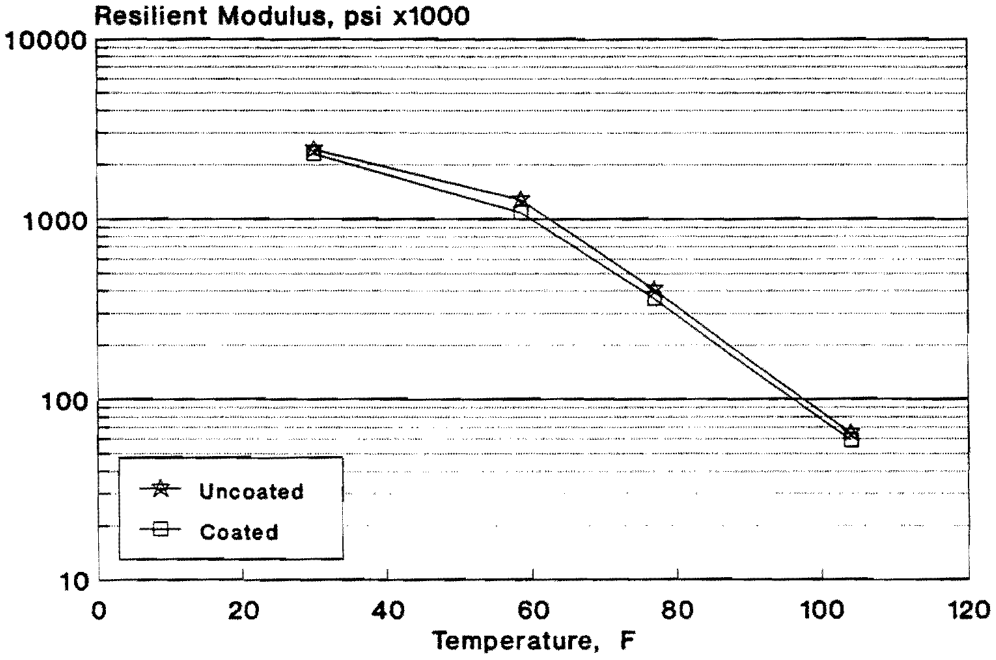

Figure 22. Resilient Modulus vs. Temperature for Field Mixed - Laboratory Compacted Asphalt Mixtures Containing District 17 Aggregate.

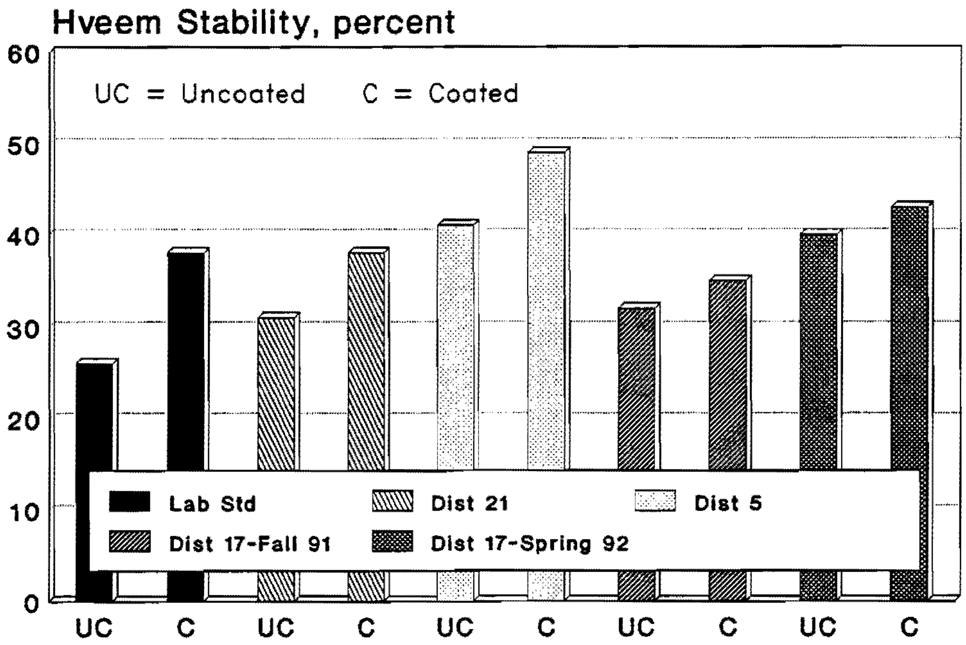

Figure 23. Hveem Stability of Mixtures Containing Uncoated (UC) and Coated (C) Aggregates.

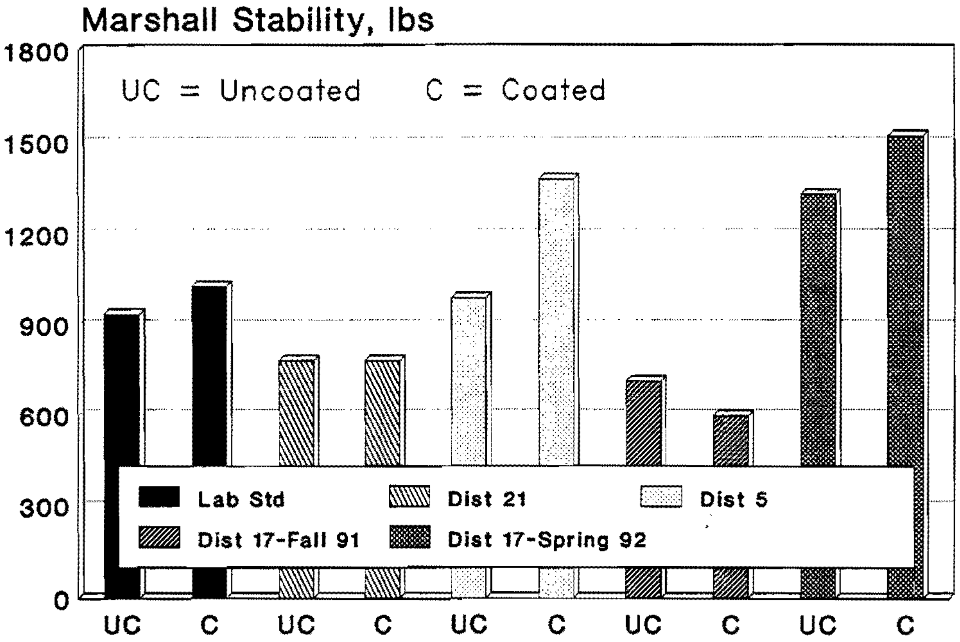

Figure 24. Marshall Stability of Mixtures Containing Uncoated (UC) and Coated (C) Aggregates.

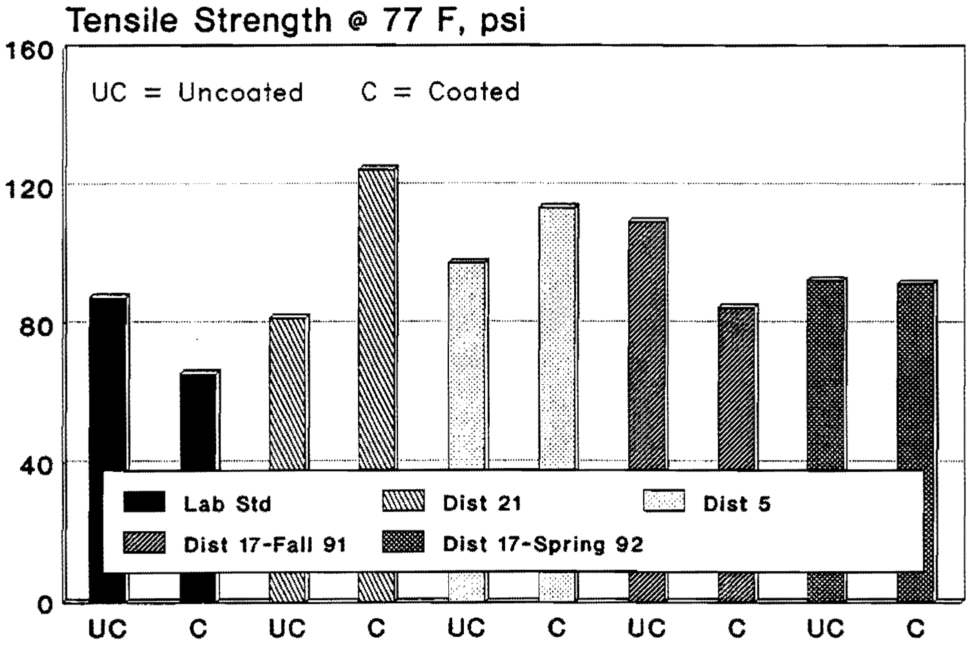

Figure 25. Tensile Strength for Mixtures Containing Uncoated (UC) and Coated (C) Aggregates.

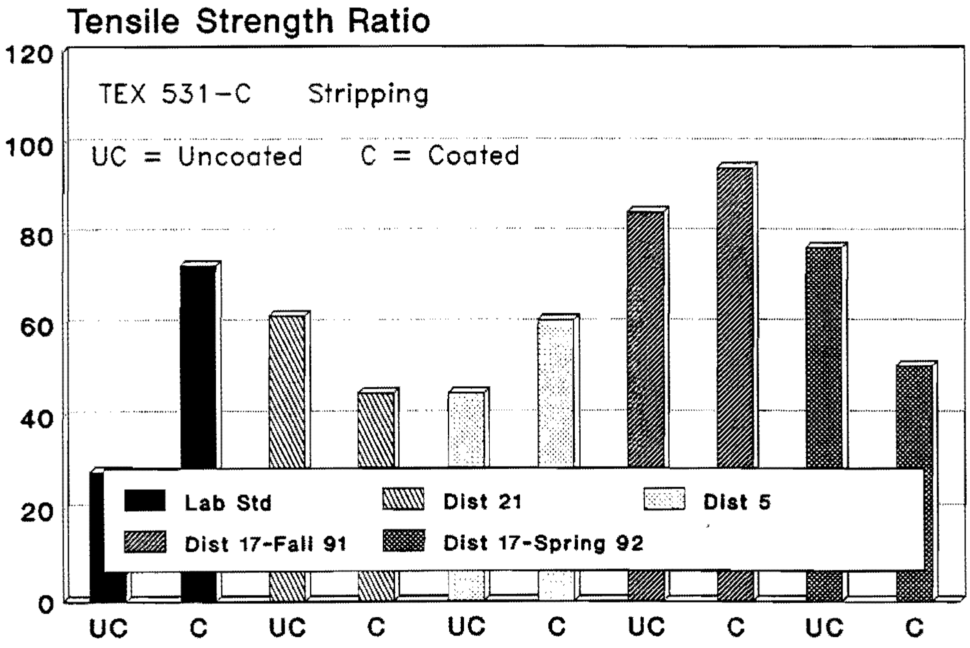

Figure 26. Tensile Strength Ratio for Mixtures Containing Uncoated (UC) and Coated (C) Aggregates.

inexplicable. Tensile strength is primarily dependent on binder properties and air void content both of which remained relatively constant in these mixtures.

Moisture Susceptibility

Indirect tension tests were performed before and after the specimens were exposed to vacuum saturation in water plus freezing and thawing. Ratios of tensile strength of specimens tested before and after moisture treatment were computed (Table 5 and Figure 26).

Tensile strength ratio (TSR) is expressed as a percent and indicates the effect of moisture on the tensile strength of a sample. The plots show that cement coating improved the moisture resistance for three of the five mixtures. The District 21 mixture and the District 17-spring 1992 mixture showed a decrease in TSR when the coated aggregates were used. The District 21 aggregate was the only one composed of crushed gravel and crushed gravel fines; cement coating was apparently detrimental to this aggregates resistance to moisture damage. The District 17-spring 1992 mixture was over-cemented and the cement was abraded off the aggregate during plant mixing and handling operations. This additional fine material in the mixture may have contributed negatively to the water sensitivity of this mixture.

Dynamic Creep Tests

Creep tests were performed to obtain information about creep compliance and resilient modulus of the mixtures containing uncoated and cement coated aggregate at different stress levels (5, 7.5, and 10 psi). Data were plotted to compare the creep curves (strain as a function of time) for the mixtures. A decrease in creep compliance or an increase in resilient modulus is usually indicative of an increase in the rutting resistance of the mixture. Creep tests on asphalt concrete typically show that modulus of the specimen decreases and the creep compliance increases with an increase in stress level at a constant rate of loading.

Creep compliance decreased with cement coating for the District 21 mixture (Figure 27). For each of the three stress levels, creep compliance decreased by about 50 percent for the coated samples as compared to the uncoated samples. Correspondingly, the modulus values for the coated specimens were approximately twice those of the uncoated specimens (Figure 28).

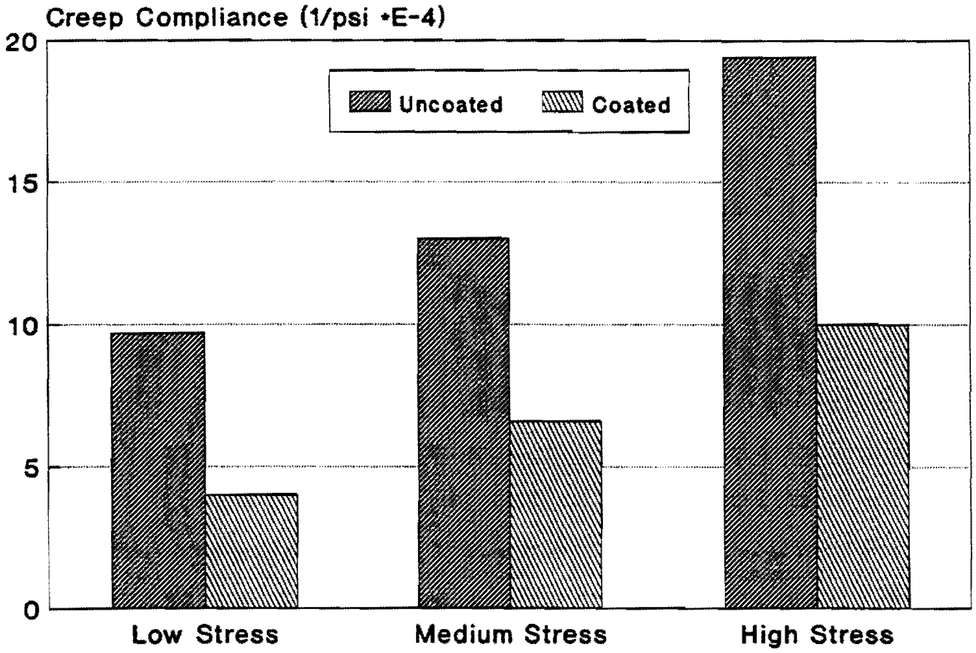

Figure 27. Creep Compliance for Asphalt Mixtures Containing District 21 Aggregates.

