23. W.K. Parr and P.J. Serafin. Four Year Test Trends on the Michigan Bituminous Experimental Road. Proc., Association of Asphalt Paving Technologists, Vol. 28, 1959, p. 295.
24. P.J. Serafin, L.L. Kole, and A.P. Chritz. Michigan Bituminous Experimental Road--Final Report. Proc., Association of Asphalt Paving Technologists, Vol. 36, 1957, p. 582.
25. W.C. Simpson, R.L. Griffin, and T.K. Miles. Correlation of the Micro-Film Durability Test with the Field Hardening Observed on the Zaca-Wigmore Experimental Project. In Special Technical Publication 277, American Society for Testing and Materials, Philadelphia, Pa., 1959, p. 52.
26. B.A. Vallerga and W.J. Halstead. Effects of Field Aging on Fundamental Properties of Paving Asphalts. In Transportation Research Record 361, TRB, National Research Council, Washington, D.C., 1971, p. 71.
27. J.A. Zenewitz and J.Y. Welborn. Predicting Asphalt Performance. Report FHWA-RD-76-133. FHWA, U.S. Department of Transportation, 1975.
28. E.H. Chipperfield and T.R. Welch. Studies on the Relationships Between the Properties of Road Bitumens and Their Service Behavior. Proc., Association of Asphalt Paving Technologists, Vol. 36, 1967, p. 421.
29. E.H. Chipperfield, J.L. Duthie, and R.B. Girdler. Asphalt Characteristics in Relation to Road Performance. Proc., Association of Asphalt Paving Technologists, Vol. 39, 1970, p. 575.
30. A.W. Cisco and L.C. Brunstrum. The Rheological Properties of Asphalts in Relation to Durability and Pavement Performance. Proc., Association of Asphalt Paving Technologists, Vol. 37, 1968, p. 448.
31. Relationship of Asphalt Cement Properties to Pavement Durability. NCHRP Synthesis of Highway Practice 59. TRB, National Research Council, Washington, D.C., 1979.

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

Significant Studies on Asphalt Durability: California Experience

GLENN R. KEMP and GEORGE B. SHERMAN

ABSTRACT

Some of the key durability studies conducted by the California Department of Transportation since the late 1930s, the conclusions reached, and how the results have been implemented in asphalt specifications are reviewed. A description is given of a recent study in which carefully prepared laboratory briquettes of three divergent types of asphalt and absorptive nonabsorptive aggregates were used. The mixes were compacted using three different void contents and weathered in the field in four different climatic areas. New asphalt tests and specification requirements that will be used in obtaining asphalt for test roads in hot desert areas are described. A summary of the major findings from these studies is also included.

PREVIOUS ASPHALT DURABILITY STUDIES

Durability studies were under way in the late 1930s. Using the criterion that asphalts hardened under field conditions at the slowest rate were the most durable, an attempt was made to evaluate asphalt products available in California (1). This required new and different test methods because the specifications then in use did not separate hardening during construction operations from the natural rate of hardening during the service life of the pavement under traffic. A test investigated during this early period was the asphalt classification by the Benson method of thin-film studies on microscope slides (2). This study led to the belief that thin films were essential for a durability determination. However, the Benson test did not lend itself well to specification purposes.

In 1939 Lang and Thomas of Minnesota (3) published their durability work using mixes of Ottawa sand and asphalt. They explored three methods of testing these samples:

1. Elongation of a test briquette,
2. Destruction by impact, and
3. An abrasion method that tumbled the briquettes in the Devel testing machine.

From these studies, an abrasion test evolved--the shot abrasion test--that used Ottawa sand and 2 percent asphalt mixtures prepared at 230°F and compacted into the lids of 3-oz ointment tins. The compacted specimens were cured under drying lamps in a special weathering machine in which the temperature was maintained at 140°F. The briquettes were then abraded by a stream of free-falling shot dropped from a prescribed height. The weight loss

due to abrasion was determined after various cycles of weathering.

