Evaluation of Recycled Rubber in Asphalt Concrete

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Final Report

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Disclaimer

Abstract

This is the final report on the research project HR-330, "Evaluation of Recycled Rubber in Asphalt Concrete" which was a joint effort between the Iowa Department of Transportation (IDOT) and the University of Northern Iowa (UNI). The purpose of this research was to evaluate the performance and the use of asphalt rubber binders and recycled rubber granules in asphalt pavement in the state of Iowa.

This five year research project was initiated in June 1991 and it was incorporated into Muscatine County Construction Project US 61 from Muscatine to Blue Grass over an existing 10 inch by 24 feet jointed rigid concrete pavement constructed in 1957. The research site consisted of four experimental sections (one section containing rubber chip, one section containing reacted asphalt rubber in both binder and surface, and two sections containing reacted asphalt rubber in surface) and four control sections.

This report contains findings of the University of Northern Iowa research team covering selected responsibilities of the research project "Determination of the aging and changing of the conventional asphalt binder and asphalt-rubber binder".

Based on the laboratory test, the inclusion of recycled crumb rubber into asphalt, affects ductility of modified binder at various temperatures.

Introduction

Used truck and car tires are non-biodegradable solid waste products. The Department of Energy has reported existence of an estimated 2-3.5 billion tires in our nation's stockpiles and landfills. The existing stockpile grows by 279 million tires annually. Unlike other solid waste, whole tires cannot be buried in a landfill because they often float to the surface, as a result tires are being stockpiled at an alarming rate, posing the risk of fire as well as a health hazard.

Alternatives to land filling waste tires often encompasses various methods ranging from the retreading process where old tires are buffed and a new tread is bonded to the old casing; the pyrolysis process in which tires are processed into oil, carbon black, and combustible gases; energy recovery from burning whole or waste tire chips in various boilers and cement kilns; to molded rubber products and artificial reefs using whole waste tires.

In 1969, a method was developed by C. H. McDonald to include rubber into asphalt. Mr. McDonald's purpose was to improve the asphalt. Asphalt rubber advocates claim that the inclusion of crumb rubber from waste tires increases the life of asphalt pavement by providing a higher softening point and less brittleness at low temperatures, and a lower softening point at high temperatures. Also some reports indicate a significant lower sound level and improved skid resistance. The process involves mixing crumb rubber from waste tires with hot asphalt, creating an 'asphalt rubber'. Asphalt rubber as a seal coat and a binder in hot mixes has been utilized for over 20 years.

Due to environmental awareness and waste tire disposal concerns in the United States it has been suggested to utilize some of the waste tires for production of asphalt rubber and construction of flexible pavements. The Intermodal Surface Transportation Efficiency Act (instituted by Congress in 1991) mandated the evaluation of potential usage of recycled materials in the construction of highways. One of the ISTEA provision (section 1038) requires states receiving federal highway funds to use rubber asphalt for at least 5 percent of construction in 1994, and 5 percent incremental increase annually thereafter, realizing a maximum of 20 percent usage by 1997 [1]. The goal of rubberized asphalt requirements of the ISTEA is to reduce the nation's immense stockpiles of scrap tires.

Two methods are often used to incorporate reclaimed waste tire rubber into conventional asphalt. The first method is referred to as the "wet process" in which 5 to 30 percent crumb rubber modifier is added to hot conventional asphalt cement and the mix is allowed to blend at a temperature of 340 degrees Fahrenheit for a period of time ranging from a few minutes to 45 minutes [2]. The second process is known as the "dry process" where 0.5%

to 3% by weight of total mix, fine and coarse crumb rubber particles are added to the aggregate. Both wet and dry processes were utilized for resurfacing of US 61.

Significance of Binder Rheology

Understanding the rheological properties of modified and unmodified asphalt binders has generated a great interest among engineers and researchers in the past few years. Based on the laboratory tests, one of the major causes of permanent deformation (rutting) of flexible pavement at elevated temperature may be reduced slightly by the addition of ground tire rubber to asphalt concrete [3,4]. Another cause of flexible pavement failure is low temperature cracking where viscoelastic asphalt concrete at warm temperatures changes and behaves as an inelastic material at colder temperatures, making it incapable of dissipating thermal stress [5]. The possible improvements in crack resistance and cohesion may be attributed to the rheological characteristics of the binder [6,7].

A multitude of new testing equipment and test methods have been developed and proposed in recent years. The conclusion of a 150 million dollar research program in 1993 which was established by Congress in 1987 to improve the nation's roads known as Strategic Highway Research Program (SHRP), produced an assortment of testing equipment and new specifications. Three testing methods and associated equipment have been developed by SHRP to measure rheological properties of unmodified or modified asphalt binders [8]. These include, Direct Tension Tester to measure the tensile strength and fracture properties of binder, Dynamic Shear Rheometer to measure phase angle and stiffness of binder, and Bending Beam Rheometer to determine the flexural creep stiffness of binder. The two subsequent test methods have been proposed for acceptance by the American Society for Testing and Materials.

The proposed practice for rheological measurements of bitumens using The Dynamic Shear Rheometers (D-4 proposal P 244) and the proposed test method for determining The Flexural Creep Stiffness of asphalt binder using the Bending Beam Rheometer (D-4 Proposal P 245) have been published in 1994 Annual Books of ASTM Standards under volume 4.03 Road and Paving Materials. The new and innovative Superior Performing Asphalt Pavements (Superpave™) hot mix design method relies on rheological properties of asphalt binders.

Ductility (Aging)

Conventional AC-5 asphalt cement obtained from IDOT material testing lab on June 6, 1991 and Asphalt-rubber binder obtained from research site on July 8, 1991 were divided and placed into eight 9 by 9 by 2 inch deep metal pans. Two pans containing asphalt-rubber and two pans containing conventional asphalt were placed outside and exposed to outside elements since the summer of 1991. To prevent dust, pollens, rain, and snow contamination, outside containers were covered with acrylic glass. The other four pans were kept in the laboratory to be used as a control group.