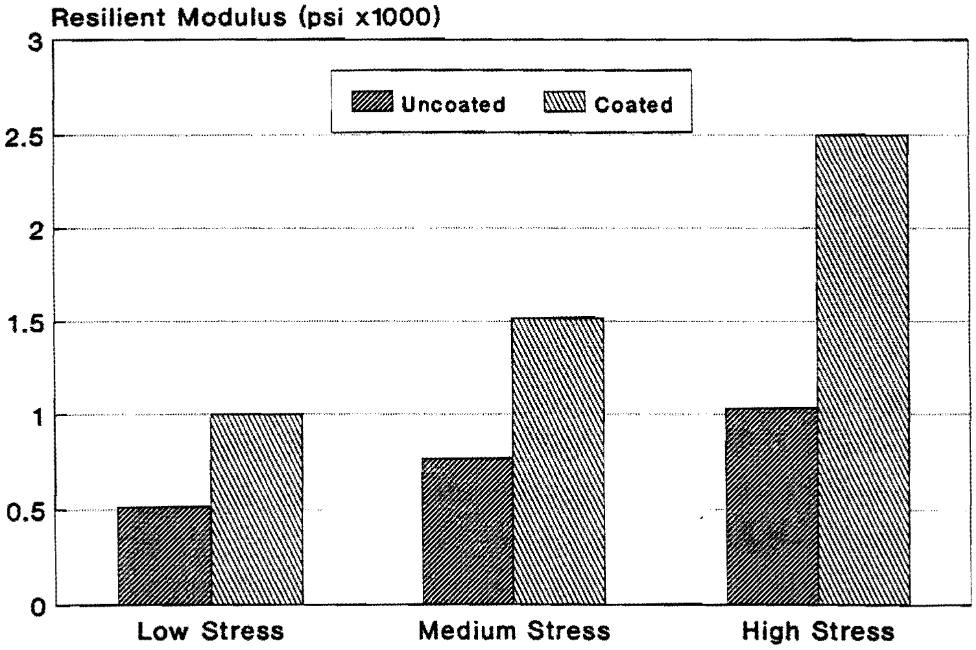

Figure 28. Resilient Modulus for Asphalt Mixtures Containing District 21 Aggregates.

For the District 5 mixture (Figures 29 and 30), the creep compliance was higher while the resilient modulus was lower for coated samples than for the uncoated samples, and this difference increases with increasing stress level. This means that the cement coating is affecting the properties of this mixture in a detrimental way. The negative effect of the coating is not noticeable at low stress level; whereas, at higher stress levels, creep compliance for the coated mixture is twice that of the uncoated mixture.For the District 17 mixture (Figures 31 and 32), cement coating reduced creep compliance and increased resilient modulus values when compared to the corresponding uncoated samples. This effect is apparent at all stress levels. Therefore, the District 17 mixture with coated aggregates is more resistant to rutting than with uncoated aggregates.

While these bar charts describe the effect of the cement coating on various mixtures in a quantitative manner, the creep curves in Appendix C provide detailed information about the relative performance of a representative sampling the mixtures tested.

The laboratory standard mixture was tested at room temperature (77°F) and at a very high stress level (60 psi). Figure C1 shows the coated sample as having far lower strain values as compared to the uncoated sample and, in all probability, a much better rutting resistance. This is typical of several similar tests performed on this mixture.

The District 21 mixture yielded a low compressive strength such that, at high stress level, the sample failed before the test was completed (10,000 seconds) (Figure C2). At all stress levels, the coated District 21 samples showed lower strain values than the uncoated samples (Figures C3 and C4). This indicates that cement coating improved rutting performance for District 21 mixture.

Figure C5 illustrates the low stress creep curve for District 5. The uncoated samples exhibited lower strain to begin with, but exhibited a higher rate of increase in strain with time and a higher total strain at the conclusion of the test. At around 4000 seconds, near the time period used to calculate creep compliance (3600 seconds), the curves for untreated and treated materials intersect, thus giving the same calculated value of creep compliance and modulus. A second coated specimen from District 5 tested at the same stress level, failed to withstand the loading for more than 3000

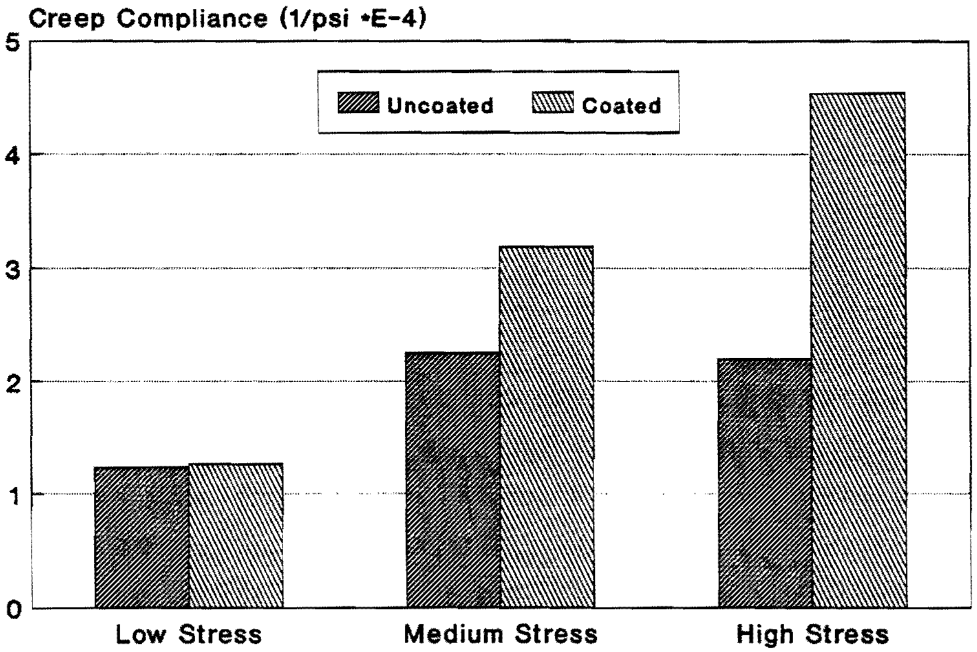

Figure 29. Creep Compliance for Asphalt Mixtures Containing District 5 Aggregates.

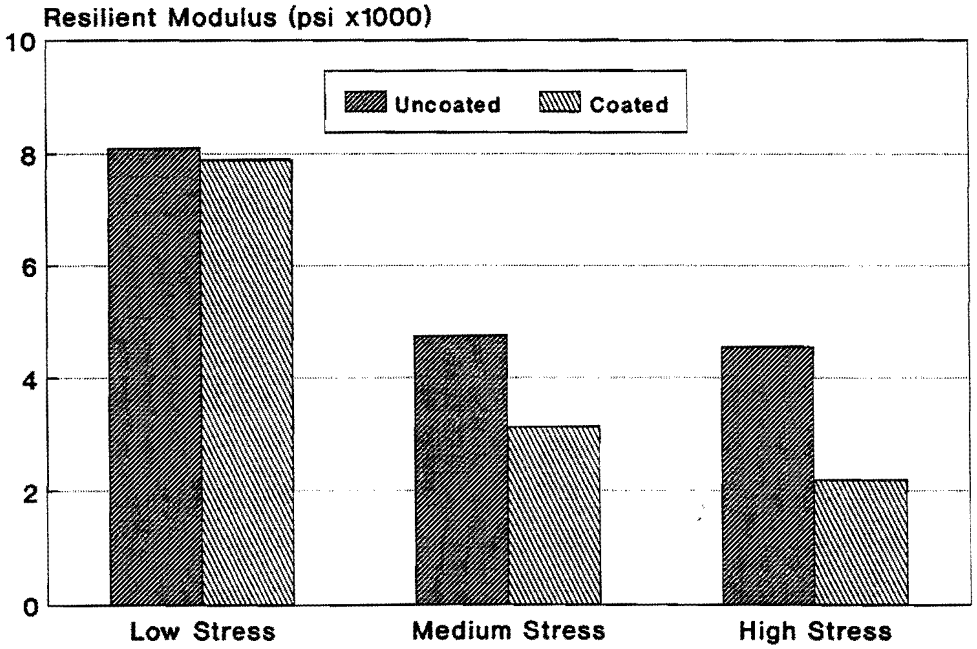

Figure 30. Resilient Modulus for Asphalt Mixtures Containing District 5 Aggregates.

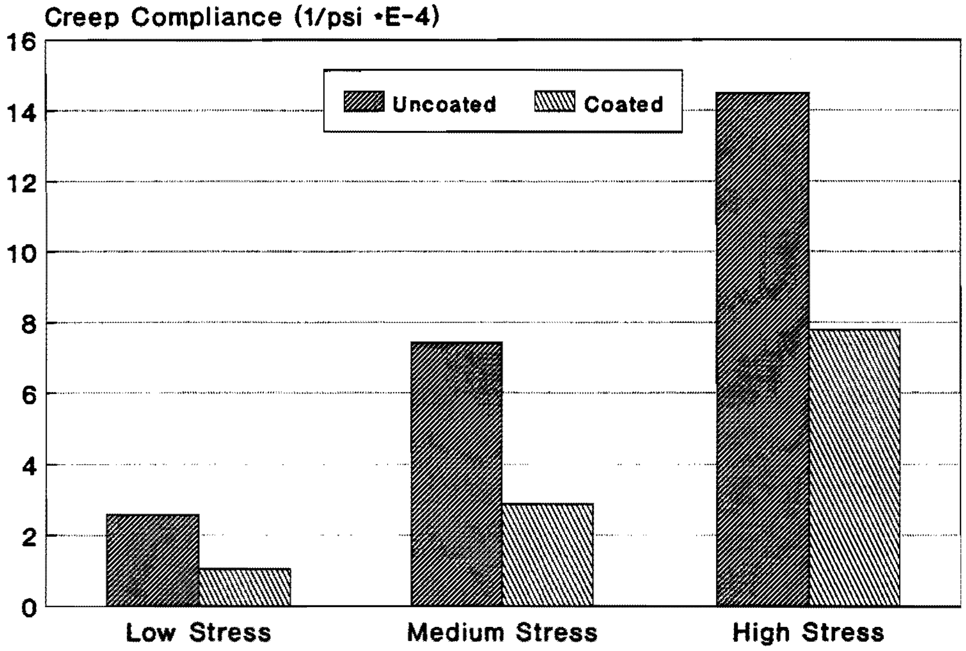

Figure 31. Creep Compliance for Field Mixture from District 17 Test Pavement.

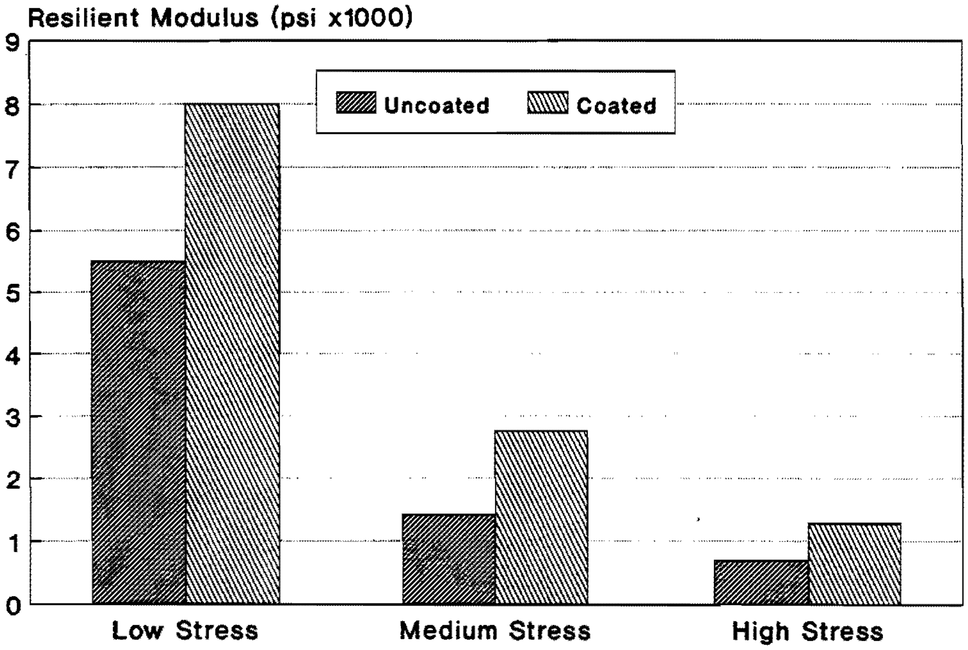

Figure 32. Resilient Modulus of Field Mixtures from District 17 Test Pavement.

seconds. Figure C6 shows that the uncoated material performed better than the cement coated material as it has lower strain values throughout the test. Similarly, medium and high stress level creep curves for the District 5 mixture (Figures C7 and C8) show the creep curves for the coated specimen above that of the uncoated specimen, consistently indicating a detrimental effect of cement coating for this particular material.

Creep curves for the District 17 field mixture (Figures C9 and C10) exhibit lower values of strain for the coated materials as compared to the uncoated materials. Hence, the cement coating appears to enhance rutting resistance for the District 17 mixture.

Three out of the four mixtures tested indicated that cement coating of aggregates improved rutting resistance of the resulting asphalt mixture. However, cement coating did not affect all the mixtures in a positive manner. This mixed performance is likely due to the loss of much of the cement coating due to abrasion during mixing and the fact that this loose cement acted as filler to varying degrees in the compacted mixtures.

Predicted Long-Term Performance

There are several analytical tools available to analyze and predict long-term performance of pavements with respect to permanent deformation (rutting) and fatigue cracking. MICH-PAVE, a nonlinear finite element program developed at the Michigan State University, is capable of calculating the stresses, strains, and surface deflections developed in a pavement section due to a passing vehicle of known weight in a specified climate. This program was used to predict the relative performance of mixtures containing uncoated and coated laboratory standard aggregate and aggregates from Districts 21, 5, and 17 (Table 6). The pavement structure, climate, and traffic associated with the test pavement at College Station were used as input values for the computer program. The values computed for fatigue cracking and rutting should be considered only as relative values for the case tested and not as actual pavement performance.

