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Background of SUPERPAVE ASPHALT BINDER TEST METHODS

NATIONAL ASPHALT TRAINING CENTER
DEMONSTRATION PROJECT 101

TECHNOLOGY APPLICATIONS
Innovation Through Partnerships

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16. Abstract

This manual represents the first formal training document that embodies the complete series of SUPERPAVE asphalt binder test equipment and procedures. These tests and procedures represent the results of the SHRP 5-year research effort to investigate and improve asphalt cement technology. This manual was developed under the FHWA's National Asphalt Training Center. Students attending the center utilize this manual to obtain a better understanding of the underlying theory behind asphalt cement testing, as well as how to perform each of the new procedures.

17. Key Words

Asphalt cement, binder, dynamic shear rheometer, bending beam rheometer, pressure aging vessel, direct tension device, PG-grading system

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FOREWORD

From October 1987 through March 1993, the Strategic Highway Research Program (SHRP) conducted a $50 million research effort to develop new ways to test and specify asphalt binders. Near the end of SHRP, the Federal Highway Administration assumed a leadership role in the implementation of SHRP research. An integral part of FHWA's implementation strategy was a project to develop a nationally accessible training center aimed at educating both agency and industry personnel in the proper use and application of the final SHRP asphalt products referred to as SUPERPAVE™. This project was administered by the FHWA's Office of Technology Applications and designated Demonstration Project 101, the National Asphalt Training Center (NATC).

The NATC resides at the Asphalt Institute's Research Center in Lexington, Kentucky. While the day-to-day affairs of the NATC are directed by Institute personnel, course development and technical direction were duties shared by a team of engineers and technologists from the Asphalt Institute, the Pennsylvania State University, the University of Texas at Austin, the National Center for Asphalt Technology, Marathon Oil Company, and FHWA.

The objective of the educational program is to train students in the practical applications of SUPERPAVE asphalt products. It is composed of two parts: SUPERPAVE asphalt binder technology and SUPERPAVE asphalt mixture technology.

This manual represents the textbook students will use as a reference throughout the 40 hours of training in SUPERPAVE asphalt binder technology. The principal objective of the educational program is to train students in the proper use of the new SUPERPAVE binder test methods and equipment. Another key objective is to teach students how to interpret and apply the new SUPERPAVE binder specification. The training program consists of 40 hours of instruction. Of this 40 hours, students receive eight hours of classroom instruction, 28 hours of laboratory instruction, and four hours of classroom discussion of actual test results. By the end of the course, students will be familiar with binder test procedures and equipment and will know how to use binder test results to classify binders according to the SUPERPAVE binder specification.

This manual represents the textbook students will use as a reference throughout the 40 hours of training. Best efforts were made to present the information in an easy to understand style. It was written for laboratory technicians and engineers with no previous training in SUPERPAVE products, but with some knowledge in asphalt technology. Other instructional aids consist of provisional AASHTO test methods and a set of simplified test procedures with photos to facilitate ease of learning.

The training program and this manual do not present any information in English units. SUPERPAVE asphalt binder test procedures and the specification were developed in SI units. The NATC team believed it would be counter productive and make learning more difficult if material properties were shown in English, as well as the original SI units.

For example, it is easy for a student to understand and remember that the maximum limit on aged binder stiffness is 5,000 kPa. To show an English conversion such as, "5,000 kPa (725 psi)," serves no purpose since students have no previous knowledge of typical English values. The only exception to this is that some binder test equipment software shows English units. The NATC team has no control over these products but encourages the software developers to assist the industry and this training effort by standardizing the units, in SI, on test output.

While this manual was being developed, SUPERPAVE asphalt binder technology was still in an emerging phase. Consequently, users are cautioned that some details are highly subject to change. Users of this information are strongly encouraged to stay abreast of SUPERPAVE technology by taking advantage of the various venues that have arisen to serve this purpose. Examples include the regional asphalt user-producer groups that were organized during the latter stages of the SHRP asphalt research program.

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I.

BACKGROUND OF SUPERPAVE ASPHALT BINDER PERFORMANCE TESTS

HOW ASPHALT BEHAVES

Asphalt cement behavior depends on *temperature* and *time of loading*. Figure I-1 below shows that flow behavior of one asphalt could be the same for one hour at 60° C or 10 hours at 25° C.

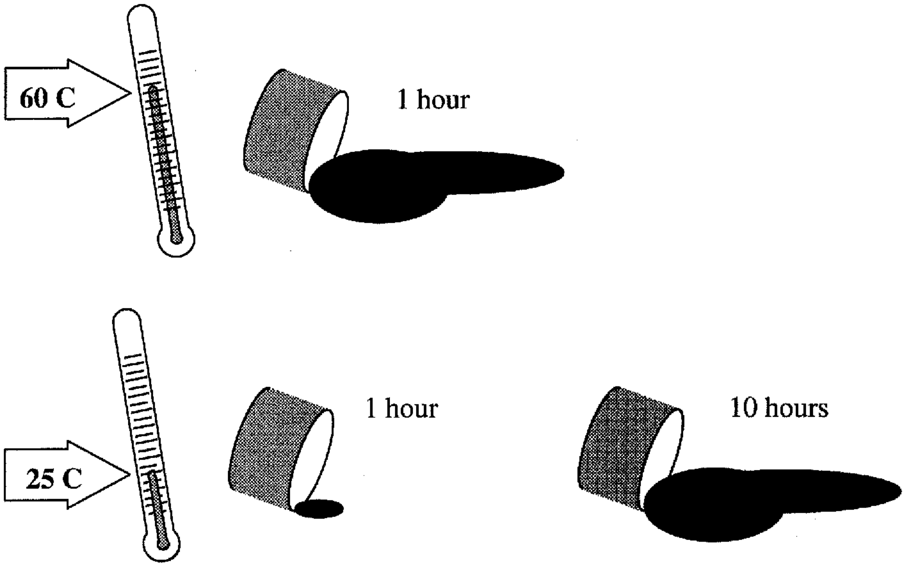


Figure I-1. Asphalt Cement Flow Behavior

In other words, time and temperature are interchangeable; high temperature and short time is equivalent to lower temperatures and longer times.

High Temperature Behavior

At high temperatures (e.g., desert climate) or under sustained loads (e.g., slow moving trucks), asphalts cements act like *viscous* liquids and flow. Viscosity is the material characteristic used to describe the resistance of liquids to flow. If a liquid such as hot asphalt cement could be observed slowly flowing under a very powerful microscope, adjacent layers of liquid, perhaps one molecule thick, would be observed flowing past each other as shown in Figure I-2.

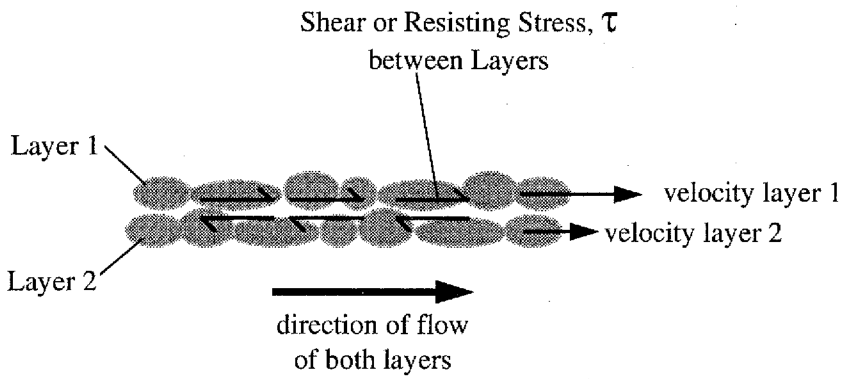


Figure I-2. Microscopic View of Liquid Flow Characteristics

The frictional or resisting force between these layers is related to the relative velocity at which they slide by each other. The resisting force between layers occurs because the layers are flowing at slightly different speeds. The top layer tries to pull the bottom layer along while the bottom layer tries to hold the top layer back. The relationship between the resisting force and relative velocity can be very different for most liquids.

Fortunately, viscosity is one characteristic (as opposed to chemical make-up for example) that can be used to express this difference. The following equation describes the situation in Figure I-2 and shows how the *coefficient of viscosity* (μ) is used to explain differences in flow characteristics among different liquids.

$$\tau = \mu \times \text{rate of shear strain}$$

In this equation, τ is the shearing resistance between the layers and the rate of shear strain is the relative speed at which layer 1 slides by layer 2. Figure I-3 shows various types of materials in terms of their viscous behavior. Viscosity (μ) is the slope of the line for each type of material shown in Figure I-3.

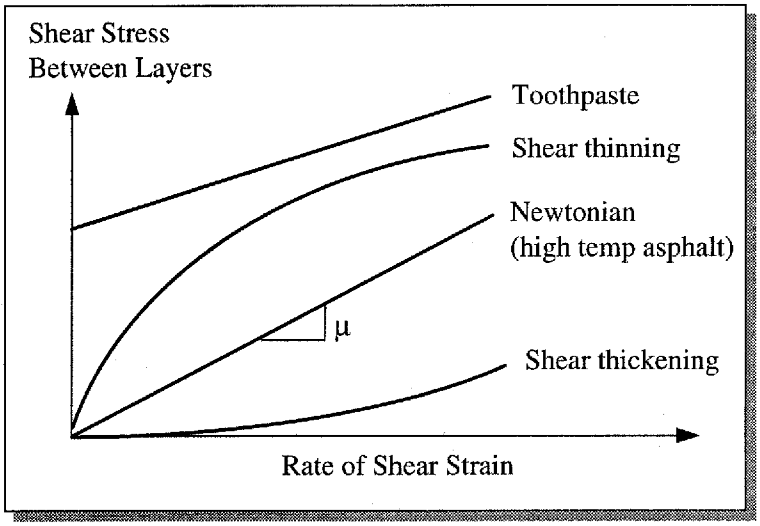


Figure I-3. Viscosity Characteristics of Various Liquids

Newtonian fluids have a straight-line (sometimes called "linear") relationship between resisting force and relative velocity. Air, water, and asphalt at high temperatures (greater than about 50° C) are common Newtonian fluids. Materials such as toothpaste are like Newtonian fluids except that they have a built-in resistance to flow that must be overcome before their layers can begin sliding by each other. At moderate temperatures, asphalt is a "shear thinning liquid" since its viscosity decreases when the relative velocity increases. Some polymer solutions are shear thinning liquids while others are "shear thickening liquids." Shear thickening means that the viscosity increases with increasing relative velocity between layers.

Viscous liquids like hot asphalt are sometimes called *plastic* because once they start flowing, they do not return to their original position. This is why in hot weather, some asphalt pavements flow under repeated wheel loads and wheel path ruts form. However, rutting in asphalt pavements during hot weather is also influenced by aggregate properties and it is probably more correct to say that the asphalt *mixture* is behaving like a plastic.

Low Temperature Behavior

At low temperatures (e.g., winter days) or very rapid loading times (e.g., fast moving trucks), asphalts behave like *elastic* solids. Elastic solids are like rubber bands. That is, when loaded they deform, and when unloaded, they return to their original shape. Any elastic deformation is completely recovered (Figure I-4).

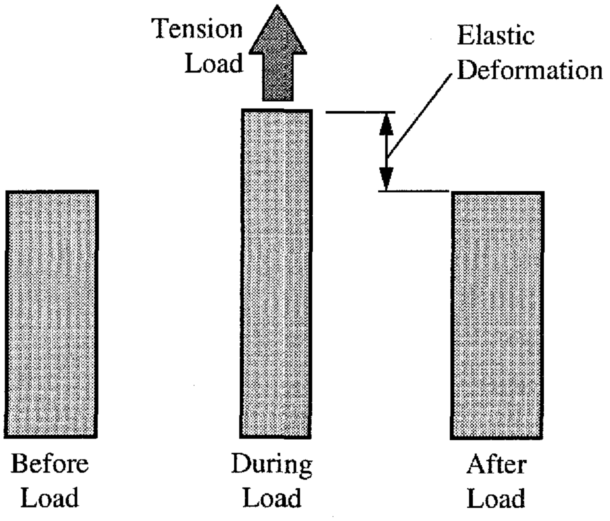


Figure I-4. Behavior of Elastic Solids

If too much load is applied, elastic solids may break. Even though asphalt is an elastic solid at low temperatures, it may become too brittle and crack when excessively loaded. This is the reason "low temperature cracks" sometimes develop in asphalt pavements during cold weather. In these cases, loads are applied by internal stresses that build up in the pavement when it tries to shrink and is restrained (e.g., during and after a sudden cold front).

Aging Behavior

There remains another special characteristic about asphalts. Because they are composed of organic molecules, they like to react with oxygen from the environment. This reaction is called oxidation and it changes the structure and composition of asphalt molecules. A more brittle structure always results and that is the origin of the terms "oxidative hardening" or "age hardening." Oxidative hardening happens at a relatively slow rate in a pavement although it occurs at a faster rate in a hot, desert climate when compared to a cool climate. Likewise, oxidative hardening is seasonal since it happens more in summer than in winter. Because of this type of hardening, old asphalt pavements are more susceptible to cracking. Even relatively new asphalt pavements may be excessively prone to oxidative hardening if not thoroughly compacted. In this case, the lack of adequate compaction causes high air voids, which allow a greater amount of air to permeate the asphalt mixture causing a greater degree of oxidative hardening.

In fact, a considerable amount of oxidative hardening occurs before the asphalt is ever placed. Namely, during hot mixing and other construction operations. Because these activities occur at such high temperatures and the asphalt is in such thin films, the oxidation reaction occurs at a much faster rate.

Another form of hardening occurs during hot mixing and construction. It is called "volatilization." At high temperatures, volatile components evaporate from the asphalt. These light, oil-like components, if allowed to remain, would otherwise soften the asphalt.

A phenomenon called "physical hardening" has been observed in asphalt cements. It occurs when asphalt cements have been exposed to low temperatures for long periods. As the temperature falls, asphalt shrinks in volume and there is an accompanying increase in asphalt hardness. Even when the temperature stabilizes at a constant low value, the asphalt cement continues to shrink and harden. Physical hardening is more pronounced at temperatures less than 0° C and must be considered when testing asphalt cements at very low temperatures.

CURRENT METHODS TO MEASURE ASPHALT PROPERTIES

The current method to characterize asphalt consistency is by either penetration or viscosity tests as shown in Figure I-5. Both of these tests have been used to measure the effect of temperature on asphalt behavior. This is done by measuring viscosity or penetration at two temperatures and plotting the results as shown in Figure I-6 below.

In this example, all three asphalts are the same viscosity grade because they are within specified limits at 60° C. While Asphalts A and B display the same temperature dependency, they have a much different consistency at all temperatures. Asphalts A and C have the same consistency at intermediate temperatures but remarkably different high and low temperature consistency. Asphalt B has the same consistency at 60° C, but shares no other similarities with Asphalt C. Because these asphalts share the same grade, they might erroneously be expected to display the same characteristics during construction and during hot and cold weather performance conditions.

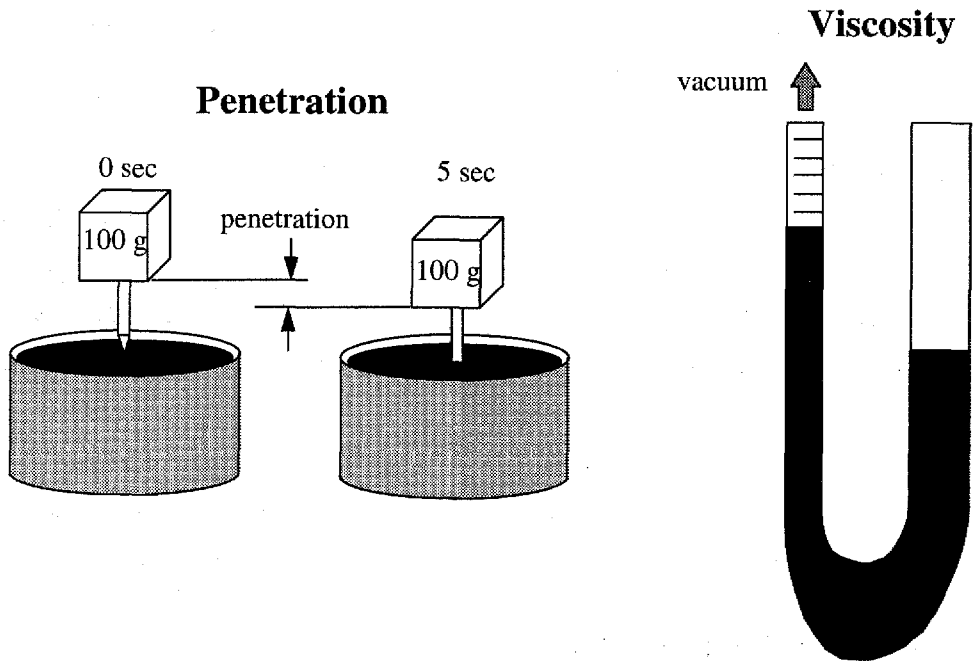


Figure I-5. Penetration and Viscosity Tests

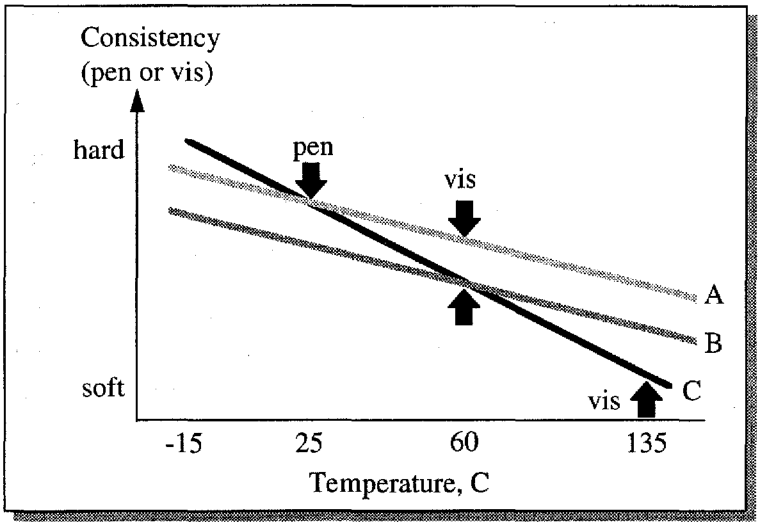


Figure I-6. Temperature Susceptibility of Three Viscosity or Penetration Graded Asphalts

Although viscosity is a fundamental measure of flow, it only provides information about higher temperature viscous behavior, not about the low temperature elastic behavior needed to completely predict performance. Penetration describes only the consistency at a medium temperature, 25° C. No low temperature properties are directly measured in the current grading system. Often, viscosity and penetration tests do not completely show the advantages or possible disadvantages of some modified asphalts.

Because of these deficiencies, many state highway agencies have amended standard test procedures and specifications to better suit local conditions. In some parts of the U.S., this proliferation of tests and specifications has caused serious problems for asphalt suppliers wishing to sell the same asphalt grades in several states. Often, states with very similar performance conditions and materials will specify remarkably different asphalts.

In the current systems for specifying asphalt, tests are performed on unaged or "tank" asphalt and on asphalt artificially aged to simulate construction aging. However, no tests are performed on asphalts that have been aged to simulate in-service aging.

SUPERPAVE TO THE RESCUE

In 1987, the Strategic Highway Research Program (SHRP) began developing new tests for measuring physical properties of asphalts. One result of this $50 million research effort is a new asphalt specification (Appendix A) with a new set of tests to match. The document is called a *binder* specification because it is intended to function equally well for modified as well as unmodified asphalts. The final product of the SHRP asphalt research program is a new system referred to as SUPERPAVE, which stands for Superior Performing Asphalt Pavements. SUPERPAVE software is a computer program that assists engineers in materials selection and mix design. However, the term “SUPERPAVE” refers to more than just the computer program. Most important, it represents an improved system for specifying component materials, asphalt mixture design and analysis, and pavement performance prediction. The system includes test equipment, test methods, and criteria.

The new SUPERPAVE tests measure physical properties that can be related directly to field performance by engineering principles. Each of these new tests will be described in detail later in this text. However, as an introduction, below is a list of the new test equipment followed by a brief description of why each is used in the new specification:

Procedure	Purpose
Dynamic Shear Rheometer (DSR)	Measure properties at high and intermediate temperatures
Rotational Viscometer (RV)	Measure properties at high temperatures
Bending Beam Rheometer (BBR) Direct Tension Tester (DTT)	Measure properties at low temperatures
Rolling Thin Film Oven (RTFO) Pressure Aging Vessel (PAV)	Simulate hardening (durability) characteristics

Dynamic Shear Rheometer

Since asphalt behavior depends on both time and temperature, the ideal test for asphalt would evaluate both. Fortunately, testing equipment that could do this already existed before SHRP and had been used for many years in the plastics industry. These devices are generically known as dynamic shear rheometers, oscillatory shear rheometers, or dynamic rheometers. By adapting these devices for use with asphalt, both time and temperature effects can be evaluated. When used to test asphalt binders, dynamic shear rheometers, or DSRs, measure the rheological properties (complex shear modulus, phase angle, etc.) at high temperatures.

The principle of operation is simple: asphalt is sandwiched between a fixed plate and a plate that oscillates back and forth as shown in Figure I-7. The oscillating plate starts at point A and moves to point B. From point B the oscillating plate moves back, passing point A on its way to point C. From point C the plate moves back to point A. This movement, from A to B to C and back to A comprises one cycle.

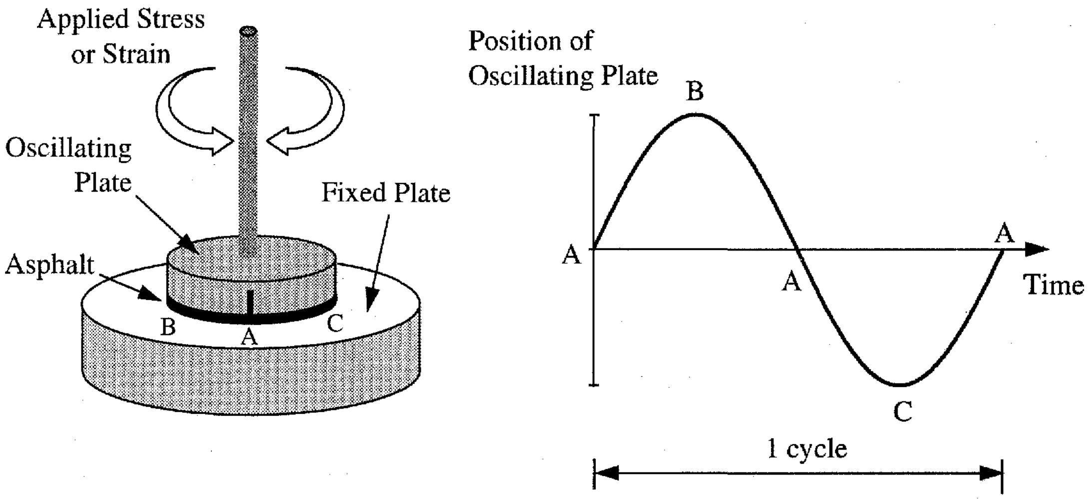


Figure I-7. Basics of Dynamic Shear Rheometer

The frequency of oscillation is simply the length of time for one cycle to occur. One complete cycle of oscillation in a second is called one hertz (Hz). For example, if the oscillation cycle shown in Figure I-7 had occurred in one second, the frequency would be one cycle per second or one Hz. If two oscillation cycles had occurred in one second, then the frequency would be two Hz.

Another way of expressing the frequency of oscillation uses the circumferential distance traversed by the oscillating plate. Circumferential distance is expressed in radians and one radian corresponds to about 57 degrees. In this case, the frequency is defined in radians per second. All SUPERPAVE dynamic shear binder tests are performed at a frequency of 10 radians per second, which is equal to about 1.59 Hz.