All tests were performed in the Soiltest AP-109 ductility tester which is capable of testing three specimens simultaneously at the rate of 5 centimeters per minute (5 cm/min). The ASTM D113 ductility test molds were utilized for casting ductility specimens. The mold release consisted of a mixture of Glycerol and talc powder. Regular tap water was used in ductility bath for testing specimens above freezing point. A cooling probe (Figure 1) capable of reaching minus 22 degrees Fahrenheit and a mixture of tap water and Ethylene Glycol were utilized for testing specimens at and below the freezing point.

In 1991, the preliminary ductility test was performed only at 70 and 100 degree Fahrenheit on both asphalt-rubber and conventional asphalt due to lack of a cooling probe. In July of 1992, a cooling probe attachment was purchased and ductility tests on control group (asphalt-rubber and conventional asphalt) were performed at 40, 32, and 20 degrees Fahrenheit. To prepare ductility samples, pans containing exposed asphalt-rubber and conventional asphalt were taken to the laboratory and placed in a forced draft oven and heated to 375 degrees Fahrenheit and only enough material was taken to complete the annual ductility (aging) tests.

Annually six exposed conventional asphalt AC-5 and six exposed asphalt-rubber were tested at 20, 32, 40, 70 and 100 degrees Fahrenheit. All specimens were kept in water for a period of ninety minutes prior to testing. A total of 60 specimens (thirty conventional asphalt AC-5 and thirty asphalt-rubber) were tested annually. Results of ductility tests on exposed AC-5 and asphalt-rubber are shown in Figure 2 and Appendix A.

In October 1995, five metal containers each containing approximately three ounces of extracted asphalt-rubber taken from specific stations from the research site were obtained and tested for ductility. Due to the extraction process these binders did not contain any rubber particles and each container was sufficient enough to make only three ductility specimens. Results of the ductility test on extracted asphalt-rubber at 32 and 100 degrees Fahrenheit is shown in Appendix A.

Tensile Creep Test

The strain properties of asphalt-rubber binder were measured in a tensile creep test apparatus (Figure 3) consisting of pulleys, cables, and weight. The tensile creep test was conducted in a ductility bath at 32, 70, and 100 degrees Fahrenheit. Specimens were cast in the brass molds consisting of the end pieces of the ASTM D113 ductility test molds, utilizing 50 millimeter long straight side pieces instead of the wedge shape side pieces of the conventional mold. The reduction of mold side pieces from 150 to 50 millimeters was necessary due to limitation in length of the ductility bath, in which specimens under dead load elongated without a rupture. Reduction in length of the mold side pieces also warranted experimentation with various weights. After trial and error, dead weight loads of 3045, 804, and 580 grams were selected.

Nine specimens (three at each temperature) were tested at 32, 70, and 100 degrees Fahrenheit. Dead weight loads of 3045 grams, 804 grams, and 580 grams were utilized respectively. Specimens were kept in the bath for a period of 60 minutes, supported by a wooden raft prior to testing. Failure of specimens at 32, and 70 degrees Fahrenheit were due to asphalt-rubber binder being elongated and drawn out of the mold under dead load. However, failure of test specimens at 100 degrees Fahrenheit were due to elongation and rupture of the test specimens as shown in Appendix A.

Scanning Electron Microscopy (SEM)

Ruptured ends of asphalt rubber binder from ductility test, crumb rubber particles, and asphalt rubber hot mix obtained from the research site were examined with scanning electron microscope in the fall of 1991. The gold coating of all specimens was accomplished with gold sputtering equipment under vacuum. A problem was encountered during the coating of the asphalt rubber binder, where the heat generated by the electrodes of sputtering equipment melted the surface of the ruptured ends of the ductility specimens rendering them featureless. An attempt was made to overcome this problem by a pulse coating process but this procedure also proved to be inadequate. There were no problems in gold coating of the asphalt rubber hot mix and crumb rubber. The purpose of obtaining SEM micrographs of plain rubber particles was to determine its morphology in aiding to distinguish the differences in the asphalt rubber binder and the asphalt rubber hot mix (Figures 4-7). Optical microscope and computer enhancement of scanned electron micrographs were ascertained to be inadequate in determination of asphalt and crumb rubber interface since it did not provide sufficient levels of detail. A more novel approach(es) may need to be devised in order to view an interfacial bond between asphalt and rubber particles.

Fatigue Test

A aggregate mix obtained from a cold feed conveyor belt at the asphalt plant during construction of US 61 on July 8, 1991 was mixed thoroughly and placed in a forced draft oven and heated to 340 degrees Fahrenheit. Conventional asphalt cement (AC-5) obtained from IDOT material testing lab on June 6, 1991 and crumb rubber (Rouse Rubber) obtained from the plant on July 8, 1991 was used at 14.94% by the weight of total binder and blended for 45 minutes at 350 degrees Fahrenheit. To ensure consistency with original asphalt-rubber binder obtained from research site, ductility test (ASTM D113) and penetration test (ASTM D5) were conducted on un-sieved asphalt-rubber binder produced in the laboratory. Results are shown in Appendix A.

Blended asphalt-rubber binder at the rate of 6.6% by the weight of total mix was then added to the aggregates to produce approximately 90 pounds of asphalt-rubber concrete binder mix. Asphalt rubber binder mix obtained from the research site during construction of US 61 and binder mix produced in the laboratory were sent to the Institute of Transportation Studies at the University of California, Berkeley for beam fatigue test. Laboratory results on beam fatigue tests performed at the University of California, Berkeley in its entirety are shown in Appendix B.

Research Site Investigation

On September 20 1995, the research site was visited by the researchers at the University of Northern Iowa and visual inspection of the control and test sections were conducted. In general both asphalt rubber and control sections appeared to be performing equally, however asphalt rubber sections appeared to have slightly more open surface than the control section which contained conventional asphalt. This view was also shared by Mr. Vernon Mark who visited the site in October.

Conclusions

Based on the laboratory test, the inclusion of recycled crumb rubber into asphalt, affects ductility of modified binder at various temperatures. The ductility test is only one of the many tests available today to measure the rheological properties of modified and unmodified asphalt. For further study and to better understand the properties of asphalt-rubber binder, it is recommended that newly developed test methods and equipment by Strategic Highway Research Program (e.g Direct Tension Tester, Dynamic Shear Rheometer, Bending Beam Rheometer) not available at the initiation of this research project be considered.