Fatigue (Table 6) is defined as the number of equivalent single axle loads (ESALs) required to cause failure in the pavement at the average annual temperature of 68°F. Mixtures containing laboratory standard, uncoated aggregates yielded better fatigue life than the similar coated aggregates.

For the mixtures from Districts 21, 5, and 17, the cement coated aggregates gave better fatigue life when compared to corresponding uncoated aggregates. The improvement in fatigue life was marginal in all cases. It should be noted that the laboratory standard is the only aggregate that contains 100 percent natural (uncrushed) aggregate. The cement abraded from the treated rock probably acted as angular filler in this otherwise clean aggregate and thus toughened the mix and improved resistance to fatigue cracking.

Rutting is the prevailing mode of asphalt concrete pavement failure at higher temperatures. Rut depth was calculated at the end of fatigue life at a service temperature of 85°F. Table 6 indicates that the laboratory standard, District 21, and District 17 mixtures with coated aggregates exhibited more resistance to rutting than those with uncoated aggregates. The District 5 mixture, on the other hand, showed the uncoated aggregates to be more resistant to rutting than the coated aggregates. This is in conformance with the data (higher compliance and lower resilent modulus for the coated aggregate) presented in Figures 29 and 30. The difference in rut depths between the mixtures containing coated and uncoated aggregates are inconsequential.

Table 6. Predicted Pavement Performance using MICH-PAVE.*

Mixture ID	Fatigue @ 68°F, No. of ESAL to failure		Rut Depth @ 85°F, inches	
	Coated	Uncoated	Coated	Uncoated
Laboratory standard	5.3E+6	6.4E+6	3.6	3.9
District 21	8.9E+6	8.7E+6	3.5	3.9
District 5	4.9E+6	4.8E+6	3.6	3.3
District 17	6.0E+6	5.9E+6	3.8	4.1

* If the indicated fatigue life (No. ESALs) occurs over a period greater than 20 years, then it is likely that the pavement will experience temperature and/or age cracking.

FIELD INVESTIGATION

The chief goal of this task was to provide a comprehensive evaluation of the overall construction process while using the cement coated aggregate to produce hot mix asphalt concrete (HMAC) and to assess early performance of the resulting pavements. Mixture design for the cement coating process as well as for asphalt concrete containing cement coated aggregate was examined. Construction elements evaluated included coating of the aggregate with cement, asphalt mix plant operations, paver functions, and compaction. Samples of construction materials were collected and tested in the laboratory in an attempt to predict pavement performance.

Based on results of polish tests and the poor abrasion resistance of the cement coating as demonstrated in the laboratory phase of this work, it was concluded by the Department that cement coated marginal aggregate would only be used in a base course, that is, the finished surface would not be exposed to traffic.

AGGREGATE COATING EXPERIMENT

After the laboratory study and before construction of the field test pavements, a field experiment was conducted to evaluate the full-scale process for coating the aggregate with portland cement. Young Brothers Contractors, Inc. of Waco, Texas agreed to assist with this experiment. They used a Cedar Rapids continuous feed pug mill plant which was equipped with a silo capable of metering portland cement onto the conveyor belt which fed aggregate to the pug mill. The pug mill was also capable of adding water to the mixture in the pug mill. TTI purchased a meter and installed it on the water feed line to provide control of water content of the mixture. Residence time for the aggregate in the pug mill was about 10 seconds. Water is normally added after about 3 seconds of mixing time for the aggregate and the cement. About one ton of each of four different size aggregates were coated each with a different quantity of portland cement (Table 7). The treated aggregates were dropped into a haul unit then dumped on the ground to form a small stockpile.

There was concern on the part of the contractor and the researchers that a cement treated stockpile of aggregate may be difficult to break apart

Table 7. Aggregates used in Full-Scale Portland Cement Coating Experiment.

Aggregates	Optimum Moisture, wt. percent	Stockpile Moisture, wt. percent	Optimum Cement Content, wt. percent	Cement Added, wt. percent
One-inch gravel	1.1	1.4	3.0	2.0
Pea Gravel	1.6	3.1	5.9	4.0
Washed Coarse Sand	2.0	4.4	7.0	5.0
Field Sand *	3.2	4.0	7.0	6.0

*Field Sand stockpile was protected from rainfall.

once the cement was hydrated. Therefore, about 10 pounds of each of the four aggregates were blended in the laboratory with five different cement contents (bracketing the optimum) and hand pressed into small simulated "stockpiles" and allowed to cure for three days. These cured laboratory stockpiles were examined after three days to estimate workability. The optimum quantities of cement called for by Bayomy et al. (1) appeared to bond the aggregate together. To insure acceptable stockpile workability and yet adequate cement coating on the aggregate, the quantity of cement added to each aggregate was reduced by one to two percent below the optimum recommended by Bayomy et al. (1) (Table 7).

This full-scale aggregate coating experiment was conducted on November 19, 1991, near the end of the asphalt pavement construction season. It had been postponed several times because of periodic rainfall. Therefore, even though the moisture contents of the aggregate stockpiles were above the optimum recommended by Bayomy et al. (1), the coating tests were performed. However, no additional water was added to any of the aggregates at the pug mill. The treated aggregates were stockpiled, covered with plastic to protect from rain that was threatening, and allowed to cure for three days.

The experiment went extremely well. The cement appeared to be properly proportioned with the four different aggregates; however, this was not verified by testing. The continuous-feed pug mill was easy to control and produced a uniform coating of cement paste on the aggregates. The aggregates in all four of the cured stockpiles were easily broken apart during normal handling operations with a front-end loader. Even the fine-grained sands in the treated stockpiles were quite friable.

CONSTRUCTION OF TEST PAVEMENTS

Essentially, two test pavements were constructed at the same site, one in the fall of 1991 and one in the spring of 1992. Even though excessive cement was used to coat the aggregate in the second test, more than 95 percent of the cement coating was abraded away on both occasions during drying and stirring in the drum mix plant. Three test pavements were originally planned, but after poor results with the first two, the Department decided not to pursue a third test pavement.

Test Site

With the aid of TxDOT, a site was selected in Brazos County on FM 2818 (Miller Lane) in College Station (construction project CRP-89(60)M). This 0.69 mile segment of curbed and guttered 4-lane municipal highway joins Texas Avenue and SH 6. The project consisted of new construction. It is a well drained pavement situated in rolling hills and overlying some very expansive clay layers.

A 12-foot wide by 1000-foot test section and a 12-foot by 1000-foot control (untreated) section were placed end-to-end on the westbound travel (outside) lane. A map showing the layout of the test pavements is shown in Figure 33.

Specific information about these pavements is furnished in Table 8. Climatic and traffic data are included in Table 9.

Pavement Structure

The pavement structure consisted of 8 inches of lime stabilized subgrade (approximately 4 percent hydrated lime by weight), 9 inches of limestone flexible base, 6 inches of Type B asphalt concrete, and 2 inches of Type D asphalt concrete. The test pavements and control pavements were composed of Type B asphalt concrete. A typical section for the pavement is described in Table 8.

Table 8. Summary of Field Projects in District 17 at College Station.

Highway Designation	FM 2818 (Miller Lane)
County	Brazos
Control Section No.	2399-01-026
Construction Project No.	CRP 89(60)M
No. Lanes in each Direction	2
Dates of Construction	
Base-1st Lift	November, 1991
Base-2nd Lift	April, 1992
Surface	April, 1992
Type of Construction	New Construction
Pavement Structure	
Layer 1 (top)	2 in. ACP Type D (3/8" max)
Layer 2	6 in. ACP Type B (7/8" max)
Layer 3	9 in. limestone flex base
Layer 4	8 in. lime treated subgrade

Table 9. Traffic and Environmental Data for Test Site in District 17 at College Station.

Traffic Data	
ADT (1992 & 2012) (estimated by TxDOT)	1,800/12,000
Trucks in ADT, precent	Not available
ATHWLD	Not available
Tandem Axles in ATHWLD, percent	Not available
Equivalent 18kip axle loads expected 1985 to 2005	Not available
Posted Speed Limit, mph	45
Weather Data	
Climate	Humid-subtropical with hot summers
Temperature	
Mean Max, °F	78
Mean Min, °F	57
No. Days/yr 90°F & above	102
No. Days/yr 32°F & below	23
Sudden drops	Yes
Frost Penetration, in.	2
Freeze index	0
Precipitation	
Mean annual precipitation, in.	39.1
Mean annual ice/snow, in.	0.5

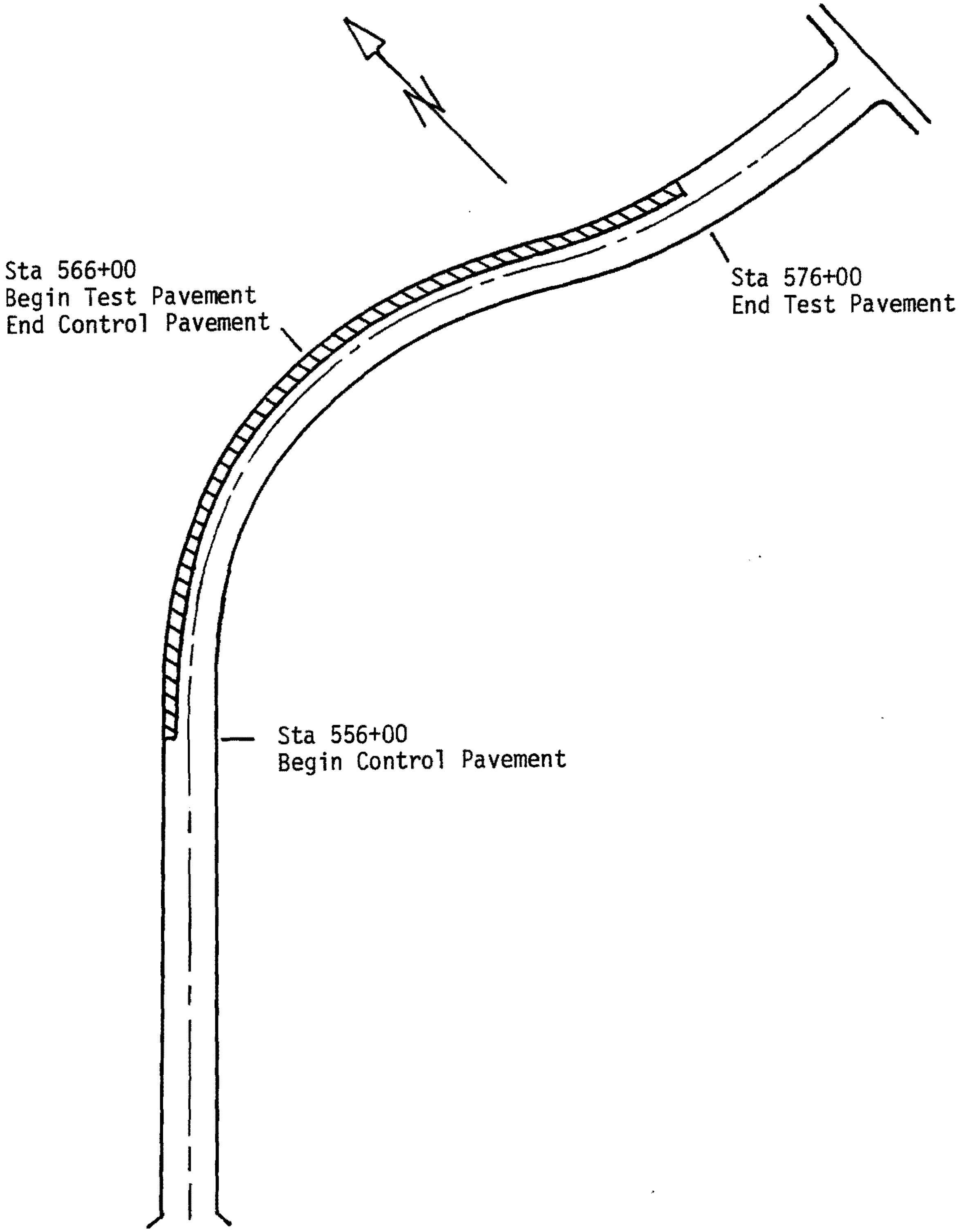

Figure 33. Map Showing Layout of Construction Project and Coated Aggregate Test Pavements and Control Pavements.

Materials

Exxon AC-20 was used in both the treated and untreated Type B asphalt paving mixtures in both the spring and fall operations.

Five aggregates were blended to produce the specified gradation. Four of them were natural, subrounded siliceous aggregates and one was crushed calcarious aggregate. The materials used included 30 percent Gifford Hill one inch river gravel, 26 percent Gifford Hill processed river gravel, 15 percent Gifford Hill washed coarse sand (concrete sand), 14 percent Kmiec field sand, and 15 percent Texas Crushed Stone washed limestone screenings. The mixture was designed to be in compliance with Texas DOT Item 340, Type B specification. Gradations of the individual aggregates and their combined gradation using the percentages shown above are shown in Table 10. The three coarser aggregates were obtained from the Waco area. The crusher screenings were obtained from Georgetown. The field sand was obtained from a pit near College Station.

Table 10. Individual Components of the Project Design Gradation.

Sieve Size	Weight Percent Passing					
	Coarse Gravel	Processed Gravel	Washed Sand	Field Sand	Crusher Screening	Combined Gradation
1 inch	100	-	-	-	-	100
7/8 inch	80.9	-	-	-	-	94.3
5/8 inch	36.7	100	-	-	-	81.0
3/8 inch	2.5	98.4	100	-	100	70.3
No. 4	0.4	45.8	97.9	-	99.7	51.6
No. 10	0.3	6.6	76.1	100	74.9	38.4
No. 40	0.2	2.5	24.7	99.5	16.1	20.7
No. 80	0.2	1.6	2.5	56.8	6.6	9.8
No. 200	0.1	1.1	0.8	7.1	2.2	1.7
Percent Combined	30 +	26 +	15 +	14 +	15 =	100

Asphalt Mixture Design

Mixture design for the control (untreated) asphalt mixture was performed by District 17 of Texas DOT. Using their standard procedures, they obtained an optimum asphalt content of 4.6 percent. After successfully coating the aggregates with cement in the field, TTI obtained materials and performed a mixture design using the treated aggregates. An optimum asphalt content of 5.1 percent was determined. Mixture design curves for the untreated and treated mixtures are shown in Figures 14 through 17.

