(77°F) water bath used in the test of asphalt cement penetration, devices that are usually available in materials laboratories, were used in performing the test.

The results of both test methods are given in Table 5. A correlation between the two test methods was obtained in the following form:

$$Y = 0.927X + 0.008 \qquad R = 0.976 \tag{2}$$

where Y = TSR at 51-mm/min (2-in/min) deformation rate and 25°C (77°F) test temperature and X = TSR at 1.6-mm/min (0.065-in/min) deformation rate and 12°C (54°F) test temperature.

The t-test indicated that there was no significant difference in the test methods at a 95 percent level of confidence. The methods were equivalent in their ability to predict stripping.

The test conditions selected in NCHRP Project 4-8(3)/1 were developed by using asphalt and aggregate sources representative of the United States; therefore, these test conditions may yield the best overall predictions. However, the modified test results are encouraging and appear to yield comparable predictions of TSR values for Virginia asphalts and aggregates.

Visual Examination of Split Specimens

After the indirect tensile tests were performed, the specimens were split apart and examined visually for stripping damage. Generally, the amount of stripping that was visible was indicative of the relative TSR, especially for the same mix with different properties (such as density) or with and without additives.

CONCLUSIONS

1. None of the mixes showed significant stripping damage after only preconditioning by vacuum saturation; therefore, either pavement damage would not occur in a short period of time or preconditioning by vacuum saturation does not predict the short-term performance of Virginia mixes. This conclusion is supported by observed stripping failures in Virginia.
2. Six of the eight mixes showed significant stripping damage after freeze-thaw preconditioning; therefore, pavements that incorporate these mixes would probably show evidence of stripping over a long period of time.
3. On the basis of results with the three asphalt cements used, asphalt cement does not significantly affect the tensile-strength ratio.
4. There was a significant difference between the performances of antistripping additives for one mix.
5. A modified test method that uses equipment now available in most materials laboratories in Virginia can be used in place of the test method that calls for a 1.6-mm/min (0.065-in/min) deformation rate and a 12°C (54°F) test temperature.
6. The relative magnitude of stripping can be detected by a visual examination of specimens.

ACKNOWLEDGMENT

I wish to express appreciation to the district materials engineers of the Virginia Department of Highways and Transportation for providing mix designs and aggregates. Special thanks also go to R. P. Lottman for his advice throughout the project.

This research was funded by the Virginia Department of Highways and Transportation. The opinions, findings, and conclusions expressed in this paper are mine and not necessarily those of the sponsoring agency.

REFERENCES

1. R. P. Lottman. Final Report—Predicting Moisture-Induced Damage to Asphaltic Concrete. Univ. of Idaho, Moscow, Feb. 28, 1974.
2. Road and Bridge Specifications. Virginia Department of Highways and Transportation, Charlottesville, Jan. 1, 1978.
3. R. P. Lottman. Working Plan and Guidelines to Participating States for NCHRP Research Project 4-8(3)/1. Univ. of Idaho, Moscow, June 10, 1975.

Publication of this paper sponsored by Committee on Characteristics of Bituminous Materials.

Abridgment

Engineering Characteristics of Dryer-Drum Asphalt Mixtures

Thomas W. Kennedy, Department of Civil Engineering, University of Texas at Austin
Adedare S. Adedimila, University of Lagos, Lagos, Nigeria

In recent years, there has been a substantial increase in the use of dryer-drum mixers. Although several investigators have studied some of the properties of the asphalt concrete mixtures produced by using these mixers, tensile strengths, resilient or elastic properties, and fatigue properties for these kinds of mixtures are not readily available. Thus, the Texas State Department of Highways and Public Transportation (TSDHPT) requested that a limited investigation be conducted to determine the characteristics of asphalt mixtures produced by using a dryer drum and to determine whether these mixtures are satisfactory.

