MATERIALS

The modern use of asphalt for road and street construction began in the late 1800s and grew rapidly with the emerging automobile industry. Since then, asphalt technology has made giant strides. Today, highly sophisticated equipment and techniques are used to build hot mix asphalt (HMA) pavements. One rule that has remained constant throughout asphalt's long history in construction is this: *A pavement is only as good as the materials and workmanship that go into it.* No amount of sophisticated equipment can make up for use of poor materials or poor construction practices. This chapter is a discussion of materials used in quality HMA pavements – what they are, how they behave and how to tell whether or not particular materials are suitable for a paving project. The objectives of this chapter are to:

- Understand the properties of asphalt cement and the asphalt grading systems used.
- Recognize the principal tests for identifying certain properties of asphalt.
- Know the procedures for safe and proper storage, handling and sampling of asphalt.
- Recognize the proper methods for handling and stockpiling aggregates.
- Understand the various aggregate classifications and sources.
- Understand certain aggregate properties and the evaluation of aggregate test procedures.

General Information

Asphalt pavements are composed of two materials: asphalt and aggregate (rock). There are many different types of asphalts and aggregates. Consequently, it is possible to make different kinds of asphalt pavements. Among the most common types of asphalt pavements are:

- Dense-graded hot mix asphalt
- Open-graded surface and base courses
- Stone-filled mixes
- Sand hot mix asphalt
- Sheet hot mix asphalt
- Asphalt emulsion mixes (cold mixes)

Hot mix asphalt pavement is the highest quality among the different types. It consists of well-graded aggregate and asphalt cement, which are heated and blended together in exact proportions at a hot mix plant. When all the aggregate particles are uniformly coated, the HMA is hauled to the construction site where an asphalt paver places it onto the prepared roadbed. Before the mixture cools, rollers compact (densify) it into a final pavement to achieve a specified density.

Other pavement types are produced and placed in similar ways. Cold mix pavements use asphalt emulsion or cutback asphalt in accordance with local environmental guidelines. They require little or no heating of materials and can often be produced at the construction site without a central plant. Only HMA is discussed in this manual.

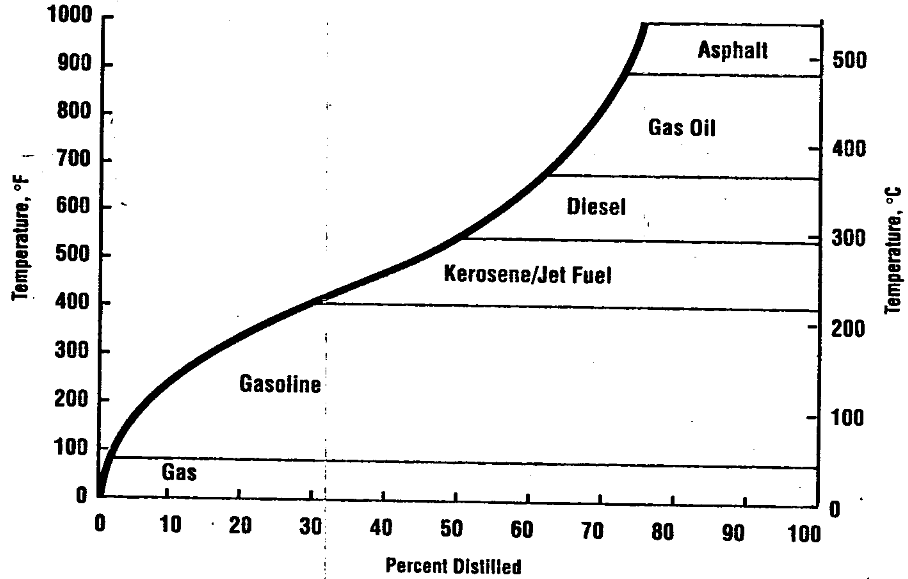

Figure 2.01 Typical Crude Oil Distillation Temperatures and Products

Asphalt

Asphalt is a black, cementitious material that varies widely in consistency from solid to semisolid (soft solid) at normal air temperatures. Asphalt is made up largely of a hydrocarbon called bitumen. Consequently, it is often called a bituminous material. Asphalt is also a thermoplastic material because its consistency changes as its temperature changes. When heated sufficiently it softens and becomes a liquid, thus allowing it to coat aggregate particles during hot mix production. When it cools, asphalt hardens and holds the particles together.

At one time natural asphalt was available, but virtually all asphalt used today is produced by petroleum refineries. The degree of control allowed by modern refinery equipment permits asphalt production for specific applications. As a result, different asphalts are produced for paving, roofing and other special applications.

Paving asphalt, commonly called asphalt cement or asphalt binder, is a highly viscous (thick), sticky material. It adheres readily to aggregate particles, making it an excellent cement. Asphalt cement is an excellent waterproofing material and is unaffected by most acids, alkalis (bases) and salts. This means that a properly constructed HMA pavement is waterproof and resistant to many types of chemical damage.

➤➤Source and Nature of Asphalt

Because asphalt is available in many types for various purposes, there is sometimes confusion about where asphalt comes from, how it is produced, and how it is classified into grades. The purpose of this section is to describe the source and nature of asphalt types suitable for hot mixing with aggregate for pavement construction. A glossary of common terms related to various asphalt types is found in Appendix B of this manual.

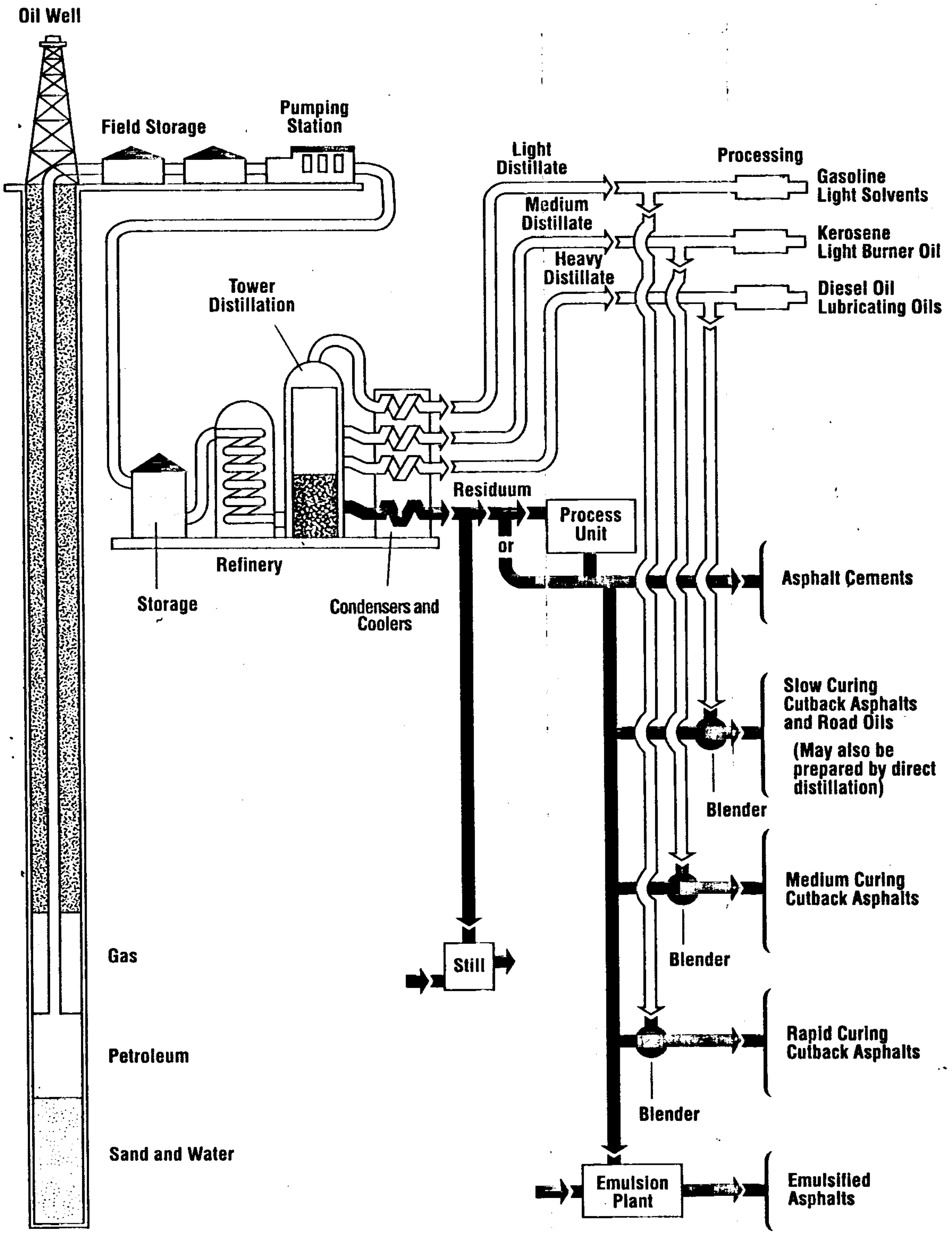

Figure 2.02 Typical Refining Process

Petroleum Refining The production of asphalt begins with the petroleum refining of crude oil. Crude oil is processed by a refinery and is initially separated into several fractions or parts by high temperature distillation as shown in Figure 2.01. Heavy fractions are produced into asphalt while lighter fractions are processed into gasoline, kerosene, diesel fuel, jet fuel and other petroleum products. First, the crude oil is heated to approximately 700°F before being released as mostly vapor into a fractionation tower. The tower contains several temperature zones to permit the vapor to condense into various fractions. A second heater and tower at 700°F may also be employed to simulate much higher temperatures by drawing a vacuum on the tower. This results in further separation into additional fractions. Each fraction is directed through further processing to make modern day fuels and other petroleum products. Figure 2.02 is a simplified illustration of a refinery showing the flow of petroleum during the refining process.

