UNDERGRADUATE ASPHALT TESTING LABORATORY

Vito A. Guido, Jameel Ahmad
The Cooper Union for the Advancement of Science and Art

INTRODUCTION

In 1987, Congress launched a five-year $150 million research program to improve the performance and durability of roads in the United States. The **Strategic Highway Research Program (SHRP)** was organized to develop performance-based asphalt specifications to directly relate laboratory analysis with field performance.

One of SHRP's products was the **SU**perior **PER**forming asphalt **PAVE**ment (Superpave) system. This system is a big step forward in asphalt technology since it offers a change from using empirical properties in mixture design to performance based specifications of asphalt materials. It provides road engineers with the tools to design roads that will perform better under extreme temperatures and heavy traffic loads. Three elements make up the system:

- Performance Graded (PG) Asphalt Binder Specification
- Volumetric Mix Design and Analysis System, and
- Mix analysis tests and a performance prediction system that includes computer software, weather database, and environmental models.

The PG Asphalt Binder Specification incorporates new and adopted test procedures to measure the physical properties over the complete range of the binder service life. The test procedures evaluate the ability of the binder to do its part in preventing the three critical distresses of asphalt pavements: permanent **deformation (rutting), low-temperature cracking,** and **fatigue cracking.**

Three adopted test procedures are used to prepare binders for properties testing:

- Rolling thin film oven test
- Pressure aging test, and
- Rotational viscosity test.

The new test procedures used to measure the properties of Superpave binders are:

- Dynamic shear test
- Bending beam test, and
- Direct tension test.

The Cooper Union School of Engineering has purchased all the equipment necessary to perform these tests, establishing a Superpave Asphalt Binder Laboratory.

SUPERPAVE ASPHALT BINDER TESTS

The asphalt binder test method is divided into two parts:
(a) aging procedure and (b) physical properties testing. The aging procedure consists of the Rolling Thin Film Oven (RTFO) procedure and the Pressure Aging Vessel (PAV) procedure. Physical properties tests incorporate Rotational Viscometer (RV) test, Dynamic Shear Rheometer (DSR) test, Bending Beam Rheometer (BBR) test, and Direct Tensile Tester (DTT) test.

An ordinary test procedure begins by measuring viscosity of unaged binder specimen using the RV. In addition, a portion of the unaged binder is aged using the RTFO and the PAV. Once the aged samples are ready, the Dynamic Shear Rheometer (DSR), Bending Beam Rheometer (BBR), and Direct Tensile Tester (DTT) are used to conduct the properties tests. The sequence of aging procedure and properties testing is illustrated in Figure 1.