Findings from laboratory tests on these field mixtures are discussed in the section entitled "Experimental Results." Standard mixture design procedures appear to be satisfactory for use with the cement treated mixtures.

Construction

Treating of aggregates with cement was accomplished in the same manner as that described in the aggregate coating experiment described above.

The six-inch Type B layer, which contained the test mixtures, was placed in two lifts. The first lift was placed in the fall of 1991. Careful planning and execution resulted in an extremely successful operation with no problems. There were no noticeable differences in mixing, placing, or compacting the uncoated and coated paving mixtures. At this time, asphalt pavement construction was halted and curbs and gutters were installed at the test site.

The second lift was placed in the spring of 1992. The treated aggregates used in the first and second lifts were prepared in separate operations. The treated aggregates in the first lift contained the proper proportions of cement; whereas, about twice (estimated) the recommended optimum cement content was inadvertently added to the aggregates during coating operations for the second lift. This error was not obvious until an attempt was made to use aggregate from the stockpiles. As a result of the excess cement, the treated aggregate stockpiles produced in the spring were well cemented and completely unworkable. The blade of a D-8 dozer was used to initially break apart the stockpiles, then the smaller pieces were broken apart by repeatedly rolling over them with the tracks of the dozer. The aggregates crushed apart by the dozer still possessed a very heavy coating of hardened cement as compared to those produced during the fall of 1991.

The washed sand stockpile was so well cemented that it could not be sufficiently broken apart by the dozer crushing procedure and, therefore, could not be used in the test. In order to avoid interrupting the construction process, the cement treated washed sand was replaced with untreated washed sand in the second (spring 1992) test.

There was concern that agglomerations of cement coated aggregates may cause problems feeding through the belt feeders at the base of the cold feed bins, particularly during the spring 1991 operations. However, no problems were observed.

Plant mixing, placing, and compacting operations were identical for the control and coated mixtures. The plant used for mixing was a Standard Havens counter flow drum mix plant with a capacity of 350 tons per hour. During the spring of 1992, temporary clogging of the baghouse occurred that may have been due to excessive fines created by abrasion of the cement from the aggregate in the drum mix plant. No other construction problems directly attributable to the coated aggregate were observed.

The mixture was hauled about 14 miles to the paving site in conventional dump trucks. A Blaw-Knox paver was used to place the mix. The breakdown roller, which was kept close behind the paver, was a 25-ton nine-wheel pneumatic roller with 75 psi air pressure in each tire. This was followed by a Bomag model 201-AD steel wheel roller with both drums vibrating only on the first pass. The finish roller was a Bomag model BW-12R nine wheel pneumatic roller with 65 psi in each tire. The mix temperature immediately behind the paver ranged from 300°F to 325°F for both the control and treated mixtures. Compaction was normally completed within 35 minutes or by the time the temperature dropped to 180°F.

Visual observation of the compacted pavement indicated that most of the cement coating had been abraded off the treated aggregate during the handling and mixing processes. Subsequent extraction of the asphalt cement and comparative visual analysis revealed that approximately 95 percent of the cement coating was removed from the aggregate even when excessive portland cement was used during the spring of 1992.

Mixture Testing

In the fall of 1991, samples of asphalt cement and coated and uncoated aggregate and paving mixtures were obtained at the mix plant and conveyed to the laboratory for testing. Plant mixtures were reheated and compacted to produce laboratory test specimens. In the spring of 1992, pavement cores were drilled and tested in the laboratory. The first and second lifts were sawn apart and tested separately. Testing and results of laboratory compacted specimens and pavement cores are discussed in earlier sections of this report.

Cost Data

Costs added by the cement coating process involve three areas: portland cement, equipment and labor for coating the aggregate with cement and stockpiling, and additional asphalt as required by the coated aggregate. The following materials costs were used as bases for computation of the cost increase associated with the aggregate coating process: portland cement - $52/ton, asphalt cement - $80/ton, hot mix asphalt concrete - $26/ton. These costs are based on actual costs or bid prices for the materials used in the test pavements. The contractor estimated that equipment and labor costs for coating the aggregate with cement and stockpiling were $3.00 to $4.00 per ton of aggregate.

For the asphalt mixture used in this study, the average quantity of portland cement added to the total combined aggregate was 3.25 percent. The coated aggregate required 0.5 percent more asphalt than the uncoated aggregate. The costs associated with coating the aggregate and using the coated aggregate to produce one ton of HMAC are as follows:

Portland cement	$1.61
Equipment & labor for coating (estimated)	$3.50
Additional asphalt cement	$0.40
TOTAL COST INCREASE	$5.51/ton of HMAC

Assuming a haul distance of approximately 250 miles for crushed stone, the estimated cost of high quality HMAC made using this crushed stone would be about $28.00 per ton. If local materials that do not require crushing can be used to make HMAC, the estimated cost would be about $20.00 per ton. However, the HMAC made using local materials would not likely meet standard specifications. If this uncrushed material can be suitably upgraded by coating with portland cement at an added cost of $5.51 per ton of HMAC, the total cost of one ton of treated HMAC would be $20.00 plus $5.51 or $25.51. This would provide a cost savings of 8.9 percent over the HMAC made using crushed stone.

CONCLUSIONS AND RECOMMENDATIONS

Based on laboratory and field evaluation of a process for upgrading marginal aggregate by coating with portland cement and curing prior to use in hot mixed asphalt concrete, the following conclusions and recommendations are given.

CONCLUSIONS

1. The guidelines developed by Bayomy et al. (1) for coating different size aggregates with cement and the water cement ratio recommended are appropriate for treating aggregate prior to use in hot mix asphalt.

2. In the laboratory or in the field, aggregate coated with cement paste in accordance with the prescribed procedure will exhibit a uniform, rough-textured surface and will not form permanent agglomerations which might adversely affect the design gradation of hot mixed asphalt concrete.

3. Asphalt mixture design can be performed successfully with cement coated aggregates using the standard TxDOT method.

4. The cement coating on the aggregate is quite susceptible to removal by abrasion. During mixing in the laboratory, 50 to 75 percent of the coating was lost. During mixing in the plant, approximately 95 percent of the coating was removed.

5. If an aggregate is unsuitable for use in a pavement surface course because of potentially poor surface friction, the cement coating process cannot be used to upgrade the aggregate.

6. When used in hot mixed asphalt concrete, cement coated aggregate exhibited increased Hveem stability when compared to similar uncoated aggregate.

7. Cement coated aggregate produces hot mixed asphalt concrete that is less sensitive to binder content than similar uncoated aggregates.

8. The use of cement coated aggregate in hot mixed asphalt concrete did not consistently alter Marshall stability, indirect tensile strength, or moisture susceptibility when compared to similar uncoated materials.

9. Creep tests on asphalt concrete specimens indicated that cement coated aggregate will provide better resistance to pavement rutting than similar uncoated materials.

RECOMMENDATIONS

1. In both the laboratory prepared mixtures and particularly in the field prepared mixtures, most of the cement coating was abraded away during the mixing process. Yet, in most instances, resistance to permanent deformation and Hveem stability of the asphalt mixtures was enhanced. A series of tests needs to be performed on mixtures in which the portland cement is added dry as a filler. This would permit a relative measurement of how much the mixture properties are altered by coating the aggregate with cement and how much they are altered by the mere presence of the cement in the mix.

2. At the present state of the art, it is recommended that the cement coating process to upgrade marginal aggregate for use in hot mixed asphalt concrete not be implemented.

3. A coating process for upgrading marginal aggregate for use in hot mixed asphalt concrete has tremendous potential at the national level. A successful coating process could qualify normally unsuitable aggregates from many local sources thus conserving higher quality aggregates and saving substantial public funds. The cost difference between coated local aggregate and high-quality aggregate hauled long distances will increase as transportation costs increase. The only problem observed in this study was the lack of toughness or abrasion resistance of the cement coating. Research is needed to develop a more abrasion resistant and yet cost effective coating.

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APPENDIX A

AGGREGATE SIEVE ANALYSIS

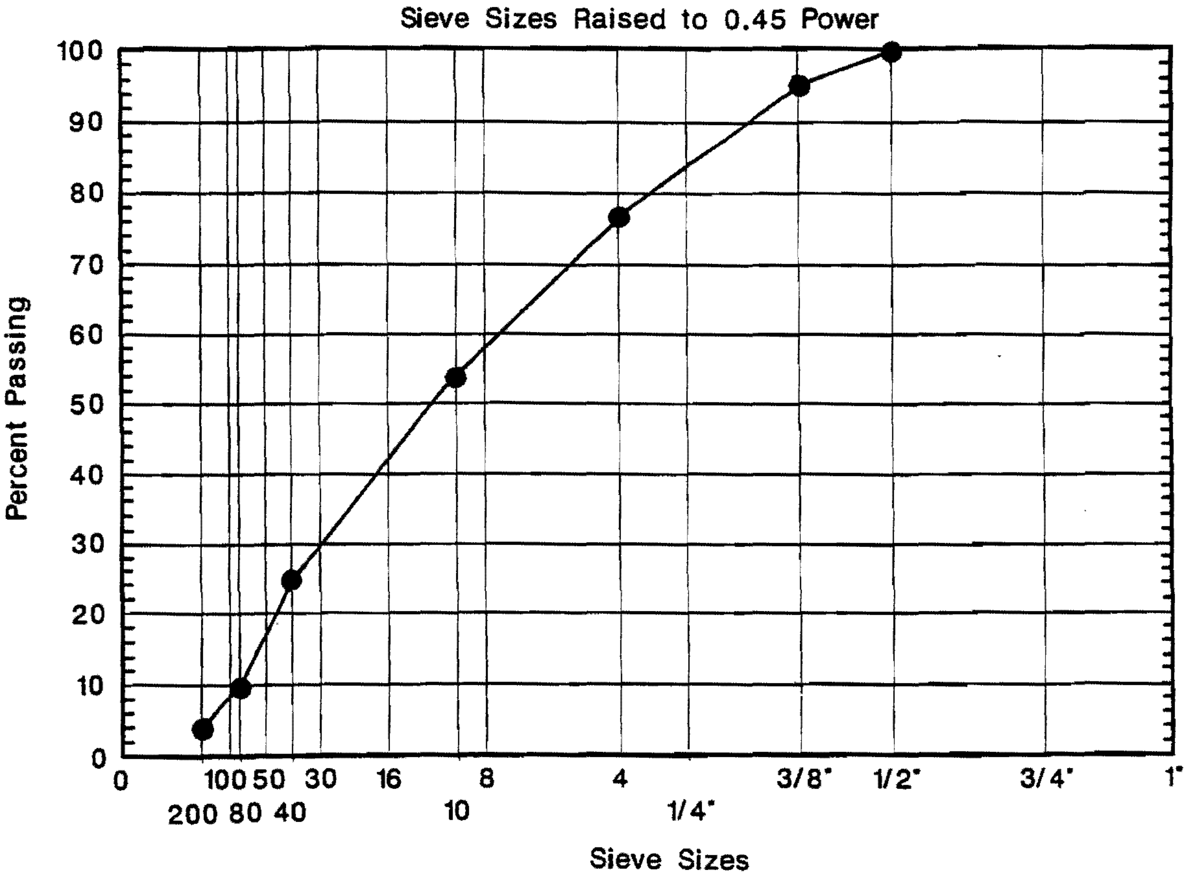

Figure A1. Gradation of Laboratory Standard Aggregates Used in Asphalt Mixtures.

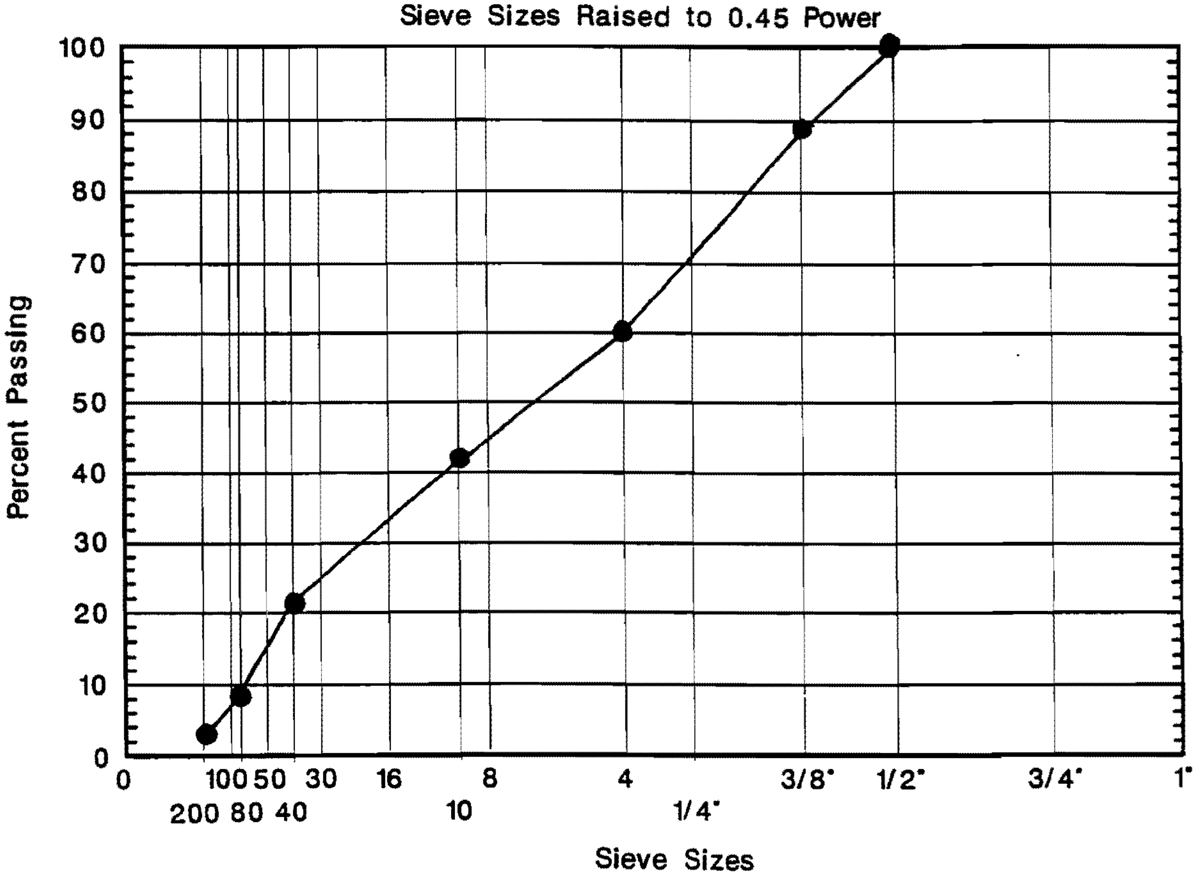

Figure A2. Gradation of District 21 Aggregates Used in Asphalt Mixtures.

