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TRC9204

Deformation of Surface and Binder Courses

R. P. Elliott, G. Gowda

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DEFORMATION OF SURFACE AND BINDER COURSES

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16. Abstract

To determine the relative rut resistance of typical AHTD surface and binder mixes, repeated load, permanent deformation tests were conducted. Both laboratory prepared specimens and specimens obtained by coring in-service pavements were tested. The accumulated permanent strain after 10,000 load repetitions was used as the measure of relative rutting resistance. The test results clearly show the surface mix to be much less rut resistant than the binder mix. The average strain of the surface mix ranged from 3 to 5.5 times the average strain in the binder mix.

Based on this finding, it is recommended that restrictions be placed on the substitution of surface for specifications to implement the recommendation.

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ABSTRACT

To determine the relative rut resistance of typical AHTD surface and binder mixes, repeated load, permanent deformation tests were conducted. Both laboratory prepared specimens and specimens obtained by coring in-service pavements were tested. The accumulated permanent strain after 10,000 load repetitions was used as the measure of relative rutting resistance. The average test results (Figures 4-5 and 4-6) clearly show the surface mix to be much less rut resistant than the binder mix. The average strain of the surface mix ranged from 3 to 5.5 times the average strain in the binder mix.

Based on this finding, it is recommended that restrictions be placed on the substitution of surface for binder. Suggestions are included for revising the specifications to implement the recommendation.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The upper few inches of a flexible pavement is generally composed of two or more layers of asphalt concrete. The top layer is referred to as the surface course and the lower layer(s) are referred to as binder course(s). The surface course mix normally contains a smaller top size aggregates than does the binder course mix. Typical aggregate gradations and some of the properties of surface and binder mixes from selected Arkansas Highways are shown in Tables 1-1 and 1-2.

Because of the larger aggregates, the binder mix is considered to be stiffer and more rut resistant than the surface mix. In general, therefore, it is best to minimize the use of surface mix and maximize the use of binder. However, there are situations where it is desirable to use surface mix in lieu of the binder mix; and, in fact, the current AHTD specifications permit the contractor to substitute surface for binder as long as there is no added cost to the contract.

One situation in which the surface mixes are substituted by the binder mixes is during late fall and winter construction. In order to not leave binder mixes uncovered over the winter, the AHTD specifications prohibit the contractor from placing the binder mix between December 1 and March 15. The contractor may continue to pave binder layers during this period provided surface mix is substituted.

Table 1-1 Typical AHTD Surface Mixes Tested in Study.

	PERCENT PASSING	
Sieve Size	Type 1 Surface Job #100288	Type 2 Surface Job #9582
3/4"	100	100
1/2"	85 - 100	87 - 100
# 4	63 - 77	55 - 69
#10	48 - 56	42 - 50
#20	30 - 38	31 - 39
#40	18 - 26	23 - 31
#80	9 - 17	8 - 16
#200	4 - 8	4 - 8
Asphalt	5.2%	5.4%
	MARSHALL PROPERTIES	
Stability	2546	1768
Air Voids	4.0%	4.5%
Flow	10.3	9.2

Table 1-2 Typical AHTD Binder Mixes Tested in Study.

	PERCENT PASSING	
Sieve Size	Ty 1 Binder Job #100288	Type 2 Binder Job #9582
1 1/4"	100	100
3/4"	77 - 91	82 - 96
1/2"	55 - 85	55 - 85
# 4	35 - 48	43 - 57
#10	27 - 35	35 - 43
#20	19 - 27	26 - 34
#40	16 - 24	20 - 28
#80	12 - 20	6 - 14
#200	3 - 7	2 - 6
Asphalt	4.1%	4.4%
	MARSHALL PROPERTIES	
Stability	2756	1364
Air Voids	3.9%	4.9%
Flow	9.8	8.5

In some cases where surface has been substituted for binder an unusual amount of early rutting has been observed. Some of this rutting might be attributed to higher stresses on the base, sub-base and subgrade as a result of the surface mix not being as stiff (lower resilient modulus) as the typical binder mix . TRC 8801, "Asphalt Gradation Variation," found binder mixes to be stiffer (higher resilient modulus) than surface mixes. The use of a less stiff mix would result in higher stresses lower in the pavement system. The difference in stiffness, however, is generally not enough to account for the observed rutting.

A more likely cause, is that the surface mix is less rut resistant than the binder mix for which it has been substituted. There is, however, no hard evidence of a difference in the relative rut resistance of the two mix types. This study was conducted to generate this evidence.

1.2 Study Objectives

The objectives of this study were to:

1) determine the relative resistance of typical AHTD surface and binder mixes to rut development,
2) develop recommendations relative to the practice of permitting surface mix to be substituted for binder mix.

1.3 Scope

Even though all pavement layers contribute to surface rutting, this study was restricted to an investigation of the potential relative rutting potential of surface and binder mixes. The asphalt concrete mixes that were tested in the research program were considered to be generally representative of the Type I and Type II surface and binder mixes used by AHTD.

The mix selection and design, field sampling and laboratory sample preparation was handled by the AHTD staff. This was done to assure that the specimens truly represented AHTD practice and experience. The laboratory rut resistance testing and data analysis were conducted by the Department of Civil Engineering, University of Arkansas, Fayetteville.

1.4 Rutting Resistance Study Work Plan

The following were the activities under this study:

A) Literature Review

A thorough review of the literature pertaining to rutting, the factors affecting it and the methodologies for evaluating rutting potential was conducted throughout the course of the study. This was done to provide constant feedback on the findings of others involved in similar research.

B) Specimen Preparation and Bulk Specific Gravity Determination

The full depth cores were taken from construction projects by AHTD personnel. The project investigators sawed and separated these into surface and binder samples of the size needed for testing. The bulk specific gravity of each sample was determined and, using the mix design data, the air void content of each sample was determined.

C) Repeated Load Dynamic Compression Study

Repeated load dynamic compression tests were conducted on the samples as a measure of rutting resistance. The repeated load dynamic compression tests were conducted using seating (static) and dynamic loads of 0.5 psi and 15 psi respectively.

D) Data Analysis

The average permanent deformations measured in the mixes during the repeated load testing were compared to determine the relative rutting resistance of the mixes. The analyses were done separately for the lab and field mixes and for the test samples obtained from different highway sections.

E) Recommendation Development

Based on the findings of this study, recommendations were developed for modifications to the current practice of substitution of the binder mixes by surface mixes. These recommendations are intended to reduce the potential for experiencing excess surface rutting as a result of substituting surface mix for binder mix.

CHAPTER 2

LITERATURE REVIEW

Excessive rutting in asphalt pavements is a major concern of highway engineers. Though the premature rutting observed in some pavements can be attributed to the repeated application of heavy axle loads operating at tire pressures as high as 105 psi, there are a number of aggregate, binder and environmental factors that also contribute to the rutting problem (1,2,3).

2.1 Types of Rutting

Dawley et.al (2) suggest three classifications of rutting - wear rutting, structural rutting and instability rutting. The different types of rutting are illustrated in Figure 2-1.

Wear Rutting

Wear rutting can be attributed to environmental and traffic influences which result in aggregate wear and progressive loss of coated aggregate particles from the pavement surface. The rate of wear rutting has been found to accelerate in the presence of ice-control abrasive.

Structural Rutting

Structural rutting is the result of permanent vertical displacement of the pavement structure under repeated loads. Structural rutting is essentially a reflection of the permanent deformation within the subgrade.

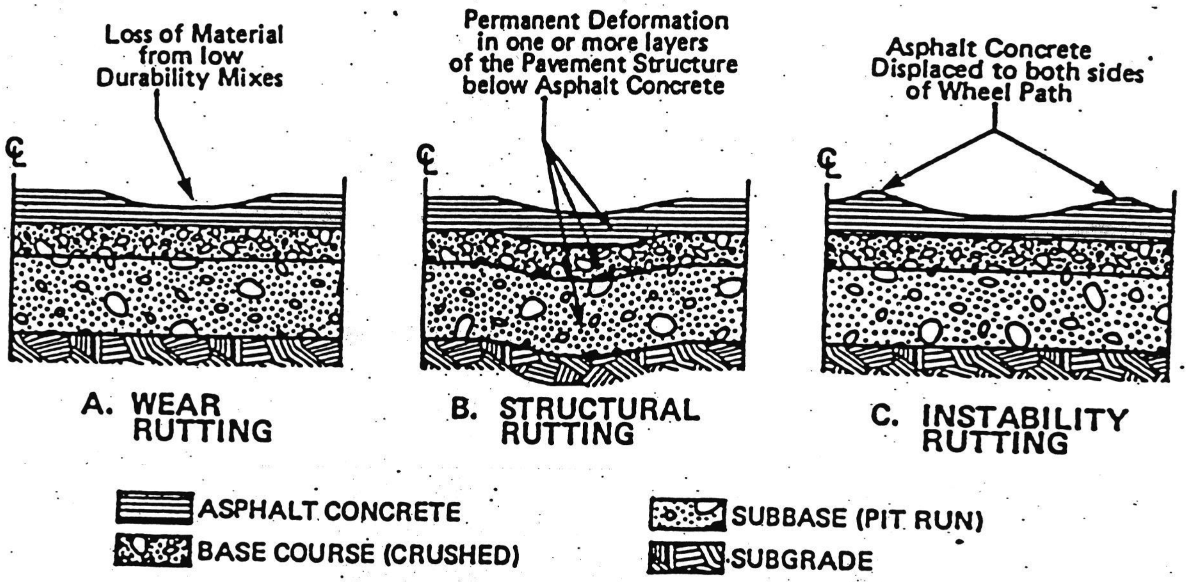

Figure 2-1 Illustration of Different Types of Rutting (Ref. 2).