There are two common types of oscillatory shear rheometers, constant stress and constant strain. Constant stress rheometers work by applying a fixed torque to move the oscillating plate from point A to point B. Depending on the consistency of the asphalt binder, the amount of torque necessary to move the plate will vary. Asphalts with greater stiffness require more torque. SUPERPAVE binder tests are conducted in the constant stress mode. Constant strain rheometers work by moving the oscillating plate from point A to point B and measuring the torque required. The difference between the two rheometers is that the constant stress rheometer maintains the fixed torque and the distance the plate moves may vary slightly between cycles. For a constant strain rheometer, the distance the plate moves is fixed and the torque will vary. For viscous materials like asphalt, plate movement does not occur at the same time as torque is applied. Even though SUPERPAVE binder tests are conducted in the constant stress mode, constant strain DSRs are capable of performing SUPERPAVE binder specification testing.

Rotational Viscometer

Some assurance was needed in the new system that the asphalt binders specified could be handled and pumped at the refinery, terminal, or hot mixing facility. Therefore, a rotational viscosity test is specified to determine the flow characteristics of the asphalt at the elevated temperatures used at these facilities. A rotational coaxial cylinder viscometer like that specified by ASTM D4402, "Brookfield Viscometer" (shown in Figure I-8) is necessary to accommodate the various types of asphalt binders to be evaluated. Unlike capillary tube viscometers (Figure I-5), the rotational devices have larger clearances between the components and therefore are applicable to a wide variety of unmodified asphalts and modified asphalts.

The rotational viscometer is linked to a digital controller that is used to automatically calculate the viscosity at the test temperature. The viscometer can also be used to develop temperature-viscosity charts for estimating mixing and compaction temperatures for use in mixture design.

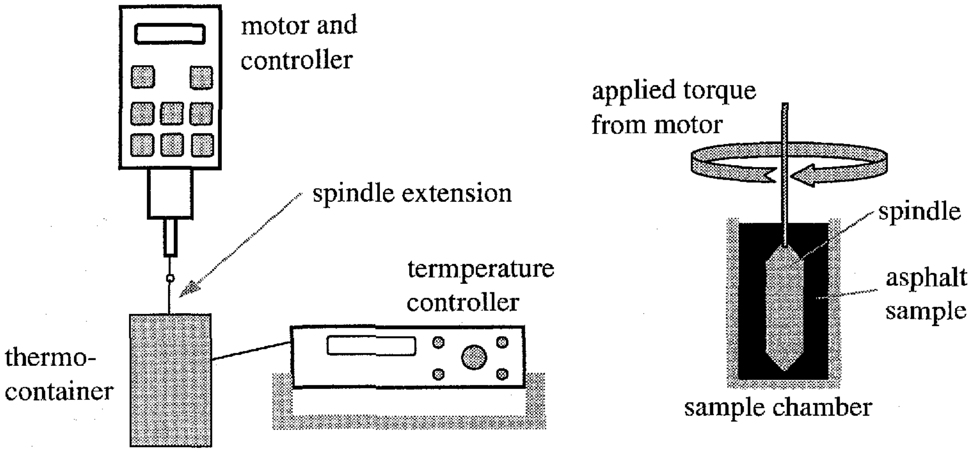


Figure I-8. Rotational Viscometer

Bending Beam Rheometer

Because asphalt binders at low temperatures are too stiff, most dynamic shear rheometers cannot be used to reliably measure properties using the parallel plate geometry (Figure I-7). Therefore SHRP developed a new test that can accurately measure stiffness and creep rate at temperatures representative of the lowest pavement temperatures.

The bending beam rheometer, or BBR, is a simple device that measures how much a binder will deflect (creep) under a constant load at temperatures corresponding to its lowest pavement service temperature when the asphalt acts more like an elastic solid. The principle of operation for this device is shown below in Figure I-9.

By loading the asphalt beam for four minutes with a constant load and measuring the deflection at the center of the beam continuously throughout the four minutes, the creep stiffness and creep rate "m" can be measured and calculated.

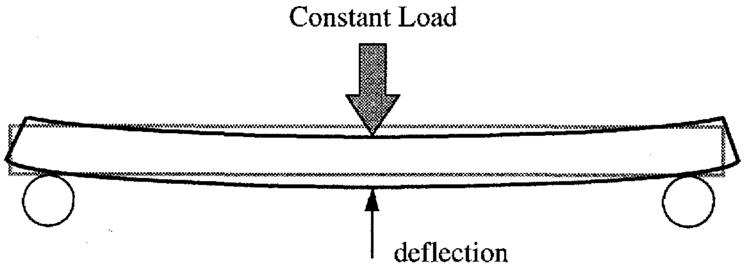


Figure I-9. Bending Beam Principle

The dynamic shear and the bending beam tests provide information pertaining to the stiffness behavior of asphalt binders over a wide range of temperatures. Although stiffness can also be used to estimate failure (strength) properties, for some binders, especially modified asphalts, the relation between stiffness and strength (failure) properties are not well known. Therefore, an additional test to measure strength and ability to stretch before breaking (strain at failure) must be conducted. That test is the direct tension test.

Direct Tension Tester

Materials, including asphalts, that undergo considerable stretching before failure are called "ductile." Those that break without much stretching are called "brittle." Even before SHRP, numerous studies of low temperature asphalt behavior showed that there is a strong relationship between stiffness of asphalt binders and the amount of stretching they undergo until breaking. Typically, stiffer asphalts are more brittle and less stiff asphalts are more ductile. This finding was confirmed by SHRP researchers using their newly developed BBR.

Unfortunately, creep stiffness as measured by the BBR is not enough to completely characterize the ability of some asphalts to stretch until breaking. For example, some binders exhibit high creep stiffness but can stretch farther before breaking than other binders. Consequently, SHRP researchers had to devise a system to accommodate these binders. These types of binders would be allowed to have a higher creep stiffness if it could be shown that they still displayed reasonably ductile behavior at low temperatures.

SHRP researchers solved this dilemma by developing a device that directly measured the failure strain for binders at very low temperatures. The device is called the direct tension tester. Although the concept of the direct tension test is simple, the equipment used to conduct the test requires special features. This is because of the very small strains and high degree of accuracy needed to run the test.

In the direct tension test, a small "dog bone" shaped asphalt specimen is pulled at a constant, slow rate until it breaks (failure). The amount of elongation at failure is used to calculate the strain at failure, which is an indication of whether the binder will behave in a brittle or ductile manner at the low test temperature. Figure I-10 shows a schematic of the direct tension principle.

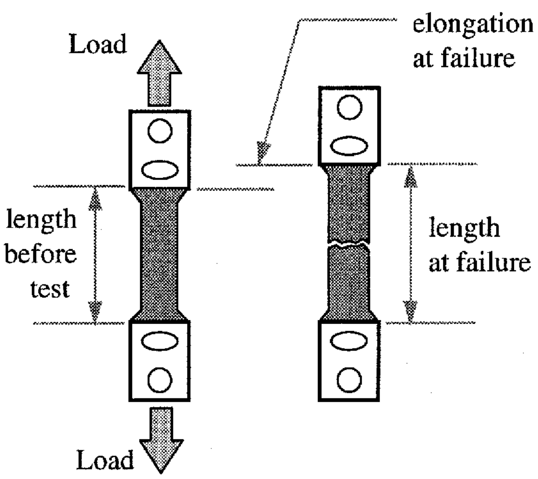


Figure I-10. Direct Tension Test Setup

Output from the direct tension test is the failure strain at the specified test temperature. Failure strain equals the change in length, or elongation, expressed as a percentage of original length.

Binder Aging Methods

As mentioned earlier, asphalt binders age primarily due to these two different mechanisms: loss of light oils present in the asphalt (volatilization) and reaction with oxygen from the environment (oxidation). During manufacturing of asphalt paving mixtures in the hot mixing facility and during laydown, binders age due to both mechanisms because of the high temperature and air flow involved in the process. For many years, the thin film oven and the rolling thin film oven tests have been used to simulate this form of aging. This has not changed in the SUPERPAVE specifications because the rolling thin film oven test is used. After the asphalt pavement is constructed and is opened to traffic, aging continues but it mostly includes only the oxidation mechanism because of the relatively moderate temperatures of the environment. To simulate this form of in-service aging, SHRP developed the Pressure Aging Vessel.

Rolling Thin Film Oven Test (RTFO)

The Rolling Thin Film Oven Test, AASHTO T240, ASTM D2872, was developed by the California Highway Department to simulate aging that occurs in asphalt plants during the manufacture of hot mix asphalt concrete. The RTFO is used because it is repeatable and continually exposes fresh binder to heat and air flow. Its rolling action in some cases keeps modifiers (e.g., some polymers) dispersed in the asphalt. Another advantage of the RTFO is it takes only 85 minutes to perform. A schematic of this equipment is shown in Figure I-11. The thin film oven test (AASHTO T 179 or ASTM D 1754) was not selected because certain modified asphalts form a surface skin which obstructs aging during the test. An additional disadvantage of the thin film oven test is that it takes five hours to perform.

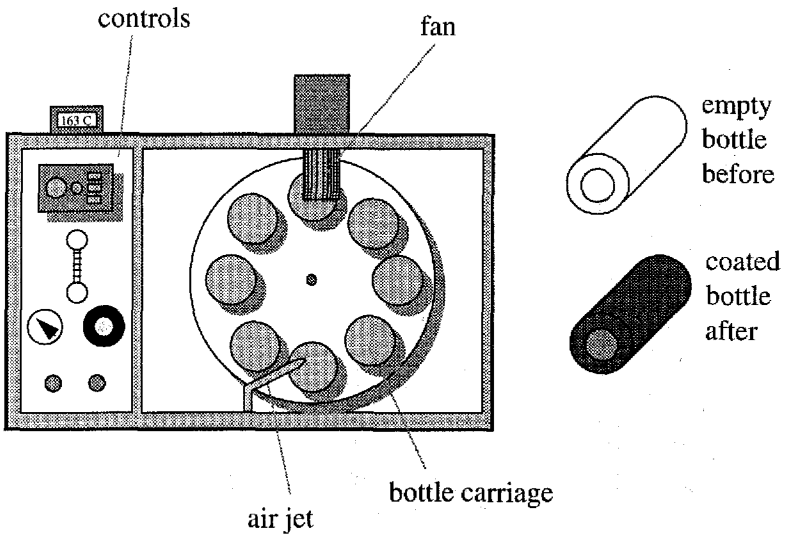


Figure I-11. Rolling Thin Film Oven

This test serves two purposes. One is to provide an aged asphalt product that can be used for further testing of physical properties. The second is to determine the mass quantity of volatiles lost from the asphalt during the test. The amount of volatile loss is an indication of the amount of aging that may occur in the asphalt during mixing and construction operations. Some asphalts even gain weight during the RTFO procedure because of the oxidative products formed during the test.

Pressure Aging Vessel (PAV)

Long term in-service aging of asphalt was not evaluated in specifications for asphalt prior to the new SUPERPAVE specifications. The device, used for many years in asphalt research, was modified by SHRP researchers and a new procedure was developed to evaluate long-term in-service aging. The device uses pressure and temperature to compress time so that very long term aging can be simulated in only 20 hours. Asphalt binders, after aging in the RTFO, are placed in the PAV and aged for 20 hours. The physical properties are measured as previously described to determine if the asphalt will be suitable after several years of service. The test is conducted at different temperatures depending on the climate in which the pavement serves. A schematic of the PAV is shown in Figure I-12.

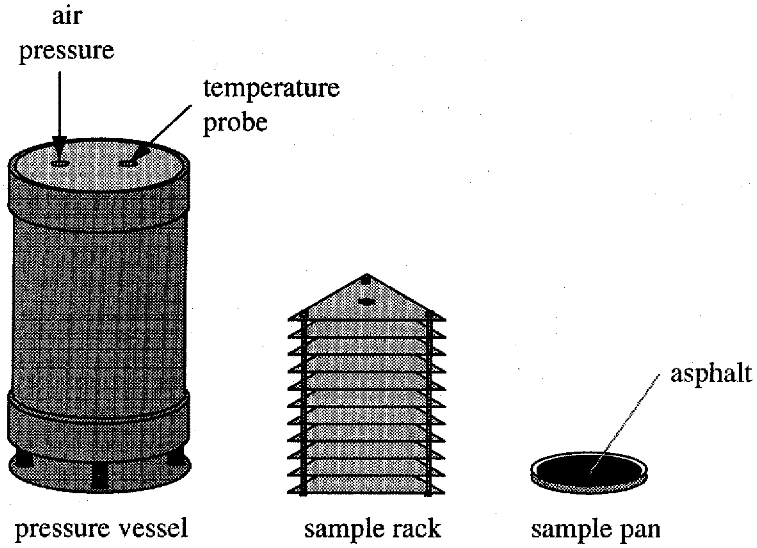


Figure I-12. Pressure Aging Vessel

II.

DYNAMIC SHEAR RHEOMETER

INTRODUCTION

The Dynamic Shear Rheometer (DSR) is used to characterize the viscous and elastic behavior of asphalt binders. It does this by measuring the complex shear modulus (G*) and phase angle (δ) of asphalt binders. G* is a measure of the total resistance of a material to deforming when repeatedly sheared. It consists of two parts: a part that is elastic (recoverable) and a part that is viscous (non-recoverable). δ is an indicator of the relative amounts of recoverable and non-recoverable deformation.

The value of G* (G star) and δ (delta) for asphalts are highly dependent on the temperature and frequency of loading. At high temperatures (well above pavement temperatures) asphalts behave like viscous fluids as indicated by the vertical arrow in Figure II-1. On the other hand, at very low temperatures (well below pavement temperatures) asphalts behave like elastic solids as shown by the horizontal arrow in Figure II-1.

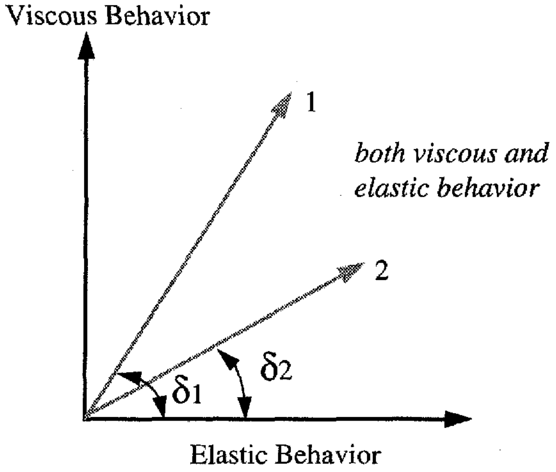
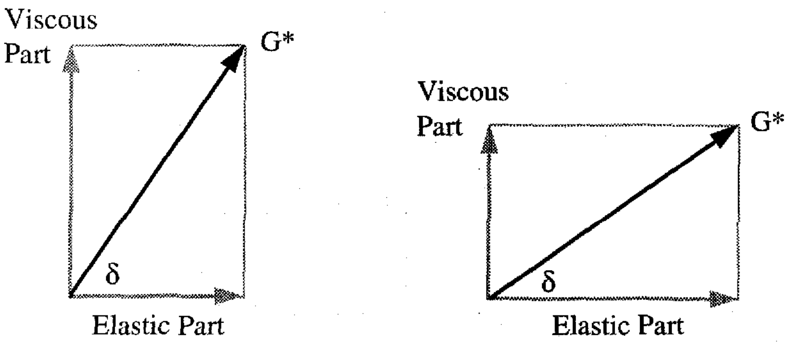


Figure II-1. Viscous and Elastic Behavior

At temperatures where most pavements carry traffic, asphalts (like those represented by arrows 1 and 2) simultaneously act like viscous liquids and elastic solids. When loaded, part of the deformation is elastic (recoverable) and part is viscous (non-recoverable). That is the reason asphalt is called a *viscoelastic* material. For example, even though both asphalts in Figure II-1 are viscoelastic, asphalt 2 is more elastic than asphalt 1 because of its smaller δ.

By measuring G* and δ, the DSR provides a more complete picture of the behavior of asphalt at pavement service temperatures. The diagram in Figure II-2 explains G*, its components, and δ.



Asphalt A

Asphalt B

Figure II-2. DSR Measurements

The diagram in Figure II-2 depicts two asphalts with the same G* (length of the diagonal) but with different phase angles. However, Asphalt A has a smaller elastic (recoverable) part than Asphalt B while Asphalt B has a lower viscous (non-recoverable) component than Asphalt A. If the same load is applied to both asphalts, Asphalt A will display more non-recoverable (permanent) deformation than Asphalt B. Because Asphalt B has a relatively large elastic component, it will recover much more from the load application. This example shows that G*, alone, is not enough to describe asphalt behavior. The δ value is also needed.

SPECIMEN PREPARATION

A disk of asphalt with diameter equal to the oscillating plate (often called a "spindle") of the DSR is needed for testing. There are two ways to prepare the sample: (1) asphalt can be poured directly onto the spindle in sufficient quantity to provide the appropriate thickness of material, or (2) a mold can be used to form the asphalt disk, then the asphalt can be placed between the spindle and fixed plate of the DSR.

In the first method, experience is necessary to apply the exact quantity of asphalt. It is not desirable to have too much or too little material. If there is too little, the test will be inaccurate. If there is too much, such as shown in Figure II-3, the sample must be trimmed.

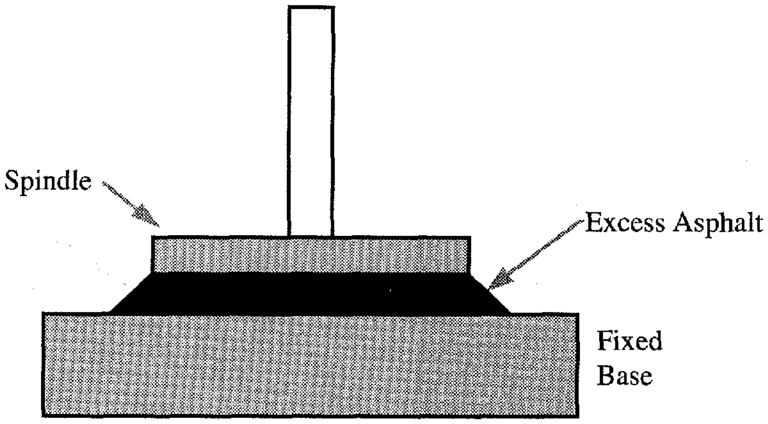


Figure II-3. Excess Asphalt in DSR

In the second method, asphalt is heated until fluid enough to pour. The heated asphalt is poured into a rubber mold and allowed to cool. The mold containing the asphalt may be placed in a refrigerator until sufficiently solid to remove the asphalt from the mold. After removal from the mold, the asphalt disk is placed between the fixed plate and the oscillating spindle of the DSR. As before, excess asphalt beyond the edge of the spindle should be trimmed.

Regardless of the method used to prepare the sample, the final step in preparing the specimen is to slightly readjust the gap (move them closer together by 50 microns) between the spindle and lower plate so that a slight bulge is evident near the edge of the spindle (Figure II-4). This step normally occurs immediately prior to testing.

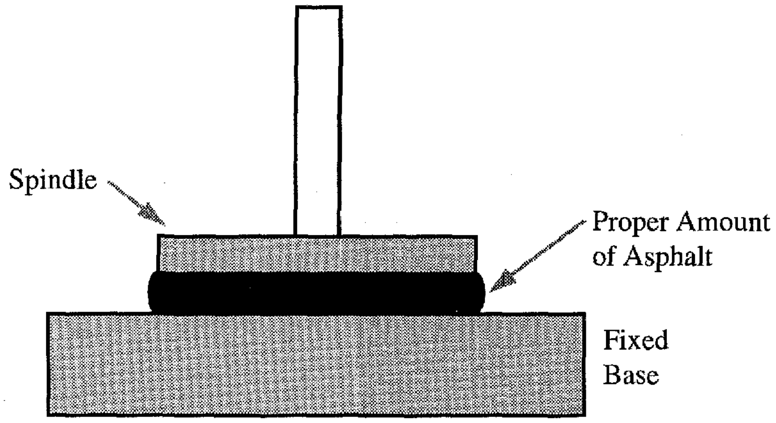


Figure II-4. Proper Sample Configuration in DSR

The thickness of the asphalt disk sandwiched between the spindle and the fixed plate must be carefully controlled. The proper specimen thickness is achieved by adjusting the gap between the spindle and fixed plate. This gap must be set before mounting the asphalt sample but while the spindle and base plate are mounted in the rheometer and at the test temperature. The gap is adjusted by means of a micrometer wheel. The micrometer wheel is graduated, usually in units of microns. Turning the wheel allows precise positioning of the spindle and base plate relative to each other. On some rheometers the micrometer wheel moves the spindle down. On other rheometers, it moves the base plate up. The thickness of gap used depends on the test temperature. High test temperatures of 46° C or greater require a small gap of 1000 microns (1 mm). Lower test temperatures in the range from 4° to 40° C require a larger gap of 2000 microns (2 mm). Likewise, two spindle diameters are used. High temperatures require a large spindle (25 mm) and low temperatures a small spindle (8 mm).

Without the specimen mounted, the operator normally sets the gap at the desired value (1000 or 2000 microns) plus an extra 50 microns. This 50 microns is dialed out using the micrometer wheel before final specimen trimming. After the specimen is trimmed flush with the upper plate, the extra 50 microns is dialed out so that the gap is exactly at the desired value and the specimen bulges slightly (Figure II-4).

TEST EQUIPMENT

The geometry of the equipment needed to measure G* and δ is shown in Figure II-5.

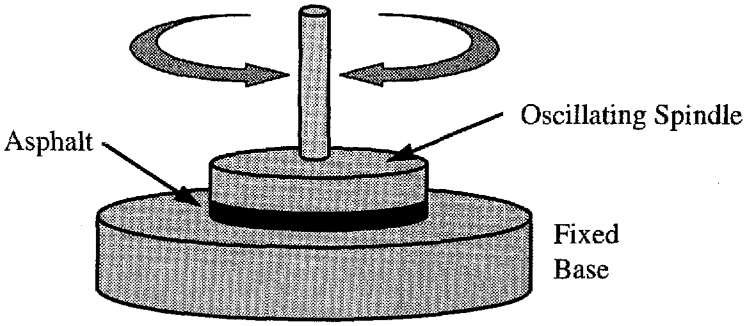


Figure II-5. Dynamic Shear Rheometer Geometry

Asphalt is sandwiched between the oscillating spindle and the fixed base. The spindle is oscillated back and forth using either a constant stress or constant strain. Constant stress means that the spindle is rotated through a certain distance until a fixed stress is achieved. Constant strain means that the spindle is rotated every time through a fixed distance, regardless of the stress achieved. While this rotation occurs, the resulting strain or stress is monitored. The relationship between the applied stress and the resulting strain provides information necessary to compute G* and δ. The diagram in Figure II-6 explains this computation.