Aging or hardening of asphalt has been associated with the evaporation and oxidation of the lighter hydrocarbon over a period of time. The ductility test used to investigate the effects of aging in this research may not be an adequate test method. In addition effects of aging on conventional asphalt and asphalt-rubber sections in the field cannot be determined at this point in time since only four and one half years have elapsed since construction of test site. A longer time period is required to determine whether or not asphalt-rubber will out perform conventional asphalt or visa versa.

It should be noted that although the scope of this laboratory research was limited to measuring only a few of the mechanical properties of asphalt-rubber binder, its chemical properties are yet unknown. Function and possible contribution of natural or synthetic rubber [Styrene-butadiene (SBR)], and variation of it's additives (carbon black, silica, etc.) as well as the crumb rubber source, rubber particles morphology, blending time, and possible cross-linking of rubber particles and asphalt may cause difficulty in the generalization of asphalt-rubber products.

The incorporation of crumb rubber modifier into asphalt pavement has economical and technical ramifications which need to be considered. The cost of asphalt rubber concrete and rubber chip mix for construction of experimental sections for this project were more than double the cost of the conventional asphalt concrete. The recycling of conventional asphalt pavement is becoming the standard practice among many highway authorities, the recyclability of asphalt-rubber concrete is not yet well proven and needs to be carefully analyzed.

Acknowledgements

The author wishes to thank the sponsors, the Highway Division of the Iowa Department of Transportation, Iowa Highway Research Board, and Federal Highway Administration. Appreciation is extended to Mr. Vernon Marks of the Iowa Department of Transportation.

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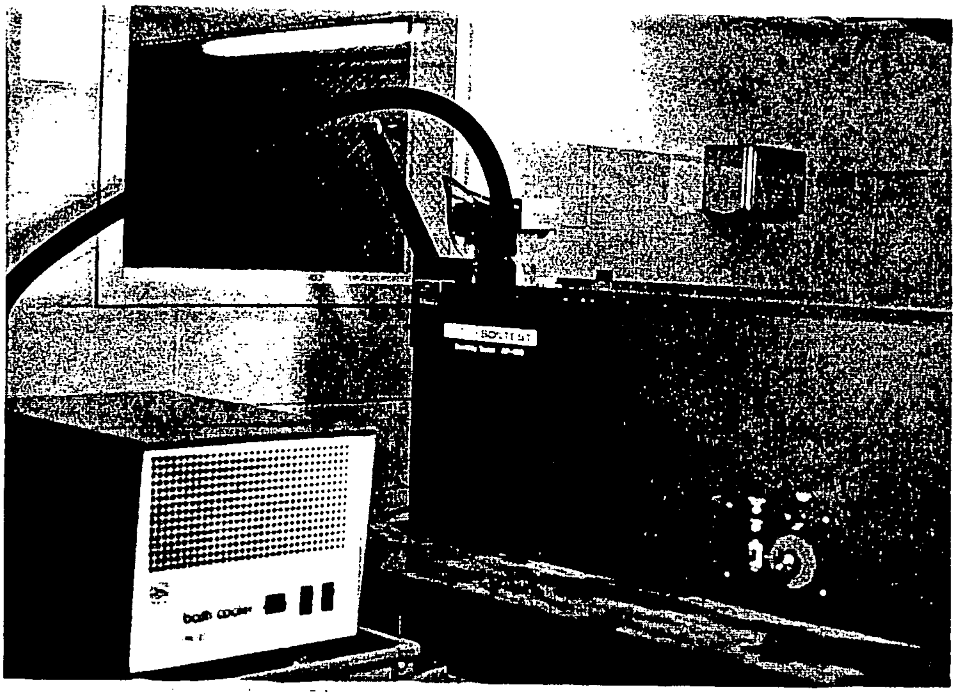
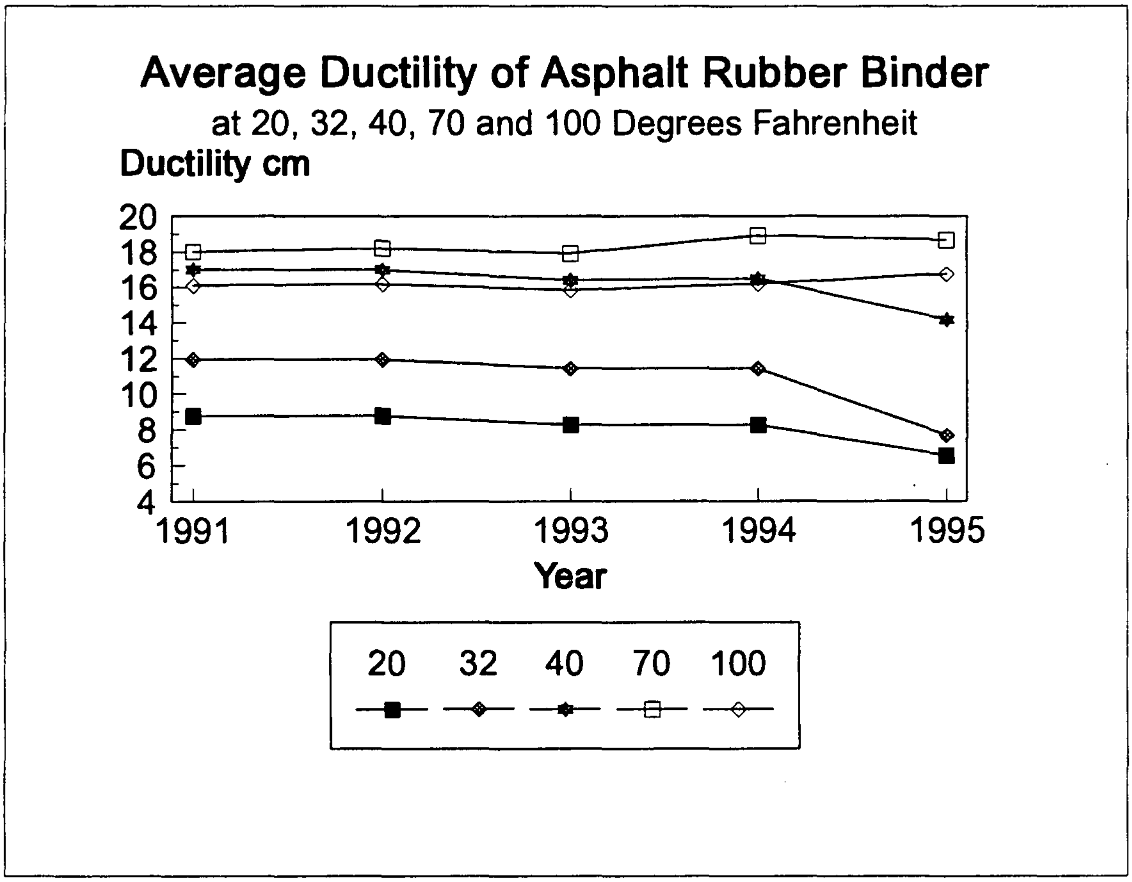