Instability Rutting

Instability rutting is the result of lateral displacement of material within the pavement system. Instability rutting occurs when the structural properties of the pavement layers are inadequate.

2.2 Mechanism of Rutting

Rutting in pavement materials develops gradually with increasing numbers of load repetitions and shows up as longitudinal depressions in the wheel paths. These depressions are often accompanied by small upheavals along their sides. Densification and shear deformation of the pavement layers are the major mechanisms of rutting in the pavement layers. Sousa et.al indicate that shear deformation rather than densification is the primary cause of rutting and that compacting the materials to higher density can minimize the shear deformation (1).

Studies by Eisenmann and Hilmer (4) conclude that rutting is primarily due to deformation flow without volume change. Figure 2-2 which shows the effect of wheel passes on the surface profile of a wheel-track test slab suggests the following.

* During the initial stages of trafficking, the rate of increase in irreversible deformation below the tires is distinctly greater than the increase in the upheaval zones. This indicates that the traffic compaction has a significant influence on rutting.

* After the initial stage, the volume decrement beneath the tires is

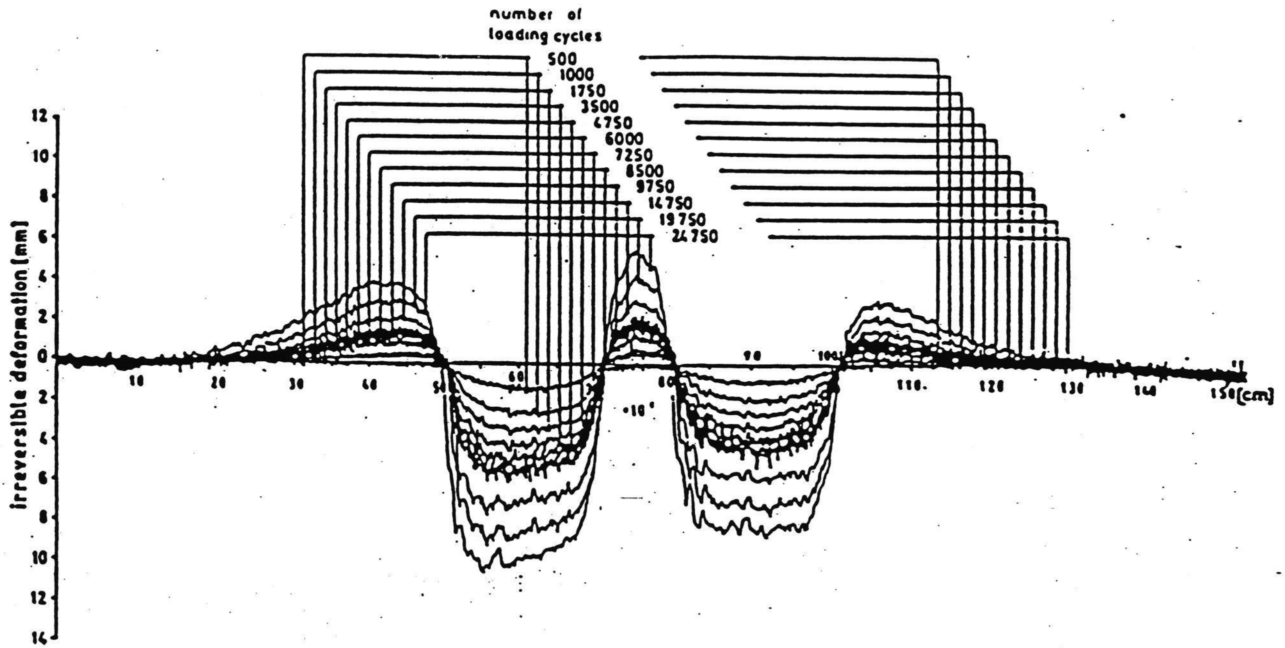

Figure 2-2 Effect of Wheel Passes on Cross Profile of Test Track (Ref. 4)

approximately equal to the volume increment in the adjacent upheaval zones. This is an indication that compaction under traffic is completed and that further rutting is caused essentially by displacement with constant volume. This phase is considered to be representative of the deformation behavior for the greater part of the lifetime of a pavement.

Studies by Hofstra and Klomp (5) indicate that the deformation in asphalt-concrete layers is greatest near the loaded surface and gradually decreases at lower levels. This is a reasonable assumption since:

a. rutting is caused due to the plastic flow and

b. more resistance to plastic flow is mobilized at greater depths where the magnitude of shear stresses is less.

Sousa et. al (1) have found a consistency between the findings from Uge and van de Loo (6) and the AASHTO Road Test measurements. Uge and van de Loo found that the rutting deformation within an asphalt layer does not increase with thickness when the thickness exceeds some threshold thickness. This finding was validated by the measurements from the AASHO Road Test which indicated that the surface rut depth reached a limiting value for an asphalt-concrete thickness of approximately 10 inches. This strongly suggests that, at least for reasonably stiff supporting materials, the rutting that occurs in the asphalt layers is mostly confined to the layers closest to the surface (1).

2.3 Factors Affecting Rutting

2.3.1 General

Rutting in the asphalt mixes are affected by the aggregates, binder, asphalt-mix properties and test or field conditions. A literature review of all the individual factors affecting the rutting resistance was beyond the scope of this study. This literature review focused on the effect of factors directly relevant to the study (viz., aggregates gradation, size, shape and binder type). Table 2.1, reproduced from Monismith et. al (10), summarizes the influence of the above mentioned factors on the rutting resistance.

2.3.2 Effect of Aggregate Properties on Rutting

The aggregate properties contributing to rutting are aggregate size, gradation, surface texture, angularity, percent fines and type of sand. Asphalt technologists agree that the size and gradation of aggregates used in an asphalt mix strongly influences the mix's rut resistance. The general consensus is that larger top size and good stone-on-stone contributes to rut resistance. However, there is disagreement on the specific gradation that is most rut resistant. Three categories of gradation has been suggested as most resistant to rutting - dense graded mixes, stone filled mixes, and open graded mixes.

Dense graded mixes are characterized by a nominal maximum particle size and a continuous gradation that plots close to the 0.45 power maximum density gradation curve (8). These mixes are said to have good rut resistance as a result

Table 2-1 Factors Influencing Rutting in Asphalt Mixes (Ref. 1).

	Factor	Change in Factor	Effect of Change in Factor on Rutting Resistance
Aggregate	Surface texture	Smooth to rough	Increase
	Gradation	Gap to continuous	Increase
	Shape	Rounded to angular	Increase
	Size	Increase in maximum size	Increase
Binder	Stiffness[a]	Increase	Increase
Mixture	Binder content	Increase	Decrease
	Air void content[b]	Increase	Decrease
	VMA	Increase	Decrease[c]
	Method of compaction	-[d]	-[d]
Test field conditions	Temperature	Increase	Decrease
	State of stress/strain	Increase in tire contact pressure	Decrease
	Load repetitions	Increase	Decrease
	Water	Dry to wet	Decrease if mix is water sensitive

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[a] Refers to stiffness at temperature at which rutting propensity is being determined. Modifiers may be utilized to increase stiffness at critical temperatures, thereby reducing rutting potential.

[b] When air void contents are less than about 3 percent, the rutting potential of mixes increases.

[c] It is argued that very low VMA's (e.g., less than 10 percent) should be avoided.

[d] The method of compaction, either laboratory or field, may influence the structure of the system and therefore the propensity for rutting.

of the volume concentration of aggregates in the mix. These mixes have high stability and are designed for low compacted air voids (4 to 8 percent). Their strength and rut resistance are attributed to aggregate interlock and viscosity of the binder (3). Figure 2-3 shows a dense graded mix with large size aggregates.

Properly compacted dense aggregate gradations show higher rutting resistance due to few air voids and many contact points between the aggregates. Sousa et.al.(1) indicate that test track results confirm that the dense gradations are superior to open gradations from a rutting standpoint due to better interlocking offered at higher temperatures.

Stone filled mixes have also been used as rut resistant mixes. These mixes are composed of a matrix of large, single sized stones (up to 1.5") with the voids in the matrix filled with a fine (small top size aggregate) asphalt concrete mix. Rut resistant is said to be achieved by the stone-on-stone contact of the matrix resisting shear displacement and the filled voids resisting the traffic densification. Figure 2-4 illustrates the stone-on-stone structure of the stone filled mix. Figure 2-5 shows typical gradations for the stone matrix and void filling intermix.