EXPERIMENTAL PROGRAM

The objectives of the study summarized in this paper were

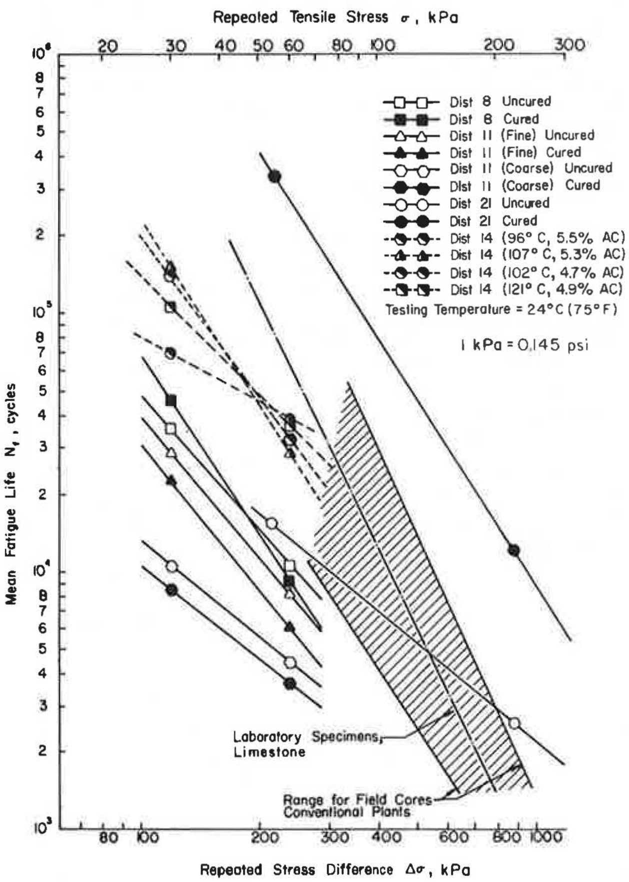
1. To evaluate the fatigue and elastic properties of

Table 1. Description of asphalt concrete projects.

County	District Project	Treatment[a]	Temperature (°C) Mixing	Temperature (°C) Compaction	Number of Specimens Fatigue	Number of Specimens Static	Asphalt Type	Asphalt Percentage[b]	Aggregate
Taylor	8	Cured	-	Same as mixing	9	3	AC-10	8.2	Lightweight
		Uncured	-		10	3			
Shelby	11								
	Fine	Cured	-	121	10	3	AC-10	5.0	Crushed iron ore, fine gradation
		Uncured	-	Same as mixing	12	3			
	Coarse	Cured	-	121	4	2	AC-10	5.0	Crushed iron ore, coarse gradation
		Uncured	-	Same as mixing	4	2			
Hidalgo	21	Cured	124-129	121	13	2	AC-20	5.2	Limestone
		Uncured	124-129	124-129	12	2			
Hays	14	Uncured	96	96	7	2	AC-10	5.5	Limestone
		Uncured	107	107	7	2		5.3	
		Uncured	102	102	7	2		4.7	
		Uncured	121	121	7	2		4.9	

Note: t°C = (t°F − 32)/1.8.
[a]Cured specimens were dried to a constant weight at 121°C before compaction. Uncured specimens were compacted at the plant temperature immediately after mixing.
[b]By weight of total mix.

Figure 1. Logarithmic relations between fatigue life and stress.



asphalt mixtures produced by using a dryer-drum plant,

2. To compare the properties of asphalt mixtures produced by using a dryer-drum plant with the properties of asphalt mixtures produced in conventional plants, and

3. To evaluate the effects of curing treatment and mixing temperature on properties of asphalt mixtures produced by using a dryer-drum plant.

Laboratory-prepared specimens of mixtures obtained during construction of five projects in Texas were tested by using the static and repeated-load indirect tensile tests. A summary of the project information is given in Table 1. Test procedures and specimen preparation are described elsewhere (1, 2).