Asphalt Refining Different types and grades of asphalt are required for various applications. To produce asphalts that meet specific requirements, a refinery employs one or more methods to achieve the properties of the desired grade. This is often accomplished by blending crude oils from various sources together before processing (when these crude oils are known to yield the desired properties).

Further control of asphalt properties can be achieved when the crude oil is processed by high temperature and vacuum distillation. Subtle adjustment to temperature and vacuum level affects the amount of soft compounds removed such that the heaviest fraction will exhibit the desired physical properties of asphalt. Some refineries are equipped with solvent-based extraction units, which are effective in removing the soft compounds from the heavy distillation fraction. Solvent extraction of soft compounds usually yields an asphalt product which is very hard and stiff – as desired for certain industrial applications. This hard asphalt can also be blended with softer or less stiff asphalt produced from other crude oils, or at other refineries, to make the final desired asphalt grade.

In summary, crude oil or crude oil blends are used to produce asphalt with specific characteristics. Asphalt is separated from the other fractions by vacuum distillation or solvent extraction and then blended with other asphalts as needed to meet the desired specification.

➤➤Asphalt Behavior

Asphalt is a *viscoelastic* material. This means that asphalt has the properties of both a viscous material and an elastic material. The property that asphalt exhibits, whether viscous, elastic or most often a combination of both, depends on *temperature* and *time of loading* (Figure 2.03). The flow behavior of an asphalt could be the same for one hour at 60°C (140°F) or 10 hours at 25°C (77°F). In other words, the effects of time and temperature are related. The behavior at high temperatures over short time periods is equivalent to what occurs at lower temperatures and longer times.

High Temperature Behavior In hot conditions (e.g., desert climate) and/or under sustained loads (e.g., slow moving trucks), asphalt cements behave and flow like *viscous* liquids (Figure 2.04). Viscosity is the material characteristic used to describe the resistance of liquids to flow. Viscous liquids, like hot asphalt, are sometimes called *plastic* because once they start flowing they do not return to their original position.

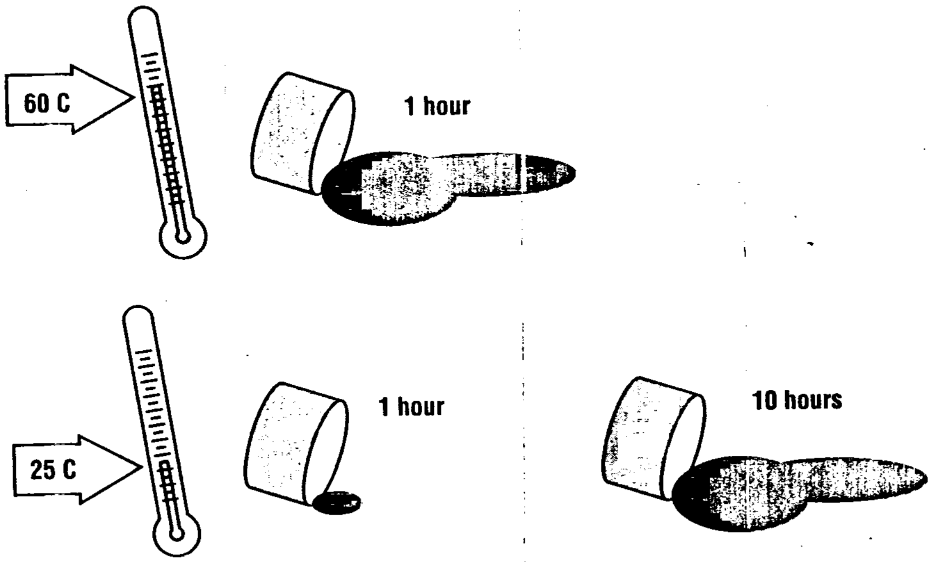

Figure 2.03 Asphalt Flow Behavior

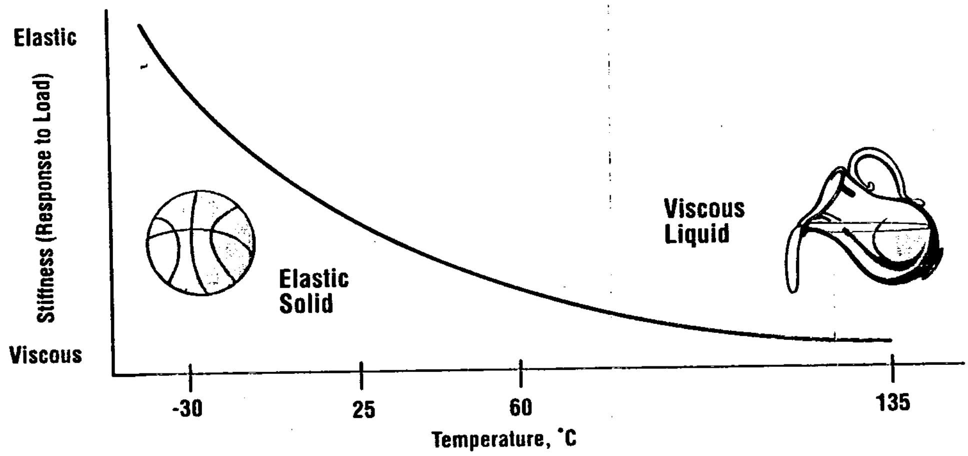

Figure 2.04 Asphalt Behavior at Varying Temperatures

Low Temperature Behavior In cold climates or under rapid loading (e.g., fast moving trucks), asphalt cements behave like *elastic* solids (Figure 2.04). Elastic solids are like rubber bands. When loaded they deform and when unloaded they return to their original shape. Any elastic deformation is completely recovered.

Low temperature cracking sometimes occurs in asphalt pavements during cold weather. In these cases non-load related internal stresses accumulate in the pavement as it tries to shrink and is restrained (e.g., as when temperatures fall during and after a sudden cold front).

Intermediate Temperature Behavior Most environmental conditions lie between the extreme hot and cold situations. In these climates, asphalt cements exhibit the characteristics of both viscous liquids and elastic solids. Because of this range of behavior, asphalt is an excellent adhesive material for paving, yet an extremely complicated material to understand and explain. When heated, asphalt acts as a lubricant, allowing the aggregate to be mixed, coated and tightly-compacted to form a smooth, dense surface. After cooling, the asphalt acts as the glue to hold the aggregate together in a solid matrix. In this finished state, asphalt is considered viscoelastic. It has both elastic and viscous characteristics, depending on the temperature and loading rate.

This kind of response to load can be related conceptually to an automobile's shock absorbing system. These systems contain a spring and a liquid filled cylinder. The spring is elastic and returns the car to the original position after hitting a bump. The viscous liquid within the cylinder dampens the force of the spring and its reaction to the bump. Any force exerted on the car causes a parallel reaction in both the spring and the cylinder. In hot mix asphalt, the spring represents the immediate elastic response of both the asphalt and the aggregate. The cylinder symbolizes the slower, viscous reaction of the asphalt, particularly in warmer temperatures. Most of the response is elastic or viscoelastic (recoverable with time), while some of the response is plastic and non-recoverable.

Aging Behavior Because asphalt cements are composed of organic molecules, they react with oxygen from the environment. This reaction is called oxidation and it changes the structure and composition of asphalt molecules. Oxidation causes asphalt cement to harden, hence the term oxidative hardening or age hardening.

In practice, some oxidative hardening occurs before the asphalt is placed. At the hot mix facility, asphalt cement is added to hot aggregate and the mixture is maintained at elevated temperatures for a period of time. Because asphalt cement exists in thin films covering the aggregate, the oxidation reaction occurs at a faster rate. "Short term aging" is used to describe the aging that occurs in this stage of the asphalt's life.

Oxidative hardening also occurs during the life of the pavement because of exposure to air and water. "Long-term aging" happens at a relatively slow rate in a pavement, although it occurs faster in warmer climates and during warmer seasons. Because of this hardening, old asphalt pavements are more susceptible to cracking. Improperly compacted asphalt pavements may exhibit premature oxidative hardening because of a higher percentage of interconnected air voids. This allows more air to penetrate into the asphalt mixture, increasing oxidative hardening.

➤➤Asphalt Classification and Grading

Classification of Asphalt Paving asphalts are classified into three general types:

- Asphalt cement
- Asphalt emulsion
- Cutback asphalt

Each is defined in Appendix B. Cutbacks and emulsions are used almost entirely for cold mixing and spraying and will not be discussed further in this chapter.

Because of its chemical complexities, asphalt specifications have been developed around physical property tests, such as penetration, viscosity and ductility. These tests are performed at standard test temperatures, and the results are used to determine if the material meets the specification criteria.