Open graded mixes which are characterized by high air voids (15 -20%) are most often considered to be less rut resistant in comparison with the dense graded and stone filled mixes. However, some researchers (3) indicate that the open graded mixes with a large top size aggregates (2.5") can resist rutting by virtue of direct stone-on-stone contact. Even though this finding conflicts with the general consensus of the asphalt technologists, Hicks et al have evidenced that the open

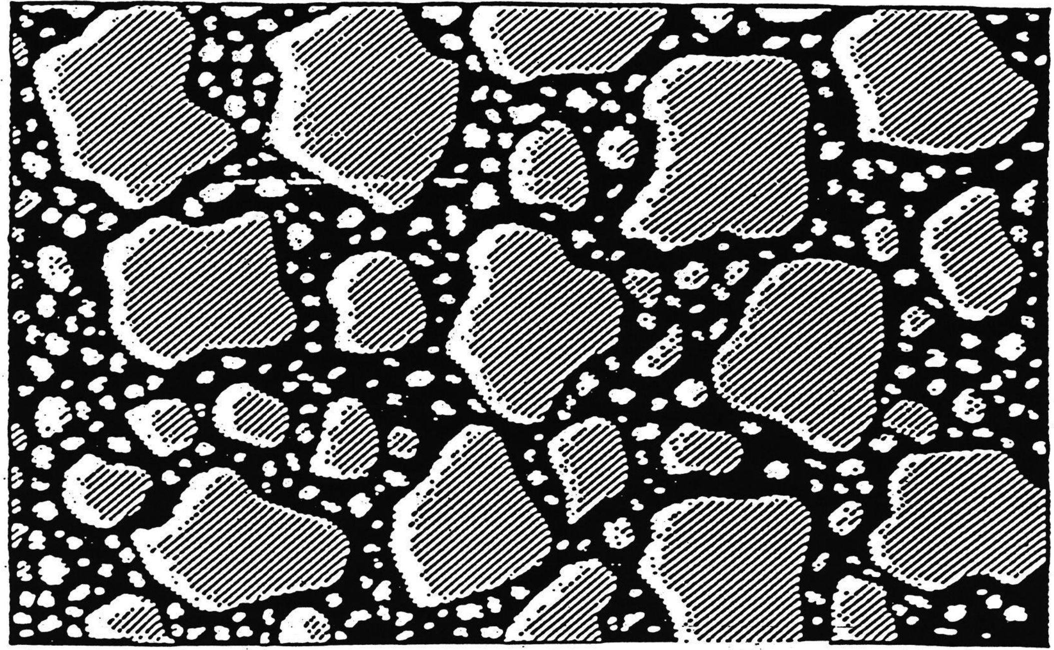


Figure 2-3 Illustration of a Dense Graded Mix (Ref. 3)

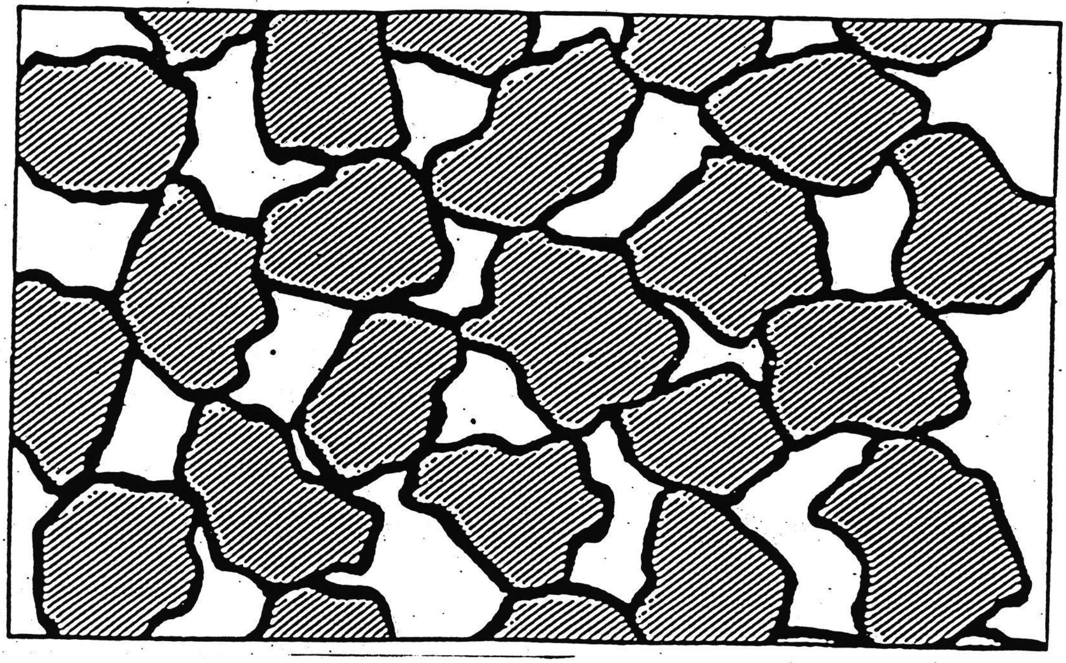


Figure 2-4 Illustration of Stone-on-stone Structure of Stome Matrix Mix (Ref. 3)

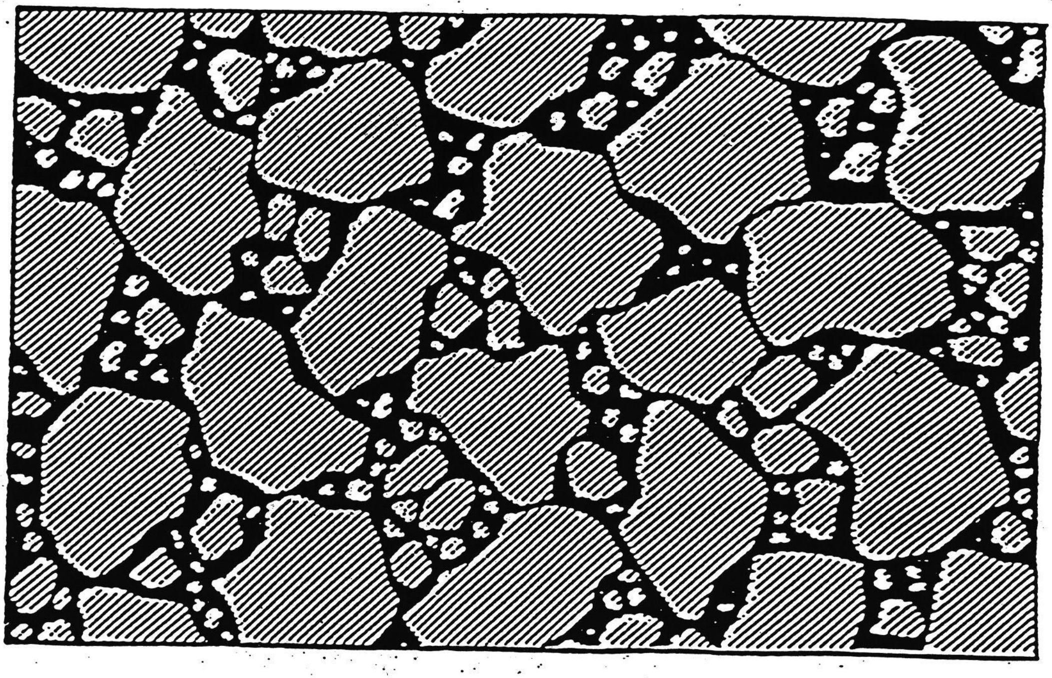


Figure 2-5 Illustration of Filled Stoned Matrix Mix (Ref. 3)

graded mixtures have exhibited good rut resistance.

Aggregate Texture and Angularity

The shape and surface texture of aggregates affects the bond between the aggregates and binder. These two factors have been studied as a single factor since it is difficult to separate the effect of surface texture from shape. Rough textured aggregates are required for thick asphalt pavements and hot climate. Studies by Uge and van de Loo (6) indicate that mixtures made from angular (crushed) aggregates deformed to a minor extent, exhibited higher stability and had higher stiffness at a given air void content.

Crushed Aggregates versus Rounded Aggregates

Considerable research has demonstrated that the crushed aggregates are superior to natural or rounded aggregates in both laboratory and field performance. Crushed aggregates exhibit a coarser texture than rounded aggregates. Studies (1) indicate that for a given aggregate gradation, the mixes with crushed aggregates have higher stability under shear creep than mixes made with rounded aggregates (Figure 2-6). Studies conducted by Field (9) using aggregates from four different sources and having fracture levels ranging from 0 to 100 percent have shown that the stability of the mixes increased with an increase in the fracture level. The improved stability was attributed to the increased shear strength offered by the sharp edges and rough texture.