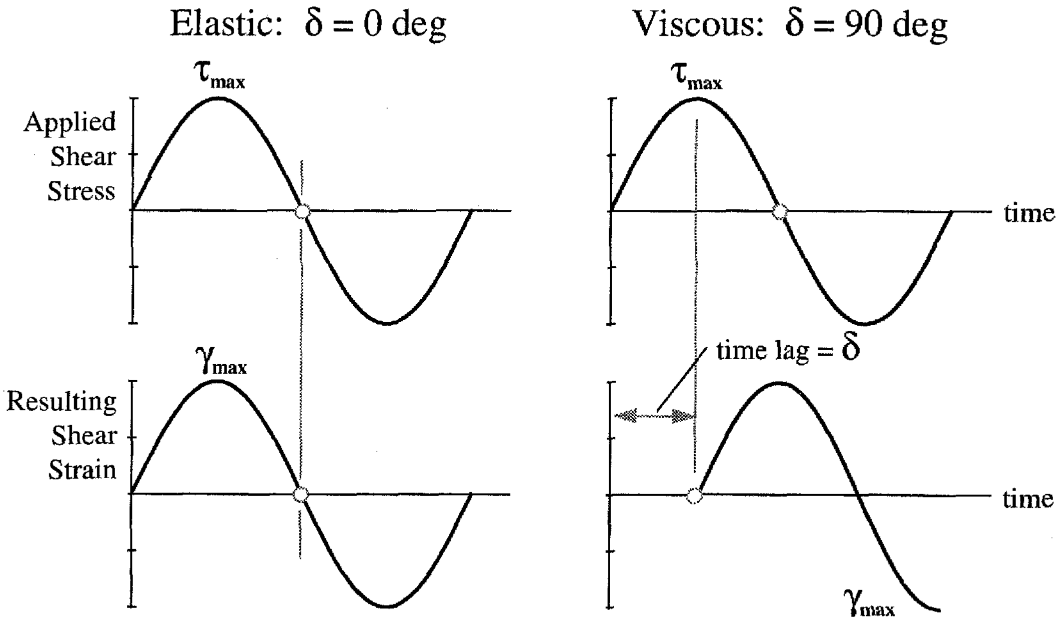


Figure II-6. Stress-Strain Output for a Constant Stress Rheometer

G* is the ratio of maximum shear stress (τ_{max}) to maximum shear strain (γ_{max}) or $\tau_{max} \div \gamma_{max}$. The time lag between the applied stress and the resulting strain (for constant stress rheometers as shown in Figure II-6) or the applied strain and resulting stress (constant strain rheometers) is the phase angle δ. For a perfectly elastic material, an applied load coincides with an immediate response, and the time lag or angle δ is zero. A viscous material (such as hot asphalt) has a relatively large time lag between load and response and thus, an angle that approaches 90 degrees. In the DSR, a viscoelastic material such as asphalt at normal service temperatures displays a stress-strain response that is between the two extremes as shown in Figure II-7.

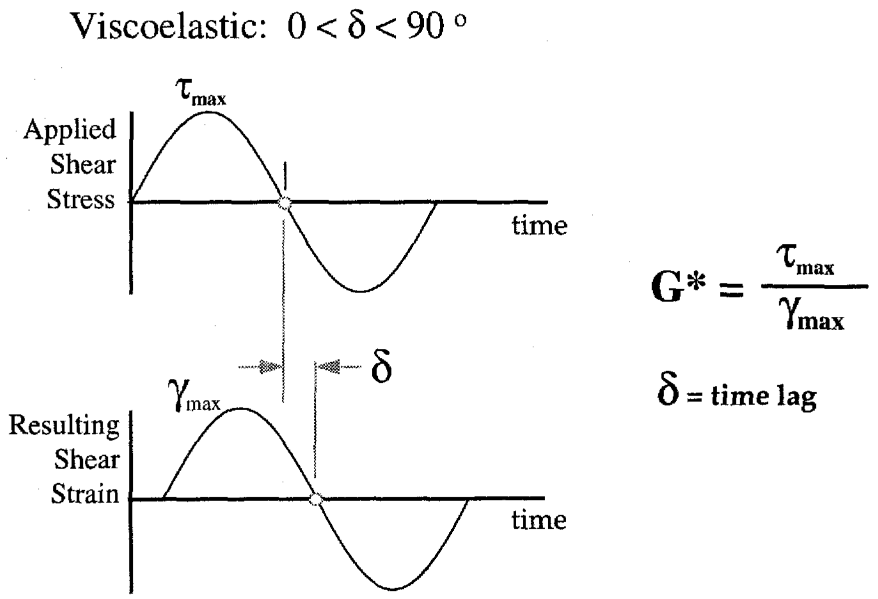


Figure II-7. Stress-Strain Response of a Viscoelastic Material

The formulas used by the rheometer software to calculate τ_{max} and γ_{max} are:

$$\tau_{max} = 2T/\pi r^3 \text{ and } \gamma_{max} = \Theta r/h$$

where,

T = maximum applied torque,
r = radius of specimen/plate (either 12.5 or 4 mm),
Θ = deflection (rotation) angle,
h = specimen height (either 1 or 2 mm).

Again, the operator need not worry about performing these calculations since they are performed automatically by the rheometer software. However, note that the radius of specimen is a crucial factor and this is why careful specimen trimming is so important. Specimen height (i.e. the gap between the plates) is also an important factor that is affected by operator skill.

Because the properties of asphalt binders are so temperature dependent, rheometers must have a precise means of controlling the temperature of the sample. This is normally accomplished by means of a circulating fluid bath or forced air bath. Fluid baths normally use water to surround the sample. The water is circulated through a temperature controller that precisely adjusts and maintains the sample temperature uniformly at the desired value. Air baths operate in the same manner as water baths except that they surround the sample with air during testing. In either case, the temperature of the air or water must be controlled so that the temperature of the sample across the gap is uniform and varies by no more than 0.1° C.

OVERVIEW OF PROCEDURE

After the asphalt sample is correctly in place and the test temperature appears stable, the operator must allow about ten minutes for the temperature of the specimen to equilibrate. It normally takes at least ten minutes for the specimen to be uniformly at the test temperature. The actual temperature equilibration time is equipment dependent and should be checked using a dummy specimen with very accurate temperature sensing capabilities.

Testing consists of using the rheometer software to set the DSR to apply a constant oscillating stress and recording the resulting strain and time lag. The SUPERPAVE specifications require the oscillation speed be 10 radians/second, which is approximately 1.59 Hz. A computer is used with the DSR to control test parameters and record test results.

The operator need not worry about setting the value of applied stress. Instead, the operator sets the approximate value of shear strain (sometimes called "strain amplitude"). Shear strain values vary from one to 12 percent and depend on the stiffness of the binder being tested. Relatively soft materials tested at high temperatures, (e.g., unaged binders and RTFO aged binders) are tested at strain values of approximately ten to twelve percent. Hard materials (e.g., PAV residues tested at moderate temperatures) are tested at strain values of about one percent.

In the initial stages of the test, the rheometer measures the stress required to achieve the set shear strain and then maintains this stress very precisely during the test. The shear strain can vary small amounts from the set value to achieve this constant stress. Variation in shear strain is normally controlled by the rheometer software and not the operator.

To begin the test, the sample is first conditioned by loading the specimen for 10 cycles. Ten additional cycles are applied to obtain test data. The rheometer software automatically computes and reports G* and δ, which can be compared with specification requirements.

DATA ANALYSIS AND PRESENTATION

The DSR is capable of measuring many variables. However, only G* and δ are required for SUPERPAVE specification testing. In most cases, the software used with the DSR does all the calculations necessary to determine G* and δ. Therefore, by recovering these values from the computer, it is a simple matter of comparing results with requirements of the SUPERPAVE specification to determine compliance. A complete report includes:

- G* to the nearest three significant figures,
- δ to the nearest 0.1 degrees,
- test plate size to the nearest 0.1 mm and gap to nearest 1μm,
- test temperature to the nearest 0.1° C,
- test frequency to the nearest 0.1 rad/sec, and
- strain amplitude to the nearest 0.01 percent.

Two forms of G* and δ are used in the specifications. Permanent deformation is controlled by limiting G*/sin δ at the test temperatures to values greater than 1.0 kPa (before aging) and 2.2 kPa (after oven aging). Fatigue cracking is controlled by limiting G*sin δ of pressure aged material to values less than 5000 kPa at the test temperature. Section VII provides more information on how G* and δ are used in the SUPERPAVE binder specification.

The method is suitable for use at temperatures ranging from 4° and 85° C where G* is between 0.1 kPa and 10,000 kPa.

CALIBRATION AND STANDARDIZATION

Temperature

Because asphalt properties are so dependent on temperature, it is important to ensure that the temperature of the specimen is kept to within 0.1° C of the desired test temperature. To check the accuracy of temperature control, a dummy specimen is placed between the parallel plates and a temperature measurement is taken. The dummy specimen consists of a resistor sandwiched between two very thin silicone rubber sheets. In this application, the resistor is known as a "thermistor" because it is being used to measure temperature. The resistance of the thermistor is highly dependent on temperature. Thus by applying a small electric current to the thermistor and measuring its resistance, a very accurate temperature measurement is achieved. By simply comparing the actual temperature between the plates using the thermistor with the indicated test temperature from the rheometer software, a check is made on the accuracy of the temperature control. If necessary, the operator may use an indicated temperature offset to accurately achieve the proper test temperature.

Load and Strain Transducers

Dynamic shear rheometers must make sensitive measurements of load (torque) and shear strain to determine complex shear modulus (G*). Calibration of these items is normally a function of the rheometer manufacturer.

Overall Calibration

An overall check on rheometer performance can be performed using a reference fluid with viscoelastic similar properties as asphalt. However, caution must be used when using such fluids because they probably will not have the same temperature dependency as asphalt.

III.

BENDING BEAM RHEOMETER

INTRODUCTION

The Bending Beam Rheometer (BBR) is used to measure the stiffness of asphalts at very low temperatures. The test uses engineering beam theory to measure the stiffness of a small asphalt beam sample under a creep load. A creep load is used to simulate the stresses that gradually build up in a pavement when temperature drops. Two parameters are evaluated with the BBR. *Creep stiffness* is a measure of how the asphalt resists constant loading and the *m-value* is a measure of how the asphalt stiffness changes as loads are applied.

SPECIMEN PREPARATION

The asphalt beam is formed by pouring heated asphalt into a rectangular mold (Figure III-1). The aluminum mold pieces are greased with petroleum jelly. Acetate strips are placed against the greased faces. The end pieces are treated with a release agent composed of glycerin and talc that have been mixed to achieve a paste-like consistency. Silicone rubber molds are also available to fabricate beam test specimens.

After a cooling period of about 45 to 60 minutes, excess asphalt is trimmed from the upper surface using a hot spatula. The asphalt specimen should remain in the mold at room temperature and demolded only when the testing procedure is ready to begin, but in no case more than three hours.

To demold the specimen, cool the assembly in a freezer for five to ten minutes or an ice bath for 30 to 45 seconds. In addition, do not use the rheometer testing bath since this may cause excessive fluctuations in the bath temperature.

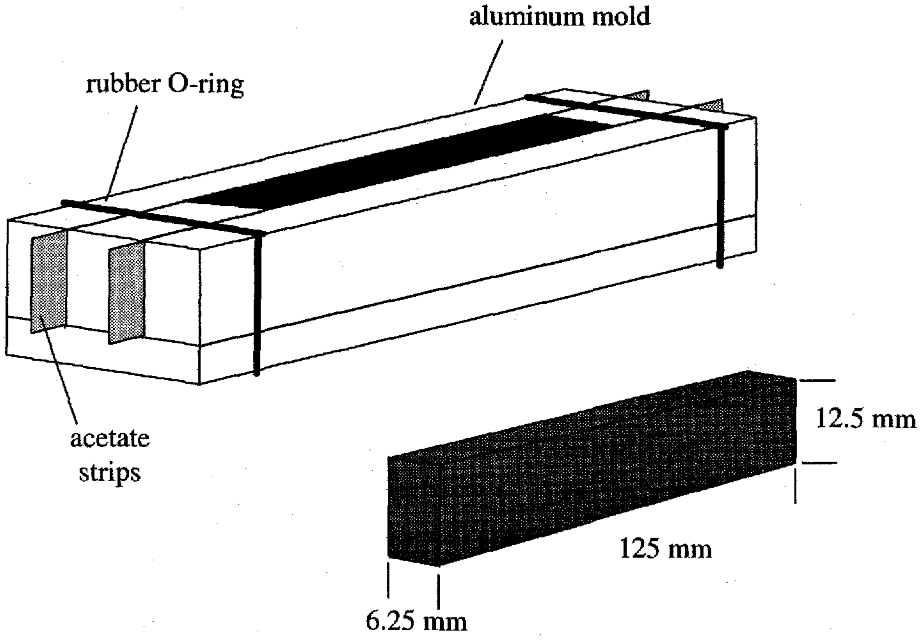


Figure III-1. Asphalt Mold Assembly

After removal of the aluminum and acetate, the resulting asphalt beams are ready for temperature conditioning. This requires that they be placed in the test bath for 60 ± 5 minutes. At the end of this period, the beams may be tested. Because the test procedure requires this tight tolerance on testing, the operator must carefully coordinate equipment preparation and specimen preparation.

TEST EQUIPMENT

Creep stiffness and m-value are measured by the BBR. The BBR is a simple device, which gets its name from the test specimen geometry and loading method used during testing. Figure III-2 is a schematic of the BBR.

The key elements of the BBR are a loading frame, controlled temperature fluid bath, computer control and data acquisition system, and test specimen. The BBR uses a blunt-nosed shaft to apply a midpoint load to the asphalt beam , which is supported at two locations. A load cell is mounted on the loading shaft, which is enclosed in an air bearing to eliminate any frictional resistance when applying load. A deflection measuring transducer is affixed to the shaft to monitor deflections. Loads are applied by pneumatic pressure and regulators are provided to adjust the load applied through the loading shaft.

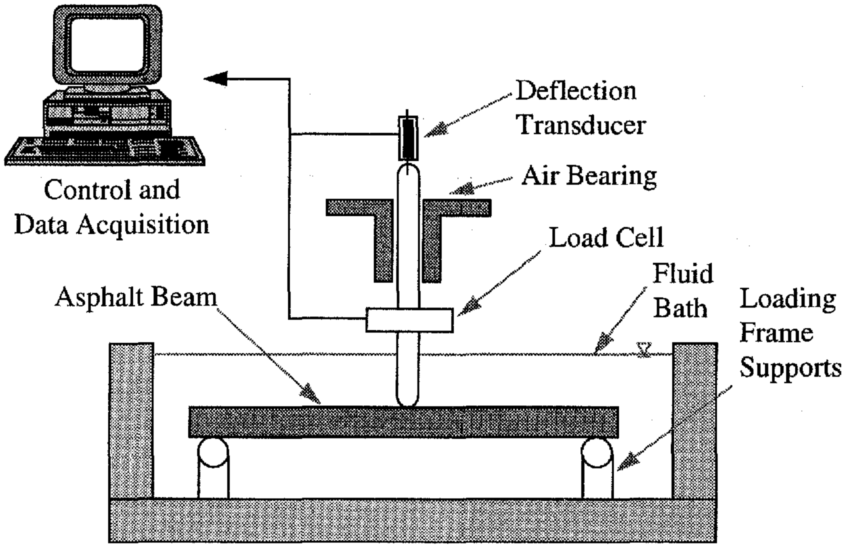


Figure III-2. Bending Beam Rheometer

The temperature bath contains a fluid consisting of ethylene glycol, methanol, and water. This fluid is circulated between the test bath and a circulating bath which controls the fluid temperature to within 0.1° C. Circulation or other bath agitation must not disturb the test specimen in a manner that would influence the testing process.

The data acquisition system consists of a computer (with software) connected to the BBR so as to control test parameters and acquire load and deflection test results.

OVERVIEW OF PROCEDURE

The operator initiates the control software before the test begins. While the test specimens are brought to test temperature in the testing bath, systems calibration and compliance are accomplished. These include calibration of the displacement transducer and load cell. Compliance of the test device is checked with a rigid stainless steel reference beam. The temperature transducer is also checked by using a calibrated mercury-in-glass thermometer. A thinner reference beam is also supplied that can be periodically used to check the performance of the overall system. This beam functions as a dummy test specimen allowing quick checks on rheometer performance. Most of the system calibration is controlled by the rheometer software and the operator need only follow the instructions provided by the software.

At the end of the 60-minute thermal conditioning period, the asphalt beam is placed on the supports by gently grasping it with forceps. A 2.5- to 3.5-gram (30 ± 5 mN) preload is manually applied by the operator to ensure that the beam is firmly in contact with the supports. A 100-gram (980 mN) seating load is automatically applied for one second by the rheometer software. After this seating step, the load is automatically reduced to the preload for a 20-second recovery period.

At the end of the recovery period, a 100-gram (980 ± 5 mN) load is applied to the beam for a total of 240 seconds. The deflection of the beam is recorded during this period as shown in Figure III-3.

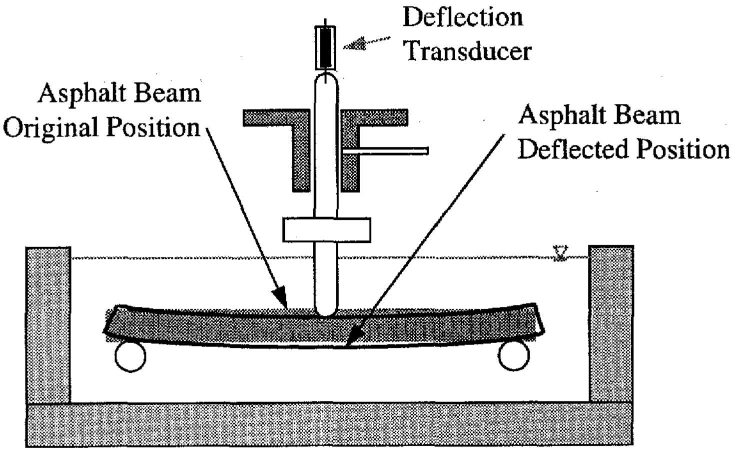


Figure III-3. Bending Beam Test

As the 100-gram (980 mN) load bends the beam, the deflection transducer monitors the movement. This deflection is plotted against time to determine creep stiffness and m-value. During the test, load and deflection versus time plots are continuously generated on the computer screen for the operator to observe. At the end of 240 seconds, the test load is automatically removed and the rheometer software performs all calculations to determine creep stiffness and m-value.

DATA ANALYSIS AND PRESENTATION

Classic beam analysis theory is used to obtain creep stiffness of the asphalt in this test. The formula for calculating creep stiffness, S(t), is as follows:

$$S(t) = PL^3/4bh^3\,\delta(t) \qquad \text{(Eq 1)}$$

where,

$S(t)$ = creep stiffness at time, $t = 60$ seconds
P = applied constant load, 100 g (980 mN)
L = distance between beam supports, 102 mm
b = beam width, 12.5 mm
h = beam thickness, 6.25 mm
$\delta(t)$ = deflection at time, $t = 60$ seconds

Although the BBR uses a computer to make this calculation, it can be determined manually by reading deflection data from the graph of deflection versus time from the printer connected to the computer. Figure III-4 depicts this graph and the procedure used to obtain $\delta(t)$.

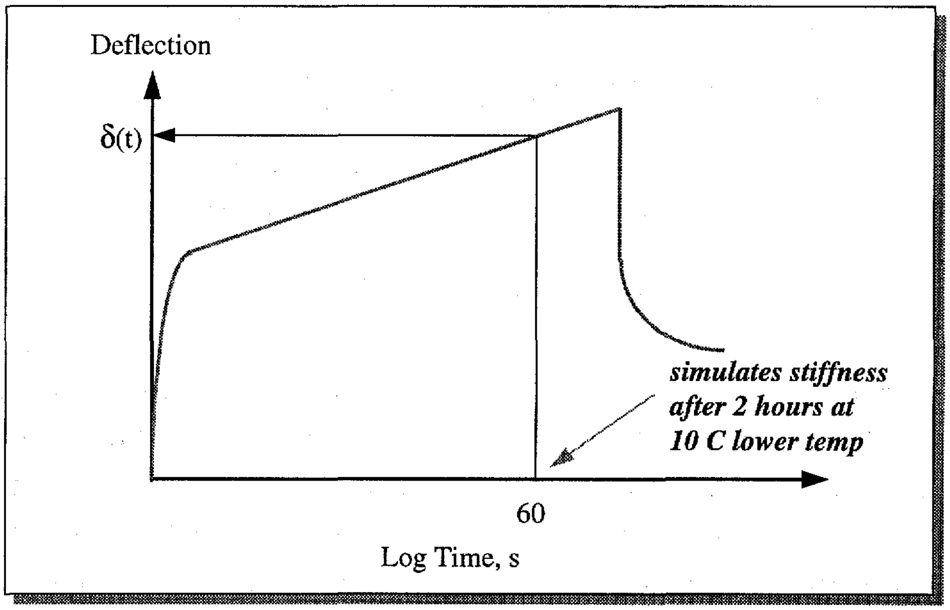


Figure III-4. Manual Method for $\delta(t)$

By using Equation 1 and the deflection from the graph above, the stiffness at time, t=60 seconds can be obtained. Creep stiffness is desired at the minimum pavement design temperature after two hours of load. However, SHRP researchers discovered that by raising the test temperature 10° C, an equal stiffness is obtained after a 60 second loading. The obvious benefit is that a test result can be measured in a much shorter period of time.

The second parameter needed from the bending beam test is the m-value. The m-value represents the rate of change of the stiffness, S(t), versus time. This value also is calculated automatically by the bending beam computer. However, to check the results from the computer, the value for m is easily obtained. To obtain m-value, the stiffness is calculated at several loading times. These values are then plotted against time as shown below.

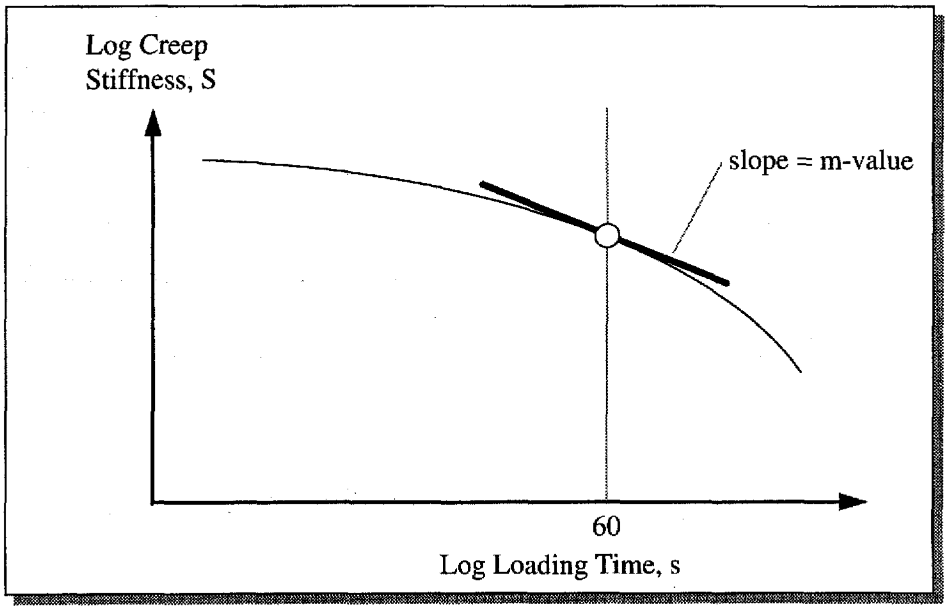


Figure III-5. Manual Method for m-value

The m-value is the slope of the log stiffness versus log time curve at any time, t. The SUPERPAVE specification requires m-value be greater than or equal to 0.300 when measured at 60 seconds.