The testing program proved two valuable points: major hardening differences were found between asphalts manufactured from various crude sources and the initial consistency of the asphalt was a major factor in the resistance to abrasion (4). The result of this work showed the durability advantage to be gained by use of the softest practical asphalt consistent with mix stability.

First Field Test Program

In 1954 and 1955 an experimental project was constructed on a major highway. It was called the Zaca-Wigmore Experimental Test Road and involved field tests of 10 different asphalts, including Arkansas Smackover Asphalt. The test results (5) clearly showed that asphalts manufactured from different sources and by different methods of production can affect the durability under equivalent conditions of traffic and climate. Performance differences between sections constructed in 1955 and 1956 showed that construction differences or foundation conditions or both could also affect asphalt durability.

Implementation of the Road Test Results

The results of these studies led to new, tighter specifications. The Thin-Film Oven (TFO) test replaced the older loss-on-heating test for estimating asphalt durability. To control temperature susceptibility, the specifications included requirements for penetration at 77°F, penetration ratio, and viscosity at 275°F. After deliberations with city, county, asphalt producers, contractors, and materials engineers from the Pacific Coast states, new asphalt specifications were adopted called the Uniform Pacific Coast Asphalt Specifications.

Because abrasion indicated the difference in performance due to consistency of the asphalt as well as its composition, further research was carried out to determine whether the viscosity change during construction operations could be predicted by laboratory tests before construction. This research (6,7) resulted in the development of the Rolling Thin-Film Oven (RTFO) test (6). This test consists of placing the asphalt into cylindrical bottles and aging the asphalt in an oven at 325°F. The asphalt is rolled and aged for 75 min. The increase in viscosity at 140°F after aging approximates that obtained during the construction process. The actual field increase will vary, however, dependent on the aggregate temperature, time of mixing, and such other variables as time held in storage silos. In spite of these difficulties, the properties of the asphalt after the RTFO test more closely defined the properties of the asphalt in the pavement immediately after construction. This led to the concept of preparing a specification based on the viscosity after the RTFO test.

Aged-Residue Viscosity-Graded Paving Asphalt Specifications

New specifications were developed to approximate the viscosity of the asphalt as it is placed in the roadway rather than as shipped by the refiner. The test simulates the condition of the asphalt in the pavement during and shortly after construction.

The aged-residue grading system was made possible by the RTFO test, which was a major improvement over the conventional TFO test because the testing time was reduced from 5 hr to 75 min, the amount of asphalt available after the test was more than doubled, and the precision was greatly improved. Multilaboratory precision for the viscosity at 140°F (coefficient of variation) was reduced to 4.2 percent, considerably less than the 11.6 percent for the TFO test. The aged-residue viscosity-graded specifications were adopted on the Pacific Coast in 1973 and by ASTM in 1975.

LONG-TERM DURABILITY STUDIES

The aged-residue grading system separated out the hardening of asphalt due to construction operations from that occurring in the pavement on long-term aging. The California Department of Transportation (Caltrans) then focused its attention on long-term durability studies. The first approach was to evaluate various tests to define asphalt durability followed by field tests. The results were somewhat inconclusive, however, because of the large number of variables inherent in field test programs. However, this program did show that oxidation is one of the most important detrimental reactions affecting asphalt durability (8).

In order to control or eliminate variabilities encountered in normal construction, it was decided to conduct a series of field weathering projects on carefully prepared laboratory-fabricated test specimens. The research plan was as follows (9).

Objective

The objective was to determine the relationship between asphalt properties, degree of compaction (voids), aggregate porosity, and weathering under various field climatic conditions using laboratory-prepared test specimens.

Materials

Asphalt materials included three AR-4000 grade asphalts prepared from three crude sources representing high-, moderate, and low-temperature susceptibility. Two aggregate sources were used, one nonabsorptive and the other a porous, absorptive aggregate.