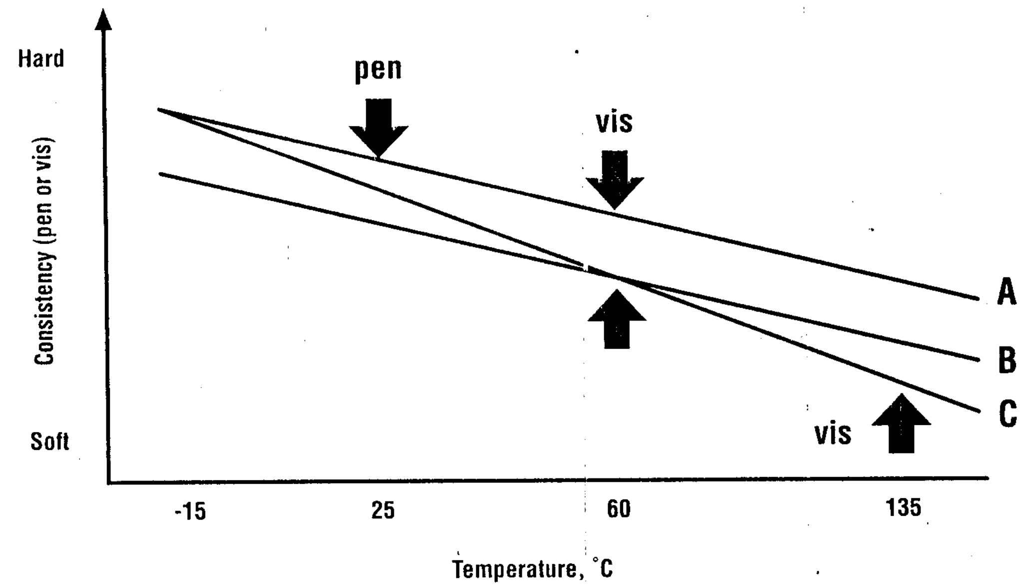

Figure 2.05 Variations of Three Viscosity-Graded Asphalts

As asphalt cement specifications evolve, limitations of previous specifications are overcome. Many asphalt tests are empirical. Field experience is required before these test results yield meaningful information. Penetration is an example of this. The penetration test represents the stiffness of the asphalt, but any relationship between asphalt penetration and performance has to be viewed through experience. Many times the correlation between test results and performance may not be very good.

Another limitation is that specifications do not illustrate the entire range of typical pavement temperatures. No low temperature properties are directly measured in the penetration and viscosity grading systems. Although viscosity is a fundamental measure of flow, it only provides information about higher temperature viscous behavior [60°C (140°F) and 135°C (275°F)]. Penetration describes only the consistency at a medium temperature [25°C (77°F)]. Low temperature behavior cannot be realistically determined from this data to predict performance.

With these limitations it is evident that penetration and viscosity asphalt specifications can classify different asphalts into the same grade. In fact these asphalts may have very different temperature and performance characteristics. Figure 2.05 shows three asphalts having the same viscosity grade because they:

- Are within the specified viscosity limits at 60°C (140°F).
- Have the minimum penetration at 25°C (77°F).
- Are above the minimum viscosity at 135°C (275°F).

While Asphalts A and B display the same temperature dependency, they have much different consistency at all temperatures. Asphalts A and C have the same consistency at -15°C but remarkably different high temperature consistency. Asphalt B has the same consistency at 60°C (140°F) but shares no other similarities with Asphalt C. Because these asphalts meet the same grade specifications, one might erroneously expect the same characteristics during construction and the same performance during hot and cold weather conditions.

Performance grading (PG) has been developed through Superpave to overcome the limitations of empirical tests and insufficient temperature characterization. The PG system uses performance-based tests to relate laboratory data to field performance. The PG tests characterize asphalts throughout the broad range of temperatures encountered in asphalt pavements.

Asphalt Specifications and Grades Asphalt cements can be graded according to four different systems:

- Penetration
- Viscosity
- Viscosity after aging
- Performance grade (PG)

The PG system has generally superceded the other systems in the U.S.

Penetration grading (ASTM D 946/AASHTO M 20) describes relative hardness based on the penetration test. In penetration grading, the higher the number the softer the asphalt. A 200-300 penetration grade asphalt is softer than a 40-50 penetration grade.

The viscosity gradings (ASTM D 3381/AASHTO M 226) use a numbering system to describe relative viscosity. The higher the number the more viscous (or thicker) the asphalt. For example, an AC-10 is softer than an AC-40.

In the viscosity after aging system (also ASTM D 3381/AASHTO M 226), asphalt is classified after it has been artificially aged. The prefix AR is used for "Aged Residue." Again; the higher the number the more viscous the material. So an AR-4000 is a softer asphalt than an AR-16000.

The performance grade, or PG system (AASHTO MP 1), describes asphalt based on the pavement temperatures under which the asphalt is expected to perform. The PG system is a part of the Superpave system. A PG 64-28 asphalt is designed for pavement temperatures as high as 64°C and as low as -28°C.

➤➤ Testing of Asphalt Cement

This section describes, in general terms, three of the test methods for classifying asphalt. The ASTM and AASHTO references that detail the equipment and procedures related to each test are listed in Appendix D.

Penetration The *penetration* test is an empirical measure of the hardness of asphalt at room temperature. The standard penetration test (Figure 2.06) begins with conditioning a sample of asphalt cement to a temperature of 25°C (77°F) in a temperature-controlled water bath. A standard needle is then brought to bear on the surface of the asphalt under a load of 100 grams for exactly five seconds. The distance that the needle penetrates into the asphalt cement is recorded in units of 0.1 mm. The distance the needle travels is called the "penetration" of the sample.

Viscosity In the *viscosity* system, the result of the viscosity test at 60°C (140°F) is used to grade an asphalt cement. This test represents asphalt viscosity at the maximum temperature the pavement is likely to experience while in service. The result of a second viscosity test performed at 135°C (275°F) approximates the viscosity of the asphalt during mixing and laydown. Knowing the asphalt consistency at these two temperatures is the major factor in determining if the asphalt meets the specification requirements.