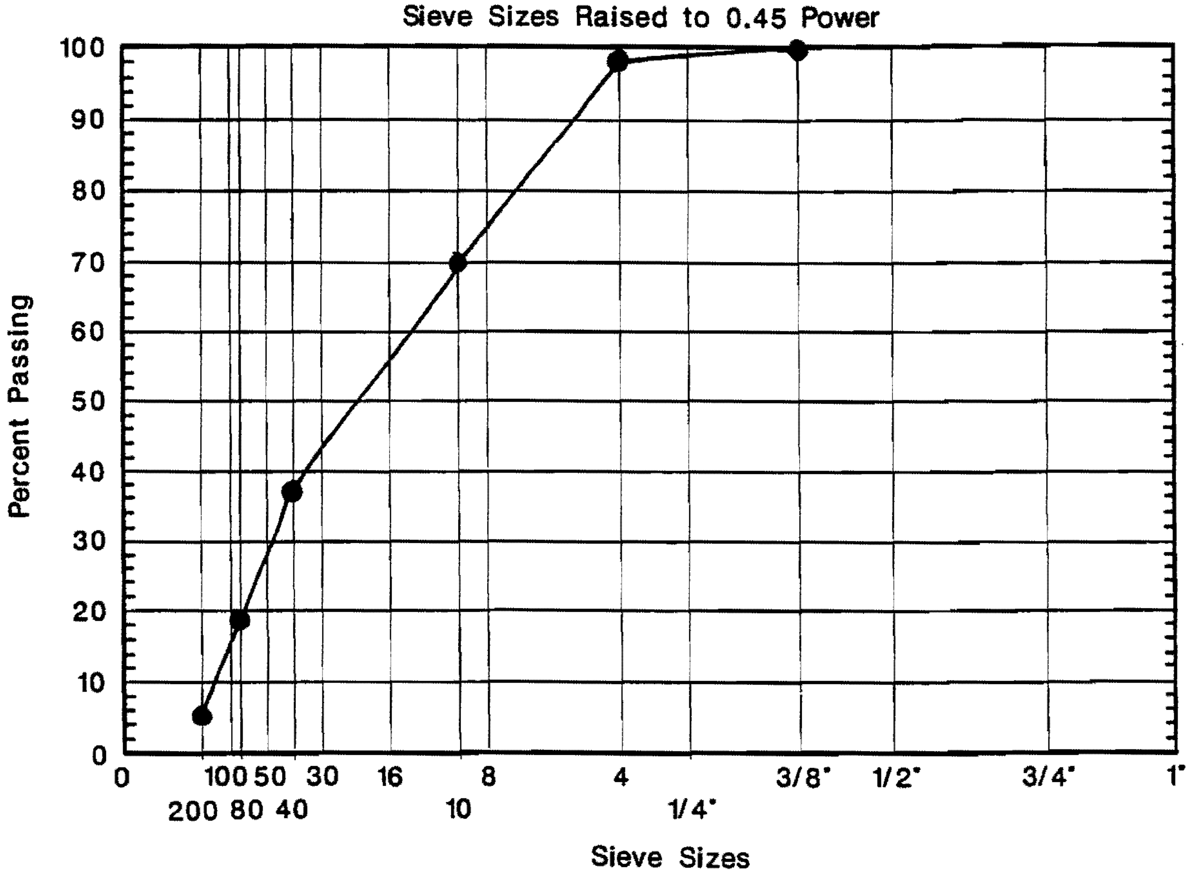

Figure A3. Gradation of District 5 Aggregates Used in Asphalt Mixtures.

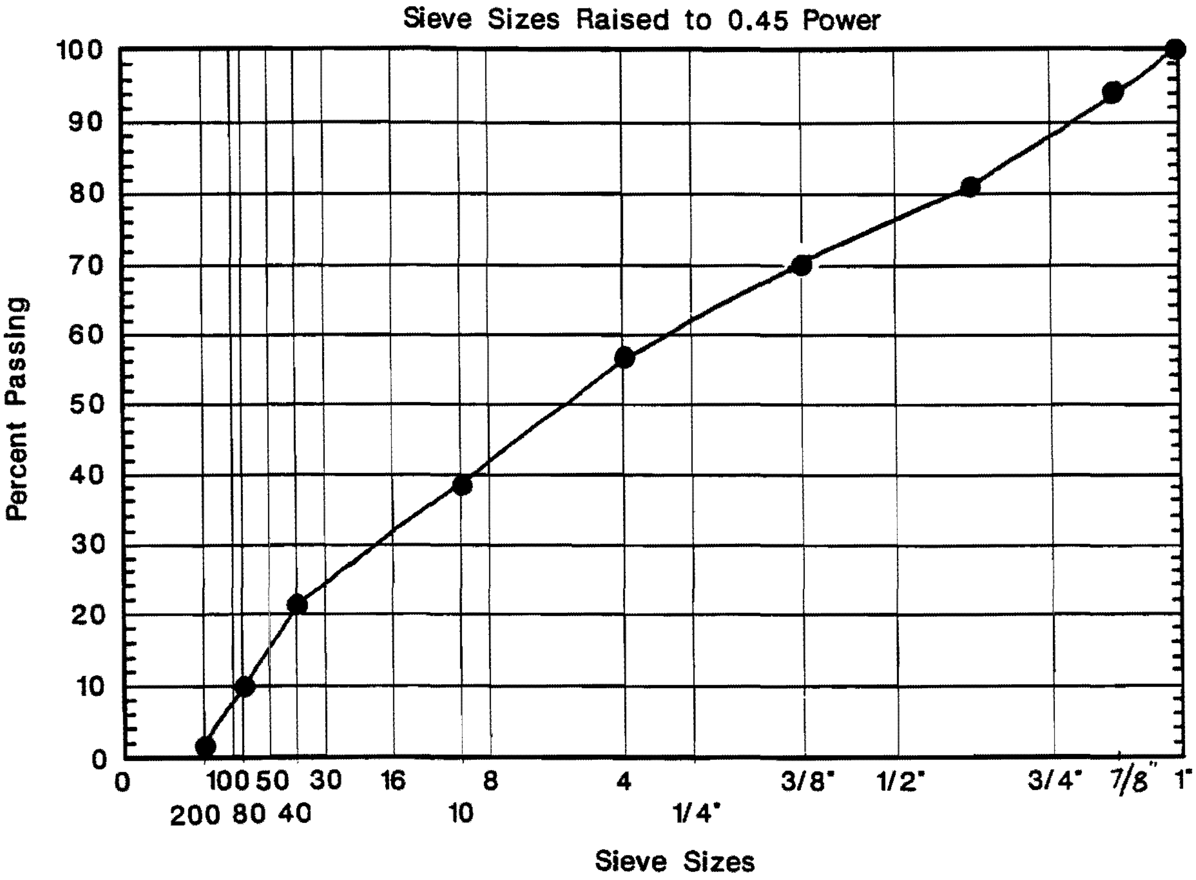

Figure A4. Gradation of District 17 Aggregates Used in Test Pavements.

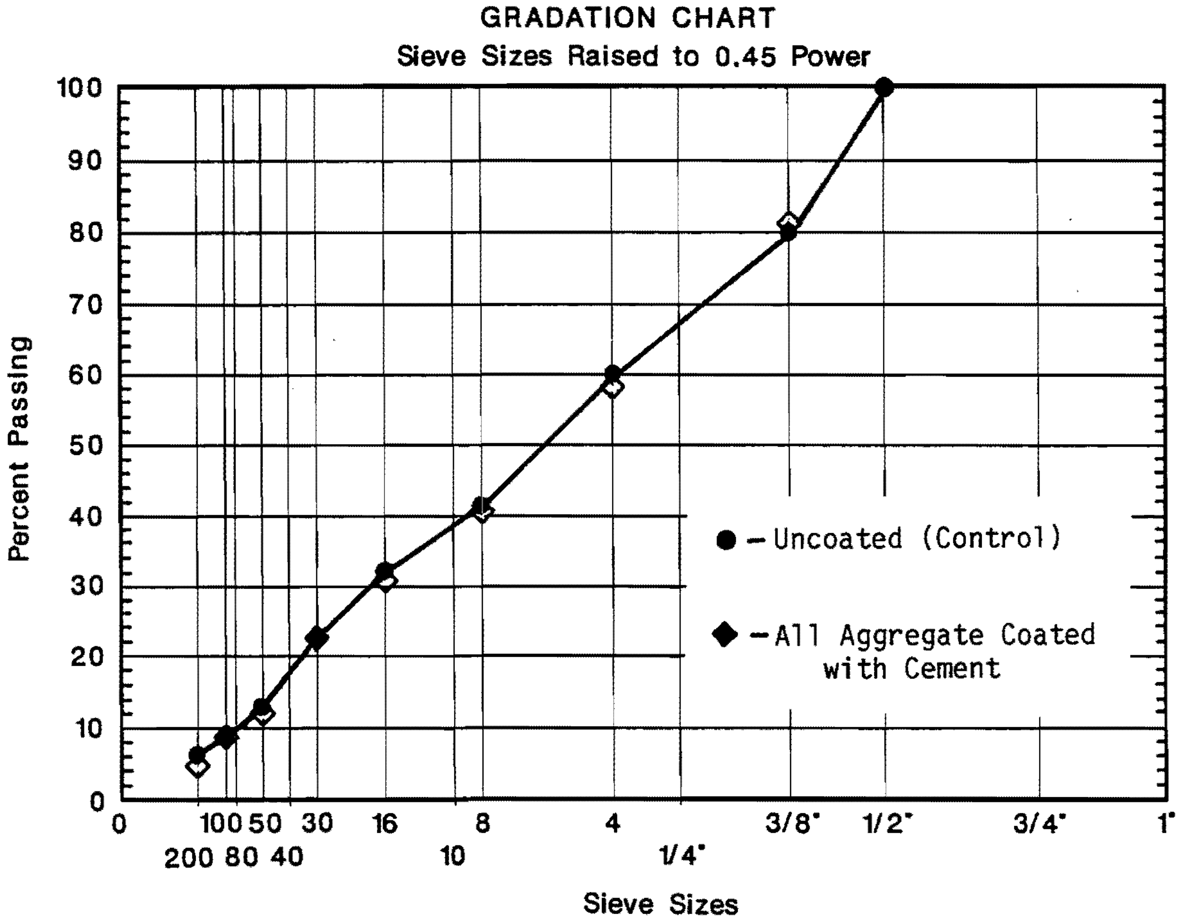

Figure A5. Grading of Uncoated and Coated Aggregates After Mixing with Asphalt, Compaction, and Extraction with Solvent.

APPENDIX B

TEST RESULTS ON HVEEM-TYPE ASPHALT CONCRETE SPECIMENS

Table B1. Results of Tests on Uncoated and Coated Specimens for Lab Standard Brazos Valley River Gravel.

Specimen ID	Air Voids, percent	Resilient Modulus, psi x 1000, at the given temperature					Hveem Stability, percent	Marshall Stability, pounds	Marshall Flow, 0.01 inch	Tensile Strength (77F), psi x 1000	Tensile Strength Ratio
		0°F	36°F	50°F	77°F	104°F					
Uncoated Specimens											
LSNC1	3.1	1930	1820	1190	264	72					
LSNC2	2.9	2010	1790	1120	261	73					
LSNC3	2.7	1950	1770	1200	279	73					
Average	**2.9**	**1960**	**1790**	**1170**	**268**	**73**					
LLNC1	6.0									91	
LLNC2	6.0									84	
LLNC3	7.9									84	
LLNC4	8.1									83	
LLNC5	6.0									(23*)	
LLNC6	5.9									(25)	
LLNC7	7.7									(21)	
LLNC8	8.1									(25)	
Average	**7.0**									**88 (24)**	**27**
LHNC1	3.5						28	990	12		
LHNC2	3.3						24	1150	15		
LHNC3	3.2						25	670	14		
Average	**3.3**						**26**	**940**	**14**		
Coated Specimens											
LSAC 104	3.9	1810	1850	900	211	54					
LSAC 106	3.9	1880	1830	960	211	54					
LSAC 107	3.3	1860	1800	930	206	55					
Average	**3.7**	**1850**	**1830**	**950**	**213**	**54**					
LLAC1	7.7									(45)	
LLAC2	6.8									63	
LLAC3	6.8									(56)	
LLAC4	7.7									68	
LLAC5	7.5									(44)	
LLAC6	7.3									68	
Average	**7.3**									**66 (48)**	**73**
HLAC1	6.6						37	980	15		
HLAC2	6.4						40	1050	16		
HLAC3	6.1						38	1050	16		
Average	**6.4**						**38**	**1030**	**16**		

* Numbers in parenthesis are for one cycle moisture conditioned samples (Tex 531-C).

Table B2. Results of Tests on Uncoated and Coated Specimens for District 21 Aggregate.

Specimen ID	Air Voids, percent	Resilient Modulus, psi x 1000, at the given temperature					Hveem Stability, percent	Marshall Stability, pounds	Marshall Flow, 0.01 inch	Tensile Strength (77F), psi x 1000	Strain @ Failure, in/in	Tensile Strength Ratio
		0°F	36°F	50°F	77°F	104°F						
Uncoated Specimens												
FNC1	3.4	1710	1230	629	117	16						
FNC2	2.9	1990	1190	549	109	15						
FNC3	3.1	1840	1140	649	117	17						
Average	**3.1**	**1850**	**1190**	**609**	**114**	**16**						
FLNC1	8.5				102					(60)	(0.0650)	
FLNC2	8.3				124					75	0.1400	
FLNC3	7.9				125					(48)	(0.1400)	
FLNC4	7.2				143					86	0.1150	
FLNC5	7.7				118					(49)	(0.1400)	
FLNC6	7.9				125					82	0.1350	
FLNC7	7.7				128					85	0.1400	
FLNC8	7.9				112					(47)	(0.1550)	
Average	**7.9**				**122**					**82 (51)**	**0.1325 (0.1250)**	**62**
FHNC1	3.8				115		31	878	15			
FHNC2	4.6				98		32	707	17			
FHNC3	3.8				115		31	806	16			
Average	**4.1**				**114**		**31**	**781**	**16**			
Coated Specimens												
FAC1	3.0	1720	1010	592	114	25						
FAC2	3.4	1800	1060	570	103	20						
FAC3	3.1	1700	1060	597	111	28						
Average	**3.2**	**1740**	**1050**	**586**	**109**	**24**						
FLAC1	6.7				110					(59)	(0.1375)	
FLAC2	7.3				98					(54)	(0.1400)	
FLAC3	6.3				112					79	0.1250	
FLAC4	6.7				110					144	0.1150	
FLAC5	8.5				103					(53)	(0.1200)	
FLAC6	8.0				106					141	0.1300	
FLAC7	8.7				102					138	0.1200	
FLAC8	5.8				120					(60)	(0.1300)	
Average	**7.3**				**108**					**125 (57)**	**0.1225 (0.1319)**	**45**
FHAC1	4.7						34	794	15			
FHAC2	4.7						41	762	17			
FHAC3	5.1						39	788	16			
Average	**4.8**						**38**	**781**	**16**			

* Numbers in parenthesis are for one cycle moisture conditioned samples (Tex 531-C).