Computer-generated output for the bending beam test automatically reports all required reporting items. It includes plots of deflection and load versus time, actual load and deflection values at various times, test parameters, and operator information. The following table shows typical information gathered and reported by system software. Figure III-6 illustrates typical output plots.

```
                        TEST INFORMATION
 Proj:  NCUPG           Target Temp:  -18.0 C       Conf
                                                    Test:   2.14e+00
 Oper:  RSW             Actual Temp:  -18.0 C       Date:   01/13/94
 Spec:  IN-10             Soak time:  60.0 min      Load
                                                   Const:   0.246103
 Time:  15:53:47         Beam Width:  12.7 mm       Defl
                                                   Const:   .002417
 Date:  01/13/94          Thickness:  6.35 mm       Date:   01/13/94
 File:  0216943.DAT

                             RESULTS
 Time,     Force,     Defl,    Measured   Estimated   Diff, %   m-value
  sec        N         mm      Stiffness  Stiffness
                                  kPa        kPa
 ------------------------------------------------------------------------
 8         .9954      .1382    580900     580000      -.1550     .217

 15        .9970      .1601    502100     503000      .1778      .236

 30        .9989      .1903    423100     424100      .2339      .256

 60        .9993      .2279    353600     352600      -.2797     .277

 120       .9994      .2785    289300     289100      -.09025    .297

 240       .9998      .3454    233400     233700      .1142      .317
 ------------------------------------------------------------------------
                      Regression Coefficients

           a=5.932   b=-.1565            c=-.03374  R^2=.999964
```

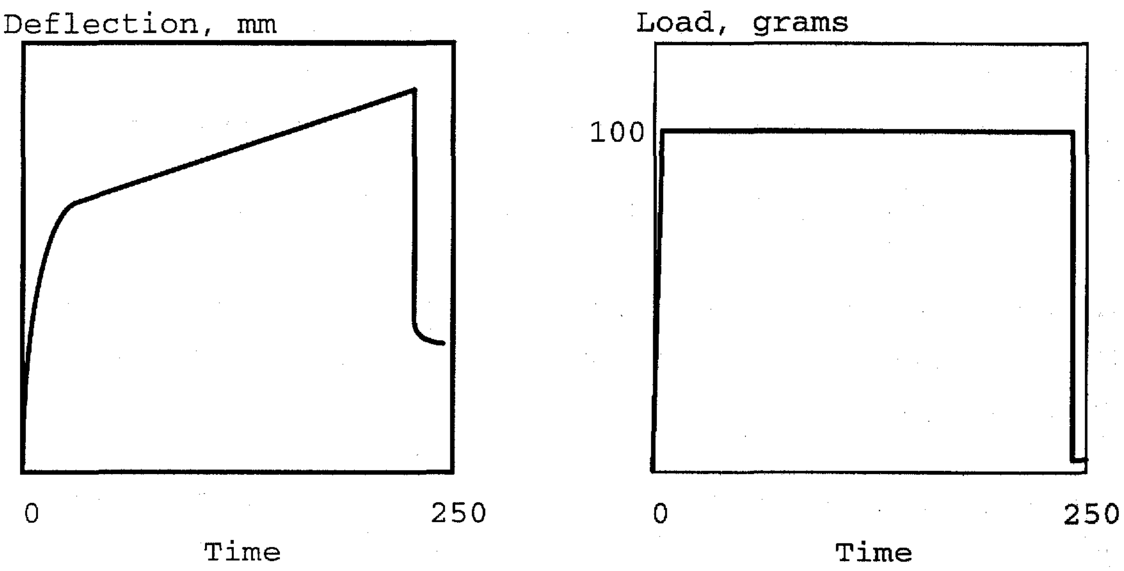


Figure III-6. Typical Deflection and Load Output

CALIBRATION AND STANDARDIZATION

Displacement Transducer

The bending beam rheometer makes highly accurate measurements of beam deflection using the displacement transducer. To verify measurements of the displacement transducer, a stepped gauge of known thickness is used.

Load Cell

The load cell accurately measures the load placed on the asphalt beam by the loading shaft. To verify the accuracy of the load cell, it is loaded with known masses while the loading shaft is resting against a rigid steel beam.

Temperature Detector

The testing bath of the bending beam rheometer has a very accurate temperature probe called a "resistance thermal detector" or RTD. The RTD is located very close to the beam supports. The accuracy of the RTD should be checked with a calibrated mercury in glass thermometer.

Compliance Check

The measured creep stiffness of the asphalt specimen is highly dependent on the measured deflection. Consequently, it is important to ensure that measured deflection consists entirely of beam deflection and that bending in the rheometer loading frame is not being included as part of the deflection measurement. Bending of the rheometer loading frame is known as "compliance." A compliance check is made by applying a standard load to the loading shaft while it is resting against a rigid steel beam. Thus, any measured deflection is the result of rheometer compliance and the rheometer software will be able to adjust the creep stiffness for the portion of measured deflection that is attributable to rheometer compliance.

Confidence Check

Overall rheometer performance is checked by loading a thin steel reference beam with known stiffness. If the beam's measured stiffness varies from its known stiffness by more than 10 percent, the overall operation of the rheometer is suspect.

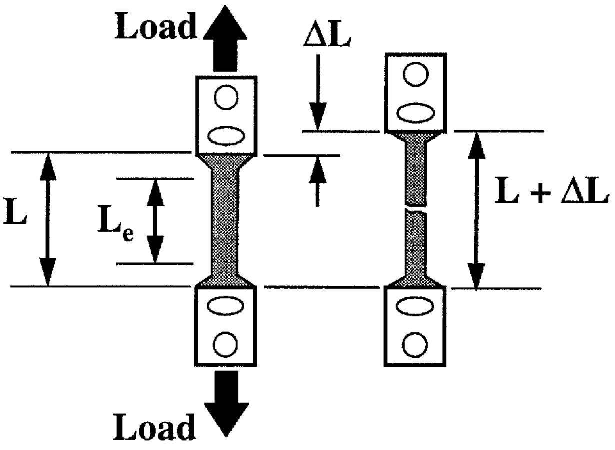
IV.

DIRECT TENSION TESTER

INTRODUCTION

The direct tension test measures the low temperature ultimate tensile strain of an asphalt binder. The test is performed at relatively low temperatures ranging from 0° to -36° C, the temperature range within which asphalt exhibits brittle behavior. Furthermore, the test is performed on binders that have been aged in a rolling thin film oven and pressure aging vessel. 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.

A small dog-bone shaped specimen (see figure below) is loaded in tension at a constant rate (Figure IV-1).



$$\text{failure strain } (\varepsilon_f) = \frac{\text{change in length } (\Delta L)}{\text{effective gauge length } (L_e)}$$

Figure IV-1. Direct Tension Test

The strain in the specimen at failure (ε_f) is the change in length (ΔL) divided by the effective gauge length (L). In the direct tension test, failure is defined by the stress where the load on the specimen reaches its maximum value as shown in Figure IV-2, and not necessarily the load when the specimen breaks. Failure stress (σ_f) is the failure load divided by the original cross section of the specimen (36 mm^2). The SUPERPAVE binder specification requires a minimum strain at failure of one percent.

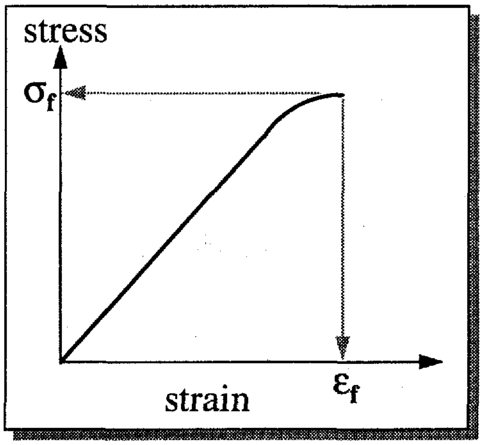


Figure IV-2. Failure Stress and Strain in Direct Tension Test

The stress-strain behavior of asphalt binders depends greatly on their temperature (Figure IV-3). If an asphalt were tested in the direct tension tester at many temperatures, it would exhibit the three types of tensile failure behavior: brittle, brittle-ductile, and ductile.

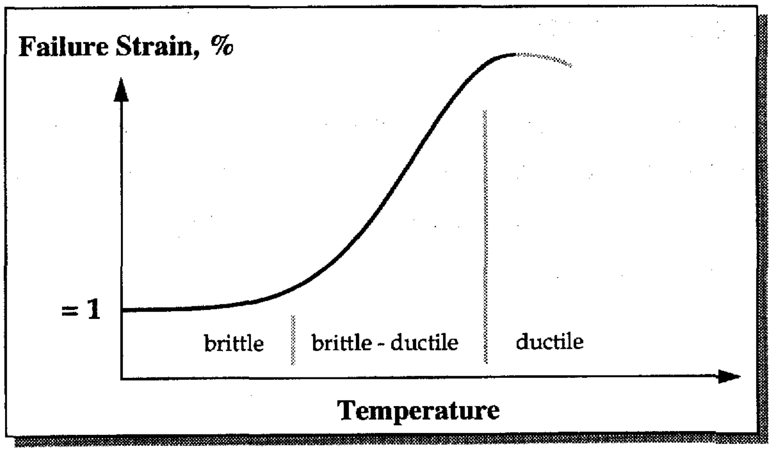


Figure IV-3. Effect of Temperature on Asphalt Tensile Failure Strain

The characteristic stress-strain relationships are shown in Figure IV-4. In this figure, the three different lines could represent the same asphalt tested at multiple temperatures or different asphalts tested at the same temperature. Brittle behavior means that the asphalt very quickly picks up load and elongates only a small amount before it cracks. An asphalt that is ductile may not even crack in the direct tension test but rather "string-out" until its elongation exceeds the stroke of the loading frame. That is why tensile failure strain is defined by the point at which the specimen stops picking up load, which is the strain at peak stress.

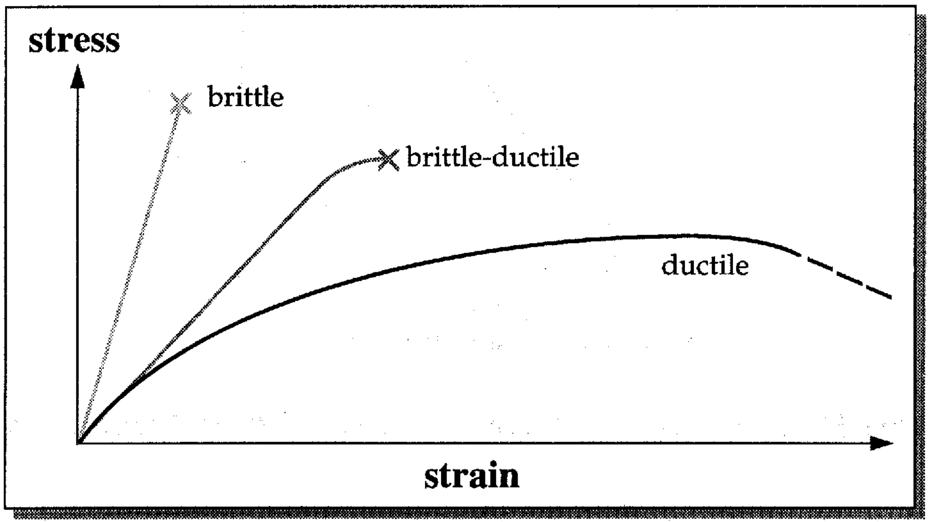


Figure IV-4. Tensile Failure Behavior of Asphalt Binders

SPECIMEN PREPARATION

Direct tension specimens are formed in a silicone rubber mold (Figure IV-5). The mold allows fabrication of four specimens. These four specimens are used to produce one test result. Plastic end inserts are placed in the mold and hot asphalt is poured between the inserts in the space shown in Figure IV-5.

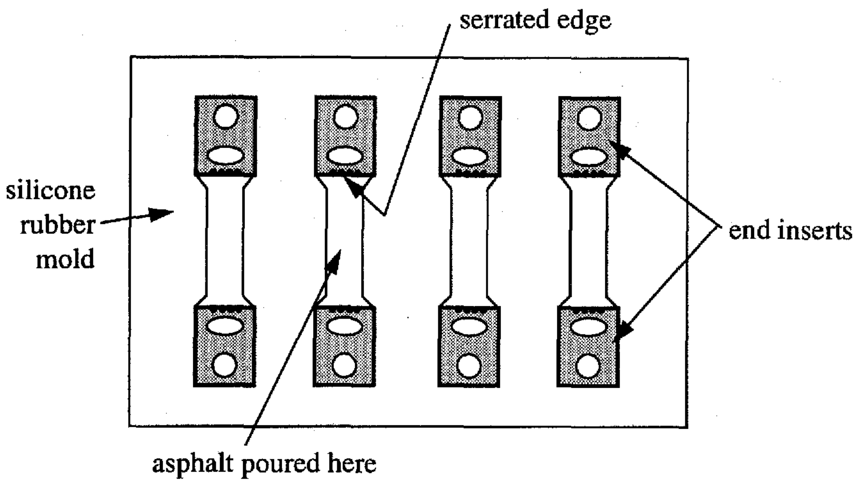


Figure IV-5. Mold Used to Prepare Direct Tension Specimens

Test specimens (Figure IV-6) weigh approximately 2 g and are 100 mm long, including the end inserts. The inserts are each 30 mm long and the formed binder test specimen is 40 mm long. The nominal cross section is 6 mm by 6 mm. A 12 mm radius is used to gradually widen the specimen to 20 mm, the end insert width. The end inserts are composed of polymethylmethacrylate, or other suitable material with a linear coefficient of thermal expansion similar to asphalt (0.00006 mm/mm/° C). Asphalt readily adheres to these materials and no bonding agent is necessary.

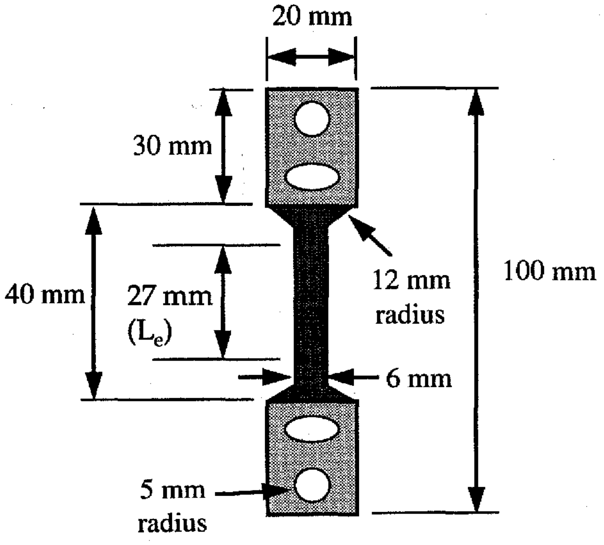


Figure IV-6. Direct Tension Specimen Dimensions

After the specimens are poured, trimmed, and demolded, they must be tested within 60 ± 10 minutes. Because the test procedure requires this tolerance on testing, the operator must carefully coordinate equipment preparation with specimen preparation.

TEST EQUIPMENT

The apparatus used to perform the direct tension test consists of three components:

- a testing machine to apply tensile load,
- an elongation measuring system, and
- an environmental system.

The universal testing machine is a loading device capable of at least 400 to 500 N at a loading rate of 1.0 mm/min. The machine must be equipped with an electronic load cell capable of resolutions of ± 0.1 N. While machines with electronic digital displays capture sufficient data to compute specification compliance, a computer can also be used with the apparatus to acquire data.

A key feature to the testing machine is the gripping system used to attach specimens to the alignment rods that apply tensile load (Figure IV-7). The grips have a ball joint connection that ensures no bending is induced in the specimen. The upper and lower alignment rods are attached to the loading frame (bottom) and load cell (top).

Because the direct tension test is performed at such low temperatures, the strains to failure are relatively small. Consequently, traditional methods of measuring strain are not suitable. Rather, a laser micrometer is used. This device consists of a laser light generator and receiving unit. A vertical plane of light is directed across the specimen in the direction of the receiver. The receiver sees two slots of light because the specimen and end inserts block the plane of laser light except for the two holes in the end insert. Using this approach the receiver monitors the movement between the upper and lower slot of light, thus, measuring the elongation in the specimen. Figure IV-8 illustrates the concept of the laser micrometer.

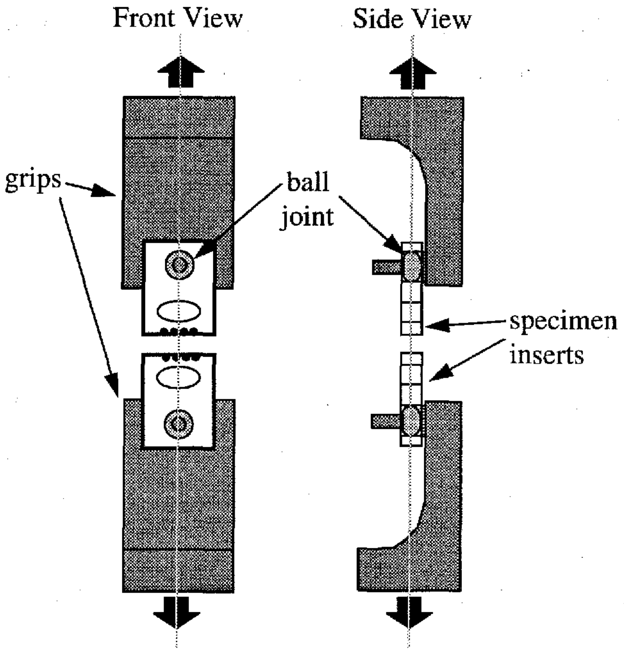


Figure IV-7. Direct Tension Specimen Grips

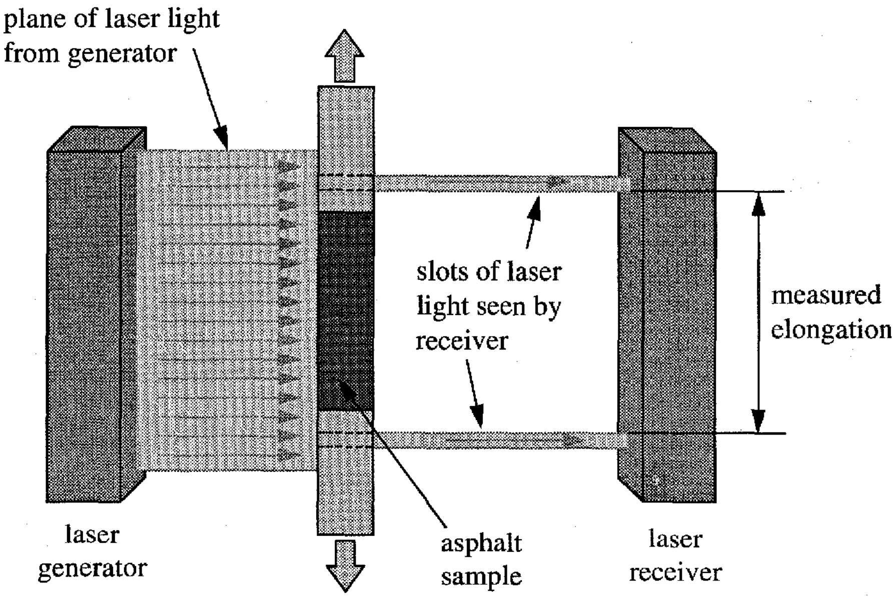


Figure IV-8. Principle of Laser Micrometer (Side View)

The environmental chamber is composed of the chamber itself and a mechanical refrigeration unit capable of producing and precisely maintaining chamber temperatures as low as -40° C ± 0.2° C. The chamber has a small access hole through which specimens can be mounted on the grips. Use of the access hole to manipulate specimens keeps the chamber temperature more consistent. Nitrogen coolant is sometimes used when periods of high humidity would otherwise cause the mechanical refrigeration unit to collect ice.

OVERVIEW OF PROCEDURE

Specimens are tested individually. A specimen is mounted on the ball joint by reaching through the access hole and not by opening the chamber door. Before the test begins, the operator initializes the load and strain indicators and zeros the laser micrometer. A tensile load is applied until the specimen fails. A normal test requires less than a minute from application of load until specimen failure. A test is considered acceptable when fracture occurs within the narrow, center portion of the specimen.

DATA ANALYSIS AND PRESENTATION

A single test result consists of the average strain to failure of the four specimens. The table below demonstrates typical test output.

<table>
<tr><td colspan="5">Batch Number - Acme Refining 759AC1196-16</td></tr>
<tr><td colspan="5">Operator - CEL</td></tr>
<tr><td colspan="5">Date - 3/15/93</td></tr>
<tr><td colspan="5">Time - 14:16:26</td></tr>
<tr><td>Test Number</td><td>Peak Load, N</td><td>Peak Stress, kPa</td><td>Strain at Peak Stress, mm/mm</td><td>Peak Elong., mm</td></tr>
<tr><td>000091</td><td>65.70</td><td>1845.9</td><td>0.00369</td><td>0.099</td></tr>
<tr><td>000092</td><td>64.72</td><td>1818.6</td><td>0.00540</td><td>0.146</td></tr>
<tr><td>000093</td><td>56.45</td><td>1586.9</td><td>0.00459</td><td>0.124</td></tr>
<tr><td>000094</td><td>64.94</td><td>1825.6</td><td>0.00549</td><td>0.148</td></tr>
<tr><td>Mean</td><td>62.95</td><td>1769.3</td><td>0.00479</td><td>0.129</td></tr>
<tr><td>Std Dev</td><td>4.36</td><td>122.1</td><td>0.00083</td><td>0.023</td></tr>
</table>

In this case, the test result of interest is the average of strain at peak stress, 0.00479 mm/mm, which is 0.5 percent strain (i.e., 0.00479 x 100 % = 0.479 % or with rounding, 0.5 %). This value would *not* meet the specification requirement of one percent minimum strain. Although they are not used to determine specification compliance the following are also required reporting items:

- test temperature to the nearest 0.1° C,
- rate of elongation to the nearest 0.01 mm/min,
- failure stress to the nearest 0.01 MPa,
- peak load to the nearest N, and
- type of break observed (brittle, brittle-ductile, or no break).

CALIBRATION AND STANDARDIZATION

Load Cell

Because peak strain is defined by peak stress, it is important that the load cell accurately measure the applied load. The accuracy of the load cell can be determined by suspending dead masses from the load cell.

Extensometer

The accuracy of the laser extensometer can be checked by using a gauge that functions as a dummy specimen. The dummy specimen works in the same fashion as an asphalt test specimen by blocking a portion of the laser light source. It is mounted on the grips in two configurations, which allow for two measurements: a long dimension and a short dimension. By comparing the measured dimensions of the dummy specimen with their known values, and also with previous dummy specimen measurements, the accuracy and consistency of the laser extensometer can be checked.

Temperature Detector

The testing chamber of the direct tension tester has a very accurate temperature probe called a "resistance thermal detector" or RTD. The RTD is located very close to the shelf that holds the test specimens. The accuracy of the RTD should be checked with a calibrated mercury in glass thermometer.

Crosshead Loading Rate

The loading rate to which the specimen is subjected can be checked using a dial gauge and stopwatch. The dial gauge is mounted so that it senses the movement of the crosshead. By measuring the distance traveled by the crosshead over a certain period of time (approximately one minute), the actual loading rate can be calculated.

V.

ROTATIONAL VISCOMETER

INTRODUCTION

Rotational viscosity is used to evaluate high temperature workability of binders. A rotational coaxial cylinder viscometer, such as the Brookfield apparatus is used rather than a capillary viscometer. Some asphalt technologists refer to this measure as "Brookfield viscosity." This method of measuring viscosity is detailed in ASTM Method D 4402, "Viscosity Determination of Unfilled Asphalts Using the Brookfield Thermosel Apparatus."

High temperature binder viscosity is measured to ensure that the asphalt is sufficiently fluid when pumping and mixing. Consequently, rotational viscosity is measured on unaged or "tank" asphalt and must not, according to the SUPERPAVE binder specification, exceed 3 Pa-s when measured at 135° C.

Rotational viscosity is determined by measuring the torque required to maintain a constant rotational speed of a cylindrical spindle while submerged in a sample at a constant temperature (Figure V-1).

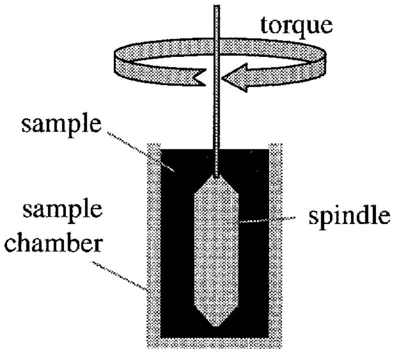


Figure V-1. Principle of Rotational Viscometer

The torque required to rotate the spindle at a constant speed is directly related to the viscosity of the binder sample, which is determined automatically by the viscometer.

SPECIMEN PREPARATION

Approximately 30 g of binder is heated in an oven so that it is sufficiently fluid to pour. In no case should the sample be heated above 150° C. During heating, the sample occasionally should be stirred to remove entrapped air. Asphalt is weighed into the sample chamber. The amount of asphalt used varies depending on the spindle. A larger spindle means that less asphalt can be placed in the chamber. Typically, less than 11 grams are used. The sample chamber containing the binder sample is placed in the thermo container and is ready to test when the temperature stabilizes, usually about 15 minutes.