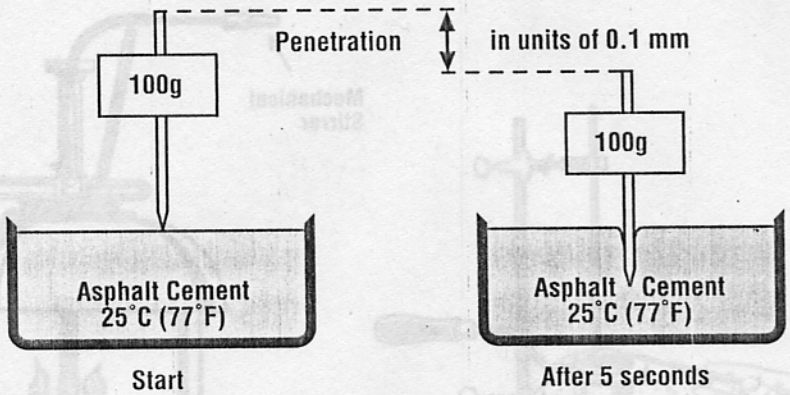

Figure 2.06 Penetration Test

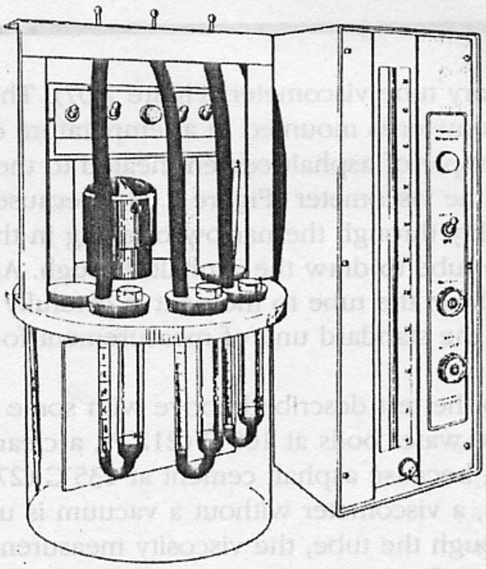

Figure 2.07 Capillary Tube Viscometer In Temperature-Controlled Water Bath

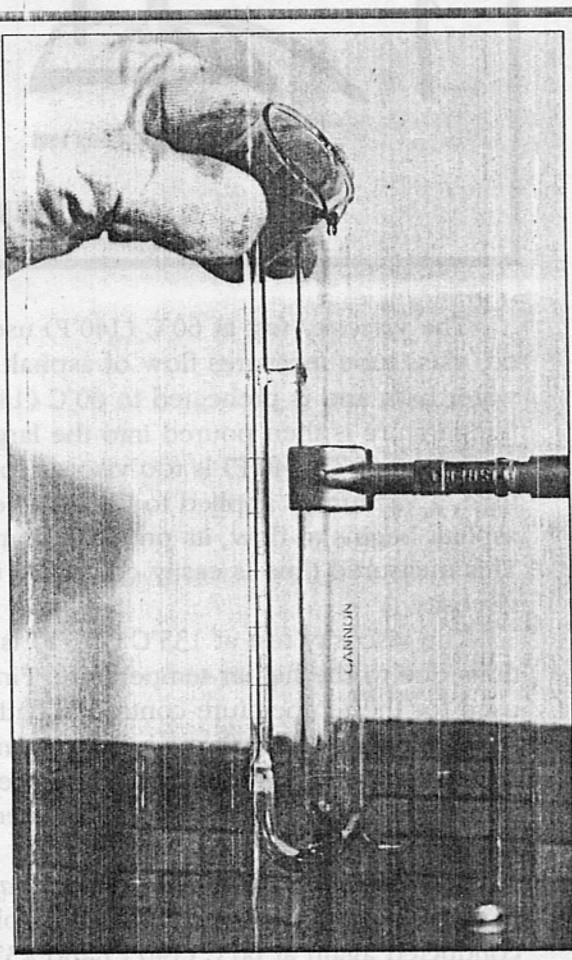

Figure 2.08 Pouring Asphalt Cement Sample Into Viscometer

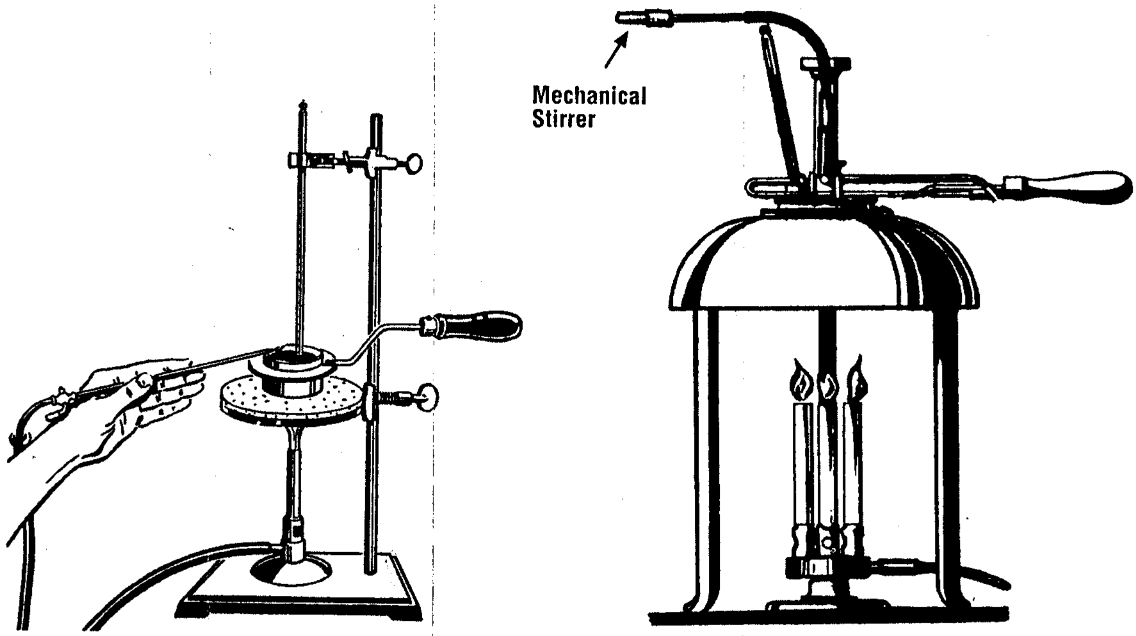

Figure 2.09 Flashpoint Tests

The viscosity test at 60°C (140°F) uses a capillary tube viscometer (Figure 2.07). This calibrated, glass tube measures flow of asphalt. The viscometer is mounted in a temperature controlled water bath and is preheated to 60°C (140°F). A sample of asphalt cement heated to the same temperature is then poured into the large end of the viscometer (Figure 2.08). Because asphalt cement at 60°C (140°F) is too viscous to flow readily through the narrow opening in the capillary tube, a vacuum is applied to the small end of the tube to draw the asphalt through. As the asphalt begins to flow, its progress from one mark on the tube to the next is carefully timed. This measured time is easily converted to poises, the standard unit of measurement for asphalt viscosity.

The viscosity test at 135°C (275°F) is similar to the test described above with some adaptations due to the higher temperature. First, because water boils at 100°C (212°F), a clear oil is used for the temperature-controlled bath. Second, because asphalt cement at 135°C (275°F) is fluid enough to flow through the viscometer tube, a viscometer without a vacuum is used. Third, because gravity is used to induce flow through the tube, the viscosity measurement is in centistokes instead of poises (see Appendix B for definitions).

Viscosity After Aging The *viscosity after aging* system classifies asphalt cements after they have been artificially aged using the Rolling Thin Film Oven procedure. The viscosity tests are conducted again at 60°C (140°F) and 135°C (275°F), but in accordance with Table 3 of the referenced specifications. The AR grade is determined from the viscosity test result at 60°C (140°F).

Flashpoint The *flashpoint* of asphalt cement is the lowest temperature at which volatile gases separate from a sample to "flash" in the presence of an open flame. Flashpoint must not

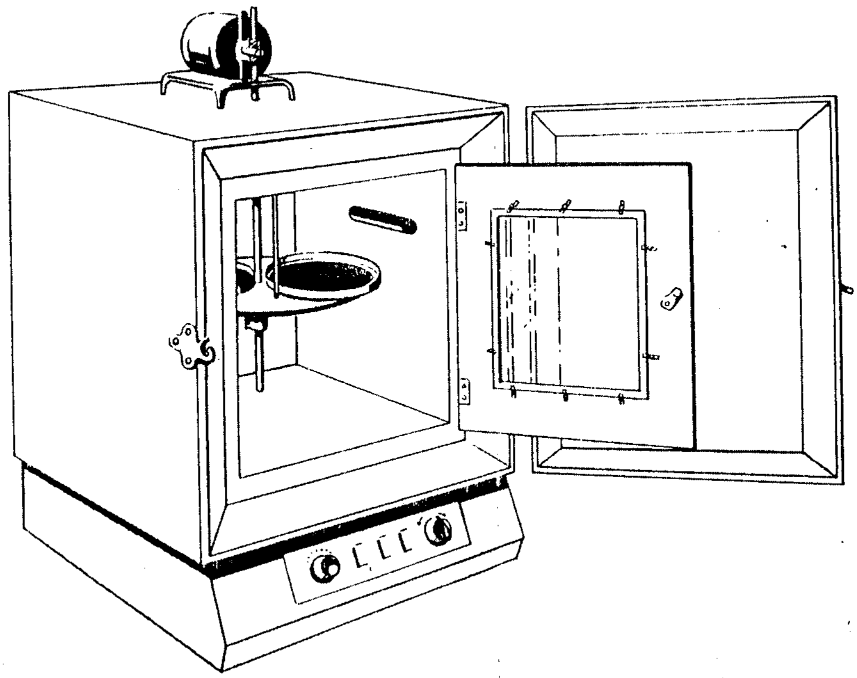

Figure 2.10 Thin Film Oven

be confused with the firepoint, the lowest temperature at which the asphalt cement will burn. Flashpoint involves only instantaneous combustion of the volatile fractions separating from the asphalt. The asphalt flashpoint is determined to identify the maximum temperature at which it can be handled and stored without danger of flashing. This is important information since asphalt cement is usually heated in storage to keep its viscosity low enough so that the material can be pumped.

The basic procedure for determining flashpoint is to gradually heat a sample of asphalt cement in a brass cup while periodically moving a small flame over the sample (Figure 2.09). The temperature at which an instantaneous flashing of vapors occurs across the surface is the flashpoint. The Cleveland Open Cup Test is the most common procedure for determining flashpoint. The Pensky-Martens Test is sometimes used.

Thin Film Oven (TFO) and Rolling Thin Film Oven (RTFO) Procedures These procedures for preparing asphalt specimens simulate conditions that occur during hot mix plant operations. Additional tests are conducted after the TFO or RTFO procedures to simulate the asphalt's properties after construction. The TFO procedure involves placing a measured sample of asphalt cement into a flat-bottomed pan so that the sample covers the pan bottom to a depth of about 3 mm (1/8-inch). The sample and pan are then placed on a rotating shelf in an oven (Figure 2.10) and kept at a temperature of 163°C (325°F) for five hours. The aged sample is then tested for its viscosity, penetration or both.

The RTFO procedure has the same purpose as the TFO test but uses different equipment and procedures. As Figure 2.11 shows, the equipment includes a 163°C (325°F) oven with a rotating vertical carriage that holds sample bottles. The asphalt sample is placed in the bottle,

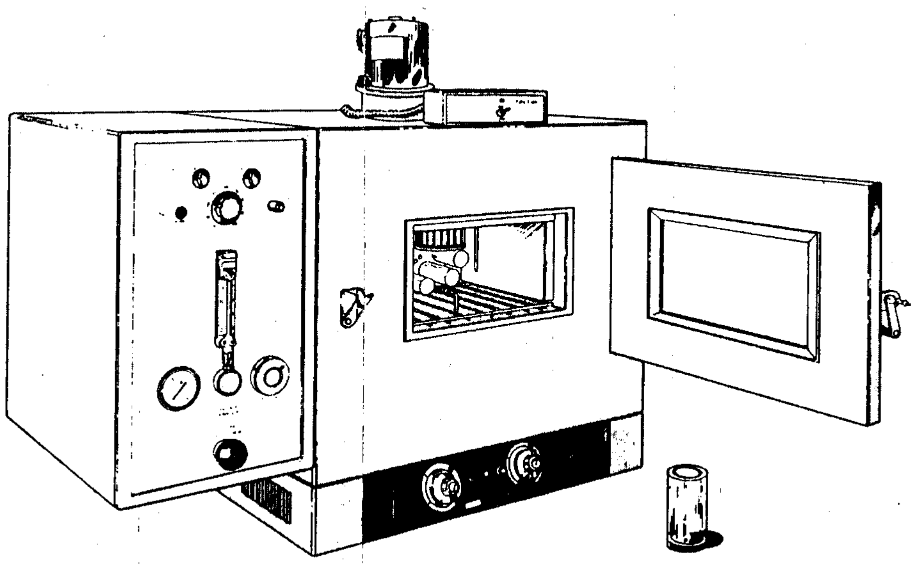

Figure 2.11 Rolling Thin Film Oven

and the bottle is placed in the carriage. The carriage rotates, continuously exposing fresh films of asphalt cement as it coats the inside of the bottle. Once during each rotation, the bottle opening passes a nozzle that blows air into the bottle.