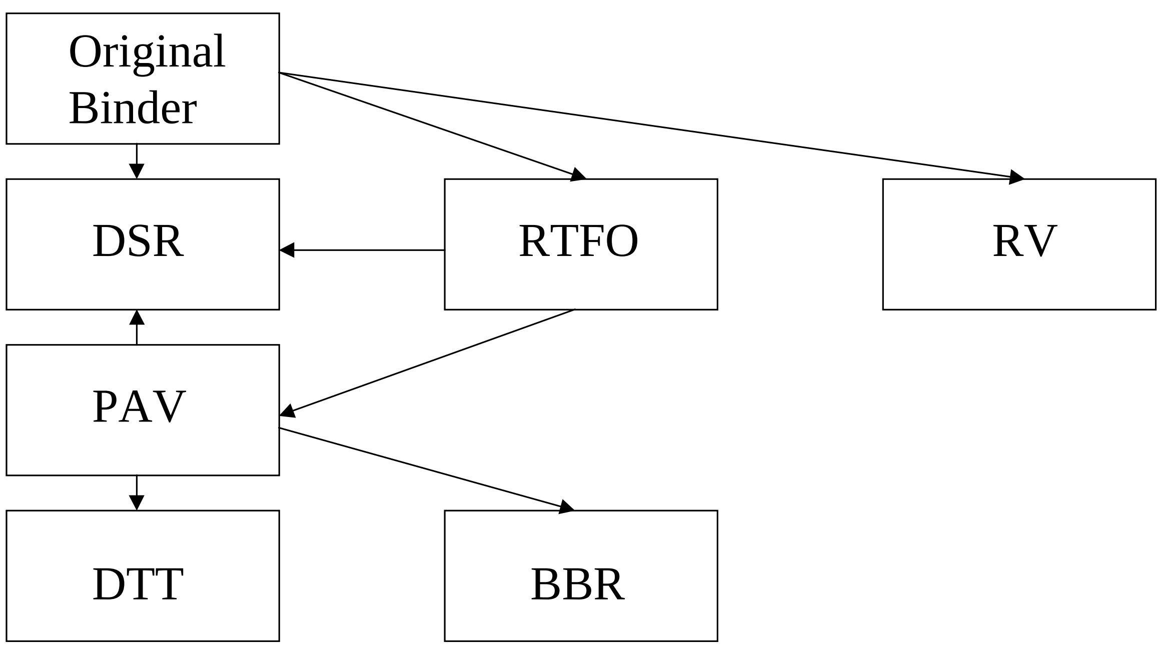

Figure 1: Sequence of Superpave Asphalt Binder Test Procedures

The Rolling Thin Film Oven (RTFO)

The RTFO procedure serves two purposes. First, it prepares aged binder that will be used for further testing of physical properties. Second, it is used to determine the mass quantity of volatile lost from the asphalt during the aging process. This procedure simulates the aging process the binder undergoes in the mixing plant and during construction.

During the test, fresh films of binder are continuously exposed to heat and air flow inside the RTFO. The oven is preheated to the aging temperature, 163°C, for a minimum of 16 hours prior to testing. Eight cylindrical glass jars are filled with 35 grams of unknown binder and placed into a rotating carriage inside the oven in a horizontal position. The test begins by rotating the carriage with the jars and exposing the binder films to a stream of air for a period of 85 minutes.

After the aging process is completed, two bottles are used to calculate the volatile mass. The binder from the other six jars is collected into a container and stored for further testing. Part of the RTFO aged binder is subjected for further aging in the Pressure Aging Vessel and the other part is used for properties testing in the DSR.

Pressure Aging Vessel (PAV)

The purpose of the PAV procedure is to expose the RTFO aged binder to inservice aging conditions by exposing it to a constant pressure under high temperature. This procedure simulates inservice aging of up to five years. The Pressure Aging Vessel receives compressed clean air from a cylinder and is designed to operate at 90, 100, and 110 degrees Celsius.

A maximum of ten samples can be tested at one time. The samples are weighed into shallow pans, which are loaded on a rack. The rack is inserted into the vessel and the lid is closed and fastened with bolts. The binder is then exposed to the test temperature (normally 100ºC) and to a pressure of 2.1 MPa for a period of 20 hours. During the twenty-hour test, the temperature and pressure are being recorded every 10 seconds by a computer or a control device.

The PAV completes the aging process and the binder is ready for the properties testing on the DSR, BBR, and DTT.

Rotational Viscometer (RV)

The purpose of the Rotational Viscosity test is to determine the flow characteristics of the binder to provide some assurance that it can be handled at the hot mixing plant.

This procedure is consistent with ASTM D4402, Standard Method for Viscosity Determination of Unfilled Asphalts Using the Brookfield Thermosel Apparatus. The RV consists of a set of different spindles, a Thermosel, a temperature controller, and the viscometer itself. The viscometer has a digital interface that presents the viscosity, shear rate, shear stress, temperature, speed, and percent torque, during the test. The RV automatically calculates the viscosity at the test temperature. Rotational viscosity is determined based on the torque required to maintain a constant rotational speed of a cylindrical spindle while submerged in an asphalt binder sample at a constant temperature.

The viscosity is measured on original (unaged) asphalt binder. A sample is weighed into a disposable aluminum chamber. The chamber is inserted into a Thermosel, which is heated up to the test temperature. A spindle is lowered into the chamber and rotates at a constant speed for a period of 15 minutes. Three viscosity readings are recorded and the average is reported as the binder viscosity.