Mix Design

The asphalt concrete prepared from the foregoing materials conformed to California type B, 3/4-in. medium grading specifications. The optimum percentage of asphalt, as determined by stability tests, was used with each type of aggregate.

Fabrication of Test Briquettes

The test specimens were compacted to three void ranges: 3 to 5 percent, 7 to 9 percent, and 10 to 12 percent.

Laboratory Weathering

The California tilt-oven durability test was used in the laboratory to simulate field weathering of the asphalts used in the briquette study.

Field Weathering

The laboratory-prepared test briquettes were exposed to the weather in four climatic conditions:

1. High mountain climate with mild dry summers and severe and wet snowy winters; average yearly temperature of 41.6°F; precipitation, 19.7 in.;
2. Coastal climate with mild humid summers and mild wet winters; average yearly temperature of 52.1°F; precipitation, 31.7 in.;
3. Interior valley climate with hot summers and cold wet winters; average daily temperature of 63°F; precipitation, 14.2 in.; and
4. Low desert climate with mild to warm winters and very hot dry summers; average daily temperature of 73°F, precipitation, 5.4 in.

Complete sets of test specimens were weathered at each location for 1, 2, and 4 years.

In the hot, low desert test site, the results from the briquette studies were compared with those from a previous field test project, the Calipatria Test Road. Results from the latter indicate that briquette weathering per unit of time is slightly more severe than actual road weathering conditions in the hot Indio Desert climate. These results indicate that 24 months of briquette weathering is approximately equal to 32 months of road weathering.

High average air temperature (thermal oxidation) is the most significant factor affecting the rate and amount of asphalt hardening. Viscosity at 140°F versus time is shown in Figure 1 and viscosity at 77°F versus time in Figure 2. Void content also contributes to the rate of oxidation. The effect of voids is similar among all asphalts; higher percentages of voids are the most detrimental (see Figure 3). Aggregate porosity also has a significant effect in hot climatic regions (Figure 4).

It appears that the California tilt-oven asphalt durability test could be used to predict asphalt hardening resulting from a 2-year exposure at the hot Indio site. Further, the test could be used to prepare hot-climate asphalt specifications to control field hardening in hot climatic areas.

In addition to improved hot-climate asphalt, it is believed that the following factors will improve asphalt durability:

1. Adherence to compaction specifications to reduce voids;
2. The selective use of asphalts that are most suited to the quality of aggregate available;
3. Avoidance of use of absorptive aggregate, if possible, in hot climates;
4. Use of the softest grade of asphalt consistent with mix curing and stability constraints; and
5. Insulation of the pavement with a cover such as a reflective chip seal, especially in hot climates.

IMPLEMENTATION OF ASPHALT DURABILITY STUDY

Caltrans will include additional requirements for an AR-4000 grade of asphalt on experimental projects in low desert environments starting in 1984. The additional requirements are given in Table 1. These include penetration at 77°F, viscosity at 140°F, and