Ductility *Ductility* is a measure of how far a sample of asphalt cement can be stretched before it breaks into two parts. It is used in the penetration and viscosity classification systems. Ductility is measured by an "extension" test in which a briquette of asphalt cement is extended, or stretched, at a specific rate and temperature (Figure 2.12). Extension is continued until the thread of asphalt cement joining the two halves of the sample breaks. The length in centimeters of the specimen at the moment it breaks is the ductility.

Solubility The *solubility* test measures the purity of asphalt cement. A sample is immersed in a solvent to dissolve the asphalt. Impurities such as salts, free carbon and nonorganic contaminants do not dissolve. These insoluble impurities are filtered out of the solution and measured as a proportion of the original sample.

Specific Gravity *Specific gravity* is the ratio of the weight of any volume of a material to the weight of an equal volume of water, both at a specified temperature. As an example, a substance with a specific gravity of 1.6 weighs 1.6 times as much as water. The specific gravity of asphalt cement is not normally indicated in the job specifications. Nonetheless, knowing the specific gravity of the asphalt cement being used is important for two reasons:

- Asphalt expands when heated and contracts when cooled. This means that the volume of a given amount of asphalt cement will be greater at higher temperatures than at lower ones. Specific gravity measurements provide a yardstick for making temperature-volume corrections, which are discussed later.

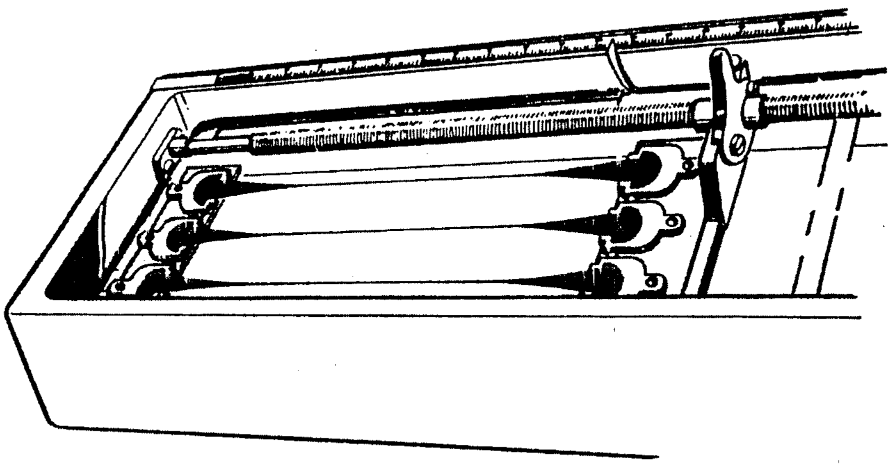

Figure 2.12 Ductility Test

- Specific gravity of the asphalt is essential in the determination of the effective asphalt content and the percentage of air voids in compacted mix specimens and compacted pavement.

Specific gravity of asphalt is usually determined using a pycnometer. Because specific gravity varies with the expansion and contraction of asphalt cement at different temperatures, results are normally expressed in terms of Sp. Gr. (Specific Gravity) at a given temperature for both the material and the water used in the test. Example: Sp. Gr. 1.05 at 15.6°/15.6°C (60°/60°F) means that the specific gravity of the asphalt cement tested is 1.05 when both the asphalt cement and the water are at 15.6°C (60°F). The specific gravity of every asphalt cement is available from the asphalt producer.

➤➤Superpave Asphalt Tests

The Superpave asphalt mix design system includes the performance graded (PG) asphalt binder specification. The term "asphalt binder" is used because the material can be either an unmodified or a modified asphalt cement, as long as it meets the specification criteria. The Superpave asphalt binder tests measure physical properties that can be directly related to field performance in terms of rutting, fatigue cracking and low temperature cracking. The tests are performed on asphalt at a wide range of temperatures and aging conditions with all specification criteria expressed in metric units only. Superpave characterizes asphalt at the actual pavement temperatures it will experience, and at the periods of time when distresses are most likely to occur. Details of the Superpave binder test procedures and the PG specification can be found in the Asphalt Institute's Superpave Binder manual, Superpave Series No. 1 (SP-1).

Aging Tests Superpave uses the rolling thin film oven (RTFO) and the pressure aging vessel (PAV) for aging the binder to simulate the condition of the asphalt immediately after construction (RTFO) and after years of in-service aging in the pavement (PAV). The RTFO procedure was described earlier. The PAV procedure involves placing an asphalt sample, which has already

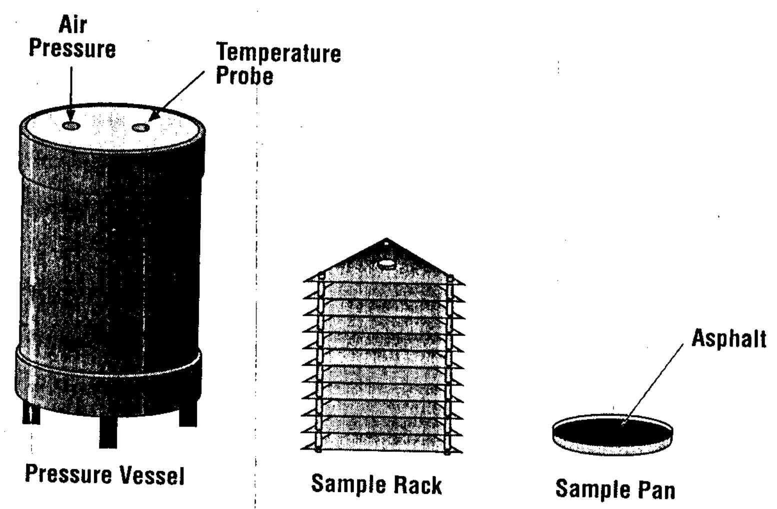

Figure 2.13 Pressure Aging Vessel and Components

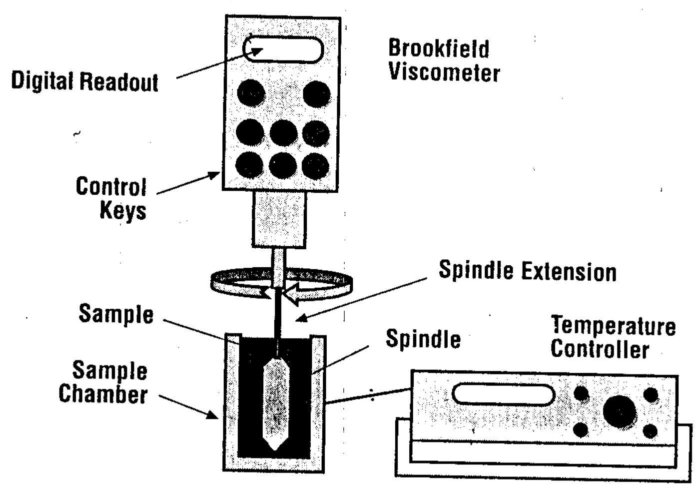

Figure 2.14 Rotational Viscometer

been aged in the RTFO procedure, inside a stainless steel pressure vessel (Figure 2.13). The vessel, heated to 100°C, is then pressurized to 2070 kPa for 20 hours. The PAV samples are then used for further testing and evaluation.

Rotational Viscometer The rotational, or Brookfield, viscometer (Figure 2.14) measures viscosity of the unaged or tank asphalt at 135°C. The test is used to determine if the asphalt is fluid enough to handle during shipment, pumping and mixing.

Dynamic Shear Rheometer As discussed earlier, asphalt is a viscoelastic material, meaning that it simultaneously behaves as an elastic material (e.g. rubber band) and a viscous material (e.g. molasses). The Dynamic Shear Rheometer (DSR) is used to characterize the viscous and elastic