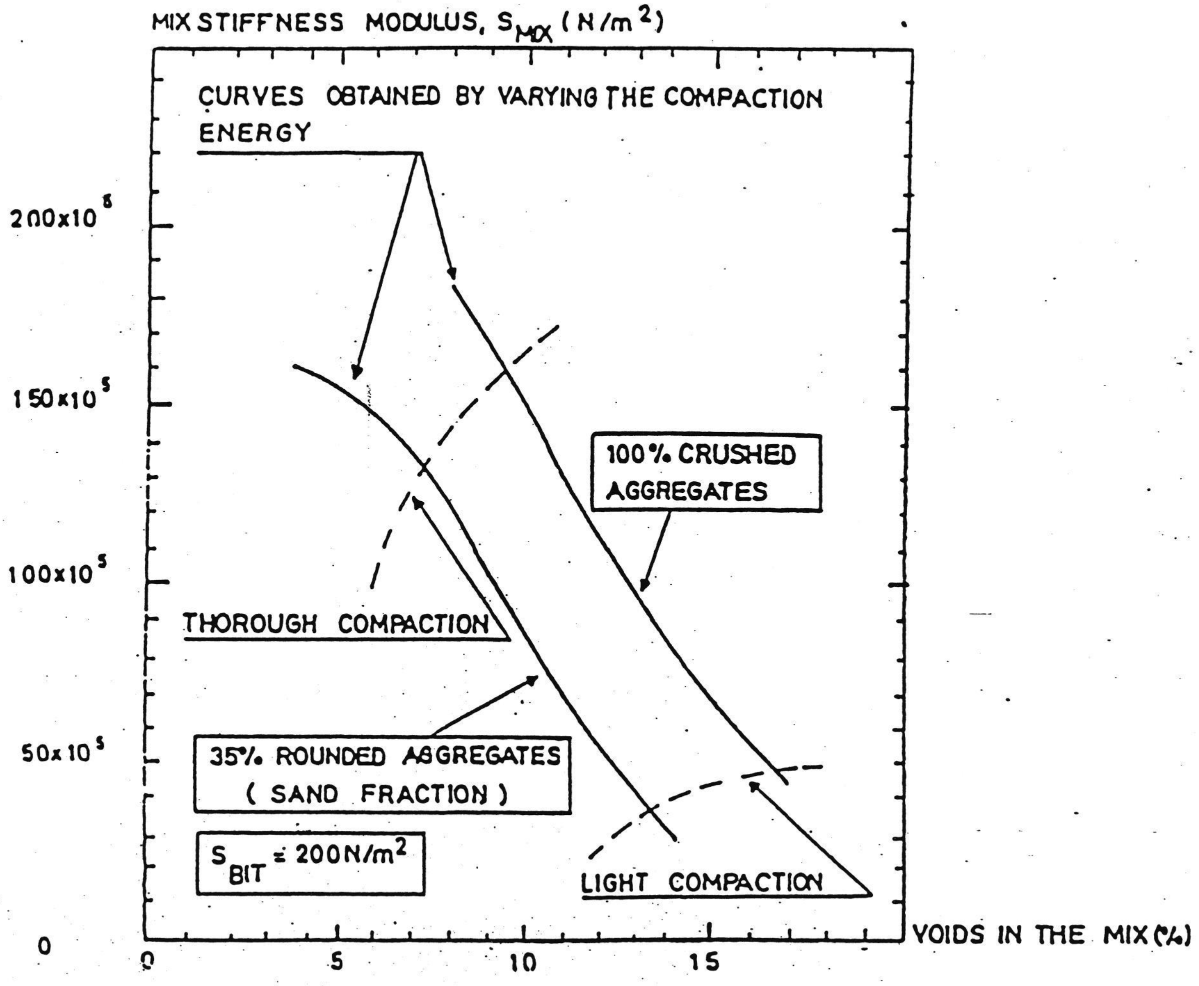


Figure 2-6 Effect of Aggregate Angularity on Mix Stiffness (Ref 6)

2.3.3 Binder Properties

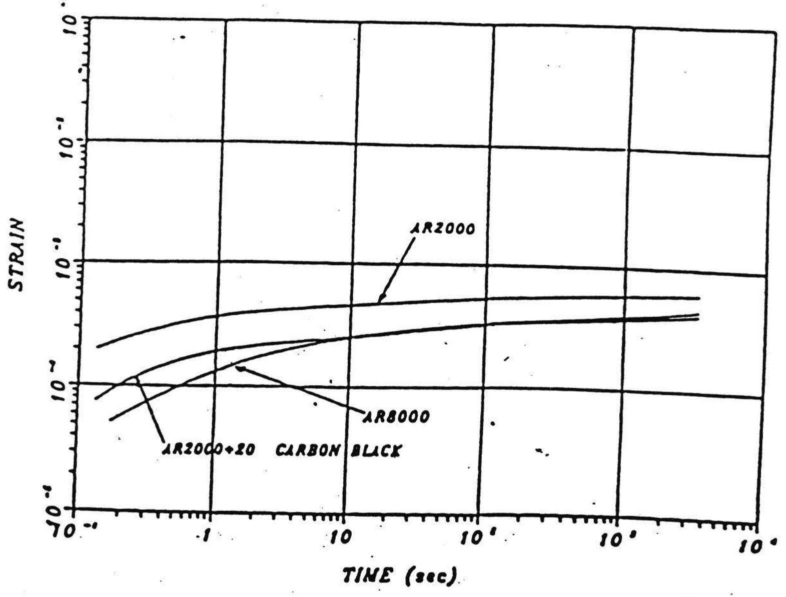
The use of less viscous asphalt make the mixture less stiff and therefore more susceptible to irrecoverable deformations (rutting). Asphalt cements exhibiting higher viscosity are recommended for thick pavements constructed in hot regions. Monismith and Tyebali (10) have used modifiers such as polymers and carbon black micro-fillers to increase the viscosity of binders at high temperatures without adversely effecting the binder properties at low temperatures. These modified mixes have shown better resistance to permanent deformation (Figure 2-7) than the unmodified binder.

2.3.4 Other Relevant Studies

TRC-8903, a project funded by AHTD at the University of Arkansas, investigated the effect of gradation variations on mix performance. This study (11) produced evidence that the aggregate gradation and type have a significant effect on the relative rutting resistance of the Arkansas mixes. The specific findings from this study were:

- Excess amount of natural sand in the mixes was a factor which caused the mixes to be less rut resistant.
- Substitution of natural sand by crushed sand improves the rutting resistance of the asphalt concrete mixes.

In addition to the above findings, the investigators recommended the evaluation of mixes with fine and coarse aggregate gradations to broaden the



a. Creep

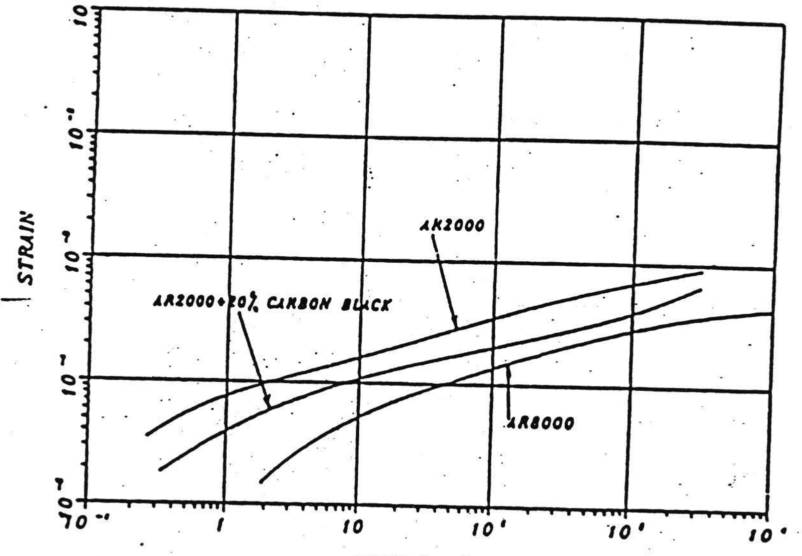


Figure 2-7 Influence on Asphalt Viscosity and Additives on Mix Rutting Resistance (Ref. 10)

knowledge about the rut resistance characteristics of the typical mixes used in the State of Arkansas before making conclusive recommendation about the causes for the poor rutting resistance offered by some surface mixes.

Studies conducted at the University of Nevada (12) identified mixes that offer higher rutting resistance. Repeated load triaxial tests on environmentally conditioned, four-by-eight inch cylindrical specimens under a static confining pressure and repeated deviator stress indicated that the aggregate gradation, type of binder and the environmental conditioning undergone by mixes as the key factors affecting the permanent deformation characteristics.

Barksdale et.al (13) studied the rutting resistance characteristics of surface and binder mixes corresponding to a standard Georgia DOT mix design and a coarser mix with slightly larger top size aggregate. The rutting measurements were made using a Loaded Wheel Tester (LWT). The study indicated that:

1. For a given type of mix i.e, surface or binder, the coarser mixes have better rutting resistance than the Standard GDOT Mix.
2. The Surface mixes are less rut resistance than binder mixes.
3. The rutting resistance of surface mixes is more variable than that of binder mixes (coefficient of variation of 28% versus 37.5%). The greater variation was attributed to the aggregate properties.

2.4 Summary of the Literature Review

The literature review indicates that most researchers are in general agreement that the aggregate gradation contributes significantly to the rutting resistance of the mixes. Barksdale et.al's research (13) is important to this study since it has given prior information about the relative rutting resistance of surface and binder mixes used by the Georgia DOT.

CHAPTER 3

TESTING PROGRAM

Under this study rutting resistance was measured as resistance to the development of permanent deformation in test specimens subjected to a dynamic, repeated load compression test. The study involved testing both laboratory prepared specimens and specimens obtained from field coring of newly constructed asphalt surfaces.

3.1 Mix Selection, Sample Preparation & Field Coring

A total of 7 mixes were tested under this study. Four of these were surface mixes and three were binder mixes. Four mixes, 2 surface and 2 binder, were tested using laboratory prepared mixes. The other three mixes were tested using only field obtained specimens. All mixes were selected for the study by the AHTD research staff in consultation with the principal investigator. The mix designs were established in accordance with the AHTD standard practice. The testing and laboratory sample preparation was performed by the AHTD Staff. The mix designs of the surface and binder mixes tested in this program are listed in the Appendix.

For the laboratory specimens, 5 samples of each mix type were molded using Marshal compaction equipment. These were provided to the research staff along with their mix design and density-void analysis data.

Field core samples of surface and binder mixes from 4 different construction jobs were provided by the AHTD research staff. The field samples were divided into surface and binder samples by sawing the cores. The surface and binder layers were marked and then sawed to the size of Marshal specimens (2.5 inch thickness) for testing. Cores that did not have at least 2.5 inches of surface (or binder) were not tested. The reason for not testing these was that end condition effects would invalidate the relative deformation comparisons.