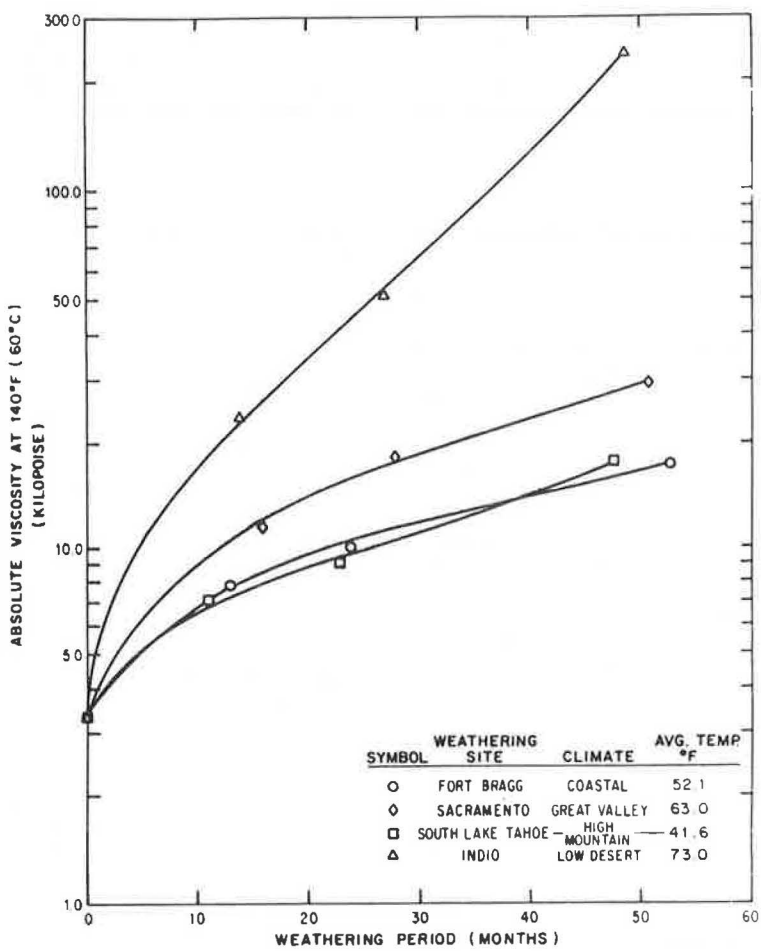

FIGURE 1 Effect of climate on hardening: combined asphalts, aggregates, and voids at 140°F.

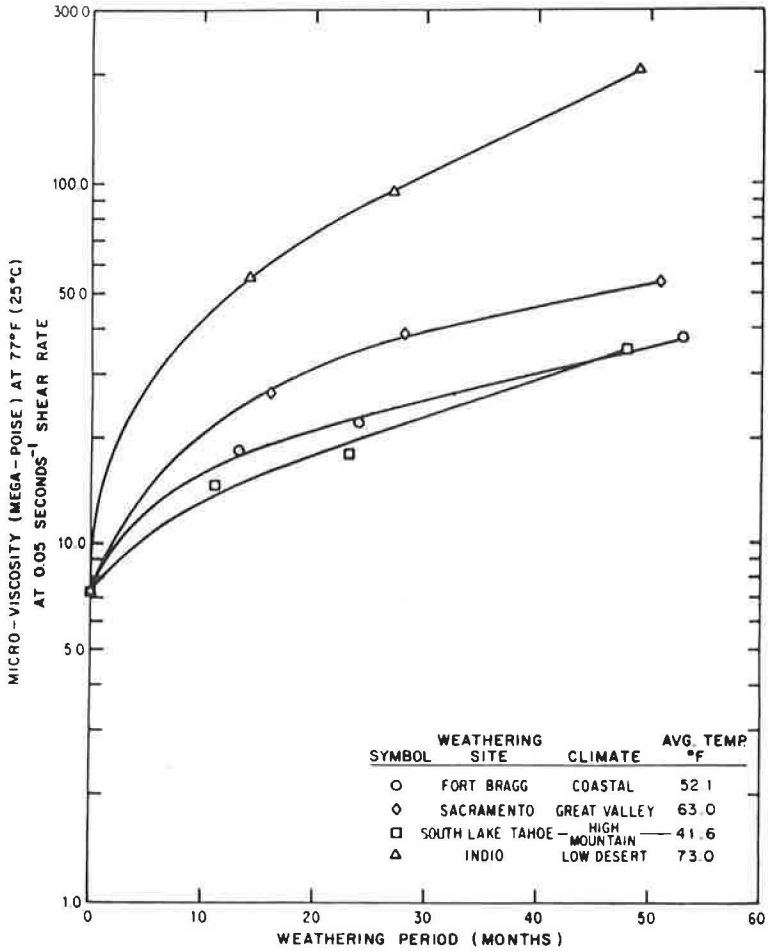

FIGURE 2 Effect of climate on hardening: combined asphalts, aggregates, and voids at 77°F.

ductility after aging in the California tilt-oven durability test.