Dynamic Shear Rheometer (DSR)

The DSR measures the stiffness and viscoelastic properties of the binder at intermediate and high temperatures. The stiffness is measured by calculating the shear modulus and the viscoelasticity is measured by the phase angle of the binder. The results of the dynamic shear test indicate the binder's ability to withstand permanent deformation (which is often evidenced as rutting in the pavement) and fatigue cracking.

The DSR operation is basic, asphalt is "sandwiched" between two parallel plates, one that is fixed and one that oscillates. The speed of oscillation is 10 radians per second or approximately 1.59Hz.

The sample is submerged in water at the test temperature. The water is circulated by a circulator which heats or cools the water. The water in the circulator and in the DSR bath (where the sample is submerged) must reach temperature equilibrium before any measurements are taken. After the system reaches temperature equilibrium, the test can begin.

The DSR software package (Bohlin Instruments) calculates the shear module and the phase angle of a binder specimen. The shear module indicates what is the total resistance of the binder to deformation. The phase angle indicates how much of the binder is elastic and how much of it is viscous. If the results of the test are within the Superpave Standard Specifications then the binder has high probability to withstand permanent deformation within the temperature it was tested.

Bending Beam Rheometer (BBR)

The Bending Beam procedure measures how much a binder reflects or creeps under a constant load at a constant low temperature. The test results are used to predict low temperature cracking problems.

A sample of PAV residue is molded into a shape of a beam with a rectangular cross section and conditioned at the test temperature. The beam is simply supported inside a bath filled with ethyl alcohol located in the BBR. The specimen must be completely submerged and the temperature of the liquid is below O°C. A blunt-nose shaft applies load to the midpoint of the simply supported asphalt beam. A load cell is mounted on the loading shaft which is enclosed in an air bearing to eliminate friction during loading. The load is applied pneumatically at a very slow rate to simulate the thermal stresses that gradually develop in a pavement when temperature drops. A transducer on the loading shaft monitors the deflection.

A computer program controls the data acquisition, calculation of creep stiffness (S), and creep rate (m). Creep stiffness is the resistance of the binder to creep loading and creep rate is the change in asphalt stiffness with time during loading.

The **S** and **m** values provide engineers with some indication on the performance of pavement low temperatures. Both tests, the BBR the DSR provide stiffness behavior of asphalt binders over a wide range of temperatures. Although stiffness can also be used to estimate failure or strength properties, for some binders the relationship between stiffness and strength properties is not well known. Therefore, an additional test, the DTT test, must be conducted to measure strength and the ability to stretch before breaking (strain at failure).

Direct Tension Tester (DTT)

At a temperature below O°C asphalt binder becomes very brittle and breaks easily without much stretching. It is very important for asphalt to have the capacity of stretching before it fails. The instrument that measures the amount of binder strain before fracture at very low temperatures is the Direct Tension Tester.

The test is performed at the temperature range where asphalt generally exhibits brittle behavior, i.e., O°C to -36°C. Furthermore, the test is performed on binders that have been aged in both the RTFO and PAV. Consequently, the test measures the performance characteristics of binders as if they had been exposed to hot mixing in a mixing facility and some in-service aging.

In the direct tension test, a sample in the shape of a dog bone is immersed in ethyl alcohol at low temperature. The sample is pulled at a slow, constant rate until it fails. The elongation at failure is used to calculate the failure strain, which is an indication of the capacity of the binder to stretch at the low temperature test. The elongation is measured by a laser device and the data is transmitted to a computer which calculates the physical properties of the binder specimen.

A typical test's results comprise a strain at failure, peak load, peak stress, and strain at peak stress. The results of the DTT provide information on the ability of the binder to stretch before breaking at low temperatures.

CONCLUSIONS AND RECOMMENDATIONS

The Superpave program is a remarkable step forward in asphalt technology. It is a method that provides direct relation between the binder test results in the laboratory and its performance in the field.