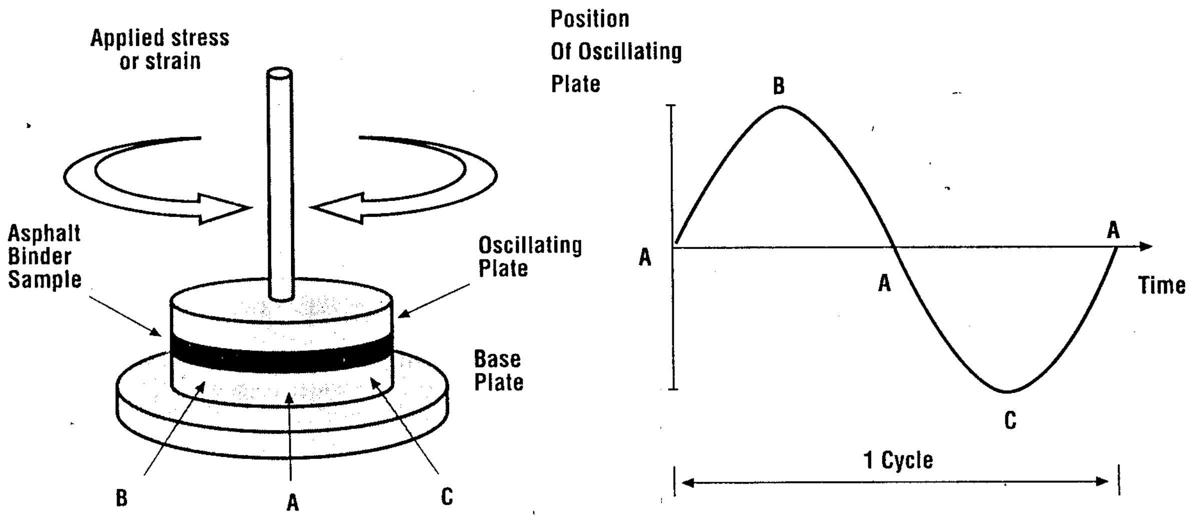

Figure 2.15 Dynamic Shear Rheometer Operation

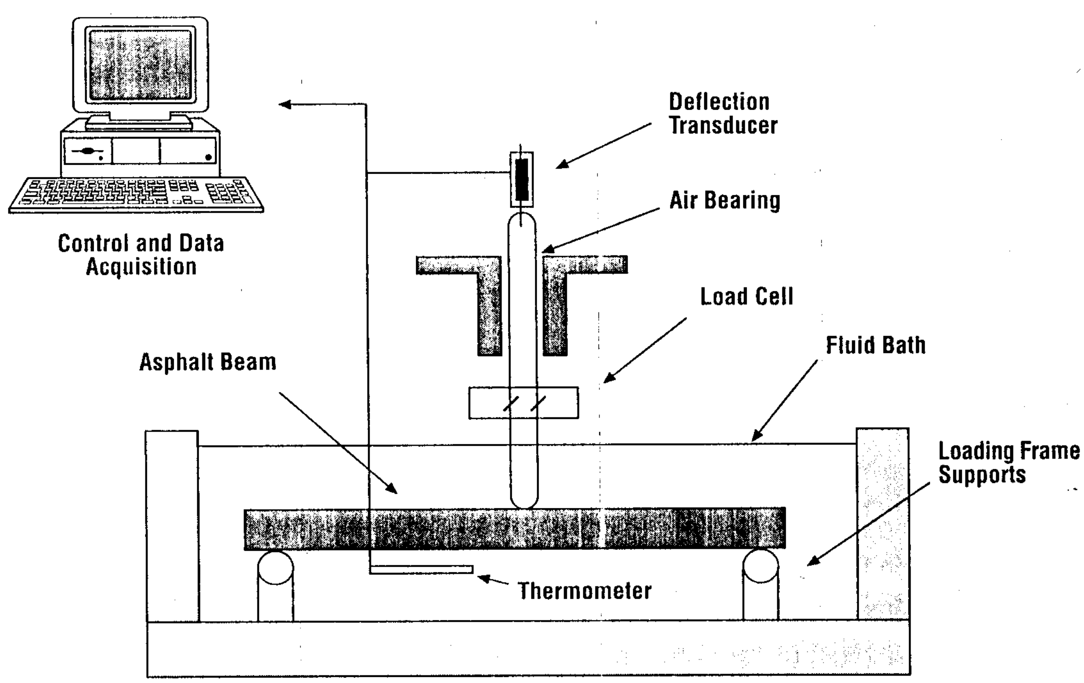

Figure 2.16 Bending Beam Rheometer

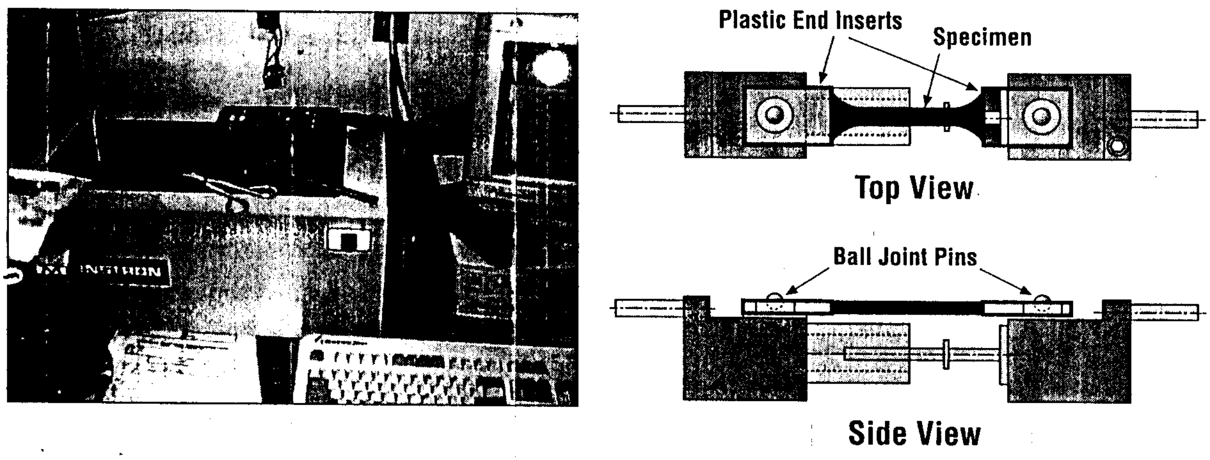

Figure 2.17 Direct Tension Tester

behavior of asphalt binders. It does this by measuring the viscous and elastic properties of a thin binder sample sandwiched between an oscillating plate and a base plate (Figure 2.15).

The relationship between these two properties is used to measure the ability of the binder to resist permanent deformation and fatigue cracking. To resist rutting, a binder needs to be stiff and elastic; to resist fatigue cracking, the binder needs to be flexible and elastic. The balance between these two needs is a critical one.

Bending Beam Rheometer The Bending Beam Rheometer (BBR) is used to measure asphalt stiffness at very low temperatures (Figure 2.16). 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 the temperature drops. The BBR test results help determine the asphalt's resistance to low temperature cracking.

Direct Tension Tester The direct tension test (Figure 2.17) measures low temperature ultimate tensile strain of an aged asphalt binder. It is performed at temperatures ranging from 0°C to -36°C, the temperature range within which asphalt exhibits brittle behavior. The direct tension test supplements the BBR in determining the asphalt's low temperature performance.

➤➤Asphalt Handling, Storage and Sampling

The safety record for handling, storing and sampling asphalt is good. Nonetheless, to prevent accidents resulting in property damage, personal injury and loss of life, everyone must know and follow good safety practices. When an accident does occur, everyone must know how to react and what first-aid treatment is appropriate. Personnel should be aware of the potential sources of contamination that might exist where asphalt is stored or handled. Proper practices must be followed to prevent contamination of samples. Finally, an understanding of the changes in volume that asphalt undergoes when heated or cooled is especially important when comparing asphalt quantities measured at different temperatures.

Safe Handling of Hot Asphalt At an asphalt plant, asphalt temperatures commonly exceed 150°C (300°F). Metal surfaces of plant equipment often range between 65°C (150°F) and 95°C (200°F). Consequently, momentary contact with hot asphalt or with plant equipment, including tanks, pipelines, dryers, boilers and boiler houses, can severely burn exposed flesh. Four general precautions against burns are:

- Be aware of where burn hazards are located.
- Use designated walk areas and stay clear of hazardous situations.
- Always wear appropriate work clothing.
- Know and follow all plant safety procedures related to handling hot material and equipment.

If a burn does occur, the general treatment guidelines are:

- In the case of localized asphalt skin burns, apply cold water or an ice pack to reduce the heat in the asphalt and the skin.
- In cases where burns cover more than 10 percent of the body (approximately the skin area of one arm or half a leg), apply lukewarm water instead of cold water. Lukewarm water will reduce the temperature of the asphalt and skin without causing shock that could be induced by applying cold water or ice to major burns.
- Do not remove the asphalt from the skin.
- Do not cover the burned area with a bandage.
- Have a physician examine the burn immediately.

Hydrogen sulfide is a product of the reaction between hydrogen and sulfur naturally present in asphalt. In low concentrations hydrogen sulfide is not dangerous; however, in the high concentrations sometimes found in storage tanks and other closed areas it can be lethal. To prevent overexposure to hydrogen sulfide fumes:

- Keep your face at least two feet away from asphalt tank hatch openings.
- Stay upwind of open hatches.
- Avoid breathing fumes when opening hatch covers or taking samples.

In case of overexposure to hydrogen sulfide fumes:

- Move victim immediately to fresh air.
- Administer oxygen if breathing is difficult.
- Start artificial respiration if breathing stops.
- Have victim examined by a physician immediately.

Storing Asphalt At a stationary asphalt plant, asphalt is stored in heated, insulated tanks with an average capacity of about 75,000 liters (20,000 gallons). Smaller, trailer-mounted tanks are used for portable plants. Their capacity is generally about one-half of stationary tanks. To keep stored asphalt fluid hot enough to be pumped readily, storage tanks are equipped with steam heating coils, hot oil coils or gas-fired or electric heaters. Certain precautions regarding tank temperatures must be followed to ensure safety:

- Tank temperatures should be checked and recorded regularly. When measuring tank temperatures, an instrument designed for that purpose should be used.
- Taking temperature readings near the heating coils, tank shell or tank bottom should be avoided. Such readings are generally inaccurate indications of the overall asphalt temperature.