The California tilt-oven durability test (California test method 374) ages the asphalt for 168 hr (7 days) at a temperature of 232°F. The temperature susceptibility of the aged asphalt is determined by the penetration test at 77°F and asphalt viscosity at 140°F. Temperature susceptibility is important to minimize thermal cracking and rutting of pavements. The penetration-ductility requirements are important durability requirements. The penetration of 77°F indicates the hardness of the material, whereas the ductility test is a measure of asphalt elongation or extension at the break. The ductility requirement prevents separation of asphalt components on aging.

These experimental test sections will be studied to determine the predictive capability of the California tilt-oven durability test on asphalts exposed to severe low desert environments.

SUMMARY

The major findings are as follows:

1. Thin asphalt films are essential for durability determinations;
2. Initial consistency of the asphalt is a major factor in resistance to abrasion and shows the durability advantage to be gained by using the softest practical asphalt grade consistent with stability;
3. Different sources and methods of manufacture can affect asphalt durability under equivalent conditions of traffic and climate;
4. Construction differences or foundation conditions or both can also affect asphalt durability;
5. Construction operations have an effect on the properties of the asphalt in the pavement after construction;
6. The RTFO test is useful for predicting the viscosity of the asphalt in the pavement during and shortly after construction;
7. The aged-residue viscosity-grading system is useful because it separates the hardening due to construction operations from long-term aging of the asphalt in a pavement structure;
8. Studies of cores have indicated that thermal oxidation is one of the most detrimental factors affecting asphalt durability;
9. Air temperature (thermal oxidation) is an important factor affecting the rate and amount of asphalt hardening;
10. The more voids, the more detrimental the effect on the asphalt;
11. Aggregate porosity is particularly important in hot climates;
12. It appears that the California tilt-oven durability test can be used to predict asphalt hardening in hot climatic areas;
13. Adherence to compaction specification requirements to reduce voids will reduce the rate of asphalt hardening;
14. Use of absorbent aggregates should be avoided whenever possible in hot climatic areas;

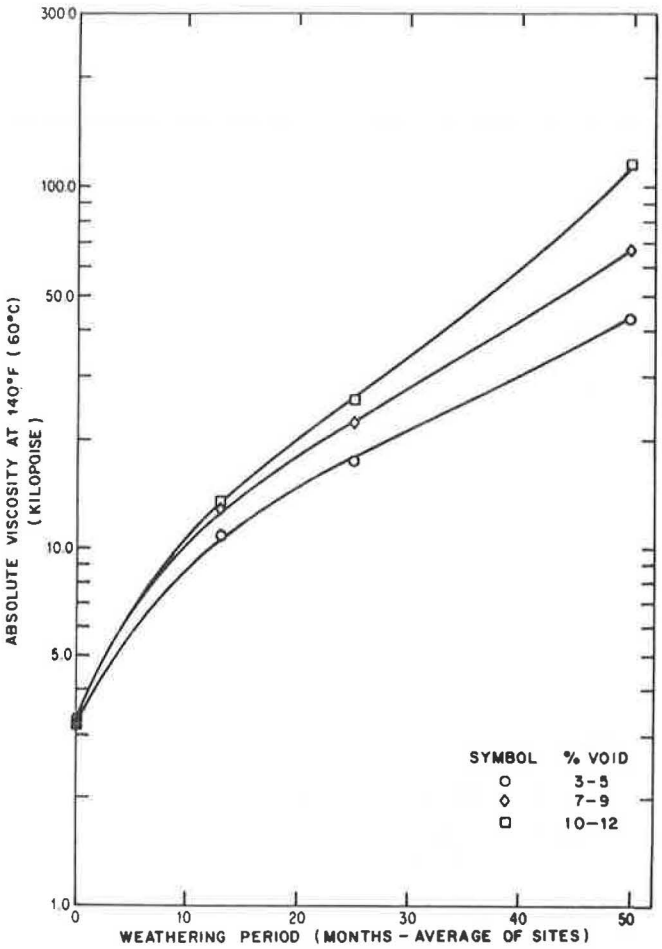

FIGURE 3 Effect of voids on hardening: combined sites, aggregate, and asphalts.