The performance of pavements can be improved if the binder selected meets all the criteria specified in the standard specification within the temperature range that the binder is supposed to perform. However, one must remember that the binder has only partial bearing on the deformation of a pavement. The dominant factor in pavement performance is the aggregate in the asphalt mixture.

SHRP's researchers have developed a method to design asphalt mixtures as well. This is known as Superpave Asphalt Mixture Design (Superpave 2). Under NSF grant award number 9551169, The Cooper Union has purchased all the equipment necessary to perform the asphalt binder evaluation and aggregate and mix evaluation. (This includes a Gyratory Compactor.) All that remains to be acquired is that equipment necessary for performance evaluation of the mix design. The equipment necessary for this are the Simple Shear Tester (SST) and the Indirect Tensile Tester (IDT). Once obtained, the Cooper Union will have a completely functional SHRP testing facility. The acquisition of this additional equipment is being sought after through a NSF proposal that was submitted in November 1997.

EQUIPMENT PURCHASED

A total of approximately $173,000.00 ($75,000.00 NSF and $98,000.00 Cooper Union) was spent under this grant to purchase the equipment necessary to perform all the SHRP tests that satisfy Superpave criteria, except those tests for the performance evaluation of the mix. The equipment necessary to perform these tests is being sought after in a NSF equipment grant proposal submitted in November 1997. In Table I can be found a summary of the major equipment items purchased and their manufacturers. In addition to the $98,000.00 spent by Cooper Union, a major commitment to this project was made by completely renovating an under-utilized space and converting it into the new asphalt laboratory. Included in this renovation was the installation of the necessary number of fume hoods to perform all testing in a non-hazardous environment. Approximately $85,000.00 was spent on the renovation.

TABLE I

MAJOR EQUIPMENT PURCHASED

EQUIPMENT ITEM[1]	MANUFACTURER
Bending Beam Rheometer	Cannon Instrument Co.
Direct Tension Tester	Instron
Dynamic Shear Rheometer	Bohlin Instruments
Gyratory Compactor	Interlaken Technology Corp.
Pressure Aging Vessel	Prentex Alloy Fabricators Inc.
Rolling Thin Film Oven	Despatch
Rotational Viscosimeter	Brookfield Engineering Laboratory Inc.

[1] See photos at the end of the paper for the equipment purchased under NSF grant award number 9551169.

DISSEMINATION AND EVALUATION

A new undergraduate course will be introduced into the Civil Engineering curriculum, CE 353 "Bituminous Materials and Mixtures". This course is under development but will not be introduced into the curriculum until the final phase of the laboratory has been completed -- the capability to evaluate in the laboratory the performance of the mix in the field.

At present, a laboratory manual is being prepared for those SHRP testing procedures associated with the evaluation of the asphalt binders. The laboratory manual is being tested by performing research on three-asphalt binder used in the New York City area, AC-10, AC-20 and AC-30. A complete evaluation of the impact of this new asphalt testing laboratory on the Civil Engineering curriculum cannot be made until the laboratory is complete, CE 353 is in place, and several semesters have passed since CE 353 is first introduced.

Photo No. 1: Bending Beam Rheometer

Photo No. 2: Direct Tension Tester

Photo No. 3: Dynamic Shear Rheometer

Photo No. 4: Gyratory Compactor

Photo No. 5: Pressure Aging Vessel

Photo No. 6: Rolling Thin Film Oven

Photo 7: Rotational Viscosimeter

VITO A GUIDO: is a professor of Civil Engineering at the Cooper Union – Albert Nerken School of Engineering. Dr. Guido is the curriculum coordinator for the geotechnical engineering program and director of the soil mechanics laboratory and new SHRP asphalt technology laboratory. His research has included reinforced subgrades and the use of recyclables in asphalt and concrete.

JAMEEL AHMAD: is a professor of Civil Engineering and department chairman at the Cooper Union – Albert Nerken School of Engineering. Dr. Ahmad is the curriculum coordinator for the structural engineering program and director of the materials laboratory. He is also the director of the Cooper Union Research Foundation (CURF) and head of the biomedical engineering program.