TEST EQUIPMENT

The apparatus used to measure rotational viscosity consists of two items:

- Brookfield viscometer
- Thermosel™ system

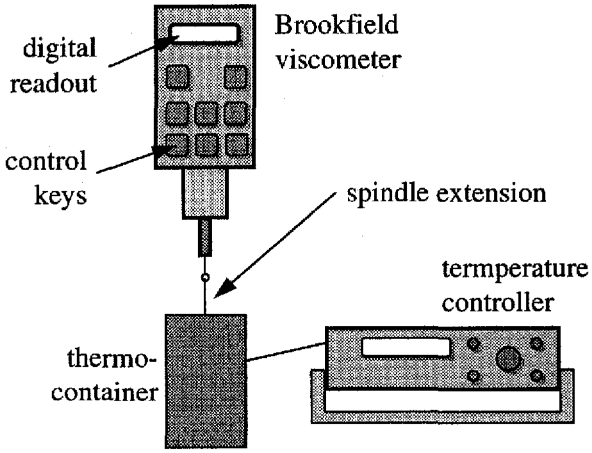


Figure V-2. Brookfield Viscometer and Thermosel System

The Brookfield viscometer consists of a motor, spindle, control keys, and digital readout. The motor powers the spindle through a torsional spring. The spring is wound as the torque increases. Torque in the spring is measured by a rotary transducer. For most rotational viscometers and specification testing, the motor should be set to operate at 20 rpm.

The spindle is cylindrical in shape and resembles a plumb bob. It is resisted from rotating by the viscous nature of the binder in which it is submerged. Many spindles are available for the Brookfield apparatus. The proper spindle is selected based on the viscosity of the binder being tested. Many binders can be tested with only two spindles: Nos. 21 and 27. Of these, spindle No. 27 is used most frequently.

Applied torque and rotational speed are indicated on the digital readout. The control keys are used to input test parameters such as spindle number, which tells the viscometer which spindle is being used. The keys also are used to set rotational speed and turn the motor on and off.

The viscometer must be leveled to function properly. A bubble-type level indicator is located on top of the viscometer and is adjusted by means of leveling screws on the base.

The Thermosel system consists of the sample chamber, thermo container, and temperature controller. The sample chamber is a stainless steel cup in the shape of a test tube. An extracting tool is used to handle the sample chamber when hot.

The thermo-container holds the sample chamber and consists of electric heating elements that maintain or change test temperature. The temperature controller allows the operator to set the test temperature at the required 135° C. A bubble-type level mounted on the base of the thermo-container stand ensures that the thermo-container is level.

OVERVIEW OF PROCEDURE

When the digital indicator on the temperature controller shows that the sample temperature has equalized, the sample can be tested. The spindle is lowered into the chamber containing the hot sample and the spindle is coupled with the viscometer using a threaded connector (Figure V-3).

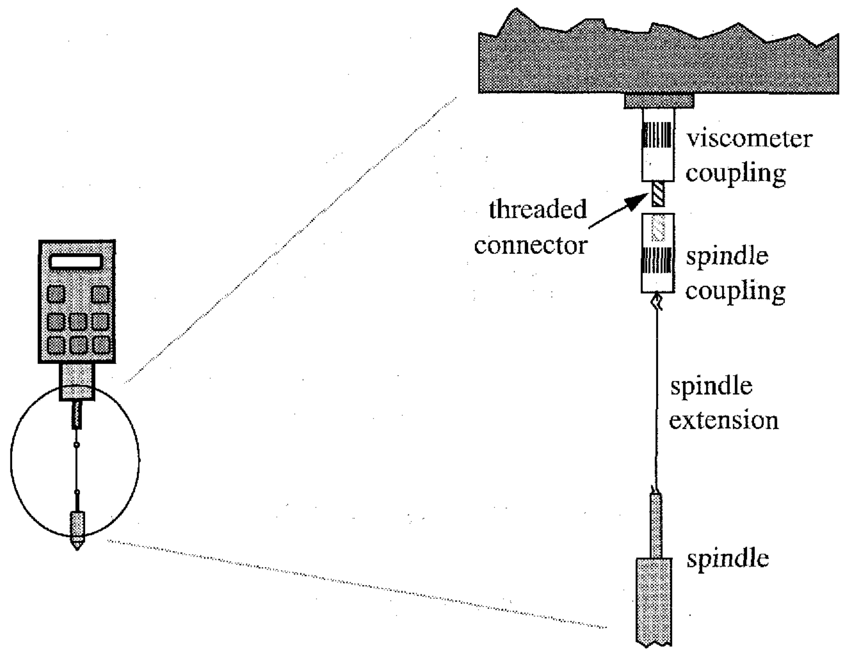


Figure V-3. Spindle and Viscometer Connection

A waiting period (normally about 15 minutes) is required to allow the sample temperature to return to 135° C. During this period, the viscometer motor is turned-on and the operator can observe the viscosity reading. As the temperature equalizes, the viscosity reading will stabilize and the operator can begin to obtain test results. The operator can set the digital display to show viscosity information that needed for the report. This information is: viscosity, test temperature, spindle number, and speed. Three viscosity readings should be recorded at 1-minute intervals. Figure V-4 shows the four possible displays that the operator can choose. Note that in this example, only the upper left item in the display changes.

In some cases, it may be desirable to determine binder viscosity at temperatures other than 135° C. For example, most agencies use equiviscous temperatures for mixing and compaction during mix design. To accomplish this, the Thermosel™ controller is reset to the desired temperature until the thermo-container to brings the sample to this temperature. This step takes about 30 minutes, after which, the test is again performed as described above.

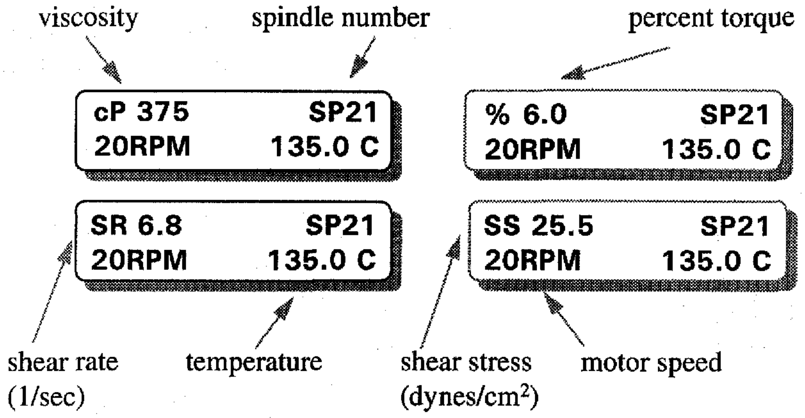


Figure V-4. Viscometer Digital Displays

DATA ANALYSIS AND PRESENTATION

The viscosity at 135° C is reported as the average of three readings. The digital output of the rotational viscosity test is viscosity in units of centipoise (cP) while the SUPERPAVE binder specification uses Pa-s. To convert, the following factor is used:

$$1000 \text{ cP} = 1 \text{ Pa}\cdot\text{s}$$

Therefore, multiply the Brookfield viscosity output in cP by 0.001 to obtain the viscosity in Pa·s.

As mentioned previously, in addition to viscosity, the test temperature, spindle number, and speed are required items to be reported.

The SUPERPAVE binder specification requirement of 3 Pa-s is applied at the discretion of a specifying agency and may be waived if the binder supplier guarantees that the binder can be handled, pumped, etc. at safe temperatures.

CALIBRATION AND STANDARDIZATION

Rotary Transducer

The accuracy of the rotary transducer is checked using a reference fluid of known viscosity.

Temperature Detector

The accuracy of the temperature reading of the Thermosel unit is checked by placing an asphalt sample in the testing chamber and equilibrating it to an given temperature. The indicated temperature is verified by using a calibrated thermometer.

VI.

BINDER AGING METHODS

INTRODUCTION

A central theme of the SUPERPAVE binder specification is its reliance on testing asphalt binders in conditions that simulate critical stages during the binder's life. The three most critical stages are:

- during transport, storage, and handling,
- during mix production and construction, and
- after long periods in a pavement.

Tests performed on unaged asphalt represent the first stage of transport, storage, and handling.

The second stage, during mix production and construction, is simulated by aging the binder in a rolling thin film oven (RTFO). The RTFO aging technique was developed by the California Highway Department and is detailed in AASHTO T-240 (ASTM D 2872). This test exposes films of binder to heat and air and approximates the exposure of asphalt to these elements during hot mixing and handling.

The third stage of binder aging occurs after a long period in a pavement. This stage is simulated by use of a pressure aging vessel (PAV). This test exposes binder samples to heat and pressure in order to simulate, in a matter of hours, years of in-service aging in a pavement.

It is important to note that for specification purposes, binder samples aged in the PAV have already been aged in the RTFO. Consequently, PAV residue represents binder that has been exposed to all the conditions to which binders are subjected during production and in-service.

SPECIMEN PREPARATION

To prepare for RTFO aging, a binder sample is heated until sufficiently fluid to pour. In no case should the sample be heated to 150° C. RTFO bottles are loaded with 35 ± 0.5 g of binder. The RTFO has an eight bottle capacity, however, the contents of two bottles must be used to determine mass loss. If mass loss is being determined, the two bottles containing samples should be cooled and weighed to the nearest 0.001 g. Otherwise, the RTFO residues from the eight bottles are poured into a single container and stirred to ensure homogeneity. RTFO residue should be poured from the coated bottle and not scraped. This material may be used for DSR testing or transferred into PAV pans for additional aging or equally proportioned into small containers and stored for future use.

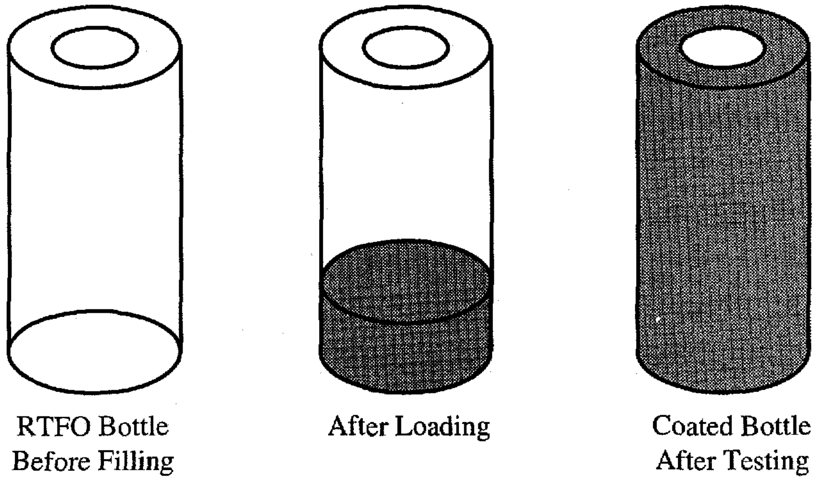


Figure VI-1. RTFO Bottle and Sample Before and After Aging

To prepare for the PAV, RTFO residue is transferred to individual PAV pans. The sample should be heated only to the extent that it can be readily poured and stirred to ensure homogeneity. Each PAV sample should weigh 50 g. Residue from approximately two RTFO bottles is normally needed for one 50 g sample.

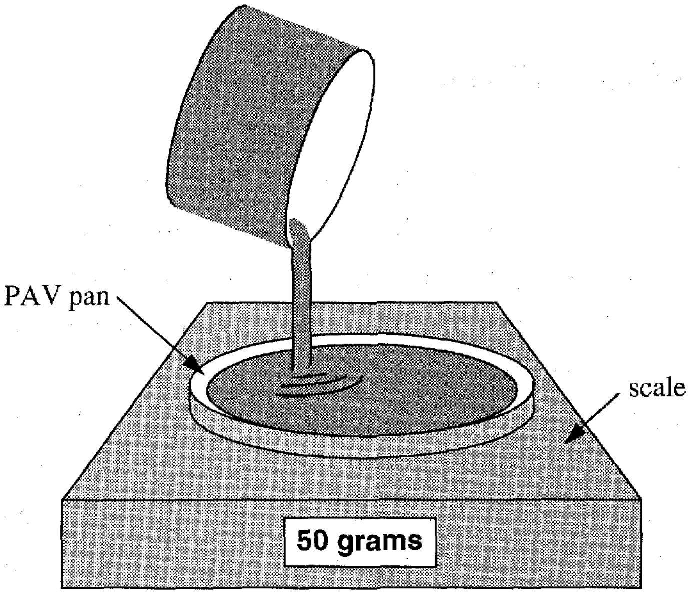


Figure VI-2. RTFO Residue Being Transferred to PAV Pans

TEST EQUIPMENT

Rolling Thin Film Oven

The RTFO procedure requires an electrically heated convection oven. Specific oven requirements are detailed in AASHTO T 240 (ASTM D 2872). The oven contains a vertical circular carriage (Figure VI-3) that contains holes to accommodate sample bottles. The carriage is mechanically driven and rotates about its center. The oven also contains an air jet that is positioned to blow air into each sample bottle at its lowest travel position while being circulated in the carriage.

Pressure Aging Vessel

The pressure aging apparatus consists of the pressure aging vessel and a temperature chamber. Air pressure is provided by a cylinder of dry, clean compressed air with a pressure regulator, release valve, and a slow release bleed valve.

The pressure vessel is fabricated from stainless steel and is designed to operate under the pressure and temperature conditions of the test (2070 kPa and either 90°, 100°, or 110° C). The vessel must accommodate at least 10 sample pans and does so by means of a sample rack, which is a frame that fits conveniently into the vessel. Figure VI-4 shows one type of vessel configuration. In this case, the vessel lid is secured by means of a shear ring assembly composed of an aluminum lock ring and bronze shear ring segments (Figure VI-5). The vessel lid is fitted with a pressure coupling and temperature transducer. The temperature transducer connects to a digital indicator that allows visual monitoring of internal vessel temperature throughout the aging period. Another type of vessel is shown in Figure VI-6. In this case, the vessel consists of a cylindrical chamber with top and bottom plates secured by a series of bolts and wing nuts. Continuous monitoring of temperature is required during the test.

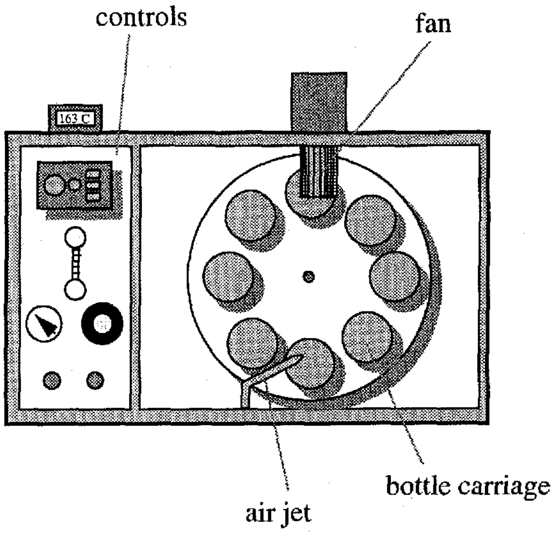


Figure VI-3. RTFO Oven

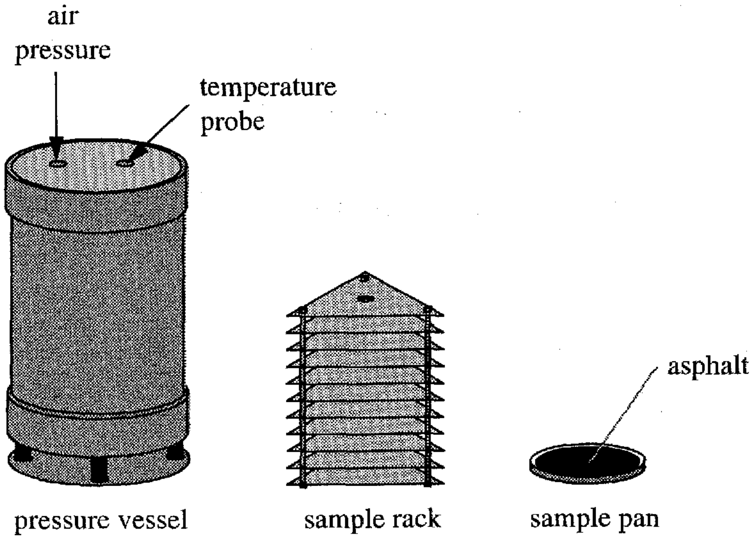


Figure VI-4. Pressure Aging Vessel and Components

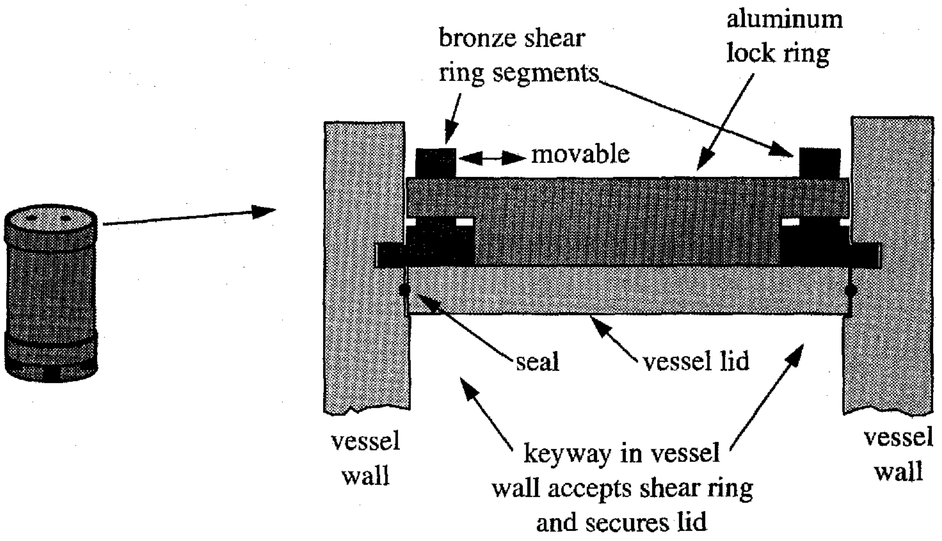


Figure VI-5. Shear Ring Assembly for Pressure Vessel Lid

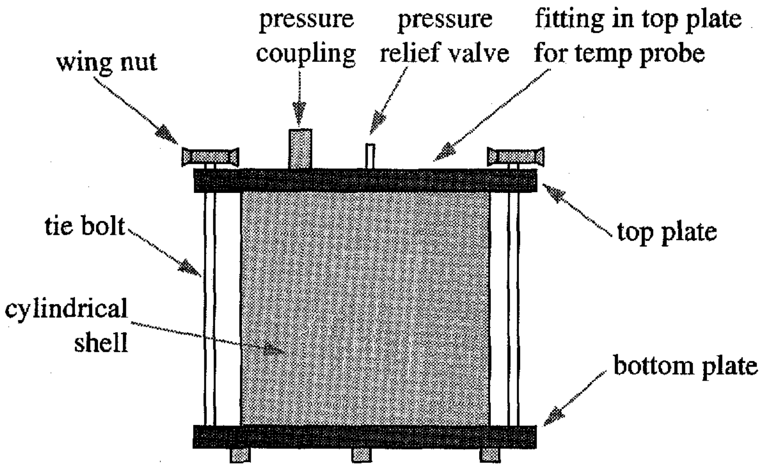


Figure VI-6. Alternative Configuration of Pressure Aging Vessel

A forced draft oven is used as a temperature chamber. The oven should be able to control the test temperature to within ± 0.5° C for the duration of the test. A digital proportional control and readout of internal vessel temperature is required.

OVERVIEW OF PROCEDURE

Rolling Thin Film Oven

The RTFO oven must be preheated at the aging temperature, 163° ± 0.5° C, for a minimum of 16 hours prior to use. The thermostat should be set so that the oven will return to this temperature within 10 minutes after the sample bottles are loaded.

Bottles are loaded into the carriage with any unused slots filled with empty bottles. The carriage should be started and rotated at a rate of 15 ± 0.2 rev/min. The air flow should be set at a rate of 4000 ± 200 ml/min. The samples are maintained under these conditions for 85 minutes.

If mass loss is being determined, the mass loss sample and bottles are allowed to cool to room temperature and weighed to the nearest 0.001 g.

Pressure Aging Vessel

To perform pressure aging, the first step requires that the temperature chamber (oven) be turned on. The vessel should be placed in the chamber, unpressurized, and allowed to reach the desired test temperature.

The PAV pans are placed in the sample rack. When the test temperature has been achieved the vessel is removed from the oven and the samples in the sample rack are placed in the hot vessel. The lid is installed and the shear ring assembly secured. This step should be completed as quickly as possible to avoid excessive loss of vessel heat.

The vessel is loaded into the temperature chamber and the pressure hose and temperature transducer are coupled to their respective mates. When the vessel temperature is within 2° C of the test temperature, air pressure is applied using the valve on the air cylinder regulator. When air pressure has been applied, the timing for the test begins.

After 20 hours, the pressure is slowly released using the bleed valve. Usually, 8 to 10 minutes are required to gradually release the pressure. If pressure is released more quickly, excessive air bubbles will be present in the sample and it may foam.

The pans are removed from the sample holder and placed in an oven at 163° C for 30 minutes. This step removes entrapped air from the samples. The samples are then transferred to a container that stores the material for further testing.

DATA ANALYSIS AND PRESENTATION

Because the RTFO and PAV protocols are considered aging techniques, no test results are reported, with the exception of mass loss after RTFO aging. Mass loss is reported as the average of the two samples after RTFO aging. It is calculated by the following formula:

$$\text{Mass Loss, \%} = [(\text{Original mass} - \text{Aged mass})/\text{Original Mass}] \times 100\ \%$$

SUPERPAVE specifications allow no more than one percent mass loss for all binder grades.

A report for the PAV only contains:

- sample identification,
- aging test temperature to the nearest 0.1° C,
- maximum and minimum aging temperature recorded to the nearest 0.1° C,
- total time during aging that temperature was outside the specified range to the nearest 0.1 min, and
- total aging time in hours and minutes.

CALIBRATION AND STANDARDIZATION

Rolling Thin Film Oven

The oven temperature is measured by a resistance thermal detector (RTD) or by a calibrated thermometer. The accuracy of the RTD is checked by a calibrated thermometer. The air flow in the RTFO is checked by means of a calibrated flow meter. The carriage rotational speed is checked by using a stopwatch to measure the length of time for the carriage to execute a certain number of revolutions.

Pressure Aging Vessel

Internal vessel temperature is monitored with an RTD. The accuracy of the RTD is verified with a calibrated thermometer. The indicated pressure on the pressure regulator is normally verified by a calibration service.

VII.

SUPERPAVE ASPHALT BINDER SPECIFICATION

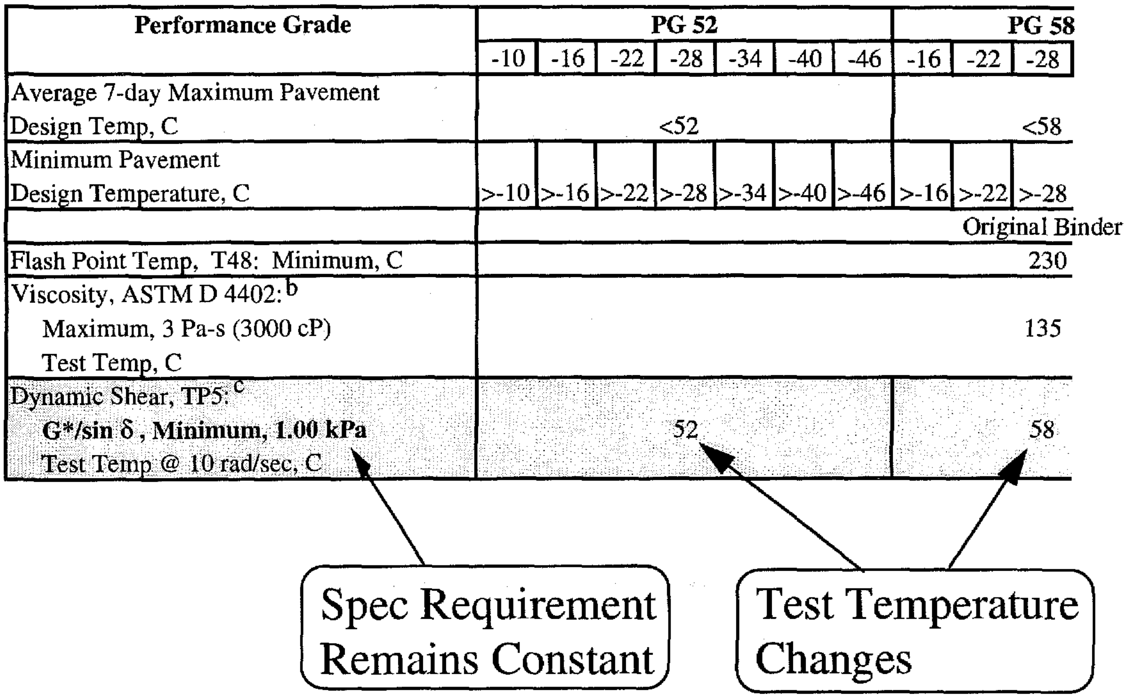
INTRODUCTION

The new SUPERPAVE asphalt binder specification (complete specification is shown in Appendix A) is intended to control permanent deformation, low temperature cracking and fatigue cracking in asphalt pavements. The specification accomplishes this by controlling various physical properties measured with the equipment described previously. This section briefly explains each of the new test parameters as they relate to pavement performance.