Table B3. Results of Tests on Uncoated and Coated Specimens for District 5 Aggregate.

Specimen ID	Air Voids, percent	Resilient Modulus, psi x 1000, at the given temperature					Hveem Stability, percent	Marshall Stability, pounds	Marshall Flow, 0.01 inch	Tensile Strength (77F), psi x 1000	Strain @ Failure, in/in	Tensile Strength Ratio
		0°F	36°F	50°F	77°F	104°F						
Uncoated Specimens												
5NC1	3.6	1627	1621	899	227	52						
5NC2	4.6	1618	1528	890	216	47						
5NC3	3.9	1641	1722	953	214	49						
Average	**4.0**	**1625**	**1624**	**914**	**219**	**49**						
5LNC3	5.9									102	0.0900	
5LNC4	5.5									91	0.1300	
5LNC6	5.5									100	0.1200	
5LNC8	5.7									100	0.1300	
5LNCA	5.1									(39)	(0.1000)	
5LNCB	5.0									(43)	(0.1400)	
5LNCC	4.7									(41)	(0.1400)	
5LNCD	4.6									(54)	(0.1100)	
Average	**5.3**									**98 (44)**	**0.1175 (0.1250)**	**45**
5HNC1	3.6						42	1182	18			
5HNC2	4.6						41	804	19			
5HNC3	3.9						39	986	16			
Average	**4.0**						**41**	**991**	**18**			
Coated Specimens												
5AC1	4.9	1385	1274	834	270	46						
5AC2	5.0	1449	1343	815	236	42						
5AC3	5.0	1426	1303	823	284	41						
Average	**5.0**	**1420**	**1307**	**824**	**263**	**43**						
5LAC2	8.5									85	0.1050	
5LAC3	9.3									54	0.1300	
5LAC7	7.8									68	0.1000	
5LAC8	7.8									72	0.1050	
5LACA	3.7									(108)	(0.1125)	
5LACB	3.5									(114)	(0.1200)	
5LACC	3.5									(112)	(0.1225)	
5LACD	3.6									(123)	(0.1300)	
Average	**6.0**									**Fo (114)**	**0.1100 (0.1213)**	**61**
5HAC1	4.9						48	1326	21			
5HAC2	5.0						49	1559	19			
5HAC3	5.0						49	1258	19			
Average	**5.0**						**49**	**1381**	**20**			

* Numbers in parenthesis are for one cycle moisture conditioned samples (Tex 531-C).

Table B4. Results of Tests on Uncoated and Coated Field Mixed-Lab Compacted Specimens for District 17 (Fall 1991).

Specimen ID	Air Voids, percent	Resilient Modulus, psi x 1000, at the given temperature					Hveem Stability, percent	Marshall Stability, pounds	Marshall Flow, 0.01 inch	Tensile Strength (77F), psi x 1000	Strain @ Failure, in/in	Tensile Strength Ratio
		0°F	36°F	50°F	77°F	104°F						
Uncoated Specimens												
17NC3	4.4	1882	1812	540	333	33						
17NC7	4.2	1900	1700	653	314	34						
17NC8	3.3	1887	1674	611	323	32						
Average	**4.3**	**1890**	**1729**	**601**	**323**	**33**						
17LNC2	6.2									(92)	0.1400	
17LNC3	6.8									(100)	0.1400	
17LNC4	6.5									121	0.1000	
17LNC5	6.7									106	0.1100	
17LNC6	6.3									(88)	(0.1300)	
17LNC7	6.5									112	(0.1250)	
17LNC8	6.4									(93)	(0.1600)	
17LNC9	6.8									(99)	(0.0950)	
Average	**6.5**									**110 (93)**	**0.1075 (0.1425)**	**85**
17HC1	4.2						32	834	15			
17HC4	4.4						31	712	12			
17HC5	4.0						34	589	13			
Average	**4.2**						**32**	**712**	**13**			
Coated Specimens												
17AC2	4.6	2047	1691	634	332	34						
17AC4	4.6	1983	1710	548	306	29						
17AC8	4.8	1968	1747	566	325	33						
Average	**4.7**	**1999**	**1716**	**582**	**321**	**32**						
17LAC2	9.8									81	0.1100	
17LAC3	6.3									90	0.0900	
17LAC4	6.3									(88)	0.1300	
17LAC5	6.3									88	0.1000	
17LAC6	6.6									(76)	(0.1800)	
17LAC7	6.6									(76)	(0.2200)	
17LAC8	6.0									(82)	(0.1400)	
17LAC9	6.1									81	(0.0900)	
Average	**6.1**									**85 (81)**	**0.0975 (0.1675)**	**95**
17HAC1	4.8						34	621	13			
17HAC3	4.3						33	511	15			
17HAC4	4.4						34	656	12			
Average	**4.5**						**34**	**596**	**13**			

* Numbers in parenthesis are for one cycle moisture conditioned samples (Tex 531-C).

Table B5. Results of Tests on Uncoated and Coated Field Mixed-Lab Compacted Specimens for District 17 (Spring 1992).

Specimen ID	Air Voids, percent	Resilient Modulus, psi x 1000, at the given temperature				Hveem Stability, percent	Marshall Stability, pounds	Marshall Flow, 0.01 inch	Tensile* Strength (77F), psi x 1000	Strain @ Failure, in/in	Tensile Strength Ratio
		30°F	58.5°F	77°F	104°F						
Uncoated Specimens											
4	3.3	2456	1309	426	65	43	1411	14	-	-	
6	3.3	2408	1150	384	62	35	1251	11	-	-	
9	3.3	-	-	427	-	-	-	-	187	0.0900	
10	2.9	2434	1395	425	68	41	1320	15	-	-	
11	2.9	-	-	408	-	-	-	-	162	0.0800	
12	3.3	-	-	381	-	-	-	-	163	0.0900	
Average	**3.2**	**2433**	**1285**	**409**	**65**	**40**	**1327**	**13**	**171**	**0.0870**	
LB1N	7.1								(70)	(0.1700)	
LB2N	7.1								(72)	(0.1600)	
LB3N	6.4								(74)	(0.1900)	
LB4N	7.2								96	0.1000	
LB5N	6.9								90	0.1300	
LB6N	6.7								92	0.0900	
Average	**6.9**								**93 (72)**	**0.1067 (0.1730)**	**77**
Coated Specimens											
1C	3.2	2304	1169	374	62	46	1411	13	-	-	
2C	3.2	-	-	376	-	-	-	-	157	0.1100	
5C	3.6	2216	1010	320	56	43	1541	15	-	-	
6C	3.6	-	-	400	-	-	-	-	162	0.0900	
10C	3.2	-	-	355	-	-	-	-	161	0.0900	
11C	3.2	2371	1095	352	58	42	1610	11	-	-	
Average	**3.3**	**2297**	**1091**	**363**	**59**	**43**	**1521**	**13**	**160**	**0.0970**	
LB1C	6.8								(42)	(0.1200)	
LB2C	6.6								(55)	(0.1200)	
LB3C	7.4								(45)	(0.1200)	
LB4C	7.4								94	0.1200	
LB5C	7.1								91	0.1100	
LB6C	6.3								92	0.0900	
Average	**6.9**								**92 (47)**	**0.1070 (0.1200)**	**51**

* Numbers in parenthesis are for one cycle moisture conditioned samples (Tex 531-C).

Table B6. Results of Tests on Pavement Cores from Test Pavement at College Station - First Lift Placed in Fall of 1991.

Specimen ID	Air Voids, percent	Resilient Modulus, psi x 1000, at the given temperature				Hveem Stability, percent	Marshall Stability, pounds	Marshall Flow, 0.01 inch	Tensile Strength (77F), psi x 1000	Strain @ Failure, in/in
		30°F	58.5°F	77°F	104°F					
Uncoated Specimens										
2	3.3	2289	997	232	29	25	1221	13	-	-
3	3.3	-	-	206	-	-	-	-	140	0.1200
4	3.3	-	-	145	-	-	-	-	138	0.1200
5	3.3	2154	973	230	30	18	1247	15	-	-
6	2.9	-	-	-	-	-	-	-	153	0.1100
8	3.7	2165	1161	258	31	32	1115	11	-	-
9	3.7	-	-	212	-	-	-	-	-	-
Average	**3.3**	**2203**	**1044**	**214**	**30**	**23**	**1194**	**13**	**144**	**0.1167**
Coated Specimens										
2C	2.4	-	-	179	-	-	-	-	150	0.1100
4C	1.6	2494	860	185	23	14	1247	14	-	-
5C	2.4	2337	870	166	22	20	1071	14	-	-
6C	2.8	-	-	147	-	-	-	-	126	0.1100
7C	3.2	2283	853	214	31	42	865	11	-	-
8C	2.8	-	-	145	-	-	-	-	156	0.1200
Average	**2.5**	**2371**	**861**	**173**	**25**	**33**	**1061**	**13**	**144**	**0.1133**

Table B7. Results of Tests on Pavement Cores from Test Pavement at College Station - Second Lift Placed in Spring of 1992.

Specimen ID	Air Voids, percent	Resilient Modulus, psi x 1000, at the given temperature				Hveem Stability, percent	Marshall Stability, pounds	Marshall Flow, 0.01 inch	Tensile Strength (77F), psi x 1000	Strain @ Failure, in/in
		30°F	58.5°F	77°F	104°F					
Uncoated Specimens										
1	4.5	1754	755	172	17	24	594	12	-	-
4	3.3	-	-	198	-	-	-	-	103	0.1200
5	4.1	2117	1018	179	19	21	617	13	-	-
6	4.5	2381	953	192	21	25	684	12	-	-
8	3.7	-	-	162	-	-	-	-	99	0.1200
10	3.7	-	-	192	-	-	-	-	108	0.1100
Average	**3.9**	**2084**	**909**	**183**	**19**	**23**	**632**	**12**	**104**	**0.1167**
Coated Specimens										
1C	4.0	-	-	226	-	-	-	-	-	-
2C	3.2	-	-	229	-	-	-	-	98	0.1200
3C	3.6	-	-	205	-	-	-	-	-	-
4C	3.2	1951	751	203	27	34	1038	13	-	-
5C	2.8	2778	1042	219	25	27	781	15	-	-
6C	5.7	-	-	183	-	-	-	-	101	0.1100
7C	4.8	2482	759	176	20	39	1320	12	-	-
8C	3.2	-	-	208	-	-	-	-	109	0.1100
9C	3.2	-	-	171	-	-	-	-	-	-
Average	**3.8**	**2404**	**851**	**202**	**25**	**33**	**1046**	**13**	**102**	**0.1133**

APPENDIX C

DATA FROM CREEP TESTS

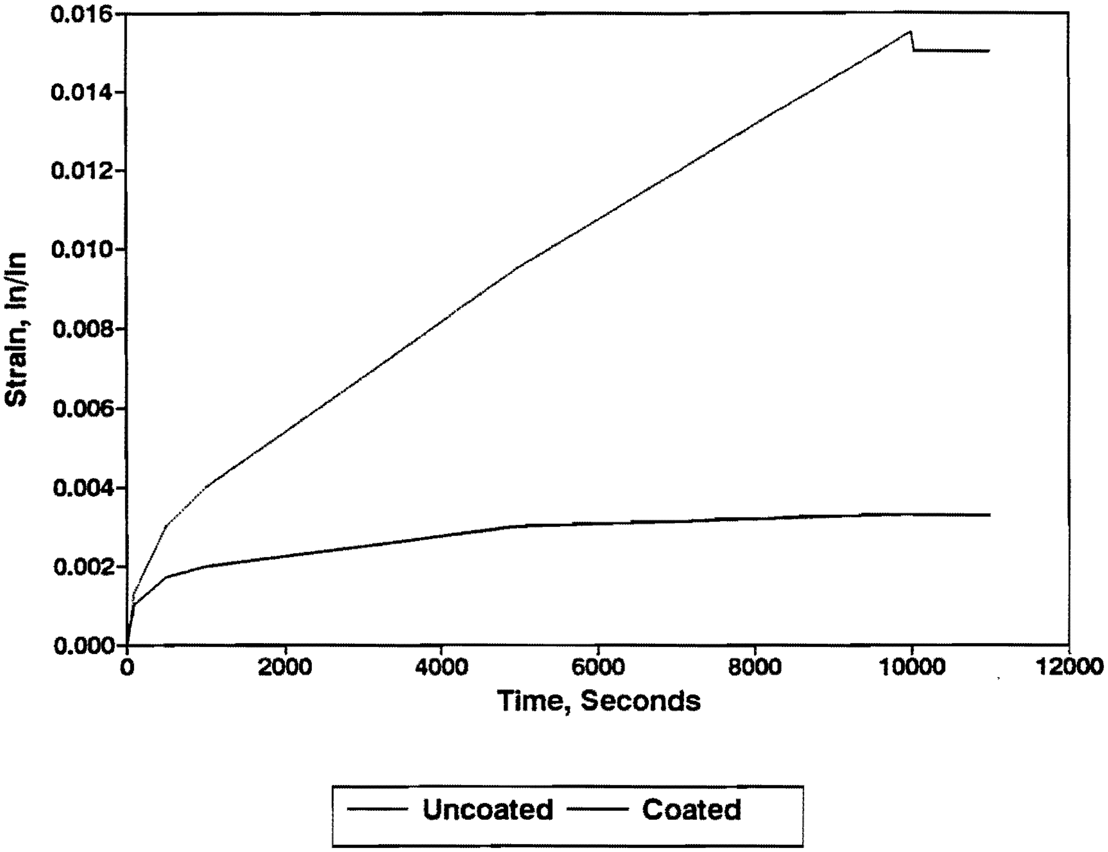

Figure C1. Dynamic Creep Results for Laboratory Standard Asphalt Mixtures - Stress = 60 psi, Temperature = 77°F.