3.2 Equipment used in the Laboratory Study

The MTS or the "Material Testing System" was used to conduct the Repeated Load Dynamic Compression Test. This test was used to measure the permanent deformation (a measure of rutting resistance) developing in the test specimens with increasing number of load repetitions.

MTS is a sophisticated equipment which uses the "closed loop" servo control hydraulic testing system to apply dynamic loads to test specimens. This system has the capability of applying loads on the test specimens in a manner that simulates the field conditions. The data acquisition was done by a computer interfaced with the testing unit.

Load Application

The timing of the dynamic loads was selected to simulate the "actual load" pulses on the pavements by the vehicles. A minimum seating stress of 0.5 psi was applied to the specimens throughout the testing to prevent impact loading. The repeated dynamic stress was set at 15 psi. This was reached in 0.02 seconds , maintained for 0.06 seconds and then relieved in 0.02 seconds. Thus, the total loading time was 0.1 seconds with the peak load being held for 0.06 seconds. The loading cycle was repeated after a rest period of 1.9 second providing a loading frequency of 30 cycles per minute. Figure 3-1 shows the representation of the loading sequence on the test specimen.

Test Temperature

The tests specimens were enclosed in an environmental chamber placed on the MTS test frame. The area of the test chamber was of sufficient size to accommodate additional test specimens awaiting testing. The temperature inside the chamber was maintained at 104° F (40° C) using a heat tape connected to a thermostat.

Measurement of Load and Deformation

The loads applied to the test specimen were measured using a load cell. The deformations of the test specimen was measured by the strain gauge attached to the test specimen. The gauge was held in place by means of a rubber band. Specifics of the strain gauge attachment are discussed below in Section 3.3.

Data Acquisition

The test data were recorded to a the computer disc on a PC interfaced with the test equipment. The data were recorded every 60 seconds throughout the experiment. The data recorded at each interval were: 1) the load repetition number, 2) load magnitudes (seating and dynamic) and 3) specimen deformation (peak and valley or loaded and unloaded condition). The data were later read into Quattro-Pro spreadsheets for data analysis.

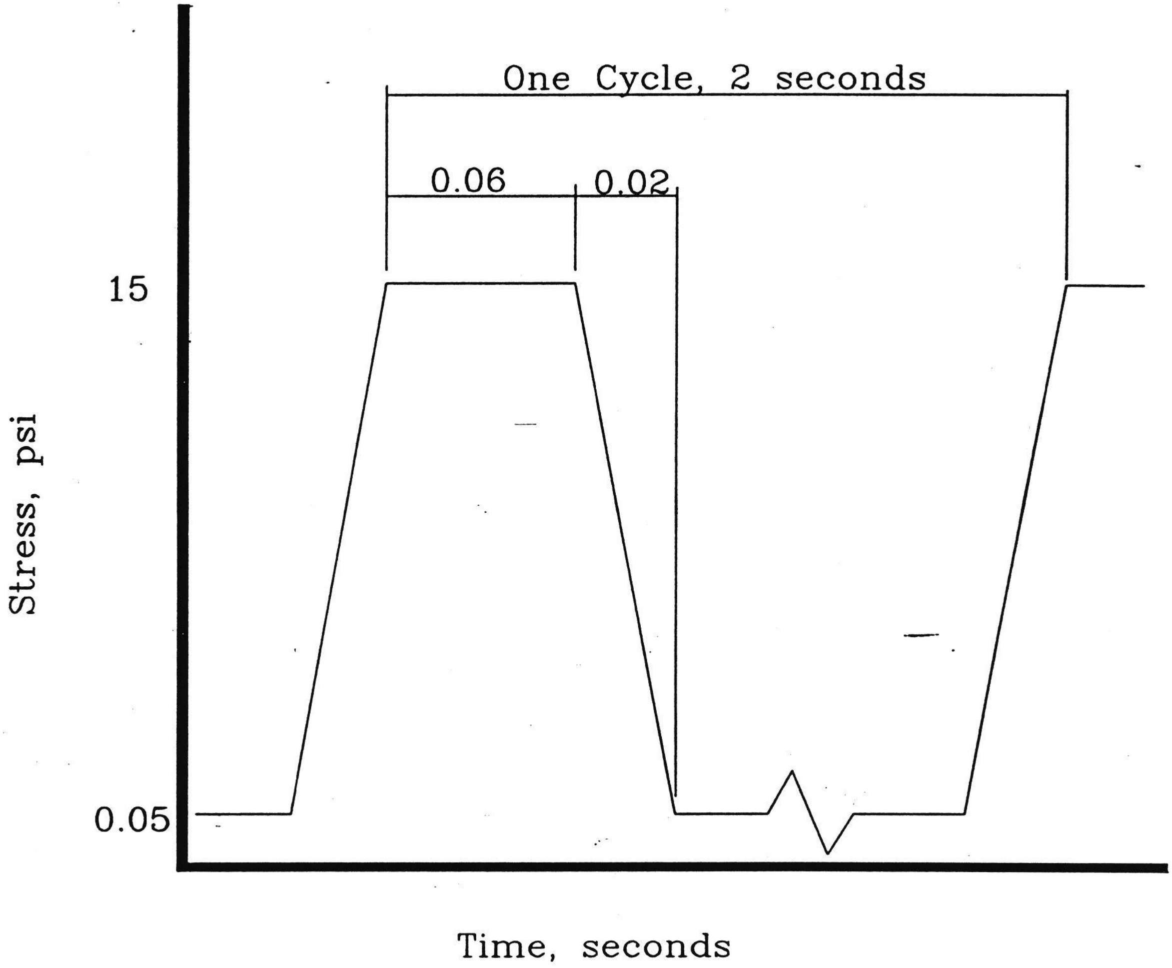


Figure 3-1 Repeated Dynamic Loading Sequence

3.3 Test Modifications from TRC-8903

Similar testing using the same basic equipment and setup was conducted under TRC-8903, Study of Rutting Resistance of asphalt Mixes. Although the study was successful, some of the data was invalidated by inconsistencies. This also made the analyses under that study difficult. Early efforts under this study focussed on identifying the cause of the inconsistency and making adjustments in the test procedures. These efforts were successful. The source of the problem was found to be the manner in which the strain gauge was mounted and the deformation of the data were measured.

In TRC-8903 the strain gauge was not attached to the specimen. Instead, it was attached at one end to an iron bar mounted to the main frame with the other end attached to the loading piston. The relative movement between the iron bar and the piston was recorded as the specimen deformation. It was suspected that other movements, in particular movements in the MTS head, might at times be contributing to the relative movement and causing the inconsistencies. To correct for this the strain gauge was moved and attached to the specimens.

Such an arrangement would seem to be obvious. However, there was some concern over the influence of the proximity of the aggregate particles at the point of attachment. The original thinking under TRC-8903 was to measure the deformation of the entire specimen and avoid this influence. Under the study, it was decided to compensate for any aggregate effect by not attaching the gauge directly to the specimen. Instead, small rubber bumper pads were attached 2.5 inches apart on the specimen sides. The gauge was then mounted with one knife edge attached to each pad. The bumper pads were square rubber pads having 0.4 inch sides with a self adhesive backing. These pads are normally used on the bottom of the boxes, file drawers, etc. The gauge was held in place with two rubber bands stretched around the specimen. The deformation recorded from this arrangement did not exhibit the inconsistencies observed with the TRC-8903 testing.

Another change from the TRC-8903 testing was the interval for data recording. Under TRC-8903 data were recorded every 600 seconds. This provided adequate data as long as no errors or inconsistencies were encountered. However, it was not adequate to permit identifying when the errors and inconsistencies occurred. To compensate for this the recording interval was reduced to 60 seconds which produced an amount of data that would be excessive under normal circumstances but proved quite valuable in pinpointing and eliminating data acquisition errors.

3.4 Repeated Load Dynamic Compression Test Procedure

Step 1: Setting the Electronics for the RLDCT

The electronics (i.e, the load, strain sensitivity and loading sequence) were set and the environmental chamber was placed on the platform of the MTS. The heat tape was attached in the chamber and the electrical connections were made with the temperature controller set to maintain the temperature at 104° F (40° C).

Step 2: Warm Up and Specimen Conditioning

The bumper pads were attached to the test specimens using an epoxy adhesive. The test specimens were then placed in an environmental chamber at 104 F for 24 hours before testing, to assure that they would be at an uniform constant temperature throughout the test. The hydraulic pump was turned on and the machine was allowed to run for 20 minutes before beginning the test. During this period the following work was accomplished:

1. Silicon grease and graphite was applied at the top of the test specimens and the bottom of the base-plate.
2. The strain gauge was attached to the bumper pads using a pair of rubber bands. It may be noted that the strain gauge was always maintained at the test temperature in the environmental chamber and was removed from the chamber only for attachment to the test specimen.
3. A 4" diameter circular steel plate was placed on the top of the specimens. This arrangement was then transferred to the environmental chamber

Step 3: Adjustment of the Seating and Dynamic Loads

The "SET POINT" controller was operated to lower the loading piston to the top of the specimen. In this study, the load was transferred from the piston to the specimen through a steel ball placed on a steel plate and centered on the specimen. The seating load (0.5 psi or 6.24 pounds) was first adjusted using the Set Point Controller. Caution had to be exercised while setting the dynamic loads to prevent the over stressing of the test specimens before actual testing. The dynamic loads were adjusted using the "Single Cycle" and "SPAN 2" controls. Operation of "Single Cycle" control resulted in the application of one cycle of dynamic load to the specimen. Knowing the magnitude of the seating and dynamic loads on the test specimen during the single load application, the "SPAN 2" control was adjusted accordingly to set the dynamic loads to 15 psi or 188.5 pounds.