Figure 1. Cooling Probe & Ductility Bath



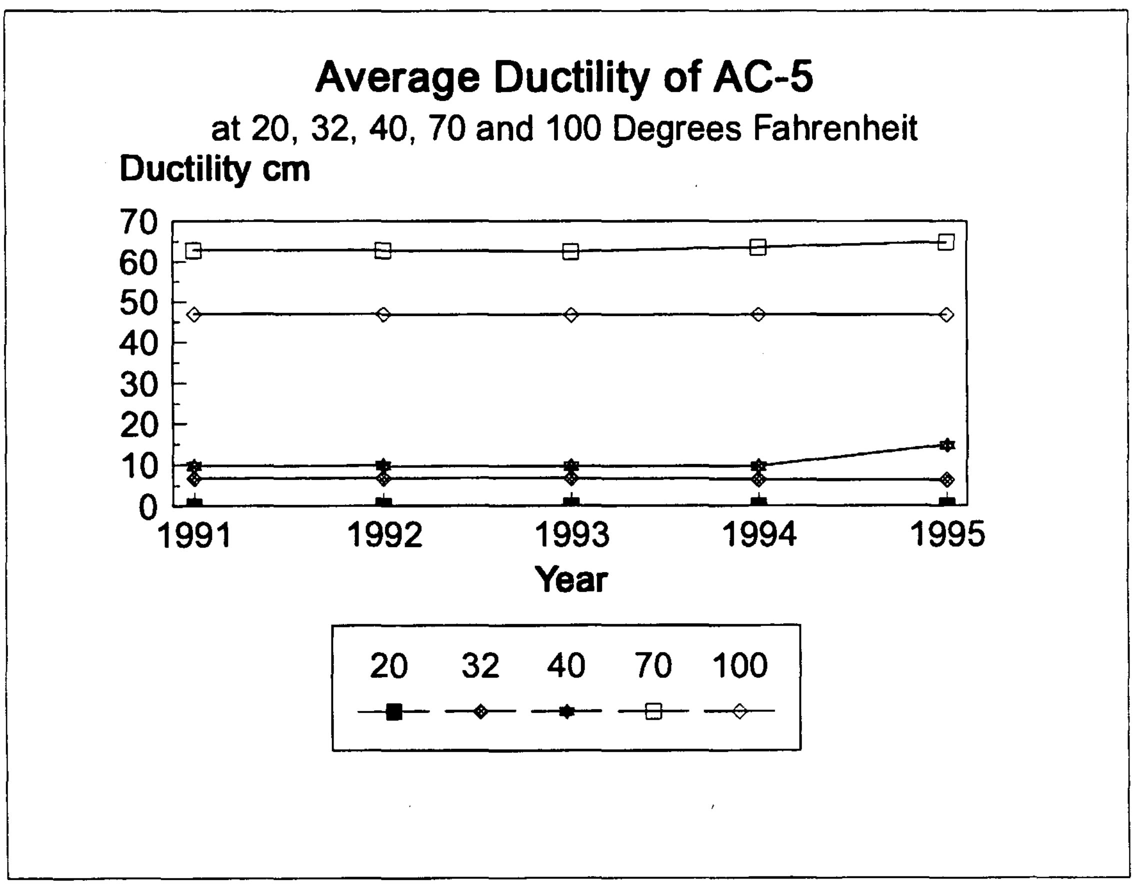


Figure 2. Ductility of Asphalt Rubber and AC-5

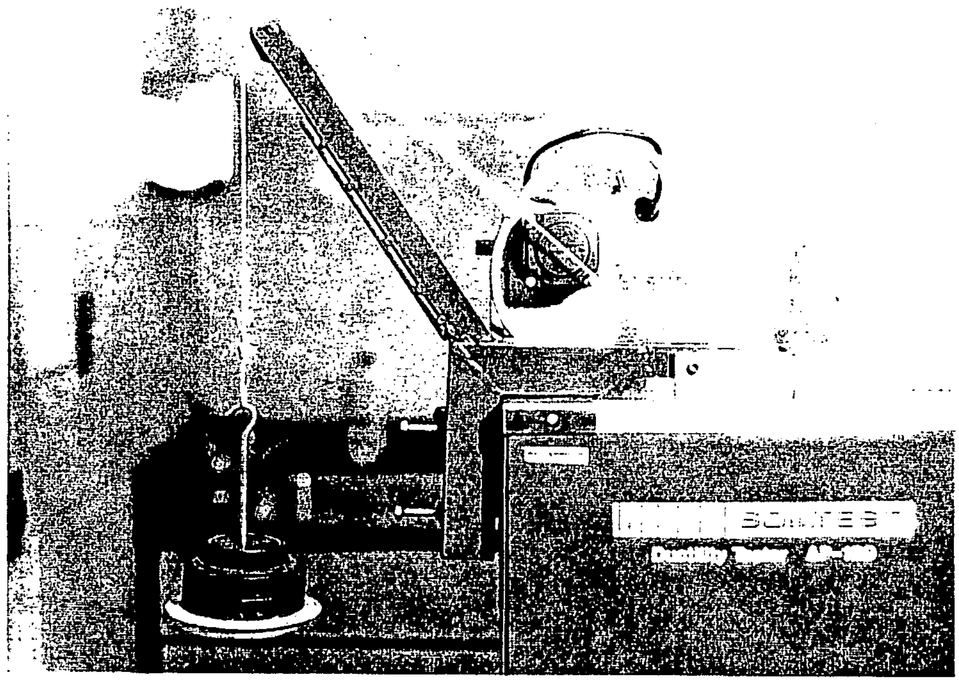


Figure 3. Tensile Creep Apparatus

Figure 4. Micrograph of rubber particles

Figure 5. Micrograph of rubber particles

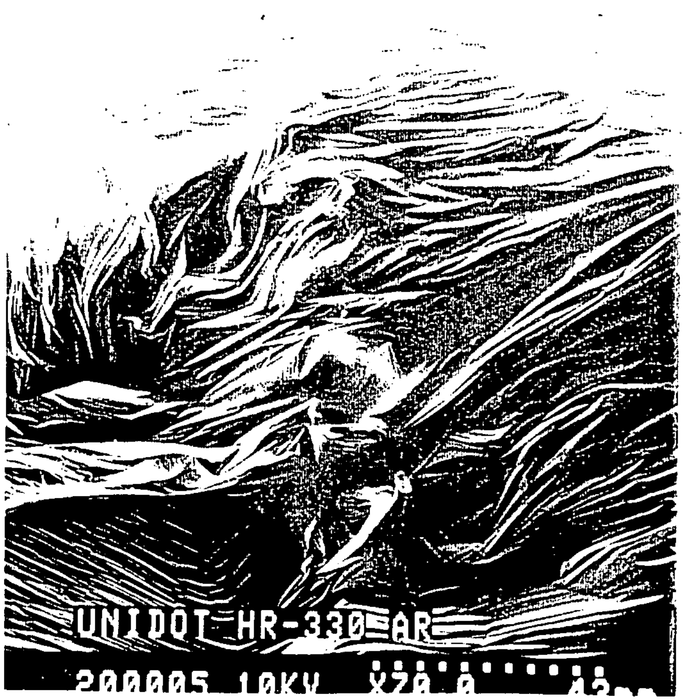


Figure 6. Micrograph of Asphalt-Rubber Binder

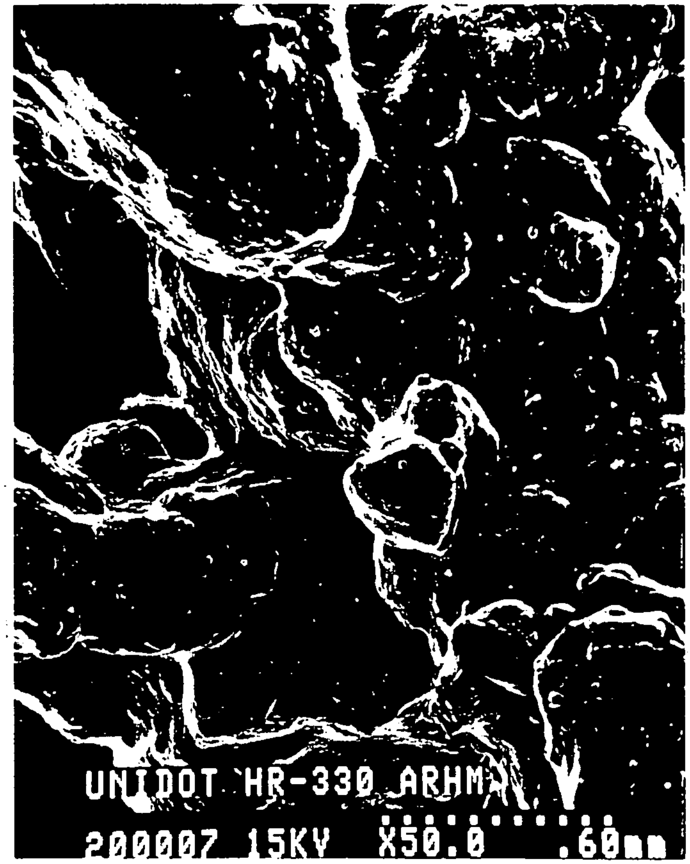


Figure 7. Micrograph of asphalt-rubber hot mix

Ductility (Aging) 1995

	Ductility Test @ 20 Degrees Fahrenheit		Ductility test @ 32 Degrees Fahrenheit		Ductility test @ 40 Degrees Fahrenheit		Ductility test @ 70 Degrees Fahrenheit		Ductility test @ 100 Degrees Fahrenheit	
Exposed	AC-5	A-R	AC-5	A-R	AC-5	A-R	AC-5	A-R	AC-5	A-R
	Fractured	7.50	6.50	7.50	13.25	14.50	66.00	19.00	49.00	16.00
	0.00	6.00	6.00	8.00	15.00	16.00	65.00	19.50	43.00	17.50
	0.00	7.00	6.25	7.00	15.00	16.25	63.25	20.00	49.00	16.25
	0.00	5.50	6.00	8.00	15.00	11.25	64.50	17.00	45.25	15.75
	0.00	6.25	6.25	8.00	15.00	13.00	63.00	18.50	46.00	17.00
	0.00	7.00	6.00	7.50	14.50	14.00	67.00	18.00	48.00	18.00
Sum	0.00	39.25	37.00	46.00	87.75	85.00	388.75	112.00	280.25	100.50
Average	0.00	6.54	6.17	7.67	14.63	14.17	64.79	18.67	46.71	16.75
STD	0.00	0.75	0.20	0.41	0.70	1.88	1.55	1.08	2.39	0.89