Table 2.01 Guideline Temperatures for Storing Asphalts			
Type & Grade	**Reference Specification**	**Minimum Flash °C (°F)**	**Storage Temperature °C (°F)**
PG 46, 52, 58, 64, 70, 76, 82	AASHTO MP 1	230	*
AC-2.5 -5 -10 -20, -30, -40	AASHTO M 226 ASTM D 3381	163 (325) 177 (350) 219 (425) 232 (450)	160 (320) 166 (330) 174 (345) 177 (350)
AR-1000 -2000 -4000 -8000 -16000	AASHTO M 226 ASTM D 3381	205 (400) 219 (425) 227 (440) 232 (450) 238 (460)	163 (325) 168 (335) 177 (350) 177 (350) 177 (350)
Pen 40-50, 60-70, 85-100 120-150 200-300	AASHTO M 20 ASTM D 946	232 (450) 219 (425) 177 (350)	177 (350) 177 (350) 168 (335)
RC-70 -250 -800 -3000	AASHTO M 81 ASTM D 2028	——— 27 (80) 27 (80) 27 (80)	71 (160) 91 (195) 99 (210) 99 (210)
MC-30 -70 -250 -800 -3000	AASHTO M 82 ASTM D 2027	38 (100) 38 (100) 66 (150) 66 (150) 66 (150)	54 (130) 71 (160) 91 (195) 99 (210) 99 (210)
RS-1	AASHTO M 140 & M 208	———	50 (122)
RS-2, HFRS-2, CRS-1, CRS-2	ASTM D 977 & D 2397	———	75 (167)
SS-1, SS-1h, CSS-1, CSS-1h, MS-1, HFMS-1		———	45 (113)
MS-2, MS-2h, HFMS-2, HFMS-2h, HFMS-2s, CMS-2, CMS-2h		———	75 (167)

* For Performance Grade Asphalt Binders, use the storage temperatures recommended by the asphalt producer or supplier.

- Tank storage temperatures for asphalt binders are typically kept close to the desired field mixing temperature, generally in the range of 150°C to 175°C (302°F to 347°F). This mixing temperature, at which the asphalt binder and aggregate are mixed, is generally established after determining the desired field compaction temperature. Because the mix will cool slightly while being stored and hauled to the job site, the mixing temperature will be set slightly higher than the compaction temperature. The asphalt binder producer or supplier should be consulted for guidelines in establishing these mixing and compaction temperatures. Binder storage and mixing temperatures should not exceed 175°C (347°F). Table 2.01 presents temperature guidelines for storing various types and grades of asphalt.
- Check storage tanks, and coils should be checked regularly for signs of damage or leakage.

Table 2.02 Guide for Loading Asphalt Products

LAST PRODUCT IN TANK	PRODUCT TO BE LOADED: Asphalt Cement/Binder	Cutback Asphalt	Cationic Emulsion	Anionic Emulsion
Asphalt Cement/Binder	OK to load	OK to load	Empty to no measurable quantity	Empty to no measurable quantity
Cutback Asphalt	Empty *	OK to load	Empty to no measurable quantity	Empty to no measurable quantity
Cationic Emulsion	Empty *	Empty to no measurable quantity	OK to load	Empty to no measurable quantity
Anionic Emulsion	Empty *	Empty to no measurable quantity	Empty to no measurable quantity	OK to load
Crude Petroleum and Residual Fuel Oils	Empty *	Empty to no measurable quantity	Empty to no measurable quantity	Empty to no measurable quantity
Any Product Not Listed Above	Tank must be cleaned	Tank must be cleaned	Tank must be cleaned	Tank must be cleaned

* Any material remaining will produce dangerous conditions

Trucks and railroad tank cars that normally carry asphalt may be used to transport other petroleum products. Contamination can cause an asphalt to not meet specifications, as well as an increased danger of fire or explosion. To minimize the potential hazards, the guidelines in Table 2.02 should be followed when loading asphalt products.

Sampling Asphalt The only way to know whether asphalt delivered to the plants meets specifications is to take samples of the material and test the samples in a laboratory. For meaningful test results, the samples must be representative of the entire shipment. Contamination or other alteration of the sample before testing is likely to produce misleading test results. Such results could be used to reject an entire shipment of asphalt cement even though it does meet specifications. Details on sampling asphalt are contained in Chapter 4.

➤➤ *Asphalt Temperature-Volume Relationships*

Asphalt expands when heated and contracts when cooled. These changes in volume can cause confusion because regardless of the temperature at which asphalt is shipped and stored, its volume at 15°C (60°F) is the basis for payments and project records. Consequently, when a shipment of asphalt is delivered at 150°C (300°F), its volume at 15°C (60°F) must be calculated and recorded.

The calculation requires two items of information:

- The temperature of the asphalt.
- The specific gravity of the asphalt.

The asphalt's temperature and specific gravity are used to locate the proper correction factor in Table 2.03. These tables have been in use for at least four decades and are the only data currently available for temperature corrections above 150°C (300°F). Nonetheless, the accuracy of the tables is not guaranteed. The asphalt's temperature and the necessary correction factor are used in this formula to calculate its volume at 15°C (60°F):

$$V = V_t(CF)$$

where,

V = Volume at 15°C (60°F)
V_t = Volume at given temperature
CF = Correction Factor from Table 2.03

EXAMPLE: A truck has just delivered 19,000 liters (5020 gallons) of asphalt at a temperature of 150°C (300°F). The specific gravity of the asphalt is 0.970. What would the asphalt's volume be at 15°C (60°F)? Because its specific gravity is at or above 0.967, the Column A factors (Table 2.03) are used to find the correction factor. For 150°C, the correction factor listed is 0.9177.

Therefore,

V = 19,000 liters x 0.9177 *OR 5020 gallons* x 0.9177
= 17,436 liters *OR 4607 gallons*

Aggregate

Aggregate, also referred to as rock, granular material, and mineral aggregate, is any hard, inert mineral material used in hot mix asphalt. Typical aggregates include sand, gravel, crushed stone, slag and rock dust. Aggregate makes up 90-95 percent by weight and 75-85 percent by volume of most HMA. Because it provides most of the load-bearing characteristics, pavement performance is heavily influenced by the choice of a proper aggregate for a particular job.

➤➤Aggregate Classification

Rock is divided into three general types: sedimentary, igneous and metamorphic (Table 2.04). These classifications are based upon the way in which each type is formed.

Sedimentary Sedimentary rocks are formed in layers by the accumulation of sediment (fine particles) that is deposited by wind and water. Sediment may contain:

- Mineral particles or fragments (as in the case of sandstone and shale).
- Remains or products of animals (certain limestones).
- Plants (coal).