Step 4: Data Acquisition

After setting the seating load to 0.5 psi, the computer program was activated. The data acquisition and the application of the repeated dynamic loads were started simultaneously.

Step 5 : Completion of the Experiment

Since each load was repeated every 2 seconds (duration 0.1 second), each experiment (10,000 load applications) took about 5.5 hours to complete. The data obtained was saved to the disk before exiting the acquisition program.

With prior planning, it was possible to test a minimum of three, and sometimes even four, test specimens each day.

CHAPTER 4

DATA ANALYSIS

A total of 111 mix specimens were tested using the procedures described in Chapter 3. Sixty-one of these were binder specimens and 50 were surface specimens. Ten of the binder and 11 of the surface specimens were prepared in the laboratory. The other specimens were sawed from cores removed from in-service pavements. Table 4.1 lists the average permanent strain accumulated in test specimens from each source after 10,000 load repetitions.

Although all field specimens were tested, many of them did not provide useful data and are not considered in this analysis. The first field samples obtained had very irregular sides. As a result the strain gauge readings from these specimens were not reliable. Other field specimens had sizeable voids and/or fractured coarse aggregate particles. These specimens were not considered to be truly representative of the mixes.

However, the major problem with most of the field specimens was the lack of companion and comparable surface and binder specimens. For meaningful comparisons, test data are needed that represent surface and binder mixes that are essentially identical in aggregate composition (other than gradation and maximum size). With some of the field cores, the surface layer was too thin to provide a specimen of adequate thickness for testing. Other cores were found to be from sites where the contractor had elected to substitute surface mix for

Table 4-1 Average Permanent Strain after 10,000 Load Repetitons.

Job #	Classification	Mix Type	Permanent Strain
100288	Lab Specimens	Ty 1 Surface	0.0027
09582	Lab Specimens	Ty 2 Surface	0.0022
100288	Lab Specimens	Ty 1 Binder	0.0005
09582	Lab Specimens	Ty 2 Binder	0.0007
09802	Hwy 62 East	Ty 1 Surface	0.0018
	Hwy 62 West	Ty 1 Surface	0.0015
09864	Hwy 126 North	Ty 2 Surface	0.0014
	Hwy 126 South	Ty 2 Surface	0.0012
09582	Hwy 23 North	Ty 2 Surface	0.0022
	Hwy 23 North	Ty 2 Binder	0.0004
	Hwy 23 South	Ty 2 Surface	0.0024
	Hwy 23 South	Ty 2 Binder	0.0008
100288	Marked Tree North	Ty 1 Binder	0.0084
	Marked Tree South	Ty 1 Binder	0.0015
100288	Location not identified	Ty 1 Binder	0.0036

binder. These cores were composed of surface mix for the full depth.

Directly comparable test data are available from only four specimen sets: 1) laboratory prepared Type 1 Mix specimens, 2) laboratory prepared Type 2 Mix specimens, 3) field specimens from Highway 23 Northbound, and 4) field specimens from Highway 23 Southbound. For the purposes of this report, the permanent strain accumulated in these specimens after 10,000 load repetitions was selected as the indicator of relative rutting resistance of the various mixes.

Figures 4-1 through 4-4 display the permanent strain after 10,000 repetitions for each test specimen from the four specimen sets. In each figure, the surface mix is seen to exhibit permanent strain that is greater than that exhibited by the binder mix. Perhaps the more significant observation is that, for each set, not one binder specimen was found to develop a strain level as high as that developed by any surface specimen in that set. This quite clearly and emphatically demonstrates the superior rutting resistance of the binder mix.

Figures 4-5 and 4-6 show the average results from the four specimen sets. The averages from the laboratory specimens are shown in Figure 4-5 with the field core averages shown in Figure 4-6. The average laboratory and field results are quite similar. After 10,000 load repetitions, the average permanent deformation in the surface specimens ranged from 3 to 5.5 times the average permanent deformation in the binder specimens.