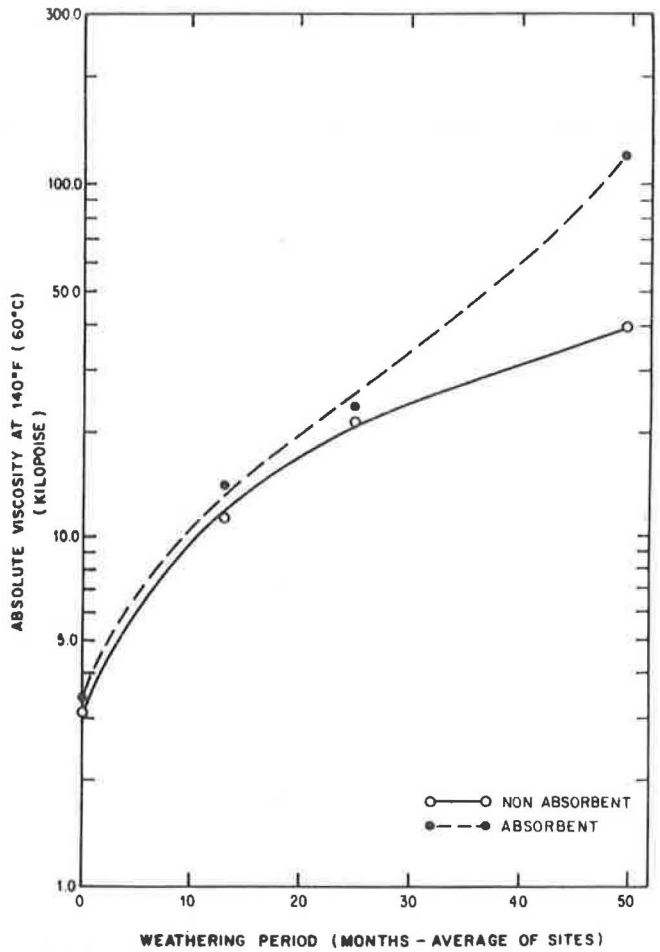

FIGURE 4 Effect of aggregates on hardening: combined sites, voids, and asphalts.

TABLE 1 Additional Specifications for AR-4000 Grade Asphalt

Test on Residue[a]	AASHTO Test Method	Minimum	Maximum
Penetration at 77°F	T49	15	
Absolute viscosity at 140°F (kpoise)	T202	–	100
Ductility at 77°F, 5 cm/min (cm)	T51	20	–

[a]From the California tilt-oven durability test.

15. In high-temperature climates an insulating layer, such as a reflective chip seal, may be desirable; and
16. A new set of requirements for durability has been added to the AR-4000 grade asphalts for use in desert environments; these are now under field study.

REFERENCES

1. F.N. Hveem. Quality Tests for Asphalts: A Progress Report. Proc., Association of Asphalt Paving Technologists, Vol. 15, 1946, p. 111.
2. J.R. Benson. Microscopic Reactions in Translucent Asphaltic Films. Proc., Association of Asphalt Paving Technologists, Vol. 9, 1937, p. 102.
3. F.C. Lang and T.W. Thomas. Laboratory Studies of Asphalt: Comments. Bulletin 15. University of Minnesota, Minneapolis, Nov. 1939.
4. T.E. Stanton and F.N. Hveem. Test Methods for Performing Accelerated Durability Tests on Asphalts. California Division of Highways, Sacramento, 1949.
5. F.N. Hveem, E. Zube, and J. Skog. Progress Report on the Zaca-Wigmore Experimental Asphalt Test Project. ASTM Special Technical Publication 277, ASTM, Philadelphia, Pa., 1959.
6. F.N. Hveem, E. Zube, and J. Skog. Proposed New Tests and Specifications for Paving Grade Asphalts. Proc., Association of Asphalt Paving Technologists, Vol. 32, 1963, pp. 271-327.