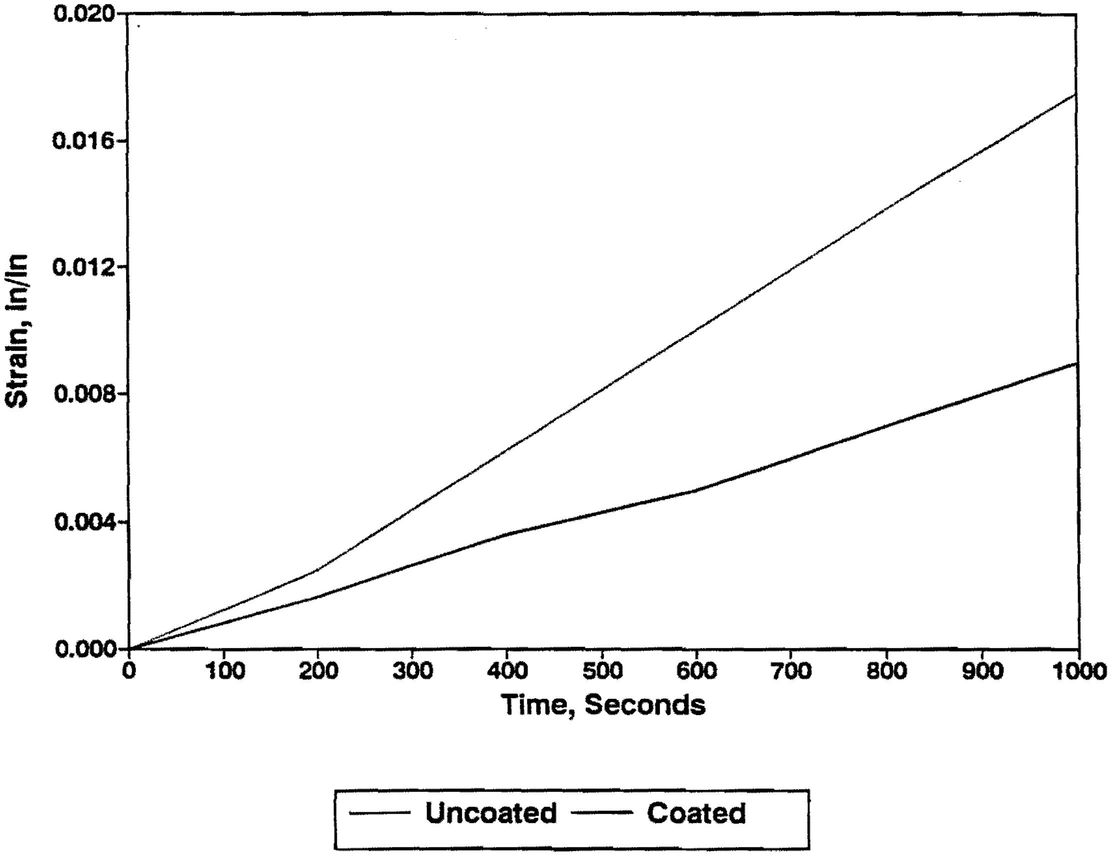

Figure C2. Dynamic Creep Results for District 21 Mixtures - Stress = 9 psi, Temperature = 104°F.

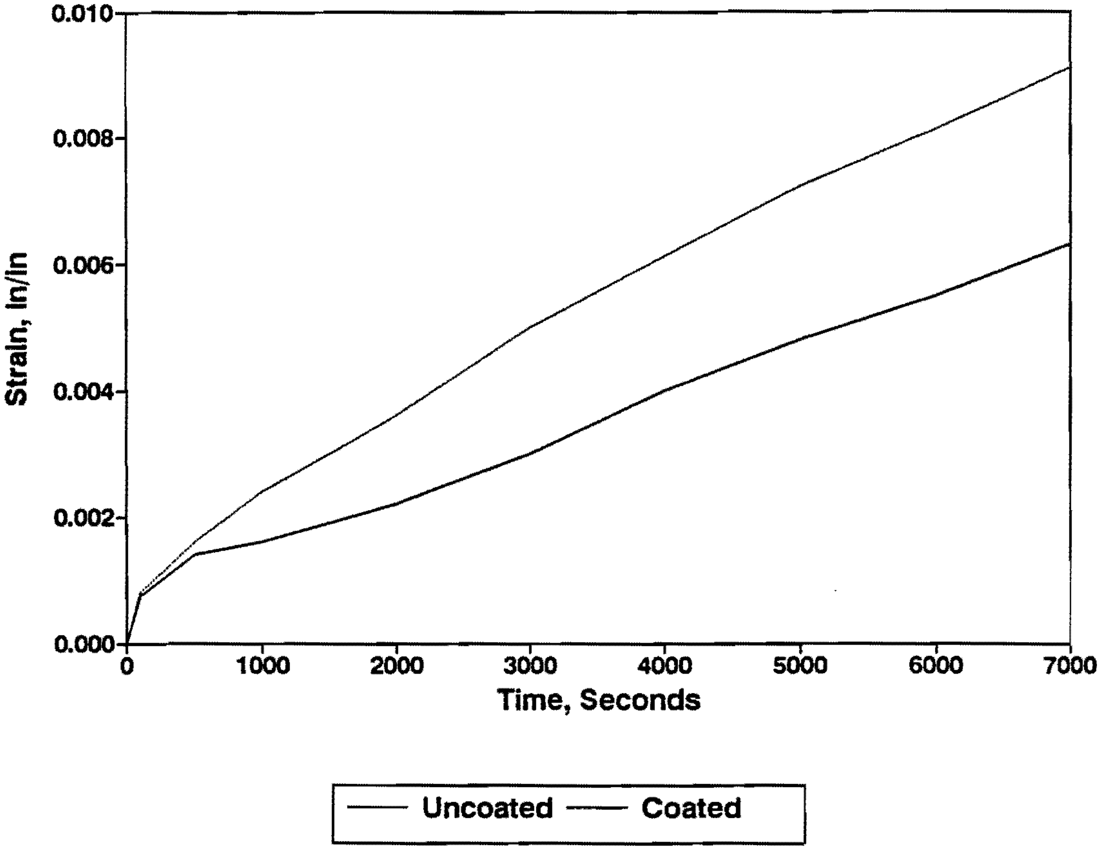

Figure C3. Dynamic Creep Results for District 21 Mixtures - Stress = 5 psi, Temperature = 104°F.

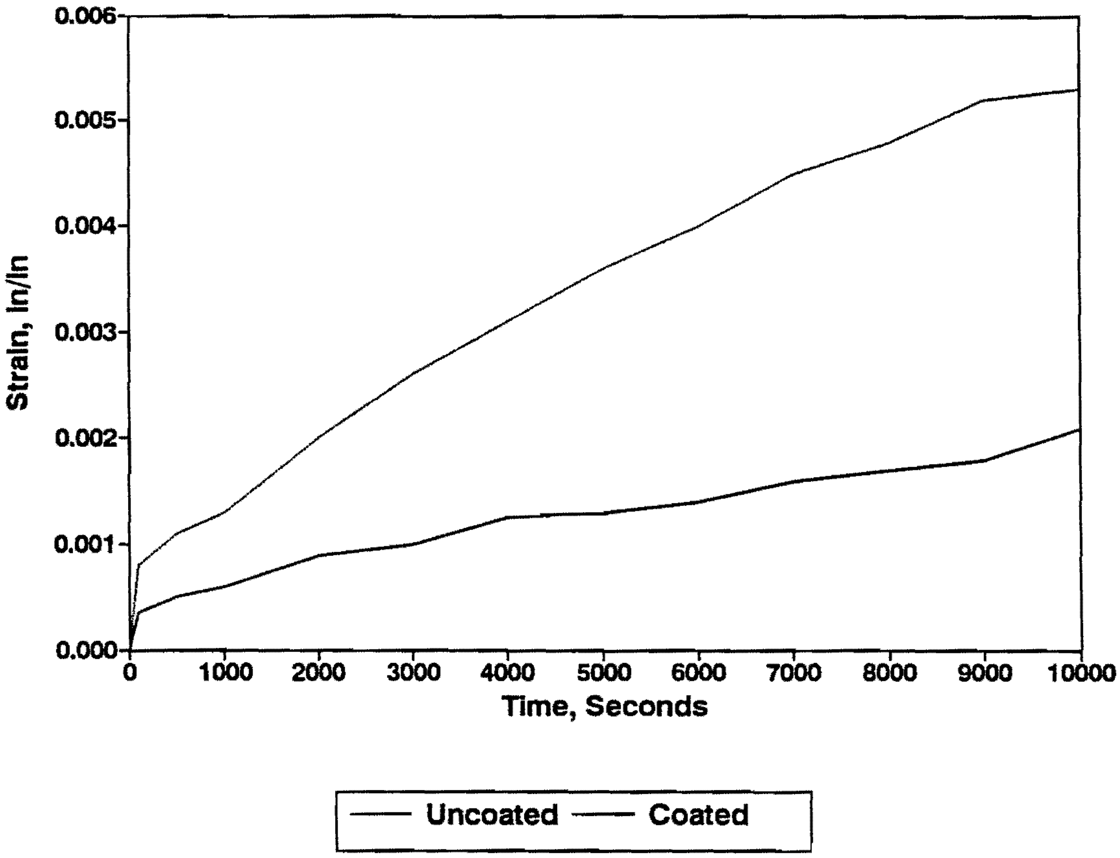

Figure C4. Dynamic Creep Results for District 21 Mixtures - Stress = 3 psi, Temperature = 104°F.

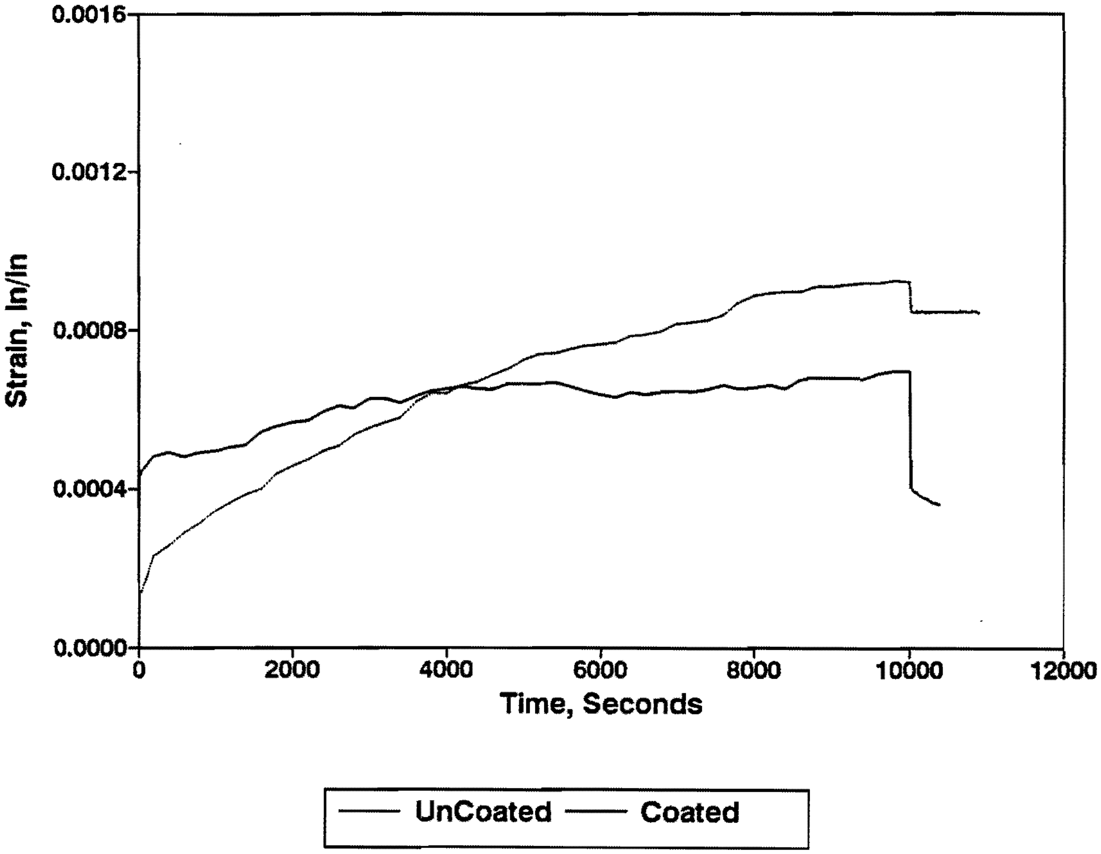

Figure C5. Dynamic Creep Results for District 5 Mixtures - Stress = 5 psi, Temperature = 104°F.