The properties analyzed were tensile strength, static Poisson's ratio, and resilient modulus of elasticity. Fatigue life was defined as the number of load applications required to completely fracture the specimen.

ANALYSIS AND EVALUATION

Fatigue Properties

Only two stress levels were used. The results of previous studies have shown a linear relation between the logarithm of applied stress and the logarithm of fatigue life for asphalt mixtures. This relation for the repeated-load indirect tensile test (3) can be expressed as

$$N_f = K'_2 \, (1/\Delta\sigma)^{n_2} \qquad (1)$$

where

N_f = fatigue life (cycles),
$\Delta\sigma$ = stress difference $\simeq 4\sigma_T$ (kPa),
σ_T = applied tensile stress (kPa), and
K'_2 and n_2 = material constants.

Values of n_2 were fairly constant, ranging from 1.24 to 2.65. These values were low compared with previously reported values for field cores of mixtures produced by conventional plants and for laboratory specimens at optimum asphalt content. Since $1/\sigma$ or $1/\Delta\sigma$ is always less than 1.0 for the normal range of stresses exerted on pavements, lower values of n_2 would generally indicate higher values of fatigue life.

Values of K'_2 ranged from 1.86×10^5 to 2.52×10^8. These values are small compared with previously reported values of K'_2 for mixtures produced by conventional plants and for laboratory specimens at optimum asphalt content, which should indicate shorter fatigue lives.

The logarithmic relations shown in Figure 1 generally indicate that the dryer-drum mixtures had lower fatigue lives for the range of stress shown. However, as the N-values indicate, the reverse would probably occur at very high levels of stress.

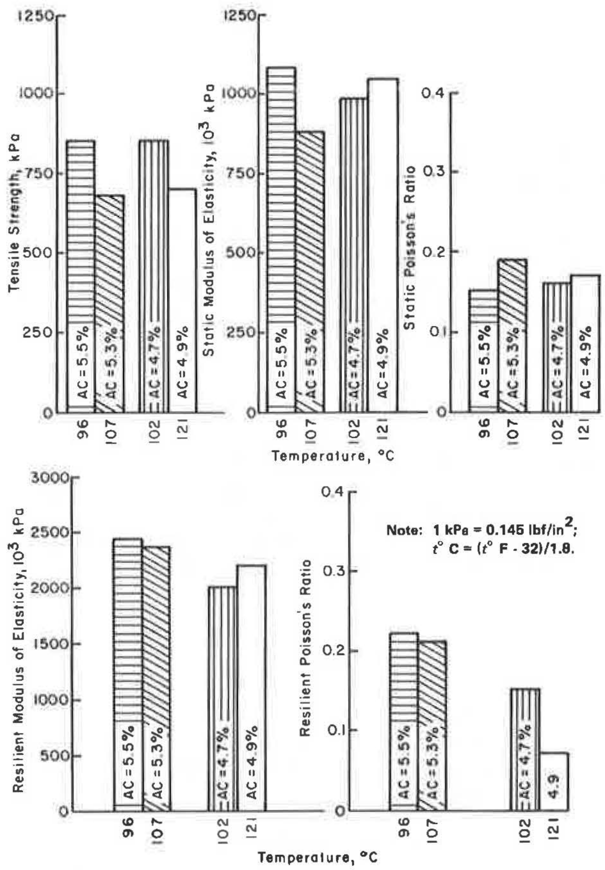
The coefficients of variation of fatigue life ranged from 2 to 82 percent; these values are generally lower than those reported by Navarro and Kennedy (4). This

Table 2. Comparison of tensile strength and elastic properties.