One important difference between the currently used asphalt specifications and this new SUPERPAVE specification is the way the specification works. Notice in Figure VII-1 that physical properties remain constant for all grades, but the temperatures at which these properties must be achieved vary depending on the climate in which the binder is expected to serve. As an example, a PG 52-40 grade is designed to be used in an environment to offer protection for an average seven day maximum pavement temperature of 52° C and a minimum pavement design temperature of -40° C.

PERMANENT DEFORMATION (RUTTING)

This form of pavement distress occurs at high service temperatures. The specification defines and places requirements on a rutting factor, $G^*/\sin\delta$, which represents the high temperature viscous component of overall binder stiffness. This factor is called "G star over sine delta." It is determined by dividing the complex modulus (G^*) by the sine of the phase angle (δ), both measured using the dynamic shear rheometer. $G^*/\sin\delta$ must be at least 1.00 kPa for the original asphalt binder and a minimum of 2.20 kPa after aging in the rolling thin film oven test. Both specification requirements are shown in the Figure VII-2.

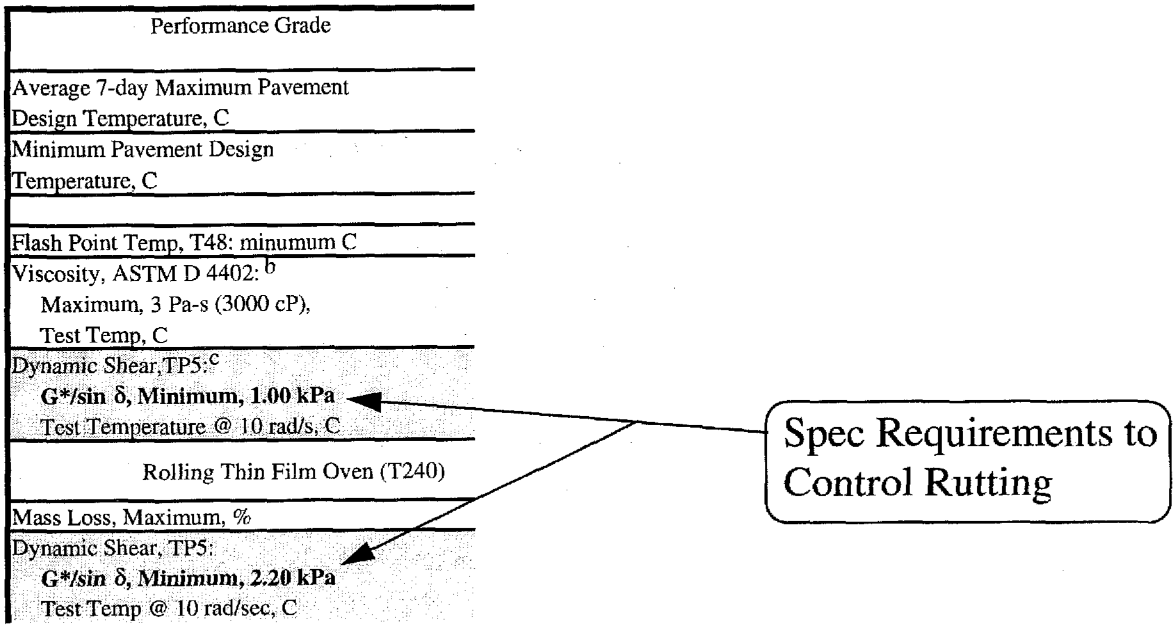


Performance Grade	**PG 52**							**PG 58**		
	-10	-16	-22	-28	-34	-40	-46	-16	-22	-28
Average 7-day Maximum Pavement Design Temp, C	<52							<58		
Minimum Pavement Design Temperature, C	>-10	>-16	>-22	>-28	>-34	>-40	>-46	>-16	>-22	>-28
	Original Binder									
Flash Point Temp, T48: Minimum, C	230									
Viscosity, ASTM D 4402:[b] Maximum, 3 Pa-s (3000 cP) Test Temp, C	135									
Dynamic Shear, TP5:[c] **G*/sin δ, Minimum, 1.00 kPa** Test Temp @ 10 rad/sec, C	52							58		

Spec Requirement Remains Constant

Test Temperature Changes

Figure VII-1. SUPERPAVE Binder Specification Example



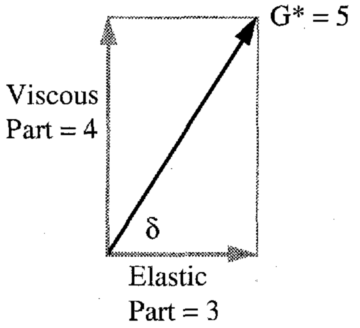
Performance Grade
Average 7-day Maximum Pavement Design Temperature, C
Minimum Pavement Design Temperature, C
Flash Point Temp, T48: minumum C
Viscosity, ASTM D 4402:[b] Maximum, 3 Pa-s (3000 cP), Test Temp, C
Dynamic Shear,TP5:[c] **G*/sin δ, Minimum, 1.00 kPa** Test Temperature @ 10 rad/s, C
Rolling Thin Film Oven (T240)
Mass Loss, Maximum, %
Dynamic Shear, TP5: **G*/sin δ, Minimum, 2.20 kPa** Test Temp @ 10 rad/sec, C

Spec Requirements to Control Rutting

Figure VII-2. SUPERPAVE Specification Rutting Factor Requirements

Using G*/sin δ to help with rutting performance makes sense. Sin δ is calculated by taking the ratio of the viscous part of G* to G*. For the two materials A and B shown in Figure VII-3 there is a significant difference between the values for sin δ.

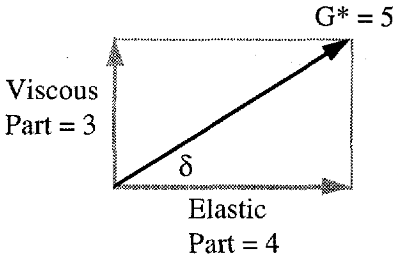
Material A



$$\sin\delta = \frac{\text{Viscous Part}}{G^*} = \frac{4}{5}$$

$$\frac{G^*}{\sin\delta} = \frac{5}{4/5} = 6.25$$

Material B



$$\sin\delta = \frac{\text{Viscous Part}}{G^*} = \frac{3}{5}$$

$$\frac{G^*}{\sin\delta} = \frac{5}{3/5} = 8.33$$

Larger value means behaves more like elastic solid

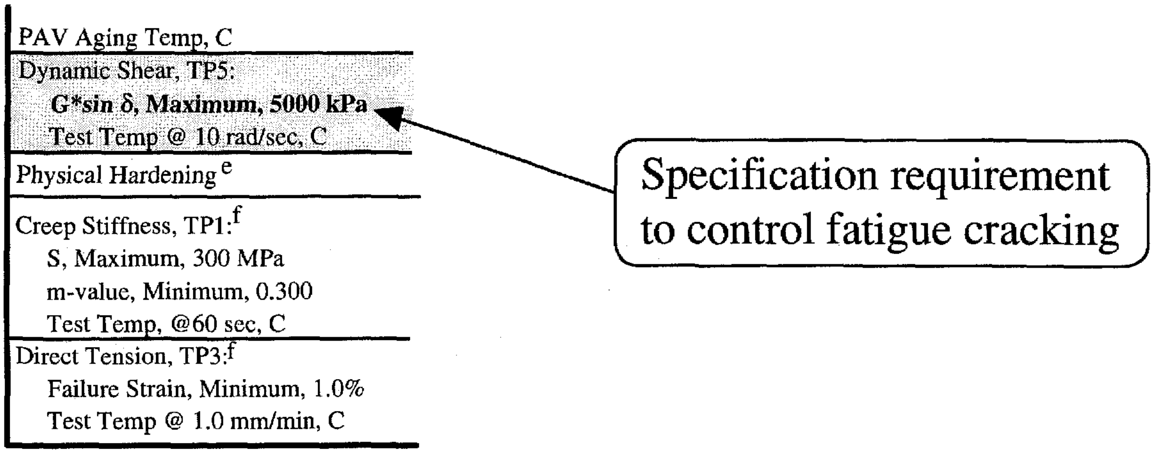
Figure VII-3. Controlling Rutting in SUPERPAVE Spec

Sin δ for Material A (4/5) is larger than sin δ for Material B (3/5). This means that when divided into G* (equal for both A and B), the value for G*/sin δ will be smaller for Material A (6.25) than Material B (8.33). Therefore, Material B should provide better rutting performance than Material A. This is sensible because Material B has a much smaller viscous part than Material A. Both higher G* and lower sin δ increase the value of G*/sin δ, which is desirable for rutting resistance.

FATIGUE CRACKING

G* and δ are also used in the SUPERPAVE asphalt specification to help control fatigue in asphalt pavements. Since fatigue occurs at low to moderate pavement temperatures after the pavement has been in service for a period of time, the specification requires that the PAV and RTFO tests be conducted prior to measuring these properties.

The dynamic shear test is used to generate G* and sin δ. However, instead of calculating a ratio of the two parameters as for rutting performance, they are multiplied. The resulting fatigue cracking factor is G*sin δ, which is called "G star sine delta." It is the product of the complex modulus, G*, and the sine of the phase angle δ. The SUPERPAVE binder specification places a maximum value of 5000 kPa on G*sin δ as shown in Figure VII-4.



PAV Aging Temp, C

Dynamic Shear, TP5:
G*sin δ, Maximum, 5000 kPa
Test Temp @ 10 rad/sec, C

Physical Hardening^{e}

Creep Stiffness, TP1:^{f}
S, Maximum, 300 MPa
m-value, Minimum, 0.300
Test Temp, @60 sec, C

Direct Tension, TP3:^{f}
Failure Strain, Minimum, 1.0%
Test Temp @ 1.0 mm/min, C

Specification requirement to control fatigue cracking

Figure VII-4. SUPERPAVE Specification Fatigue Cracking Factor Requirements

A description of how the fatigue cracking factor works is shown in Figure VII-5. In this example, Material B has a combination of G* and δ that causes it to have smaller viscous and elastic parts when compared to Material A. Because it has a smaller δ, Material B behaves more like a soft elastic material than Material A. This characteristic causes Material B to repeatedly flex and recover to its original shape better than material A. The ability to function as a soft elastic material and recover from loading is a desirable binder trait in resisting fatigue cracking. It is possible that a combination of G* and δ could result in a value for G*sin δ so large, that the viscous and elastic parts would become too high and the binder would no longer be able to effectively resist fatigue cracking. This is why the specification places a maximum limit of 5000 kPa for G*sin δ.

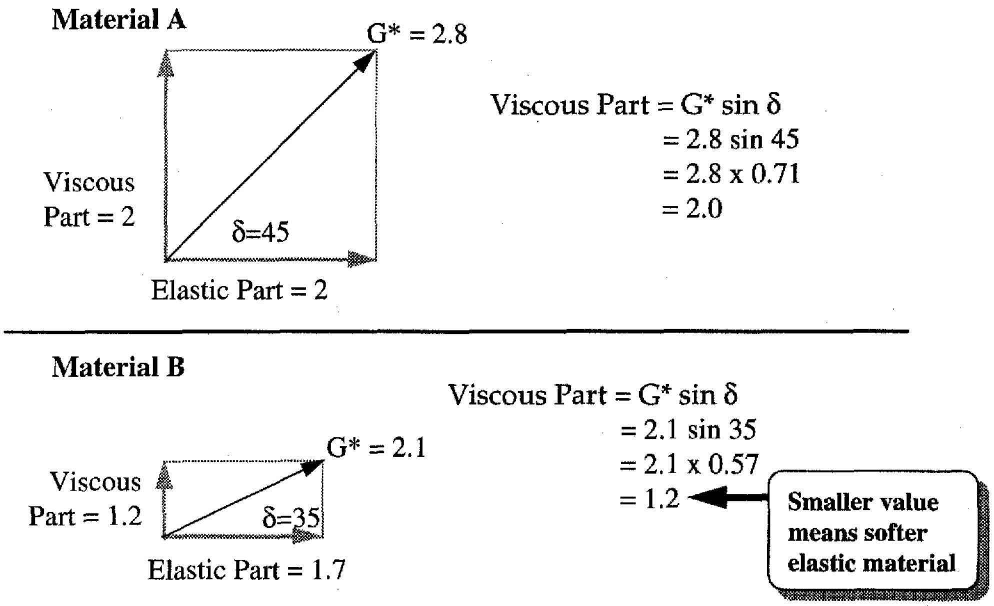


Figure VII-5. Controlling Fatigue Cracking in SUPERPAVE Spec

The dynamic shear test only provides part of the information needed to describe good cracking properties. The rest of the information is provided by the bending beam test and sometimes, the direct tension test.

LOW TEMPERATURE CRACKING

Binders act like solids at very low temperatures (<-50° C) and liquids at high temperatures (>70° C). The asphalt pavement usually exists between these extremes. The bending beam test is another way of describing whether the binder will behave more like an elastic solid or viscous liquid, but at much lower temperatures than the dynamic shear rheometer. The bending beam rheometer applies a small creep load to the beam specimen and measures the creep stiffness of the asphalt being evaluated. If creep stiffness is too high, the asphalt will behave in a brittle manner, and cracking will be more likely. Therefore, a maximum limit of 300 MPa is placed on creep stiffness to prevent this (Figure VII-6).

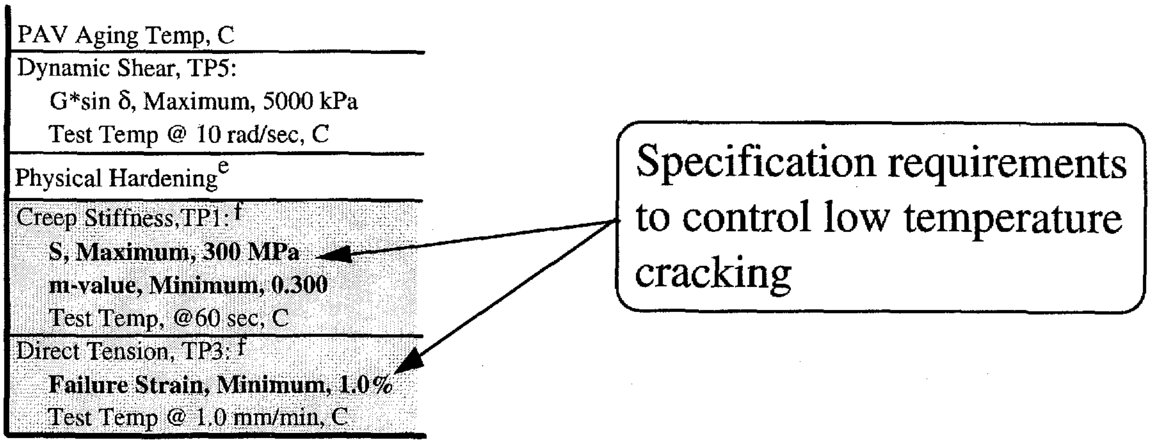


Figure VII-6. SUPERPAVE Specification Low Temperature Requirements

In the SUPERPAVE binder specification, the rate at which the binder stiffness changes with creep load at low temperatures is controlled using the m-value. A high m-value is desirable because this means that as the temperature changes and thermal stresses accumulate, the stiffness will change relatively fast. A relatively fast change in stiffness means that the binder will tend to shed stresses that would otherwise build up to a level where low temperature cracking would occur. An m-value greater than 0.300 is required by the SUPERPAVE binder specification (Figure VII-6).

As the temperature of a pavement decreases, it shrinks. This shrinkage causes stresses to build in the pavement. When these stresses exceed the strength of the binder, a crack occurs. Studies have shown that if the binder can stretch to more than 1% of its original length during this shrinkage, cracks are less likely to occur. Therefore, the direct tension test is included in the SUPERPAVE specification. It is only applied to binders that have a creep stiffness between 300 and 600 MPa. If the creep stiffness is below 300 MPa, the direct tension test need not be performed, and the direct tension requirement does not apply. The test pulls an asphalt sample in tension at a very slow rate, that which simulates the condition in the pavement as shrinkage occurs. The amount of strain that occurs before the sample breaks is recorded and compared to the 1.0 percent minimum value allowed in the specification (Figure VII-6).

COMMON SPECIFICATION CRITERIA

Other binder requirements are contained in the specification. They are included to control handling and safety characteristics of asphalt binders.

The flash point test (AASHTO T 48) is used to address safety concerns. The minimum value for all grades is 230° C. This requirement is only applied to unaged binders.

To ensure that binders can be pumped and otherwise handled at the hot mixing facility, the specification places a maximum viscosity on unaged binder. This value is 3 Pa·s (3000 cP on rotational viscometer) for all grades. Purchasing agencies may waive this requirement if the binder supplier warrants that the binder can be pumped and mixed at safe temperatures.

To preclude excessive aging (volatilization) during hot mixing and construction, a maximum mass loss is specified for all binder grades. The mass loss requirement is applied to RTFO residue and must not exceed 1.00 percent.

During storage or other static periods, particularly at low temperatures, physical hardening occurs in asphalt binders. It is caused by asphalt molecules associating with each other. Because of this physical hardening phenomenon, the SUPERPAVE specification requires that physical hardening be quantified. This requires performing the bending beam test on pressure aged binder that has been conditioned for 24 hours at the required test temperature. Two sets of beams are fabricated for creep stiffness and m-value measurements. One set is tested as normal at the required test temperature after one hour of conditioning, while the other set is tested after 24 hours of conditioning at the test temperature. Creep stiffness and m-value of the 24 hour specimens are reported. No specified values must be achieved.

SELECTING ASPHALT BINDERS

Asphalt binders are normally selected on the basis of the climate in which they are intended to serve. The following table shows the current binder grades in the SUPERPAVE specification.

High Temperature Grade	Low Temperature Grade
PG 46-	34, 40, 46
PG 52-	10, 16, 22, 28, 34, 40, 46
PG 58-	16, 22, 28, 34, 40
PG 64-	10, 16, 22, 28, 34, 40
PG 70-	10, 16, 22, 28, 34, 40
PG 76	10, 16, 22, 28, 34
PG 82	10, 16, 22, 28, 34

In this table, PG 76 and 82 grades are used only to accommodate slow transient or standing loads, or excessive truck traffic.

A module in the SUPERPAVE software assists users in selecting binder grades. SUPERPAVE contains three methods by which the user can select an asphalt binder grade:

- By Geographic Area: An Agency would develop a map showing binder grade to be used by the designer based on weather and/or policy decisions.
- By Pavement Temperature: The designer would need to know design pavement temperature.
- By Air Temperature: The designer determines design air temperatures, which are converted to design pavement temperatures.

SUPERPAVE Weather Database

SUPERPAVE software contains a database of weather information for 6500 reporting stations in the US and Canada, which allows users to select binder grades for the climate specific to project location. For each year a weather station has been in operation the hottest seven-day period is determined and the average maximum air temperature for those seven consecutive days is calculated. For all the years of record (stations with less than 20 years of records were not used) a mean and standard deviation are calculated. Likewise the coldest day of each year is identified and the mean and standard deviation are calculated.

Reliability

As used in SUPERPAVE, reliability is the percent probability in a single year that the actual temperature will not exceed the design temperature. SUPERPAVE binder selection is very flexible in that a different level of reliability can be assigned to high and low temperature grades. Consider summer air temperatures in Topeka, Kansas, which has a mean seven-day maximum of 36° C and a standard deviation of 2° C. Figure VII-6 shows the frequency distribution for this data. In an average year there is a 50 percent chance the seven-day maximum air temperature will exceed 36° C. However, only a two percent chance exists that the temperature will exceed 40° C; hence, a design air temperature of 40° C will provide 98 percent reliability.

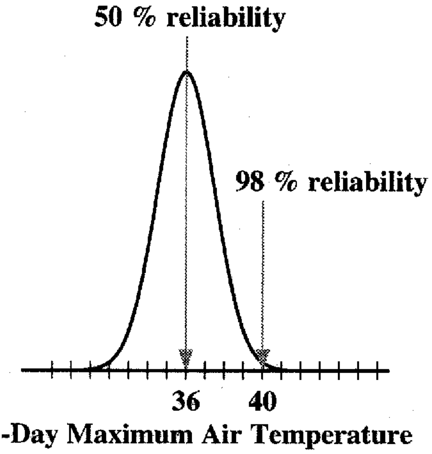


Figure VII-6. Distribution of Annual Seven-Day Maximum Air Temperature for Topeka, KS

Start with Air Temperature

To see how the binder selection works assume that an asphalt mixture is designed for Topeka. Figure VII-7 shows frequency distributions for high and low design air temperatures. In a normal summer, the average seven-day maximum air temperature is 36° C with a standard deviation of 2° C. In a normal winter, the average coldest temperature is -23° C. For a very cold winter the temperature is -31° C, with a standard deviation of 4° C.

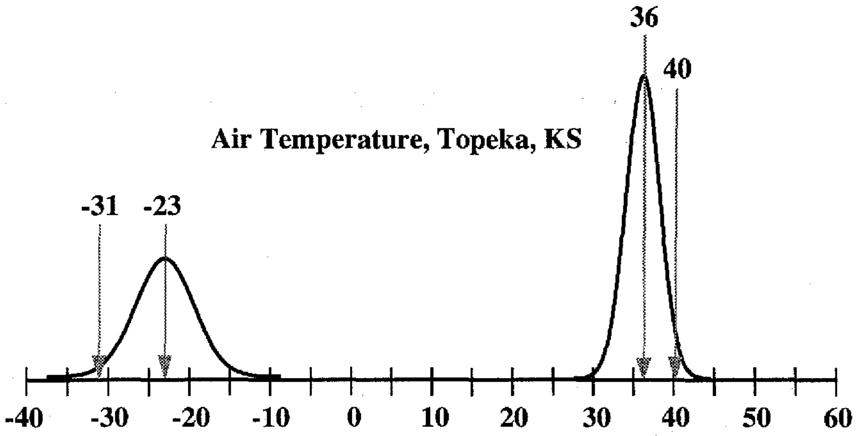


Figure VII-7. Distribution of High and Low Design Air Temperatures for Topeka, KS

Convert to Pavement Temperature

SUPERPAVE software calculates high pavement temperature 20 mm below the pavement surface and low temperature at the pavement surface. For a wearing course at the top of a pavement section, the pavement temperatures in Topeka are 56° and -23° C for 50 percent reliability and 60° (56° + 2 standard deviations) and -31° C for 98 percent reliability (Figure VII-8).