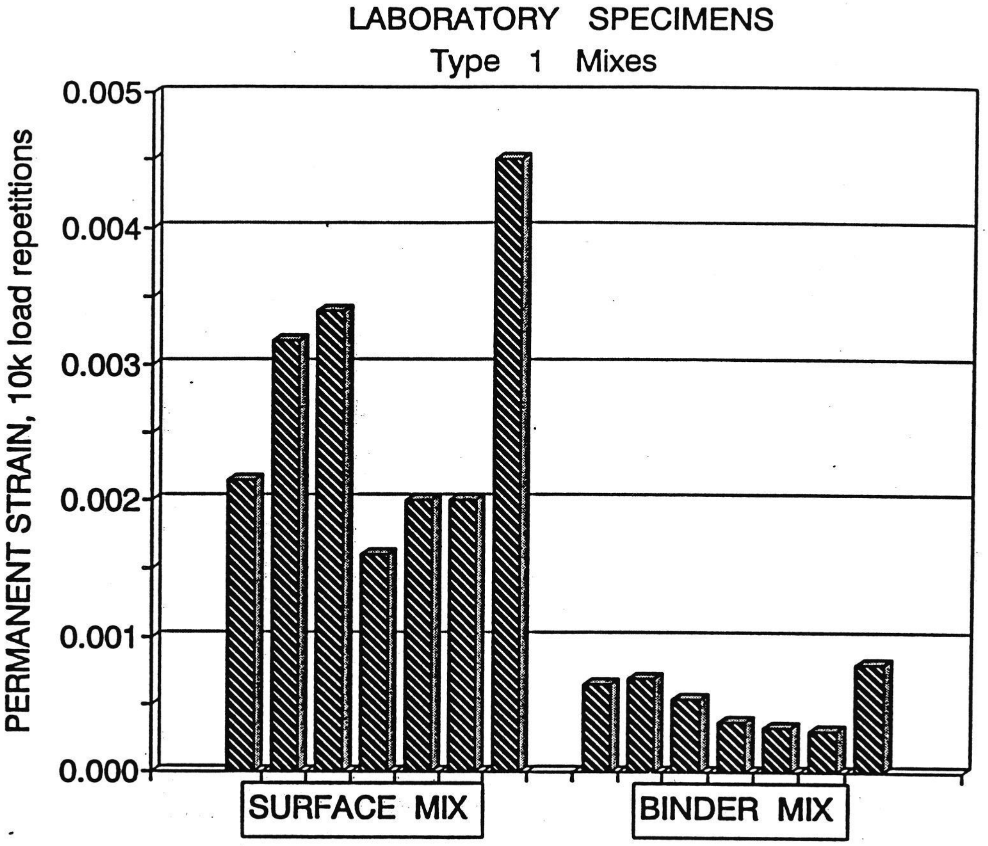


Figure 4-1 Permanent Strain after 10,000 Loads on Type 1 Laboratory Specimens

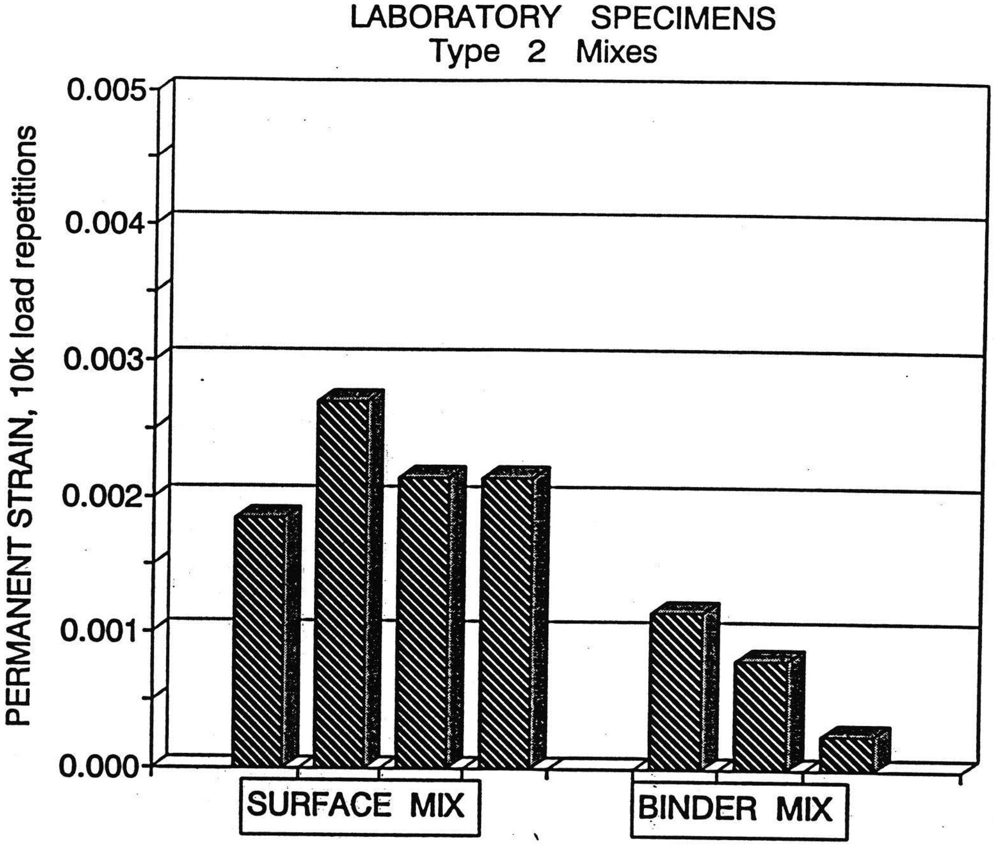


Figure 4-2 Permanent Strain after 10,000 Loads on Type 2 Laboratory Specimens

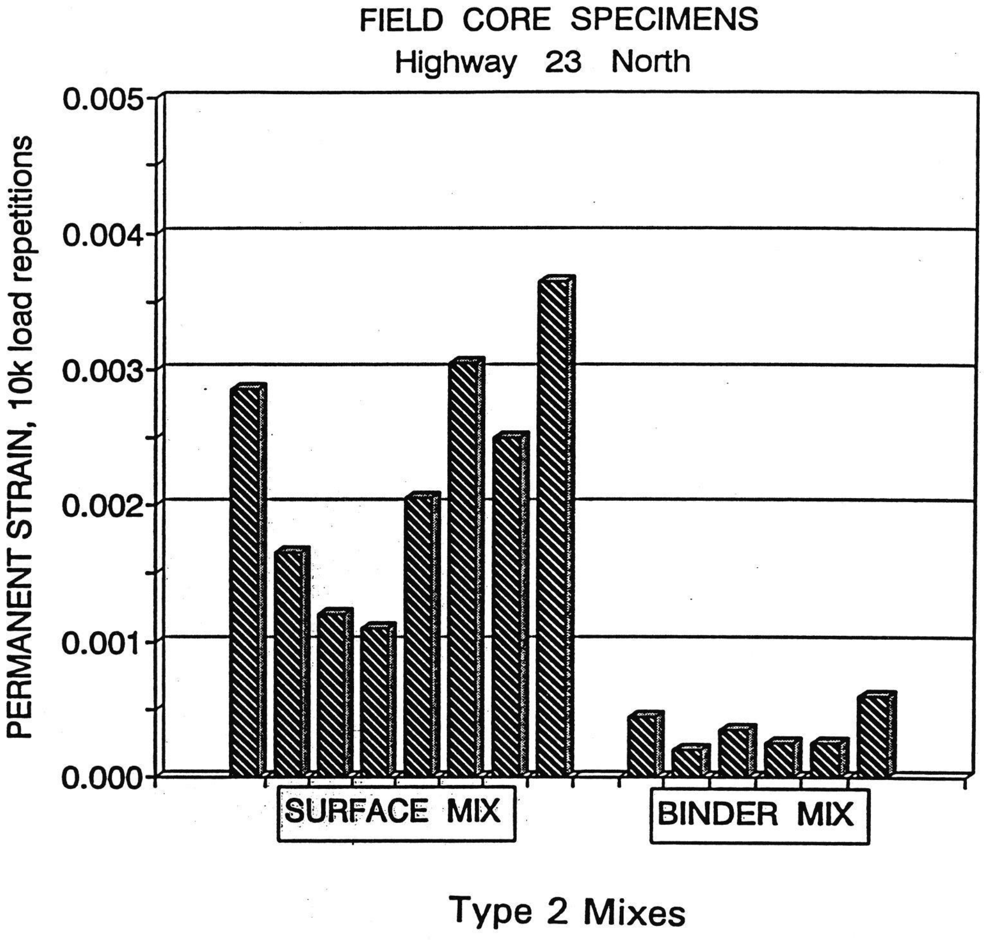


Figure 4-3 Permanent Strain after 10,000 Loads on Highway 23 North Field Cores

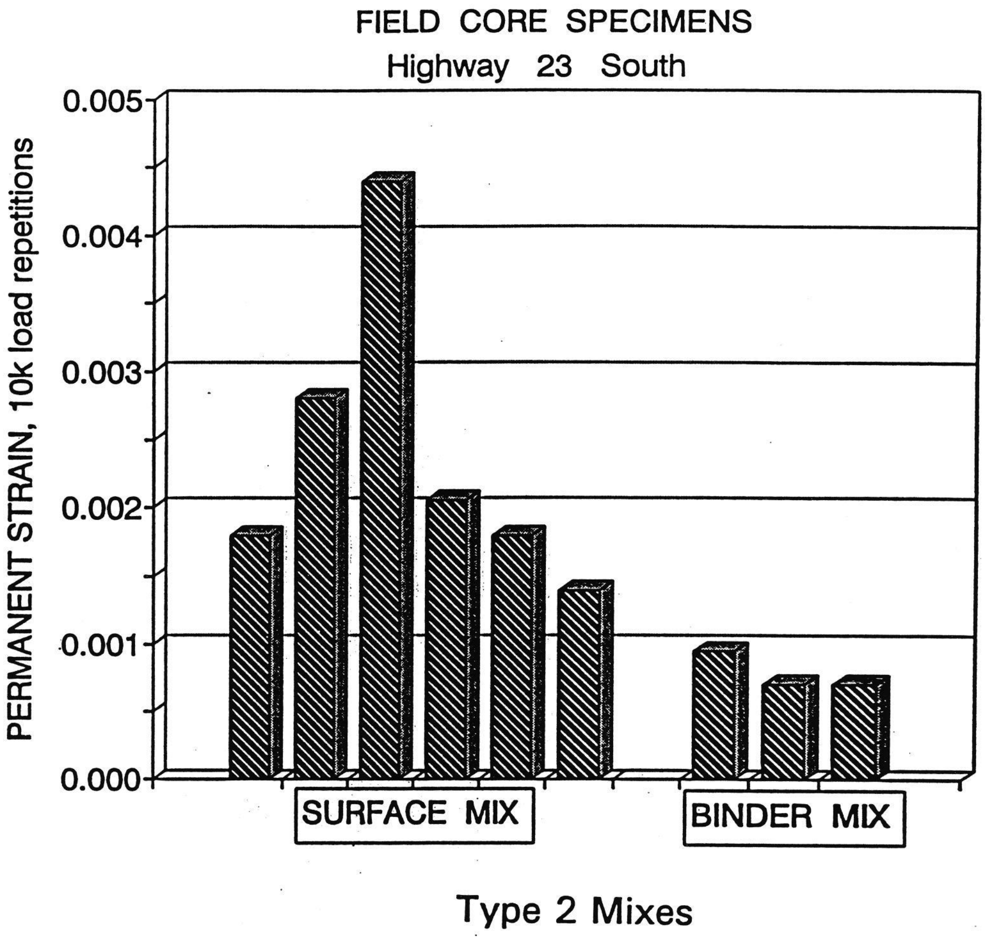


Figure 4-4 Permanent Strain after 10,000 Loads on Highway 23 South Field Cores

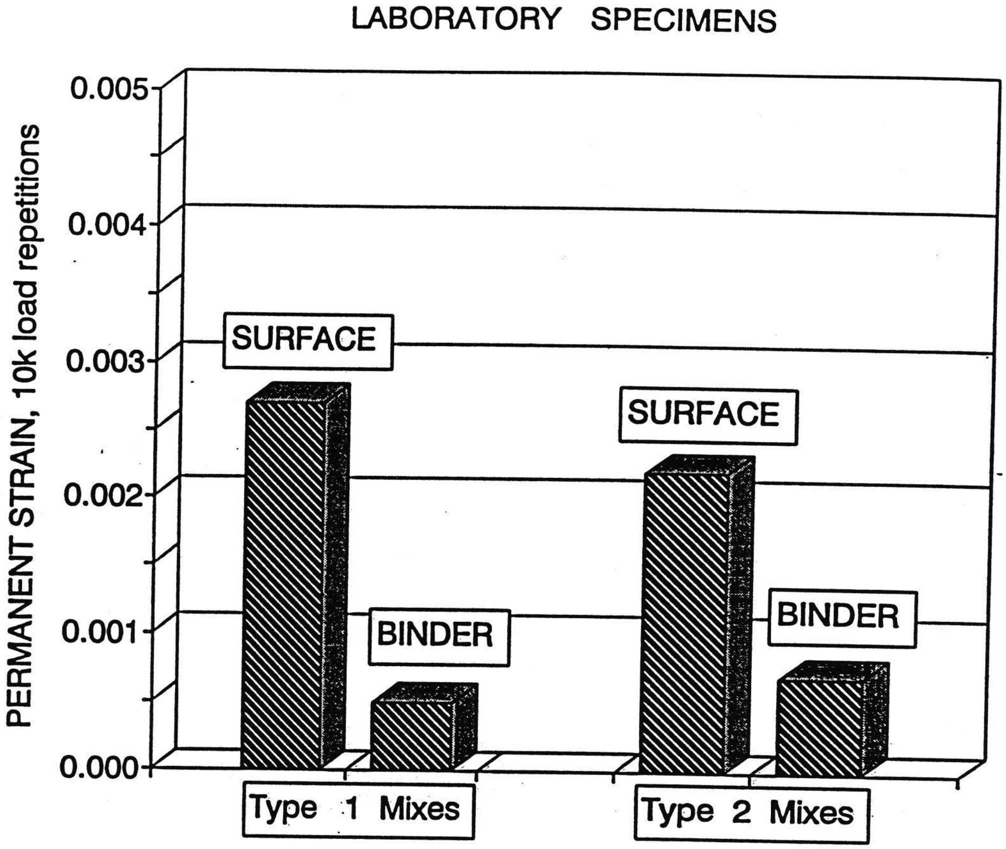


Figure 4-5 Comparison of Average Permanent Strain of Lab Specimens

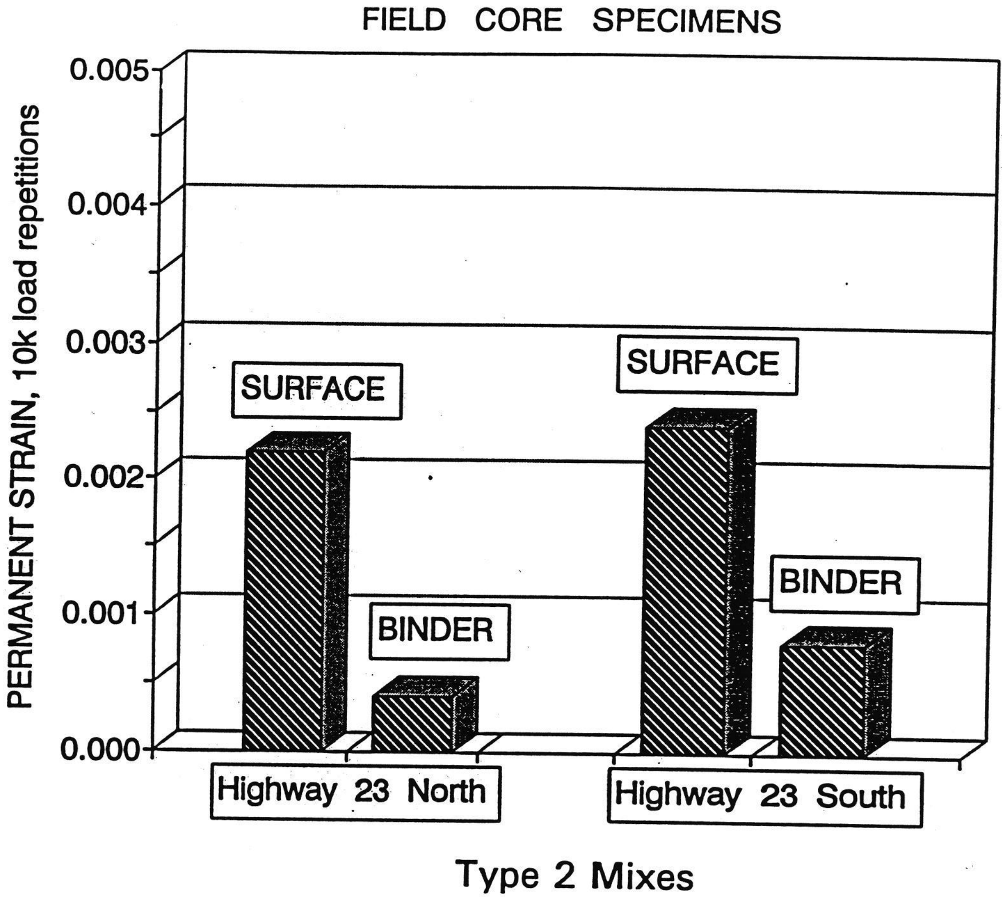


Figure 4-6 Comparison of Average Permanent Strain of Field Cores

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This study demonstrates that surface mixes are generally less resistant to rutting than binder mixes. However, it should not be concluded that all surface mixes are less rut resistant than all binder mixes. Some binder mixes are quite likely to be less rut resistant than some surface mixes. Indeed the highest single permanent deformation observed in the testing was on binder specimens that had either sizeable voids visible along the core face, high air void content (low density) or fractured coarse aggregates.

The data from these tests clearly shows that under equal loading conditions the surface mixes tested experience 3 to 5 times as much as permanent deformation (rutting) as did the comparable binder mixes. This suggests that when surface is used in place of binder the rutting after one year will be equivalent to the amount that would normally be expected after 3 to 5 years.

The actual rate of rut development on the road may be even greater than the laboratory tests suggest. The development of ruts in the field normally decreases with time. For example the time from no rut to 1/4" rut depth is typically much shorter than the time from 1/4" to 1/2". This may partially be due to the stiffening of the mix that comes with age. Since the laboratory testing was conducted over a very short time, any long term effects would not be reflected.

With the results and conclusions from this study, it is recommended that

AHTD place restrictions on the substitution of surface for binder. Such substitution should not be permitted except in rare instances when it is clearly advantageous to AHTD. To implement this recommendation, the following changes to the *Standard Specifications for Highway Construction*, Edition of 1993, are suggested.

Article 404.03, revise to read:

> *404.03, Mixture Substitutions, Substitutions will be allowed for mixes as follows:*
>
> *1) ACHM Stabilized Base may be replaced with:*
> *Type 1 Binder Course*
> *Type 2 Binder Course*
>
> *2) Type 2 Binder Course may be replaced with:*
> *Type 1 Binder Course*
>
> *3) Type 2 Surface Course may be replaced with:*
> *Type 1 Surface on shoulders, driveways, islands, and patching*
> *Type 3 Surface on driveways, islands, and patching*
>