Type	Tensile Strength (kPa)	Static Modulus of Elasticity (MPa)	Static Poisson's Ratio	Resilient Modulus of Elasticity[a] (MPa)	Resilient Poisson's Ratio[a]	Source
Dryer-drum specimens	421-1021	558-1827	0.14-0.42	1283-3489	0.05-0.38	
In-service cores	421-1089	317-1158	0.03-0.35	1524-4241	0.06-0.58	
Laboratory specimens[b]						
Limestone	1000	800	0.08	3262	0.21	
Gravel	1000	1358	0.20	2896	0.06	

Notes: 1 kPa = 0.145 lbf/in²; 1 MPa = 145 lbf/in²; $t°$ = (t°F - 32)/1.8. Testing temperature = 24°C.
[a] Average of values obtained for cycles corresponding to 30, 50, and 70 percent of fatigue life.
[b] At optimum asphalt content.

Figure 2. Effect of mixing and compaction temperature on engineering properties of mixtures from one project.



is probably partially attributable to the fact that the specimens were compacted in the laboratory.

Strength and Elastic Properties

Values of tensile strength, modulus of elasticity, and Poisson's ratio obtained for dryer-drum mixtures were approximately the same as values previously obtained for conventional mixtures (see Table 2). Thus, in terms of static elastic and strength properties, the dryer-drum mixtures should perform as well as the in-service materials and the laboratory-prepared specimens.

The mean values of the resilient modulus ranged from 1283 to 3489 MPa (186 000-506 000 lbf/in²) (Table 2). The moduli were consistent within each project; therefore, the coefficients of variation for each project were small, ranging from 4 to 25 percent. As the data given in Table 2 show, the resilient moduli obtained for dryer-drum mixtures tested in this study were slightly smaller than those of conventional mixtures but were within the range of previously reported values.

Effect of Curing Treatment and Moisture Condition

In general, there were no differences in the elastic and fatigue properties of the cured and uncured specimens. The effect of water content, however, could not be evaluated since no appreciable difference in water content was observed between the cured and uncured specimens of any given mixture. In fact, the water contents were approximately equal to those that might be expected in conventional plants.

Effect of Mix Temperature

As Figure 2 shows, an increase in mixing and compaction temperature caused a small decrease in tensile strength. The increments in the mixing and compaction temperature in this study, however, were small, and the mixtures also involved different asphalt contents. Thus, it was concluded that modulus of elasticity and static Poisson's ratio were not affected by changes in mix temperature.

As can be seen in Figure 1, the values of n_2 and K'_2 and, consequently, fatigue life were approximately equal for the group of specimens produced with 5.5 percent asphalt content at 96°C (205°F) and those produced with 5.3 percent asphalt content at 107°C (225°F). Nevertheless, there were differences in the fatigue life for the mixtures that contained 4.7 and 4.9 percent asphalt and were mixed at 102°C (215°F) and 121°C (250°F), respectively.

No consistent change in the value of the resilient modulus was observed with a change in mixing temperature (Figure 2). The resilient Poisson's ratio decreased with an increase in mixing temperature, and the change was significant at the lower asphalt content.

SUMMARY AND CONCLUSIONS

This paper summarizes the findings of a study to evaluate the fatigue and elastic properties of asphalt mixtures produced by using a dryer-drum plant. All specimens were mixed in the field and compacted in the laboratory. The resulting conclusions are summarized below.

1. The engineering properties of the dryer-drum mixtures evaluated in this study—including tensile strength, static and resilient Poisson's ratio, and static and resilient modulus of elasticity—were generally equal to those of previously evaluated in-service and laboratory-prepared mixtures. The one exception was fatigue life, which appeared to be less for the dryer-drum mixtures.

2. Based on the findings of this study and the experience and findings of others, it is felt that satisfactory mixtures can be produced by using the dryer drum. The only question relates to the effect of moisture, and it would appear from previous experience that moisture produces little if any adverse effect.

3. An increase in mixing and compaction temperature caused a decrease in resilient Poisson's ratio but did not have any significant effect on tensile strength, static and resilient modulus of elasticity, and static Poisson's ratio. There was an indication that fatigue life was improved by an increase in mixing temperature up to a certain stress level. However, the asphalt content also varied slightly.