Ductility (Aging) 1994

	Ductility Test @ 20 Degrees Fahrenheit		Ductility test @ 32 Degrees Fahrenheit		Ductility test @ 40 Degrees Fahrenheit		Ductility test @ 70 Degrees Fahrenheit		Ductility test @ 100 Degrees Fahrenheit	
Exposed	AC-5	A-R	AC-5	A-R	AC-5	A-R	AC-5	A-R	AC-5	A-R
	Fractured	8.25	6.75	11.50	10.00	15.50	62.50	19.00	47.00	15.50
	0.00	8.50	6.50	10.75	9.50	16.00	63.00	18.50	48.50	16.00
	0.00	7.50	6.25	11.25	10.00	16.00	65.00	23.00	47.50	17.00
	0.00	8.00	6.25	11.00	9.00	16.75	64.00	18.00	45.00	15.75
	0.00	9.00	6.00	12.00	9.50	17.50	63.00	17.25	46.25	16.25
	0.00	8.25	6.50	12.00	9.25	17.25	64.00	17.75	46.75	16.50
Sum	0.00	49.50	38.25	68.50	57.25	99.00	381.50	113.50	281.00	97.00
Average	0.00	8.25	6.38	11.42	9.54	16.50	63.58	18.92	46.83	16.20
STD	0.00	0.46	0.24	0.47	0.37	0.72	0.84	1.91	1.08	0.49

Ductility (Aging) 1993

	Ductility Test @ 20 Degrees Fahrenheit		Ductility test @ 32 Degrees Fahrenheit		Ductility test @ 40 Degrees Fahrenheit		Ductility test @ 70 Degrees Fahrenheit		Ductility test @ 100 Degrees Fahrenheit	
Exposed	AC-5	A-R	AC-5	A-R	AC-5	A-R	AC-5	A-R	AC-5	A-R
	Fractured	8	6	12	10	17	62	19.5	47	17.5
	0	7.5	7.25	11.5	9.5	15.5	60	18	49	15
	0	8.5	6.5	11	9	16	63	20	46.5	14
	0	9	6.5	10.5	10	16.25	65	18.5	47	14.5
	0	8.5	6.25	12.5	9.25	19	64	16	45	16
	0	8	7	11	9	14.5	61	15.5	46	18
Sum	0.00	49.5	39.5	68.5	56.75	98.25	375	107.5	280.5	95
Average	0.00	8.25	6.6	11.4	9.5	16.4	62.5	17.92	46.75	15.83
STD	0	0.52	0.46	0.74	0.46	1.53	1.87	1.83	1.33	1.62

Ductility (Aging) 1992

	Ductility Test @ 20 Degrees			
	Exposed	Unexposed	Exposed	Unexposed
	AC-5	AC-5	A-R	A-R
			8.5	8.7
			8.7	8.8
			8.8	8.8
			8.9	8.6
			8.9	8.8
			8.7	8.9
SUM			52.5	52.6
AVERAGE			8.75	8.766666
STD			0.089442	0.097979
	Ductility Test @ 32 Degrees			
	Exposed	Unexposed	Exposed	Unexposed
	AC-5	AC-5	A-R	A-R
	6.4	6.6	11.7	11.9
	6.5	6.7	11.6	12
	6.8	6.4	11.9	12.1
	6.9	6.8	12	11.8
	6.8	6.6	12.3	12
	6.8	6.9	12	11.7
SUM	40.2	40	71.5	71.5
AVERAGE	6.7	6.666666	11.91666	11.91666
STD	0.135646	0.172046	0.224499	0.146969
	Ductility Test @ 40 Degress			
	Exposed	Unexposed	Exposed	Unexposed
	AC-5	AC-5	A-R	A-R
	9.6	9.7	16.9	17
	9.6	9.9	16.8	17.1
	10	10	17.1	16.8
	9.7	9.5	17.3	16.9
	9.8	9.3	17	17.2
	9.5	9.7	17	17.2
SUM	58.2	58.1	102.1	102.2
AVERAGE	9.7	9.683333	17.01666	17.03333
STD	0.172046	0.256124	0.162480	0.162480

Ductility (Aging) 1992

	Ductility Test @ 70 Degrees			
	Exposed	Unexposed	Exposed	Unexposed
	AC-5	AC-5	A-R	A-R
	62	63.1	18.3	18.1
	62.6	62.8	18.1	18
	63	62	17.9	17.8
	63.4	63.5	17.7	17.8
	62.1	62.7	18	18.4
	63.3	62.2	18.2	18
SUM	376.4	376.3	108.2	108.1
AVERAGE	62.73333	62.71666	18.03333	18.01666
STD	0.479165	0.523832	0.172046	0.219089
	Ductility Test @ 100 Degrees			
	Exposed	Unexposed	Exposed	Unexposed
	AC-5	AC-5	A-R	A-R
	47	47.3	16.3	16.2
	48	47	16.4	16.2
	46.5	47.1	16	16.4
	47	46.2	16.3	16.2
	46.3	47	16.2	16
	47	47	16.1	16.3
SUM	281.8	281.6	97.3	97.3
AVERAGE	46.96666	46.93333	16.21666	16.21666
STD	0.588557	0.332264	0.141421	0.132664
	Ductility Test @ 125 Degrees			
	Exposed	Unexposed	Exposed	Unexposed
	AC-5	AC-5	A-R	A-R
			10.3	10.3
			10.5	10.4
			10	10.1
			9.8	10.2
			10.3	10.3
			10.5	10
SUM			61.4	61.3
AVERAGE			10.23333	10.21666
STD			0.278567	0.141421

Ductility (Aging) 1991

	Ductility test @ 70 Degrees Fahrenheit		Ductility test @ 100 Degrees Fahrenheit	
	AC-5	A-R	AC-5	A-R
	70	16.5	51	16
	73	18	48.5	16.5
	71	17	53.5	15.5
	69	17	49	17
	72	16	50	16
	70	18	52	15.5
Sum	425	102.5	304	96.5
Average	70.83	17.08	50.67	16.1
STD	1.47	0.8	1.88	0.58

Ductility of Extracted Asphalt Cement from Samples Obtained in 1995

Stations	Type	Ductility cm @ 32 °F		Ductility cm @ 100 °F		
275 - 280+00	Surface	3.5	3.5	59		
215 - 230+00	Surface	3.5	3.5	64		
220 - 225+00	Binder	3.25	3	67		
155 - 160+00	Surface	4	3.5	69		
220 - 225+00	Binder			69	68	69