7. J. Skog. Setting and Durability Studies of Paving Grade Asphalts. Proc., Association of Asphalt Paving Technologists, Vol. 36, 1967, pp. 387-420.
8. N.H. Predoehl and G.R. Kemp. Durability of Paving Asphalts: Laboratory Test and Field Data Comparison. Report CA-DOT-TL-313417-74-11. California Department of Transportation, Sacramento, March 1974.
9. G.R. Kemp and N.H. Predoehl. A Comparison of Field and Laboratory Environments on Asphalt Durability. Proc., Association of Asphalt Paving Technologists, Vol. 50, 1981, pp. 492-537.

Publication of this paper sponsored by Committee on Bituminous Materials.

Significant Studies on Asphalt Durability: Pennsylvania Experience

PRITHVI S. KANDHAL and WILLIAM C. KOEHLER

ABSTRACT

Because a widely accepted laboratory durability test for asphalt does not exist, many agencies including the Pennsylvania Department of Transportation (DOT) have resorted to controlled field experiments to evaluate and characterize those physical properties of the asphalt binder that are associated with aging and their relationship to pavement performance. Three asphalt durability projects undertaken by the Pennsylvania DOT are summarized in this paper: 1961-1962 test pavements, 1964 test pavements, and 1976 test pavements. The study was limited to the evaluation of dense-graded asphaltic concrete wearing courses in which a different asphalt source or type was used. Except for the 1961-1962 test pavements, the only significant variable was the asphalt type. Mix composition and construction techniques were held reasonably constant. After construction, periodical core samples were obtained from these pavements to determine the percentage of air voids and the rheological properties of the aged asphalts. It has been observed that aging of the pavements results in progressively lower penetration and higher viscosity, which exhibit a hyperbolic function with time. However, the accompanying decrease in low-temperature ductility after the penetration falls below 30, and the rate of gain in shear susceptibility relative to increase in viscosity at 77°F, have been found to be important factors that affect the pavement performance. Lower ductility values were associated with a higher incidence of load-associated longitudinal cracking. High stiffness modulus of the asphalt cement at low temperatures and a 20,000-sec loading time contributed to nonload-associated transverse cracking.

Durability of asphaltic concrete has been of considerable interest to the industry ever since asphalt paving became a common practice. A durable asphaltic pavement should be able to support traffic-induced stresses and strains as well as adverse effects of climatic conditions during its service life. Although the durability of asphaltic pavement is affected by other factors such as aggregate characteristics, mix design, and construction practices, most durability studies in the past have been confined to analyzing the properties of aging asphaltic binder as it is this main constituent that contributes to the cohesiveness and adhesiveness of the mixture and thereby affects pavement performance.

Because a widely accepted laboratory durability test for asphalt does not exist, many agencies [including the Pennsylvania Department of Transportation (DOT)] have resorted to controlled field experiments to evaluate and characterize those physical properties of the asphalt binder that are associated with aging and their relationship to pavement performance. Unlike many states that have limited sources of asphalt crudes, Pennsylvania, because of its geographical location, receives paving asphalts manufactured from a wide variety of crude sources such as mid-continent, South America, and the Middle East. Since the 1973 Arab oil embargo, blending of various crudes has also increased significantly. These factors have made the task of evaluating asphalt durability rather complex.

Although many asphalt durability projects have been undertaken by the Pennsylvania DOT since 1960, three projects have been studied in more detail. An attempt has been made to summarize these projects in this paper. More details such as mix composition, construction data, and periodical evaluation data can be obtained from the cited references.

1961-1962 TEST PAVEMENTS (1)

Two pavements were completed in October 1961 in Lycoming and Beaver counties, and two were con-