ACKNOWLEDGMENT

This investigation was conducted at the Center for Highway Research, University of Texas at Austin. We wish to thank the sponsors, the Texas State Department of Highways and Public Transportation, and the Federal Highway Administration, U.S. Department of Transportation.

The contents of this paper reflect our views, and we are responsible for the facts and the accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This paper does not constitute a standard, specification, or regulation.

REFERENCES

1. A. S. Adedimila and T. W. Kennedy. Fatigue and Resilient Characteristics of Asphalt Mixtures by Repeated-Load Indirect Tensile Test. Center for Highway Research, Univ. of Texas at Austin, Res. Rept. 183-5, Aug. 1975.
2. M. Rodriguez and T. W. Kennedy. The Resilient and Fatigue Characteristics of Asphalt Mixtures Processed by the Dryer-Drum Mixer. Center for Highway Research, Univ. of Texas at Austin, Res. Rept. 183-8, Dec. 1976.
3. B. W. Porter and T. W. Kennedy. Comparison of Fatigue Test Methods for Asphalt Materials. Center for Highway Research, Univ. of Texas at Austin, Res. Rept. 183-4, April 1975.
4. D. Navarro and T. W. Kennedy. Fatigue and Repeated-Load Elastic Characteristics of Inservice Asphalt-Treated Materials. Center for Highway Research, Univ. of Texas at Austin, Res. Rept. 183-2, Jan. 1975.

Publication of this paper sponsored by Committee on Characteristics of Bituminous Paving Mixtures to Meet Structural Requirements.

Evaluation of Oregon's First Project in Hot-Mix Asphalt Recycling

William G. Whitcomb, Department of Civil Engineering, Oregon State University, Corvallis
Gordon Beecroft and James E. Wilson, Oregon Department of Transportation, Salem

Pavement recycling has been suggested as a workable alternative to more conventional methods of pavement rehabilitation and a means of offsetting some of the problems that result from spiraling energy costs and shortages of raw materials. The Woodburn asphalt recycling paving project, Oregon's first experience with using a hot-mix process in large-scale recycling of asphalt concrete, is discussed. The project is described, overlay and mix designs are indicated, the construction program and the specific equipment used are reviewed, the program of materials sampling and testing and data collection is described, and test results are summarized. Special emphasis is given to an investigation of possible changes in material properties through the construction process. A summary is presented of the factors that most affect the production of emissions. Costs and fuel consumption are examined, and possible savings over a similar, conventional paving project are highlighted. Specific recommendations are presented for the benefit of other agencies that are considering similar projects, and future research needs are outlined.

The need to reduce fuel consumption and conserve natural resources has been an item of ever-increasing importance during recent years. In 1976, the highway division of the Oregon Department of Transportation (DOT) was faced with the problem of disposing of nearly 45 000 Mg (50 000 tons) of asphalt concrete pavement placed for temporary purposes in the rehabilitation of I-5 between Salem and Woodburn. Officials of the division recognized the possibility of using this asphalt concrete as raw material for recycling and, with the assistance of federal funding through Region 15 of the Federal Highway Administration (FHWA), a demonstration project that became known as the Woodburn asphalt pavement recycling project was initiated.

To fulfill the objectives of the national demonstration project program for asphalt pavement recycling, a comprehensive work plan was developed that specified the responsibilities of the highway division through the project's duration. Included in the plan was a program for sampling, testing, and evaluation before and during construction. In addition, provision was made for post-construction testing and evaluation to continue for years to come.

This paper discusses the results of the investigations performed by the highway division of the Oregon DOT in fulfilling its responsibilities through the first year of project evaluation. Specifically, the objectives of this paper are to

1. Present a description of the project, including its location, overlay thickness design, asphalt concrete mix design, and final mix specifications;
2. Indicate the final construction procedure and equipment used;
3. Describe the program of materials sampling and testing and collection of data on weather, pollutant