Tensile Creep Test

3045 Grams @ 32 °F			804 Grams @ 70 °F			580 Grams @ 100 °F	
Time Minutes	Elongation cm		Time Minutes	Elongation cm		Time Minutes	Elongation cm
0.00	0.00		0.00	0.00		0.00	0.00
1.00	0.00		0.25	1.00		0.25	1.00
2.00	0.50		0.50	1.50		0.50	1.50
3.00	1.50		0.75	2.00		0.75	2.00
4.00	1.50		1.00	2.50		1.00	7.50
5.00	2.50		1.25	3.50		1.25	7.50
6.00	2.50		1.50	4.50		1.50	7.50
7.00	2.50		1.75	5.50		1.75	7.50
8.00	3.00		2.00	6.50		2.00	7.50
9.00	3.00		2.25	8.00		2.25	10.00
10.00	3.50		2.50	9.00		2.50	30.50
11.00	4.00		2.75	10.00		2.75	Ruptured
12.00	Drawn Out		3.00	11.50		3.00	
13.00			3.25	13.50		3.25	
14.00			3.50	Drawn Out		3.50	

Ductility & Penetration Test on Asphalt- Rubber Binder Produced in The Laboratory

Ductility Test @ 5 Cm/Min			
Temperature	40 Degrees	77 Degrees	100 Degrees
Curing Time	90 Min	90 Min	90 Min
	16.75	19.00	15.75
	17.00	19.25	16.00
	16.75	18.75	15.50
	16.75	19.00	16.00
	17.00	20.00	16.00
	17.50	21.00	17.25
Average	16.96	19.50	16.08

Penetration Test 100 Grams	
Time Sec.	Penetration 1/10 mm
5.00	35.00
5.00	35.00
5.00	36.00
5.00	37.00
5.00	35.00
5.00	36.00
5.00	35.00
5.00	36.00
5.00	35.00
Average	35.60

Appendix B

TEST REPORT

FATIGUE BEAM TESTS - UNIVERSITY OF NORTHERN IOWA

Specimen Preparation

Asphalt-rubber asphalt concrete material used to make the specimens was received mixed from the client. The mix was not subjected to any short-term or long-term oven aging. The mix was compacted in ingots weighing approximately 20 kg each at 140.6 C using the Strategic Highway Research Program Project A-003A (SHRP A-003A) rolling wheel method (*1*,*2*). After cooling overnight, two 38.1 x 7.5 x 5 cm (15 x 2.5 x 2 in.) fatigue beams were cut from each of the two ingots. The target air-voids content 4.7 +/- 0.5 percent was achieved, with air-void contents measured using parafilm (*3*), as can be seen in the table below.

Two tests for the maximum effective specific gravity (MESP) of the mix (ASTM D 2041, Rice Method) were performed. The MESP was determined to be 2.411.

Test Results

Test Method. The specimens were tested at 20 C using the controlled-strain fatigue beam test apparatus at the UC-Berkeley Asphalt Research Program laboratory. This equipment was developed as part of SHRP A-003A. The test uses a closed-loop computer-controlled servo-hydraulic system to apply a 10 hz sinusoidal displacement to the beam, using a third-point loading set-up (*2*,*4*). The apparatus is shown in Figure 1.

After a preliminary test on a beam that had not achieved the target air-void content, strain levels of 350 and 650 microstrain were selected, to achieve fatigue lives on the order of 500,000 and 50,000 repetitions, respectively. Failure in this test is defined as reduction in stiffness to 50 percent of the initial stiffness, where the initial stiffness is that which occurs at the 50th strain repetition. The first 49 repetitions are considered to be conditioning.

The data collected from the test included: repetitions to failure, initial flexural stiffness, initial phase angle, and total dissipated energy. The results for the four beams tested are summarized in the following table.

Specimen	Air Void (pct)	MESP Rice	Avg Micro Strain	Initial Stiffness (psi)	Repetitions to 50 % Stiffness	Initial Phase Angle (deg)	Total Dissipated Energy (psi)
UNI-2A	5.2	2.411	340	264,337	441,941	41.1	4,626
UNI-2B	5.0	2.411	652	243,218	36,581	43.1	1,333
UNI-3A	5.0	2.411	345	302,081	500,000	40.8	5,860
UNI-3B	4.5	2.411	647	257,875	59,999	41.4	2,175
average	*4.9*			*266,878*		*41.6*	

Analysis

Using the results obtained from the tests described above, a least-squares regression was performed to obtain the following fatigue equation in the form:

$Nf = k_1 \text{ (microstrain)}^{k2}$

where $k_1 = 6.44\ (10^{14})$, and $k_2 = -3.604$ $(R^2 = 0.977)$.

Note: 1 microstrain = a strain of 1 (10^{-6}).

A plot of the fatigue equation (repetitions to failure versus microstrain) is shown in Figure 2.

Further analysis, and estimation of in-situ traffic loading can be performed following the method developed by Deacon, et al (*5*).

References

1. Harvey, J. and C. L. Monismith, "Effects of Laboratory Asphalt Concrete Specimen Preparation Variables on Fatigue and Permanent Deformation Test Results Using SHRP-A-003A Testing Equipment," Presented at the 1993 Transportation Research Board Annual Meeting, National Research Council, Washington, D.C.

2. Sousa, J., A. Tayebali, J. Harvey, P. Hendricks and C. L. Monismith, "Sensitivity of SHRP A-003A Testing Equipment to Mix Design Parameters for Permanent Deformation and Fatigue," Presented at the 1993 Transportation Research Board Annual Meeting, National Research Council, Washington, D.C.

3. Harvey, J., J. Sousa, J. Deacon, and C. L. Monismith, "Effects of Sample Preparation and Air-Void Content on Asphalt Concrete Properties," Transportation Research Record No. 1317, 1991.

4. Tayebali, A., J. Deacon, J. Coplantz, J. Harvey, and C. L. Monismith, "Fatigue Response of Asphalt-Aggregate Mixtures, Part I-Test Method Selection," Report prepared by the University of California at Berkeley, for the Strategic Highway Research Program, National Research Council, Project A-003A, Berkeley, November, 1992.