> *4) Type 1 Surface Course may be replaced with:*
> *Type 2 Surface on driveways, islands, and patching*
> *Type 3 Surface on driveways, islands, and patching*
>
> *Mixture substitutions ..... (no change in this paragraph)*

Article 410.1, delete last sentence for the first paragraph and the entire second paragraph.

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APPENDIX

LISTING OF MIX DESIGNS USED IN LAB TESTING

Table A-1 Type 1 Surface Mix Used in Laboratory Testing, Job #100288

Mix Materials			Mix Percentage
Aggregates			
1	Razorback Materials	Whitehall, AR	25
2	Reed Stone Company	Gilbertsville, KY	15
3	Reed Stone Company	Gilbertsville, KY	30
4	Central States Materials	Memphis, TN	15
5	Ingram Pit	Marion, AR	15
Bituminous	Ergon 30		5.2
Anti-Strip	KB LVHM		0.5% of AC

Aggregate Gradations (% Passing)

Agg	3/4"	1/2"	3/8"	#4	#10	#20	#40	#80	#200
1	100	77	65	35	19	11	7	4.2	3.1
2		100	88	26	10	6	4.5	3.5	2.5
3			100	91	58	28	18	13	10
4			100	98	86	50	8.6	2	0
5					100	97	82	51	12

Marshall Properties

Density	146.6 pcf
Voids	4.0 %
Flow	10.3
VMA	15.9 %
Stability	2546 lbs
Retained Stab	82 %

Table A-2 Type 1 Binder Mix Used in Laboratory Testing, Job #100288

Mix Materials				Mix Percentage
Aggregates				
	1	Reed Stone Company	Gilbertsville, KY	60
	2	Reed Stone Company	Gilbertsville, KY	25
	3	Griffin Pit	Memphis, TN	15
Bituminous		Ergon 30		4.1
Anti-Strip		KB LVHM		0.5% of AC

Aggregate Gradations (% Passing)

Agg	1.25"	3/4"	1/2"	3/8"	#4	#10	#20	#40	#80	#200
1	100	73	46	21	5	3	2	1	.5	.5
2				100	91	58	28	18	13	10
3								100	80	15

Marshall Properties

Density	149.2 pcf
Voids	3.9 %
Flow	9.8
VMA	13.4 %
Stability	2756 lbs
Retained Stab	85.6%

Table A-3 Type 2 Surface Mix Used in Laboratory Testing, Job #09582

Mix Materials			Mix Percentage
Aggregates			
1	Preston Quarry	Van Buren, AR	21
2	Sharps Quarry	Lowell, AR	23
3	West Fork Quarry	West fork, AR	11
4	Sharps Quarry	Lowell, AR	22
5	Bingham Drag Sand	Pitcher, OK	7
6	Arkansas River Sand	Fort Smith, Ar	16
Bituminous	Ergon 30		5.4
Anti-Strip	Perma-Tac		0.5% of AC

Aggregate Gradations (% Passing)

Agg	3/4"	1/2"	3/8"	#4	#10	#20	#40	#80	#200
1	100	69	43	7.4	4.2	3.6	3.6	3.4	2.2
2		100	82	20	3.6	2.9	2.9	2.5	2.3
3				100	66	39	27	16.5	10.6
4				100	72	47	34	22	13.8
5				100	78	45	20	5.6	2.3
6					100	97.5	86	22	0.5

Marshall Properties

Density	143.8 pcf
Voids	4.5 %
Flow	9.2
VMA	16.6 %
Stability	1768 lbs
Retained Stab	70.1 %

Table A-3 Type 2 Binder Mix Used in Laboratory Testing, Job #09582

Mix Materials			Mix Percentage
Aggregates			
1	McClinton Anchor	West Fork AR	25
2	McClinton Anchor	West Fork AR	26
3	McClinton Anchor	West Fork AR	32
4	Arkansas River Sand	Fort Smith, AR	17
Bituminous	Ergon 30		4.4
Anti-Strip	none		

Aggregate Gradations (% Passing)

Agg	1.25"	3/4"	1/2"	3/8"	#4	#10	#20	#40	#80	#200
1	100	57	19	10	2.2	1.4	1.3	1.2	1.1	1
2		100	80	52	3.1	1.7	1.6	1.5	1.4	1.3
3					100	66	39	27	16	10
4						100	98	86	22	0.5

Marshall Properties

Density	149.5 pcf
Voids	4.9 %
Flow	8.5
VMA	15.0 %
Stability	1364 lbs
Retained Stab	93%