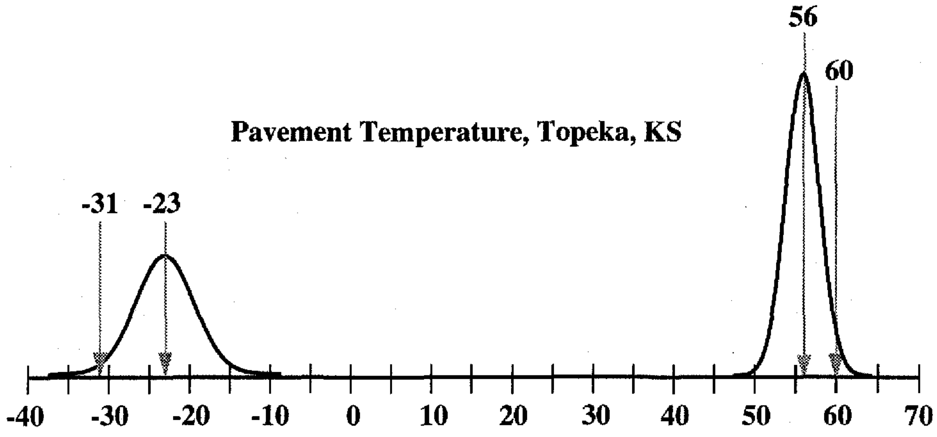


Figure VII-8. Distribution of High and Low Design Pavement Temperatures for Topeka, KS

Select Binder Grade

For a reliability of at least 50 percent, the high temperature grade must be PG 58. Selecting a PG 58 would actually result in a higher level of reliability of about 85 percent because of the "rounding up" to the next standard grade. The next lower grade only protects to 52° C, less than 50 percent reliability. The low temperature grade must be a PG -28. Likewise, rounding to this standard low temperature grade results in almost 90 percent reliability. For 98 percent reliability, the needed high temperature grade is PG 64; the low temperature grade is PG -34.

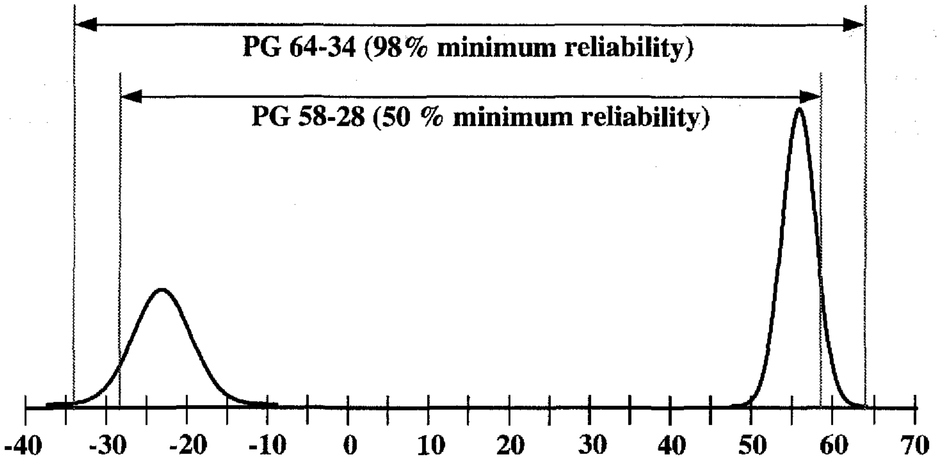


Figure VII-9. Various Binder Grades for Topeka, KS

Manipulating temperature frequency distributions is not a task that the designer need worry about. SUPERPAVE software handles the calculations. For any site, the user can enter a minimum reliability and SUPERPAVE will calculate the required asphalt binder grade. Alternately the user can specify a desired asphalt binder grade and SUPERPAVE will calculate the reliability obtained.

Effect of Loading Rate on Binder Selection

SUPERPAVE binder selection by climate only assumes that a binder will be used in a mixture subjected to fast moving loads. The loading rate used by the dynamic shear rheometer is 10 radians per second, which corresponds to a traffic speed of approximately 90 kilometers per hour. Much slower loading rates are experienced by pavements near intersections, toll booths, etc. In some cases, loads are not moving but rather are stationary. In these cases, a binder would have to exhibit a higher stiffness to overcome the slower loading rate.

To accommodate these situations, the high temperature grade should be increased by at least one or two grades. For example, if a temperature based selection resulted in a desired binder grade of PG 64-22, to account for slow transient loads, the designer would select one grade higher binder, a PG 70-22. If standing loads were anticipated, the designer would select a PG 76-22. Loading rate has no effect on the selected low temperature grade. Pavement design temperatures of 76° or 82° C do not correspond to any climate zone in North America. Specifying this grade is simply a means of ensuring that the binder will have higher stiffness at 64° C, the actual high pavement design temperature. Because the highest possible pavement temperature in North America is about 70° C, two additional high temperature grades, PG 76 and PG 82, were necessary to accommodate slow loading rates.

VIII.

SPECIFICATION TESTING

INTRODUCTION

There are two forms of testing associated with the new SUPERPAVE binder specification: *conformance* testing and *classification* testing. In both cases, a series of tests is performed on a binder sample and decisions are made on the basis of the results of these tests. To distinguish between these two forms of testing, consider the situation where an asphalt laboratory technician must test a sample of unknown properties.

Conformance testing answers the question, "does this material meet all the requirements of a PG 64-16?" In other words, specification conformance testing is an accept/reject form of testing where the properties of a binder sample are compared to the required properties for a single grade.

Classification testing answers the question, "what specification grade or grades does this sample meet?" In this case, a coordinated series of tests must be performed to classify the unknown material according to the SUPERPAVE binder specification.

Purchasing agencies such as state DOTs usually are concerned with conformance testing. For example, during a paving project, an agency laboratory often will collect and test an asphalt sample to make sure it conforms to the appropriate specification. If one or more test results do not achieve specified values, the sample is merely reported to be "out of spec." No further testing is necessary.

Research and development laboratories usually perform classification testing . For example, if an asphalt being tested does not meet the requirements of a PG 64-34, then the laboratory continues testing to see whether the asphalt might meet another grade.

While classification and conformance testing share all of the same tests, they vary in the decisions made as a result of each test. This section describes the steps and decisions necessary to conduct both types of testing.

CLASSIFICATION TESTING

Classification testing is a trial and error process. When performing SUPERPAVE binder tests on an asphalt sample of unknown performance grade, a technician observes test results and decides the direction in which the testing will proceed. In most cases, the decision will be to perform the same test at another temperature.

One important difference between the new SUPERPAVE binder specification and those currently in use is that under the new system, a binder sample often will meet several performance grades. A thorough understanding of this principle illustrates the reasoned approach that is employed in classification testing.

Binder Property	Binder Aging Condition	Test Result	Requirement
Flash Point	Unaged	293° C	230° C min
Viscosity at 135° C	Unaged	0.3 Pa-s	3 Pa-s max
Dynamic Shear, G*/sin δ at 64° C	Unaged	1.31 kPa	1.00 kPa min
Mass Loss	RTFO aged	0.32 %	1.00 % max
Dynamic Shear, G*/sin δ at 64° C	RTFO aged	2.63 kPa	2.20 kPa min
Dynamic Shear, G*sin δ at 22° C	PAV aged	4517 kPa	5000 kPa max
Creep Stiffness, S at -18° C	PAV aged	274 MPa	300 MPa max
m-value at -18° C	PAV aged	0.346	0.300 min

Consider the example shown in the preceding table of an asphalt binder that has been shown to conform to the requirements of a PG 64-28. The table shows test results at various temperatures. The following table shows a portion of the SUPERPAVE binder specification. The lightly shaded portion shows the temperature requirements that are common to all PG 64 grades. The darkly shaded portion shows the intermediate and low temperature requirements that are unique to a PG 64-28.

Performance Grade	**PG 52**							**PG 58**					**PG 64**				
	-10	-16	-22	-28	-34	-40	-46	-16	-22	-28	-34	-40	-16	-22	-28	-34	-40
Average 7-day Maximum Pavement Design Temperature, °C [a]	<52							<58					<64				
Minimum Pavement Design Temperature, °C [a]	>-10	>-16	>-22	>-28	>-34	>-40	>-46	>-16	>-22	>-28	>-34	>-40	>-16	>-22	>-28	>-34	>-40
Original Binder																	
Flash Point Temp, T48: Minimum, °C	230																
Viscosity, ASTM D 4402; [b] Maximum, 3 Pa·s (3000 cP), Test Temp, °C	135																
Dynamic Shear, TP5: [c] G*/sin δ, Minimum, 1.00 kPa Test Temperature @ 10 rad/s, °C	52							58					64				
Rolling Thin Film Oven (T 240) or Thin Film Oven (T179) Residue																	
Mass Loss, Maximum, %	1.0																
Dynamic Shear, TP5: G*/sin δ, Min, 2.20 kPa Test Temp @ 10 rad/sec, °C	52							58					64				
Pressure Aging Vessel Residue (PP1)																	
PAV Aging Temp, °C[d]	90							100					100				
Dynamic Shear, TP5: G*sin δ, Maximum, 5000 kPa Test Temp @ 10 rad/sec, °C	25	22	19	16	13	10	7	25	22	19	16	13	28	25	22	19	16
Physical Hardening [e]	Report																
Creep Stiffness, TP1: [f] S, Maximum, 300 MPa m-value, Minimum, 0.300 Test Temp, @60 sec, °C	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	-6	-12	-18	-24	-30
Direct Tension, TP3 [f] Failure Strain, Minimum, 1.0% Test Temp @ 1.0 mm/min, °C	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	-6	-12	-18	-24	-30

A PG 64-28, by definition, also is classified as a PG 64-22 and a PG 64-16. PG 64 binders (and in fact, all grades of binders) share the same unaged and RTFO aged G*/sin δ requirements. That is, they must all have a G*/sin δ of greater than 1.00 kPa for the unaged material and greater than 2.20 kPa for RTFO aged material. What distinguishes these PG 64 materials are their low temperature properties measured on RTFO/PAV aged materials. The PG 64-28 has a creep stiffness of 274 MPa at -18° C. If the creep stiffness had been performed at -12° or -6° C, it would be lower because creep stiffness gets smaller as temperature rises. The m-value of the PG 64-28 is 0.346 at -18° C. When tested at higher temperatures such as -12° or -6° C, the m-value would increase. Thus, both creep stiffness and m-value would move even farther from the specified values if the PG 64-28 binder were tested at higher temperatures. This is the reason that the PG 64-28 would, by definition, also classify as a PG 64-22 and PG 64-16.

Somewhat less obvious is the fact that this PG 64-28 also meets the requirements of a PG 58-22, and PG 58-16. Because the PG 64 grade has a G*/sin δ value of 1.31 kPa at 64° C, it clearly would have an even greater value at lower temperatures such as 58° C. The same concept also holds true for RTFO aged materials. Furthermore, the PG 64-28 meets the low temperature requirements of some PG-58 grades, but only down to a low temperature grade classification, -22° C. A *key specification provision* that must be understood when applying the specification is that the G*sin δ determined at intermediate temperatures may control the low temperature binder grade.

In this example, the binder has a G*sin δ of 4517 kPa at 22° C. In order for this material to be classified as a PG 58-28, it would have to have a G*sin δ of no more than 5000 kPa at 19° C. In fact, it could not possibly have had a G*sin δ of less than 5000 kPa at 19° C because then it would have been classified as a PG 64-34, which it was not. In other words, a PG 64-28 *may not* correspond to a PG 58-28 because they have different temperature requirements on G*sin δ.

The PG 64-28 probably meets the requirements of some PG 52 grades, most likely, PG 52-16 and PG 52-10. As always, the unaged and RTFO aged G*/sin δ requirements of PG 52 grades are the same as for the PG 64 binders. Thus, the PG 64-28 meets the high temperature properties of all PG 52 grades. However, unlike the analysis to this point, the low temperature portion of the PG 52 grade cannot be determined by simple deduction from knowing how the SUPERPAVE specification is applied. Instead, it must be determined by aging some of the PG 64-28 binder under the less severe PG 52 pressure aging conditions and measuring the low temperature properties of the aged residue. PG 52 binders are subjected to less rigorous pressure aging conditions (20 hours, 2070 kPa, 90° C) than PG 58 and PG 64 binders (20 hours, 2070 kPa, 100° C). Again, the factor that controls the low temperature grade is the binder's G*sin δ measured at intermediate temperatures.

It is also possible that the PG 64-28 binder might meet enough requirements to be classified as a PG 70 binder. In this example, it is unlikely that the binder in question would be classified as a PG 70 grade since its original and RTFO high temperature properties are very close to their minimum acceptable levels. The G*/sin δ of the unaged material would very likely fall below the minimum acceptable value of 1.00 kPa when tested at 70° C. A knowledgeable technician would make this determination first, thus eliminating the need for further, unnecessary testing.

This example illustrates the reasoned approach used by technicians when classifying binders of unknown grade according to the new SUPERPAVE binder specification. What follows is a general outline that should be used when classifying binders. This process shown in the flow charts shown in Figures VIII-1 through VIII-5.

The Classification Process

The most efficient way to accomplish classification testing is to first assume that the unknown binder conforms to a mid-specification binder such as a PG 64-22, PG 58-28, or PG 52-28. Next, G*/sin δ is measured on unaged binder (Figure VIII-1).

By comparing test results on unaged binder to specification criteria, after this step, one or both of these grade possibilities can be eliminated and the analysis can be focused on fewer grades. Note that this step can be accomplished very easily since a single sample can be tested at multiple temperatures. A prudent operator will measure G*/sin δ at a given temperature and depending on the test result, raise or lower the test temperature to achieve a passing or failing value. In classification testing, it is desirable to test the binder specimen at least at one passing and one failing test temperature.

Next, a sample of the unknown binder is aged in the RTFO. G*/sin δ of the residue is then measured. Again, comparing these test results to specification requirements may eliminate one of the original grade assumptions and cause the technician to focus on a particular grade. Figure VIII-2 summarizes this step.

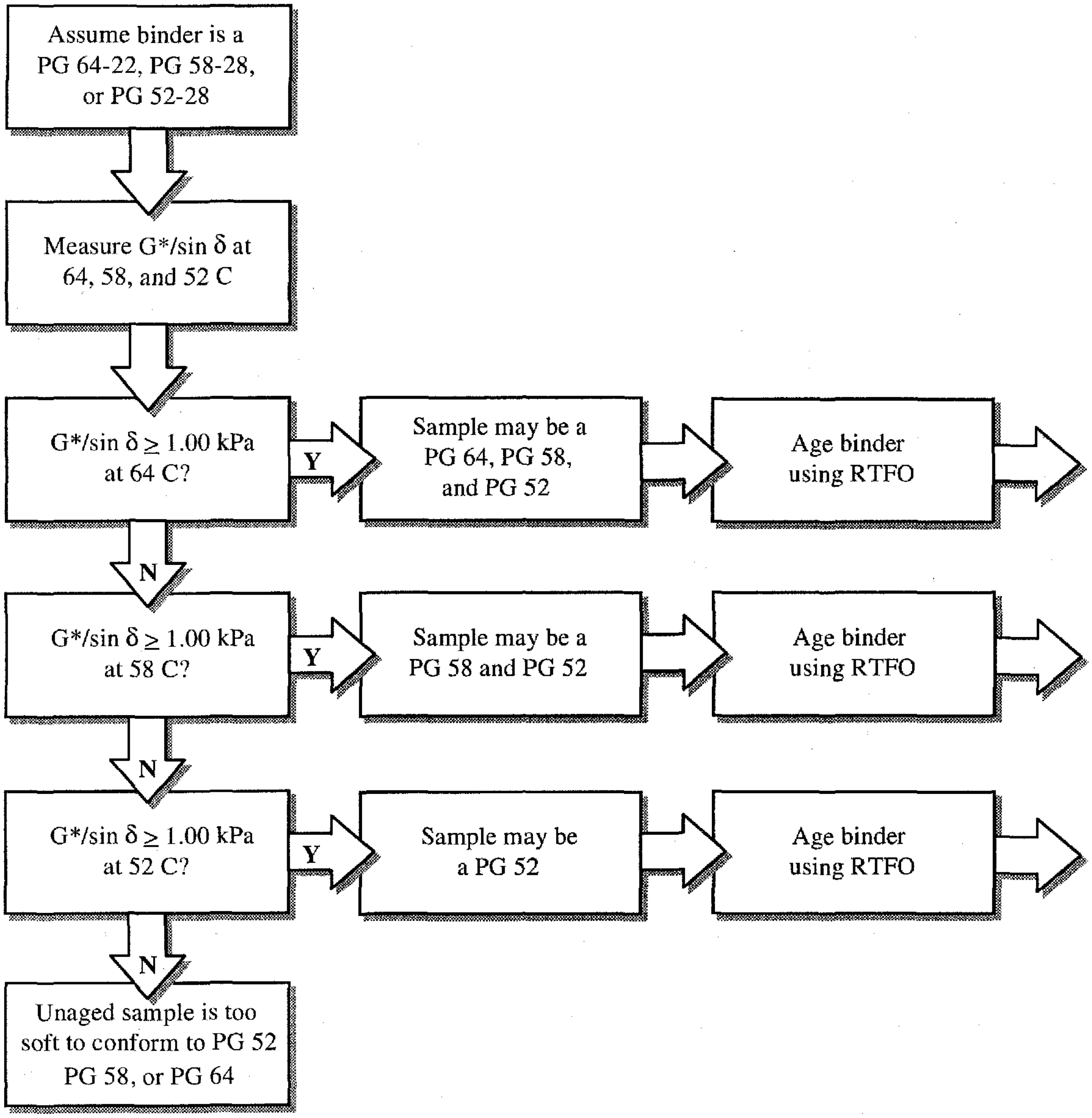


Figure VIII-1. Classification Testing - Unaged Binders

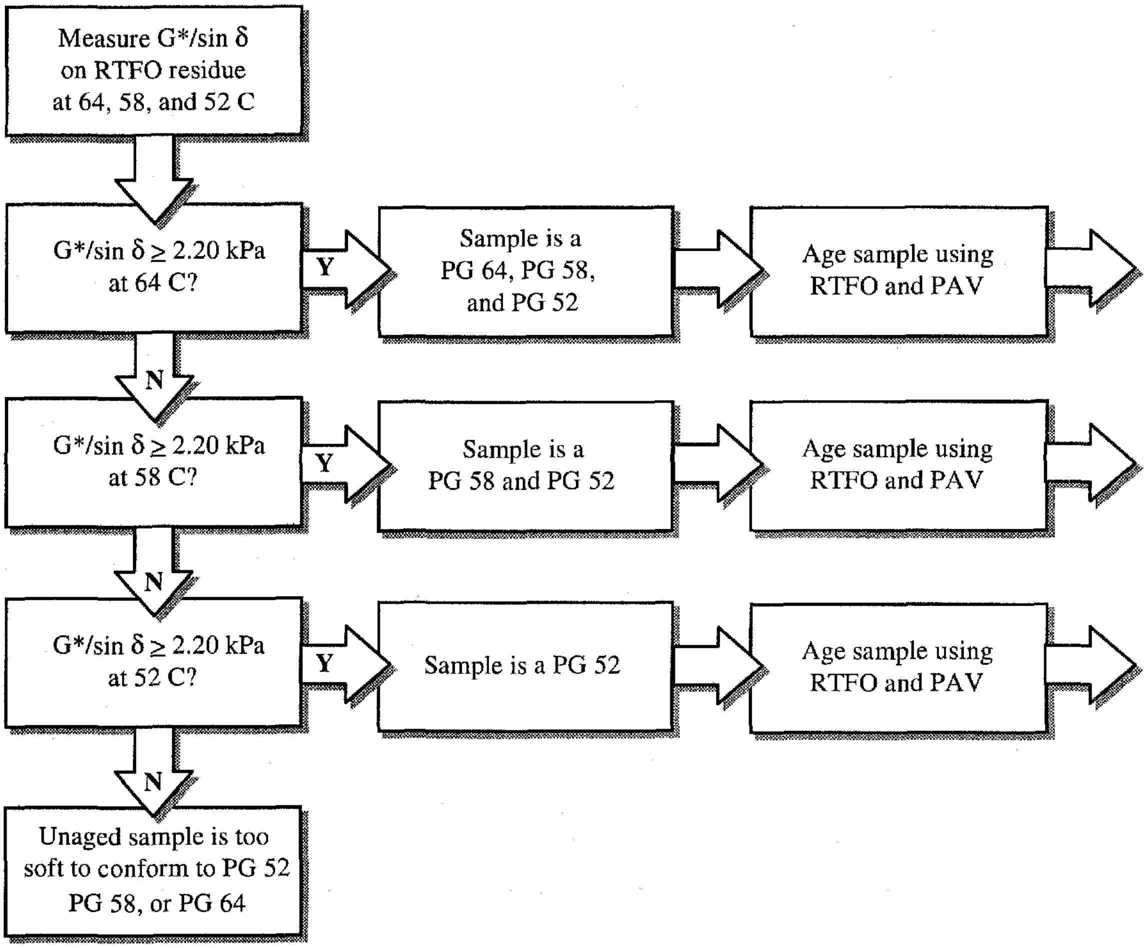


Figure VIII-2. Classification Testing - RTFO Aged Binders

Next, a sample is aged first in the RTFO and then in the PAV. Lower temperature, pressure aged properties (G*sin δ, creep stiffness, etc.) of the binder are measured next. Again, the tests should be performed at temperatures corresponding to mid-grades such as -28 or -22. Note that these values are grades and not actual test temperatures. G*sin δ for these two temperatures would be measured at 19° and 22° C, respectively, for a PG 58 grade. Creep stiffness, m-value, and tensile strain at failure for -28 and -22 grades are measured at -18 and -12, respectively.

Since it is the easiest property to determine, begin by measuring G*sin δ at mid-range temperatures for the assumed grade. The mid-range temperatures depend on the high temperature grade. For example, mid-range temperatures for a PG 58 are 22°, 19°, and 16° C. For a PG 64, mid-range temperatures are 19°, 22°, and 25° C. Again, this can easily be accomplished by testing a single specimen. During this test, the technician can observe test results and measure G*sin δ at a lower temperature if necessary. The technician should search for the lowest temperature that still meets the maximum G*sin δ requirement of 5000 kPa. This temperature is used as a ***starting point temperature*** for creep stiffness and tensile failure strain measurements. Figures VIII-3 and VIII-4 show the steps necessary to obtain a starting point for creep stiffness testing for PG 58 and PG 64 grades. Similar flow charts would be evident for PG 70 and PG 52 grades.

Next, creep stiffness and m-value are measured on PAV residue at this starting point temperature. By observing these test results, the technician may proceed in one of three ways. Figure VIII-5 shows how creep stiffness and m-value results are used to establish binder grade.

First, if both the creep stiffness and m-value meet specified values (300 MPa and 0.300) at the first trial temperature, the technician need not perform any additional tests. The low temperature grade is established. While it is possible that acceptable values of creep stiffness and m-value could be obtained at lower temperatures, these temperatures would already have been eliminated by the G*sin δ results.

Second, if the creep stiffness at this temperature exceeds the maximum acceptable value, 300 MPa, but is less than 600 MPa and the m-value meets the specified value of 0.300, the technician should proceed with measuring the tensile strain at failure. If the tensile strain at failure exceeds the minimum 1.0 percent specification limit, then a creep stiffness value in the range from 300 to 600 MPa is considered acceptable. Again, the low temperature grade has been established. If the tensile failure strain is less than 1.0 percent, then the technician needs to fabricate another set of beams and measure creep stiffness and m-value at one grade higher temperature.

Third, if at the starting point temperature, the creep stiffness exceeds 600 MPa or the m-value is less than 0.300, the technician should fabricate additional beam samples and measure creep stiffness and m-value at one grade higher temperature. Note that the tensile strain at failure has no bearing on the limiting m-value.