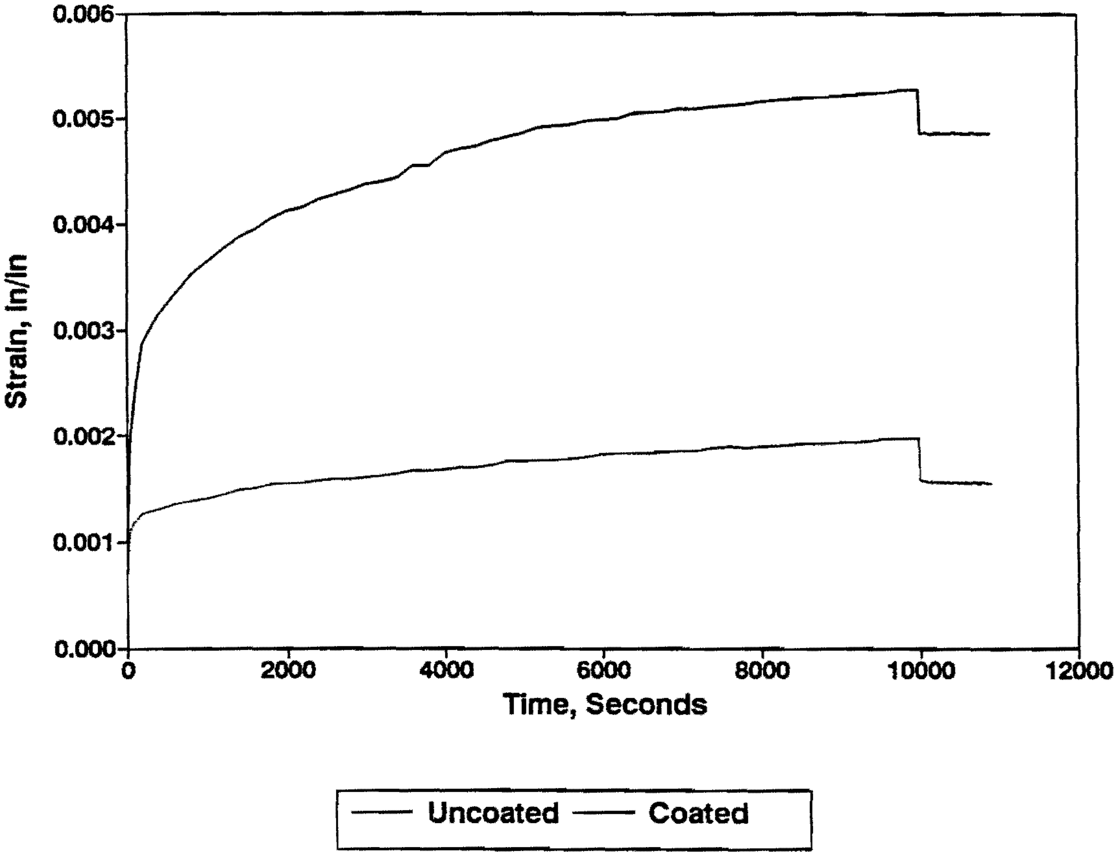

Figure C6. Dynamic Creep Results for District 5 Mixtures - Stress = 5 psi, Temperature = 104°F.

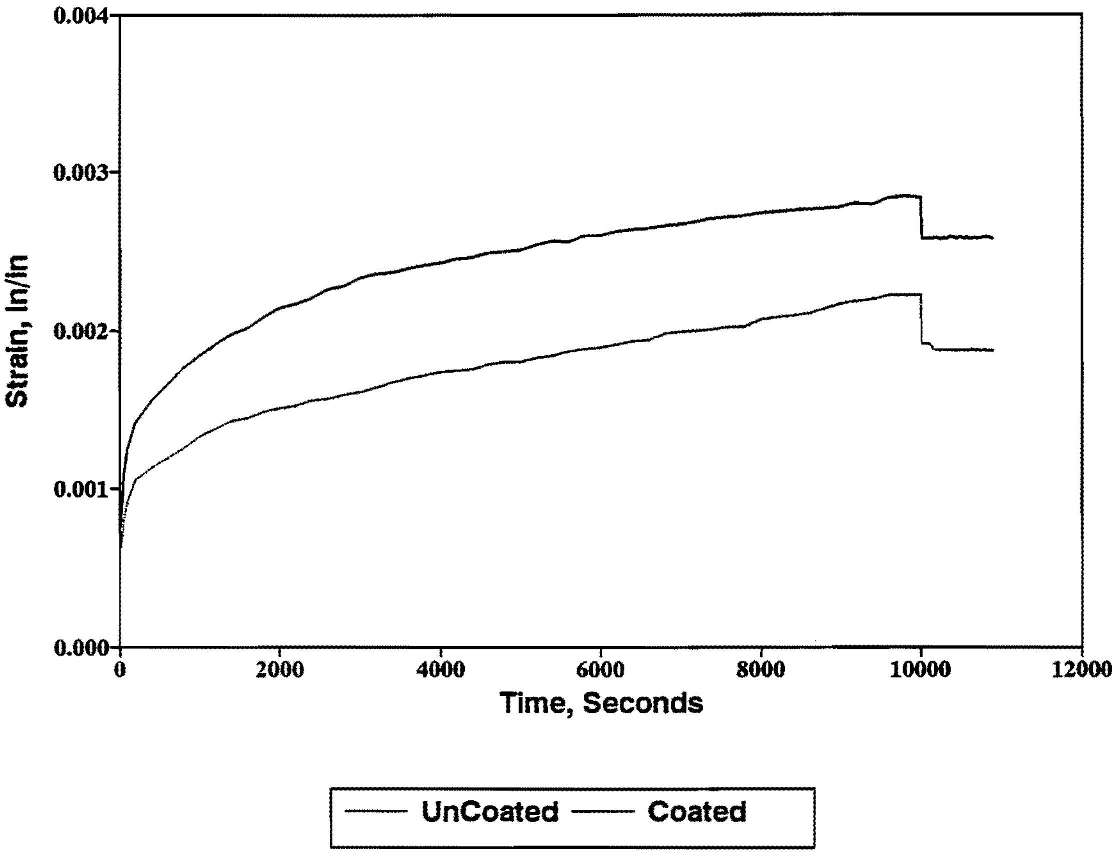

Figure C7. Dynamic Creep Results for District 5 Mixtures - Stress = 7.5 psi, Temperature = 104°F.

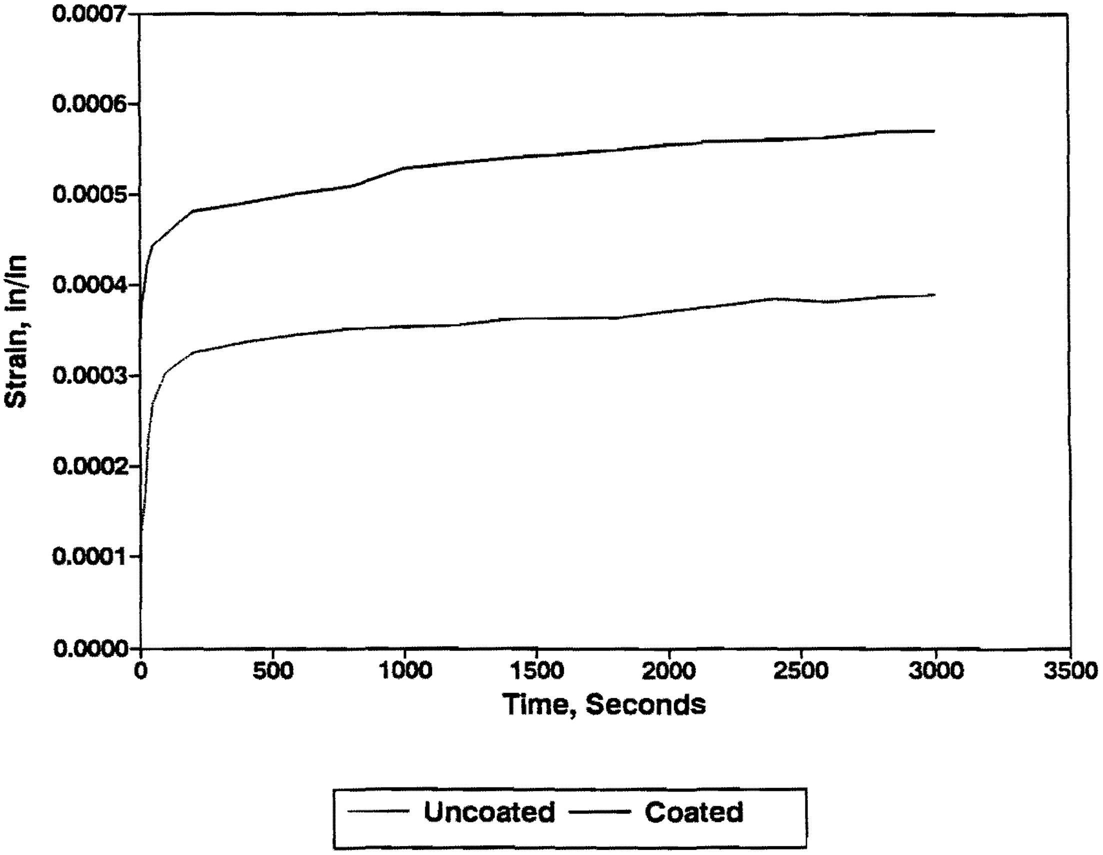

Figure C8. Dynamic Creep Results for District 5 Mixtures - Stress = 10 psi, Temperature = 104°F.

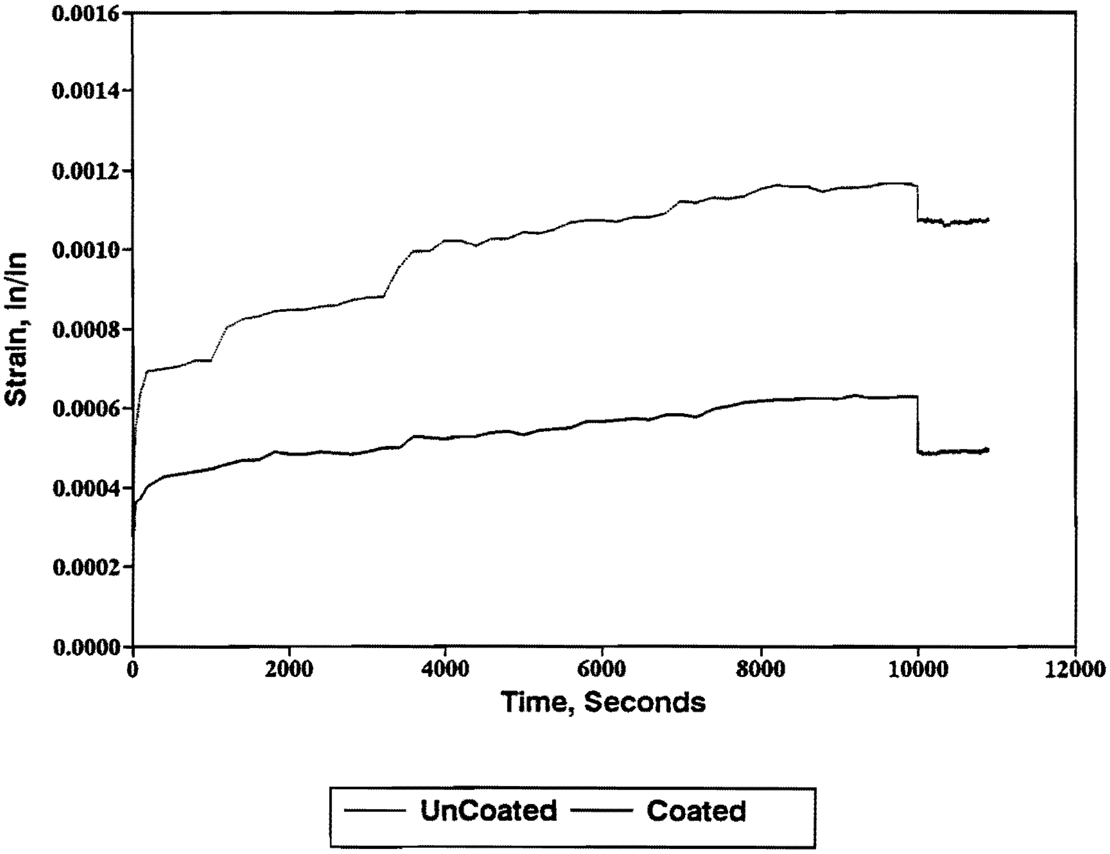

Figure C9. Dynamic Creep Results for District 17 Mixtures - Stress = 5 psi, Temperature = 104°F.

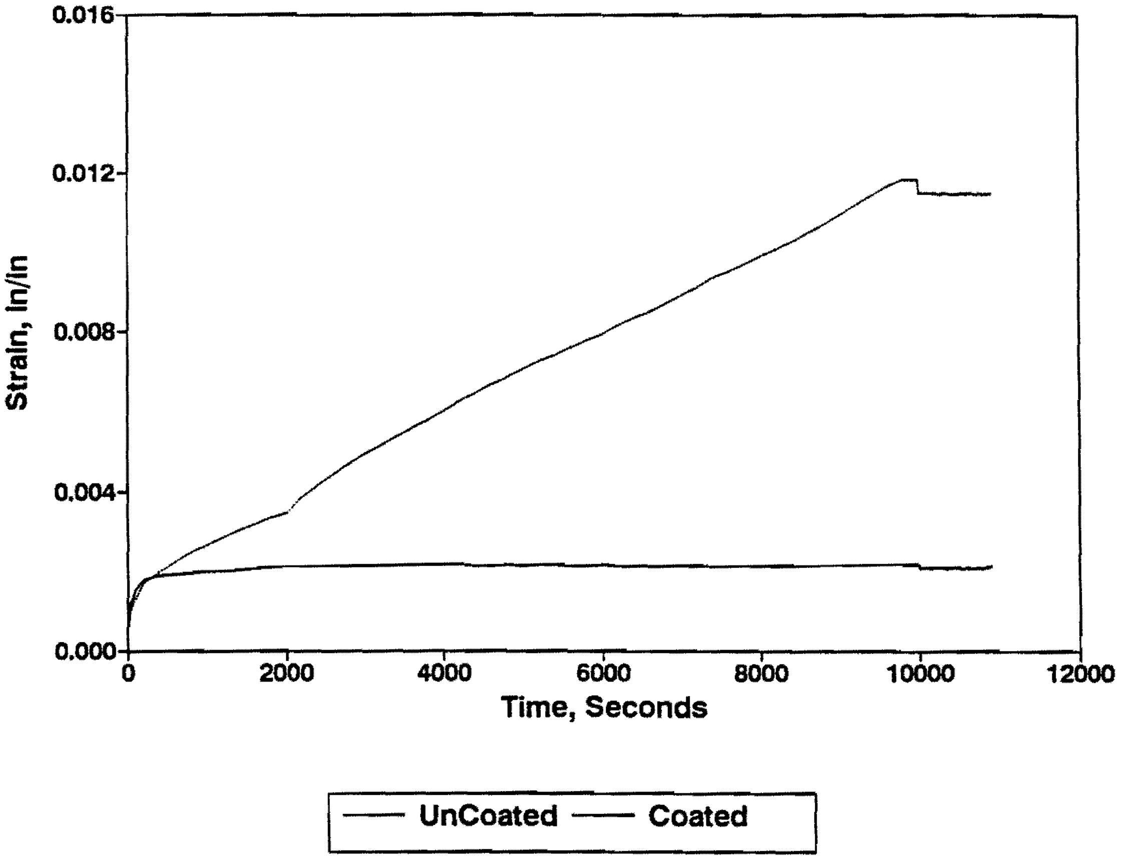

Figure C10. Dynamic Creep Results for District 17 Mixtures - Stress = 7.5 psi, Temperature = 104°F.