5. Deacon, J., A. Tayebali, J. Coplantz, F. Finn and C. Monismith, "Fatigue Response of Asphalt-Aggregate Mixtures, Part III - Mixture Design and Analysis," Report prepared for the Strategic Highway Research Program Project A-003A, Institute of Transportation Studies, University of California, Berkeley, May, 1993.

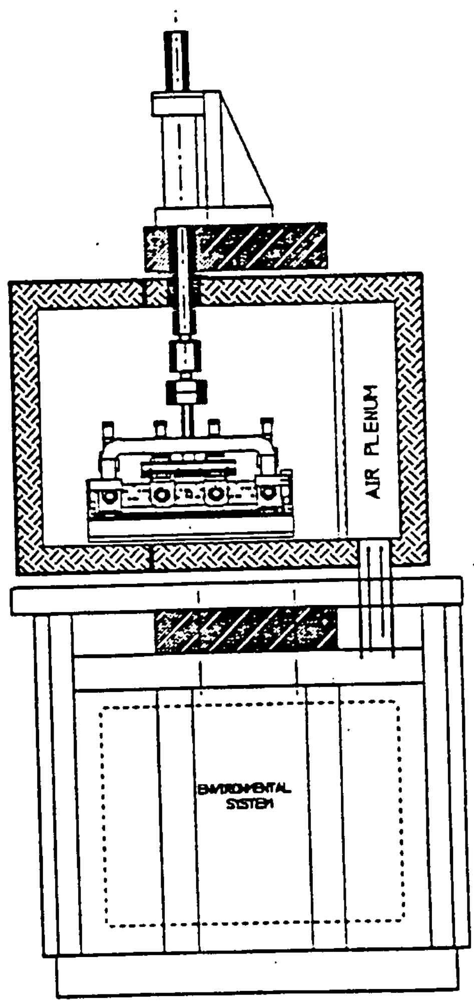


Figure 1. Schematics of alternative stand-alone fatigue test system (cross section). (Drawings courtesy of James Cox and Sons, Inc.)

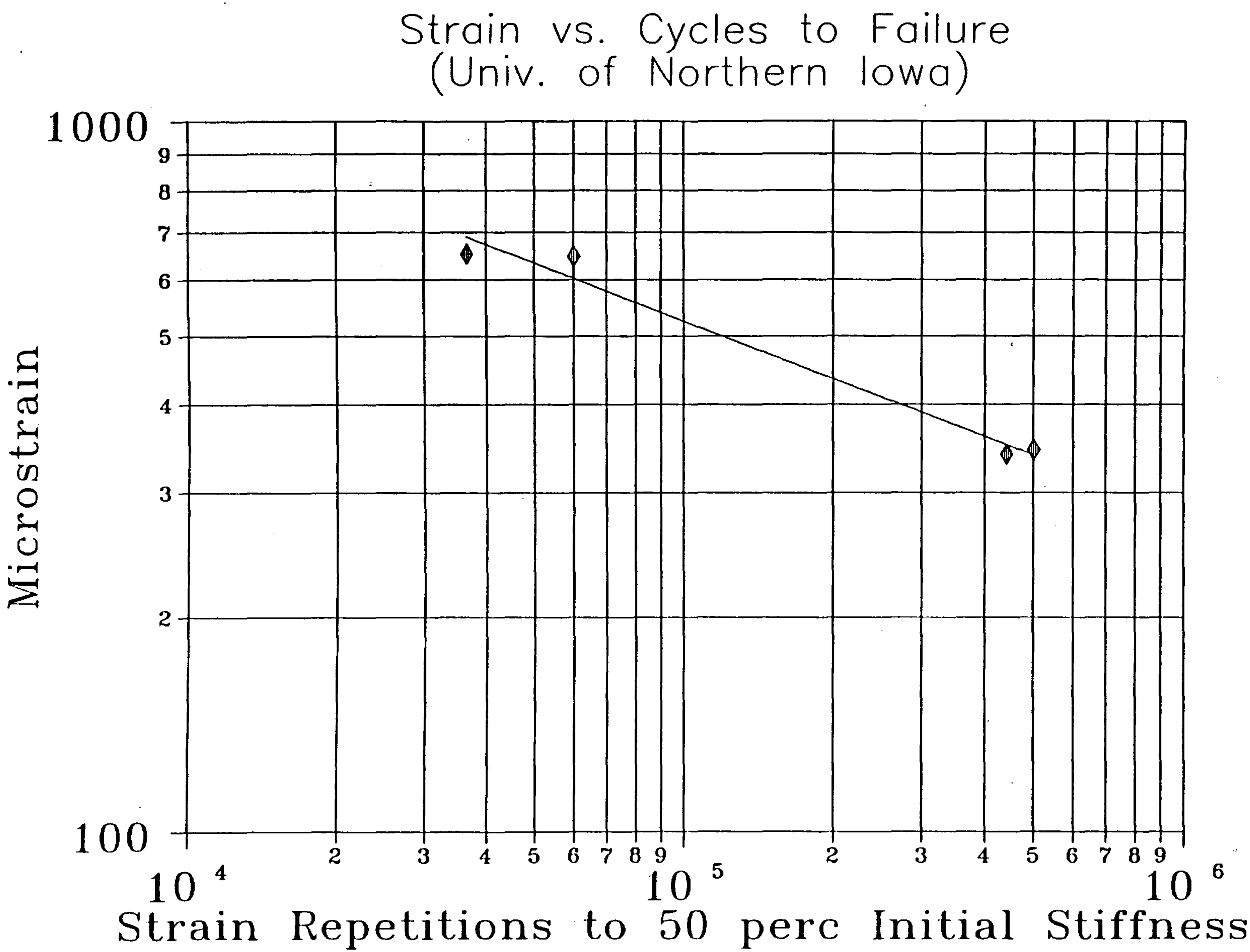


Figure 2. Strain versus repetitions to failure relation for UNI asphalt-rubber mix.