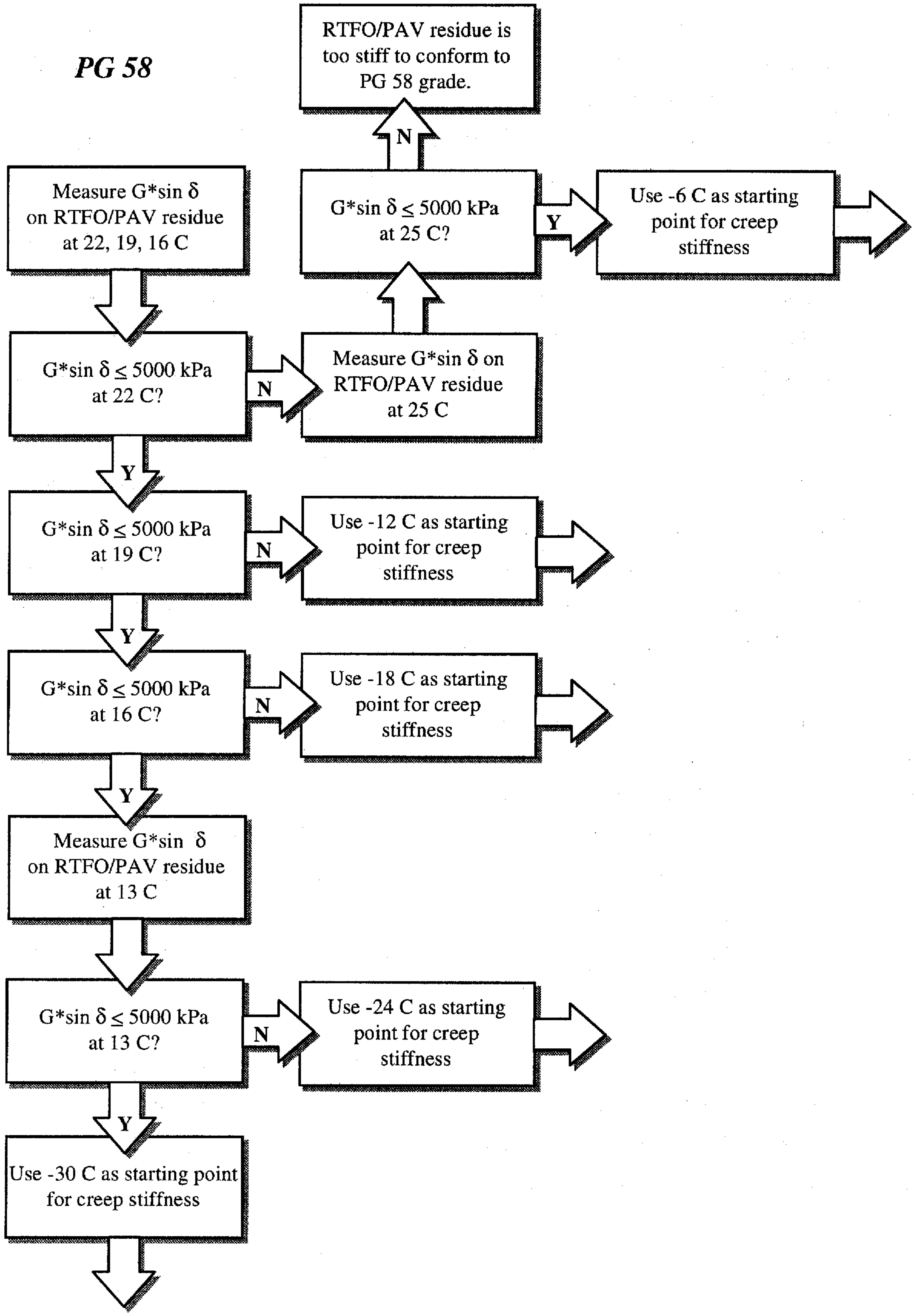


Figure VIII-3. Classification Testing - Low Starting Point Temperature (PG 58)

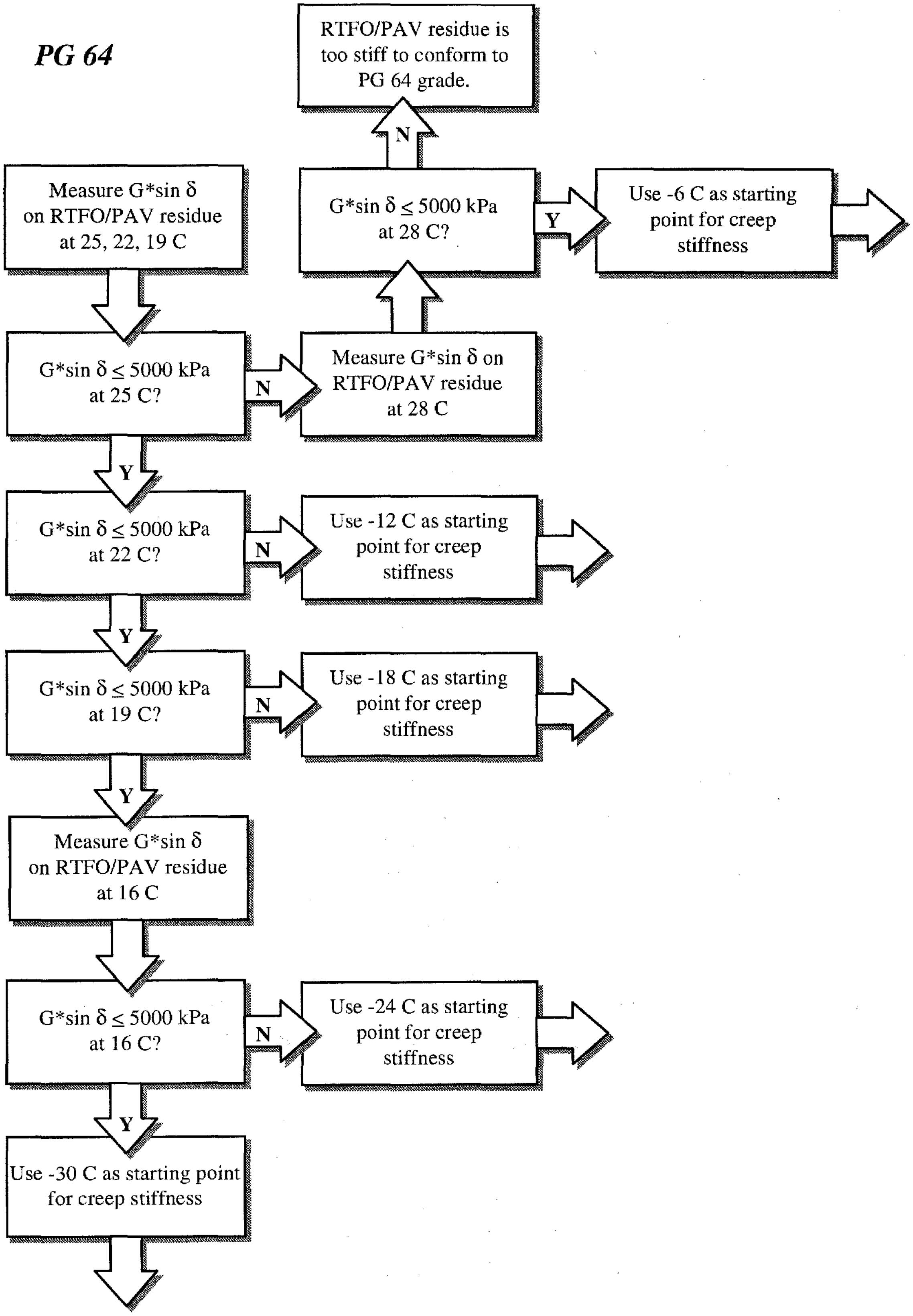


Figure VIII-4. Classification Testing - Low Starting Point Temperature (PG 64)

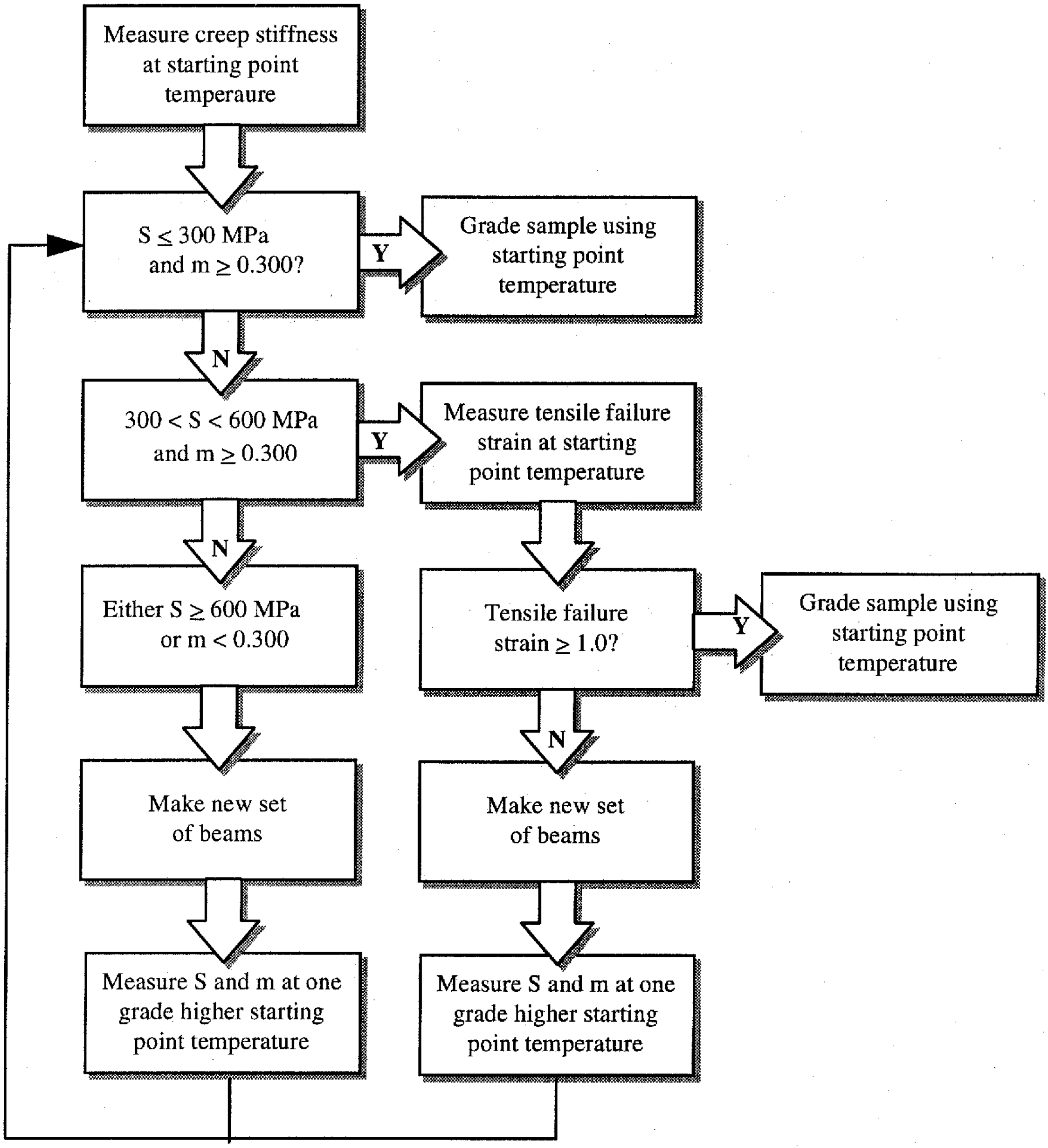


Figure VIII-5. Classification Testing - Establishing Low Temperature Binder Grade with Creep Stiffness, m-Value, and Tensile Failure Strain

Even though the G*sin δ results established the starting point temperature for creep stiffness and m-value measurements, the technician may need to cycle through progressively higher temperatures until acceptable values result. In these cases, it is not necessary to measure G*sin δ at these higher temperatures since an acceptable value would have already been established at a lower temperature.

CONFORMANCE TESTING

As previously discussed, conformance testing determines whether a binder sample meets the requirements for a particular performance grade. This process is similar to but somewhat easier than classification testing. It involves performing binder tests only at the temperatures required for the unique grade. Each step in the conformance testing process is followed by a accept/reject decision. If after any step a specified requirement is not achieved, the technician need go no further. Figure VIII-6 shows some of the steps in the conformance testing process for a PG 58-22. The same flow chart would be used for any other grade by simply changing the temperatures at which the criteria are to be achieved.

Several decisions are necessary in this process and they involve the creep stiffness test result. These are shown in Figure VIII-7 which is a continuation of the conformance testing process for the PG 58-22 used in Figure VIII-6.

If the measured value is less than or equal to 300 MPa and the m-value is greater than or equal to the specified value of 0.300, then the conformance testing process is complete and the binder conforms to the specified grade. If the measured value is between 300 and 600 MPa *and* the m-value meets the minimum specified value of 0.300, then the tensile strain at failure needs to be measured to verify that it is greater than or equal to 1.0 percent, in which case the binder conforms to the specified grade. If in this situation, the tensile failure strain is less than 1.0 percent, then the binder fails to conform to the grade specified. If the creep stiffness value is greater than 600 MPa and/or the m-value is less than 0.300, the binder fails to conform to the grade for which it is being tested and the tensile failure strain does not need to be measured.

COMMON TESTING

Several other test results are necessary to fully characterize binders according to the SUPERPAVE specification. These results are accept/reject types, but are constant for all grades. Consequently, they share equal roles in classification and conformance testing.

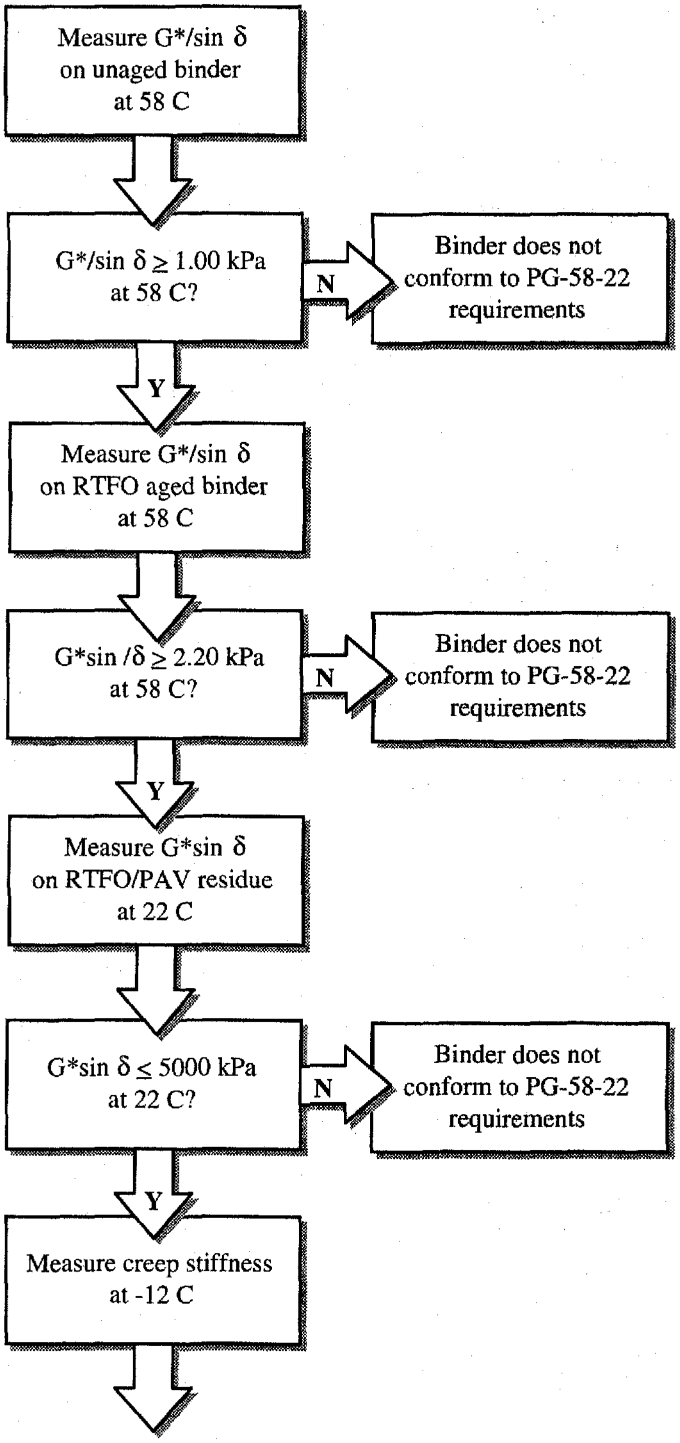


Figure VIII-6. Conformance Testing Process for a PG 58-22

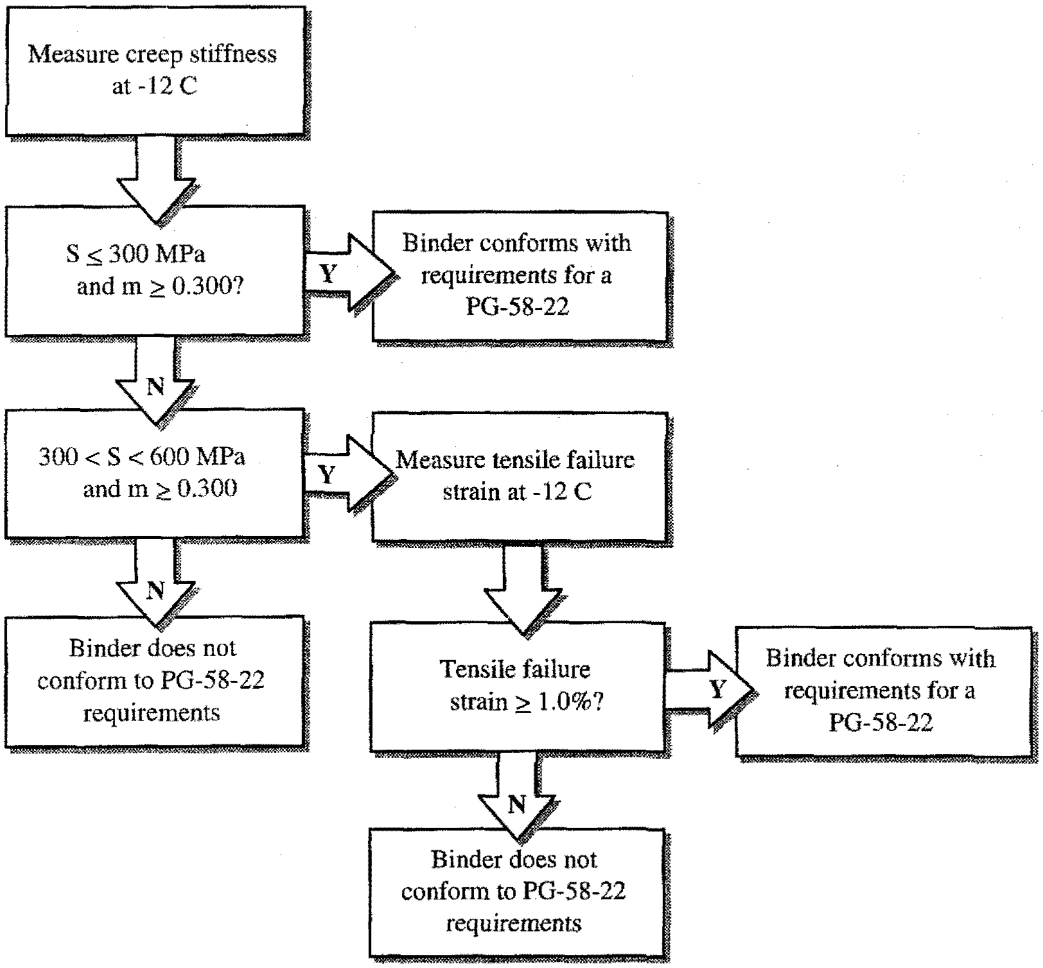


Figure VIII-7. Conformance Testing Process for a PG 58-22 (continued)

The rotational viscosity of the unaged binder is measured at 135° C using a rate of 20 rpm to ensure that the binder can be adequately pumped at the hot mixing facility. A maximum value of 3 Pa-s is allowed. A note in the specification indicates that higher values are allowed if the supplier of the binder "warrants that the asphalt binder can be adequately pumped and mixed at temperatures that meet all applicable safety standards."

The SUPERPAVE binder specification requires that binder flash point be measured by AASHTO T48 (Cleveland Open Cup). Regardless of grade, a minimum value of 230° C is required.

While no limiting values are specified, the physical hardening needs to be determined and reported for the pressure aged binder. This requires measuring the creep stiffness and m-value of the pressure aged binder at the same grading temperature that was used to classify the sample. To accomplish this, another sets of beams is fabricated using pressure aged binder. This set is conditioned for 24 hours and likewise tested for creep stiffness and m-value. These values are reported, although no specified values need be achieved.

As part of the RTFO aging process, the mass loss must be measured. The maximum acceptable value is 1.00 percent, which is constant for all performance grades.

APPENDIX A

Performance Graded Binder Specification

Performance Graded Binder Specification

Performance Grade	PG 52							PG 58					PG 64					PG 70			
	-10	-16	-22	-28	-34	-40	-46	-16	-22	-28	-34	-40	-16	-22	-28	-34	-40	-10	-16	-22	-28
Average 7-day Maximum Pavement Design Temperature, °C[a]	<52							<58					<64					<70			
Minimum Pavement Design Temperature, °C[a]	>-10	>-16	>-22	>-28	>-34	>-40	>-46	>-16	>-22	>-28	>-34	>-40	>-16	>-22	>-28	>-34	>-40	>-10	>-16	>-22	>-28
Original Binder																					
Flash Point Temp, T48: Minimum °C	230																				
Viscosity, ASTM D 4402:[b] Maximum, 3 Pa·s (3000 cP), Test Temp, °C	135																				
Dynamic Shear, TP5:[c] G*/sin δ, Minimum, 1.00 kPa Test Temperature @ 10 rad/s, °C	52							58					64					70			
Rolling Thin Film Oven (T240) or Thin Film Oven (T179) Residue																					
Mass Loss, Maximum, %	1.00																				
Dynamic Shear, TP5: G*/sin δ, Minimum, 2.20 kPa Test Temp @ 10 rad/sec, °C	52							58					64					70			
Pressure Aging Vessel Residue (PP1)																					
PAV Aging Temperature, °C[d]	90							100					100					100(110)			
Dynamic Shear, TP5: G*sin δ, Maximum, 5000 kPa Test Temp @ 10 rad/sec, °C	25	22	19	16	13	10	7	25	22	19	16	13	28	25	22	19	16	34	31	28	25
Physical Hardening[e]	Report																				
Creep Stiffness, TP1:[f] S, Maximum, 300 MPa m-value, Minimum, 0.300 Test Temp, @ 60 sec, °C	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	-6	-12	-18	-24	-30	0	-6	-12	-18
Direct Tension, TP3:[f] Failure Strain, Minimum, 1.0% Test Temp @ 1.0 mm/min, °C	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	-6	-12	-18	-24	-30	0	-6	-12	-18

Notes:

a. Pavement temperatures can be estimated from air temperatures using an algorithm contained in the SUPERPAVE software program or may be provided by the specifying agency, or by following the procedures as outlined in PPX.

b. This requirement may be waived at the discretion of the specifying agency if the supplier warrants that the asphalt binder can be adequately pumped and mixed at temperatures that meet all applicable safety standards.

c. For quality control of unmodified asphalt cement production, measurement of the viscosity of the original asphalt cement may be substituted for dynamic shear measurmeents of G*/sin δ at test temperatures where the asphalt is a Newtonian fluid. Any suitable standard means of viscosity measurement may be used, including capillary or rotational viscometry (AASHTO T 201 or T 202).

d. The PAV aging temperature is based on simulated climatic conditions and is one of three temperatures 90° C, 100° C or 110° C. The PAV aging temperature is 100° C for PG 58- and above, except in desert climates, where it is 110° C.

e. Physical Hardening - TP 1 is performed on a set of asphalt beams according to Section 13.1, except the conditioning time is extended to 24 hrs ± 10 minutes at 10° C above the minimum performance temperature. The 24-hour stiffness and m-value are reported for information purposes only.

f. If the creep stiffness is below 300 MPa, the direct tension test is not required. If the creep stiffness between 300 and 600 MPa the direct tension failure strain requirement can be used in lieu of the creep stiffness requirement. The m-value requirement must be satisfied in both cases.

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