Table 2.03 Temperature-Volume Corrections for Asphalt

Observed Temperature, °C	Volume Correction Factor to 15°C [2]		Observed Temperature, °C	Volume Correction Factor to 15°C [2]		Observed Temperature, °C	Volume Correction Factor to 15°C [2]		Observed Temperature, °C	Volume Correction Factor to 15°C [2]	
	A	B		A	B		A	B		A	B
-25.0	1.0254	1.0290	12.5	1.0016	1.0018	50.0	0.9782	0.9752	87.5	0.9552	0.9492
-24.5	1.0251	1.0286	13.0	1.0012	1.0014	50.5	0.9779	0.9749	88.0	0.9548	0.9489
-24.0	1.0248	1.0283	13.5	1.0009	1.0014	51.0	0.9776	0.9745	88.5	0.9545	0.9485
-23.5	1.0244	1.0279	14.0	1.0006	1.0007	51.5	0.9973	0.9742	89.0	0.9542	0.9482
-23.0	1.0241	1.0276	14.5	1.0003	1.0004	52.0	0.9770	0.9738	89.5	0.9539	0.9478
-22.5	1.0238	1.0272	15.0	1.0000	1.0000	52.5	0.9767	0.9735	90.0	0.9536	0.9475
-22.0	1.0235	1.0268	15.5	0.9997	0.9998	53.0	0.9763	0.9731	90.5	0.9533	0.9472
-21.5	1.0232	1.0265	16.0	0.9994	0.9993	53.5	0.9760	0.9728	91.0	0.9530	0.9468
-21.0	1.0228	1.0261	16.5	0.9991	0.9989	54.0	0.9757	0.9724	91.5	0.9527	0.9465
-20.5	1.0225	1.0258	17.0	0.9988	0.9986	54.5	0.9754	0.9721	92.0	0.9524	0.9461
-20.0	1.0222	1.0254	17.5	0.9985	0.9982	55.0	0.9751	0.9717	92.5	0.9521	0.9458
-19.5	1.0219	1.0250	18.0	0.9981	0.9978	55.5	0.9748	0.9714	93.0	0.9518	0.9455
-19.0	1.0216	1.0247	18.5	0.9978	0.9975	56.0	0.9745	0.9710	93.5	0.9515	0.9451
-18.5	1.0212	1.0243	19.0	0.9975	0.9971	56.5	0.9742	0.9707	94.0	0.9512	0.9448
-18.0	1.0209	1.0239	19.5	0.9972	0.9968	57.0	0.9739	0.9703	94.5	0.9509	0.9444
-17.5	1.0206	1.0236	20.0	0.9969	0.9964	57.5	0.9736	0.9700	95.0	0.9506	0.9441
-17.0	1.0203	1.0232	20.5	0.9966	0.9961	58.0	0.9732	0.9696	95.5	0.9503	0.9438
-16.5	1.0200	1.0228	21.0	0.9963	0.9957	58.5	0.9729	0.9693	96.0	0.9500	0.9434
-16.0	1.0196	1.0224	21.5	0.9959	0.9954	59.0	0.9726	0.9689	96.5	0.9497	0.9431
-15.5	1.0193	1.0221	22.0	0.9956	0.9950	59.5	0.9723	0.9686	97.0	0.9494	0.9427
-15.0	1.0190	1.0217	22.5	0.9953	0.9947	60.0	0.9720	0.9682	97.5	0.9491	0.9424
-14.5	1.0187	1.0213	23.0	0.9950	0.9943	60.5	0.9717	0.9679	98.0	0.9488	0.9421
-14.0	1.0184	1.0210	23.5	0.9947	0.9940	61.0	0.9714	0.9675	98.5	0.9485	0.9417
-13.5	1.0180	1.0206	24.0	0.9943	0.9936	61.5	0.9711	0.9672	99.0	0.9482	0.9414
-13.0	1.0177	1.0203	24.5	0.9940	0.9933	62.0	0.9708	0.9668	99.5	0.9479	0.9410
-12.5	1.0174	1.0199	25.0	0.9937	0.9929	62.5	0.9705	0.9665	100.0	0.9476	0.9407
-12.0	1.0171	1.0195	25.5	0.9934	0.9925	63.0	0.9701	0.9661	100.5	0.9473	0.9404
-11.5	1.0168	1.0192	26.0	0.9931	0.9922	63.5	0.9698	0.9658	101.0	0.9470	0.9400
-11.0	1.0164	1.0188	26.5	0.9928	0.9918	64.0	0.9695	0.9654	101.5	0.9467	0.9397
-10.5	1.0161	1.0185	27.0	0.9925	0.9915	64.5	0.9692	0.9651	102.0	0.9464	0.9393
-10.0	1.0158	1.0181	27.5	0.9922	0.9911	65.0	0.9689	0.9647	102.5	0.9461	0.9390
-9.5	1.0155	1.0177	28.0	0.9918	0.9907	65.5	0.9686	0.9644	103.0	0.9458	0.9387
-9.0	1.0152	1.0174	28.5	0.9915	0.9904	66.0	0.9683	0.9640	103.5	0.9455	0.9383
-8.5	1.0148	1.0170	29.0	0.9912	0.9900	66.5	0.9680	0.9637	104.0	0.9452	0.9380
-8.0	1.0145	1.0166	29.5	0.9909	0.9897	67.0	0.9677	0.9633	104.5	0.9449	0.9376
-7.5	1.0142	1.0163	30.0	0.9906	0.9893	67.5	0.9674	0.9630	105.0	0.9446	0.9373
-7.0	1.0139	1.0159	30.5	0.9903	0.9889	68.0	0.9670	0.9626	105.5	0.9443	0.9370
-6.5	1.0136	1.0155	31.0	0.9900	0.9886	68.5	0.9667	0.9623	106.0	0.9440	0.9366
-6.0	1.0132	1.0151	31.5	0.9897	0.9882	69.0	0.9664	0.9619	106.5	0.9437	0.9363
-5.5	1,0129	1,0148	32.0	0.9894	0.9879	69.5	0.9661	0.9616	107.0	0.9434	0.9359
-5.0	1.0126	1.0144	32.5	0.9891	0.9875	70.0	0.9658	0.9612	107.5	0.9431	0.9356
-4.5	1.0123	1.0140	33.0	0.9887	0.9871	70.5	0.9655	0.9609	108.0	0.9428	0.9353
-4.0	1.0120	1.0137	33.5	0.9884	0.9868	71.0	0.9652	0.9605	108.5	0.9425	0.9349
-3.5	1.0117	1.0133	34.0	0.9881	0.9864	71.5	0.9649	0.9602	109.0	0.9422	0.9346
-3.0	1.0114	1.0130	34.5	0.9878	0.9861	72.0	0.9646	0.9598	109.5	0.9419	0.9342
-2.5	1.0111	1.0126	35.0	0.9875	0.9857	72.5	0.9643	0.9595	110.0	0.9416	0.9339
-2.0	1.0107	1.0122	35.5	0.9872	0.9854	73.0	0.9640	0.9592	110.5	0.9413	0.9336
-1.5	1.0104	1.0119	36.0	0.9869	0.9850	73.5	0.9637	0.9588	111.0	0.9410	0.9332
-1.0	1.0101	1.0115	36.5	0.9866	0.9847	74.0	0.9634	0.9585	111.5	0.9407	0.9329
-0.5	1.0098	1.0112	37.0	0.9863	0.9843	74.5	0.9631	0.9581	112.0	0.9404	0.9325
0	1.0095	1,0108	37.5	0.9860	0.9840	75.0	0.9628	0.9578	112.5	0.9401	0.9322
0.5	1.0092	1.0104	38.0	0.9856	0.9836	75.5	0.9625	0.9575	113.0	0.9397	0.9319
1.0	1.0089	1.0101	38.5	0.9853	0.9833	76.0	0.9622	0.9571	113.5	0.9394	0.9315
1.5	1.0085	1.0097	39.0	0.9850	0.9829	76.5	0.9619	0.9568	114.0	0.9391	0.9312
2.0	1.0082	1.0094	39.5	0.9847	0.9826	77.0	0.9616	0.9564	114.5	0.9388	0.9308
2.5	1.0079	1.0090	40.0	0.9844	0.9822	77.5	0.9613	0.9561	115.0	0.9385	0.9305
3.0	1.0076	1.0086	40.5	0.9841	0.9819	78.0	0.9609	0.9557	115.5	0.9382	0.9302
3.5	1.0073	1.0083	41.0	0.9838	0.9815	78.5	0.9606	0.9554	116.0	0.9379	0.9298
4.0	1.0069	1.0079	41.5	0.9835	0.9812	79.0	0.9603	0.9550	116.5	0.9376	0.9295
4.5	1.0066	1.0076	42.0	0.9832	0.9808	79.5	0.9600	0.9547	117.0	0.9373	0.9292
5.0	1.0063	1.0072	42.5	0.9829	0.9805	80.0	0.9597	0.9543	117.5	0.9371	0.9289
5.5	1.0060	1.0068	43.0	0.9825	0.9801	80.5	0.9594	0.9540	118.0	0.9368	0.9285
6.0	1.0057	1.0065	43.5	0.9822	0.9798	81.0	0.9591	0.9536	118.5	0.9365	0.9282
6.5	1.0053	1.0061	44.0	0.9819	0.9794	81.5	0.9588	0.9533	119.0	0.9362	0.9279
7.0	1.0050	1.0058	44.5	0.9816	0.9791	82.0	0.9585	0.9529	119.5	0.9359	0.9275
7.5	1.0047	1.0054	45.0	0.9813	0.9787	82.5	0.9582	0.9526	120.0	0.9356	0.9272
8.0	1.0044	1.0050	45.5	0.9810	0.9784	83.0	0.9578	0.9523	120.5	0.9353	0.9269
8.5	1.0041	1.0047	46.0	0.9807	0.9780	83.5	0.9576	0.9519	121.0	0.9350	0.9265
9.0	1.0037	1.0043	46.5	0.9804	0.9777	84.0	0.9573	0.9516	121.5	0.9347	0.9262
9.5	1.0034	1.0040	47.0	0.9801	0.9973	84.5	0.9570	0.9512	122.0	0.9344	0.9258
10.0	1.0031	1.0036	47.5	0.9798	0.9770	85.0	0.9567	0.9509	122.5	0.9341	0.9255
10.5	1.0028	1.0032	48.0	0.9794	0.9766	85.5	0.9564	0.9506	123.0	0.9338	0.9252
11.0	1.0025	1.0029	48.5	0.9791	0.9763	86.0	0.9561	0.9502	123.5	0.9335	0.9248
11.5	1.0022	1.0025	49.0	0.9788	0.9759	86.5	0.9558	0.9499	124.0	0.9332	0.9245
12.0	1.0019	1.0022	49.5	0.9785	0.9756	87.0	0.9555	0.9495	124.5	0.9329	0.9241

[2] Use column A factors for asphalts with specific gravity at 15° C of 0.967 or higher. Use column B factors for asphalts with specific gravity at 15° C of 0.850 to 0.966.

Table 2.03 Temperature-Volume Corrections for Asphalt (continued)

Observed Temperature, °C	Volume Correction Factor to 15°C [a] A	Volume Correction Factor to 15°C [a] B	Observed Temperature, °C	Volume Correction Factor to 15°C [a] A	Volume Correction Factor to 15°C [a] B	Observed Temperature, °C	Volume Correction Factor to 15°C [a] A	Volume Correction Factor to 15°C [a] B	Observed Temperature, °C	Volume Correction Factor to 15°C [a] A	Volume Correction Factor to 15°C [a] B
125.0	0.9326	0.9238	162.5	0.9104	0.8991	200.0	0.8886	0.8749	237.5	0.8673	0.8514
125.5	0.9323	0.9235	163.0	0.9101	0.8987	200.5	0.8883	0.8746	238.0	0.8670	0.8510
126.0	0.9320	0.9231	163.5	0.9098	0.8984	201.0	0.8880	0.8743	238.5	0.8667	0.8507
126.5	0.9317	0.9228	164.0	0.9095	0.8981	201.5	0.8877	0.8739	239.0	0.8664	0.8504
127.0	0.9314	0.9225	164.5	0.9092	0.8977	202.0	0.8874	0.8736	239.5	0.8661	0.8501
127.5	0.9311	0.9222	165.0	0.9089	0.8974	202.5	0.8872	0.8733	240.0	0.8658	0.8498
128.0	0.9308	0.9218	165.5	0.9086	0.8971	203.0	0.8869	0.8730	240.5	0.8655	0.8495
128.5	0.9305	0.9215	166.0	0.9083	0.8968	203.5	0.8866	0.8727	241.0	0.8652	0.8492
129.0	0.9302	0.9212	166.5	0.9080	0.8964	204.0	0.8863	0.8723	241.5	0.8650	0.8489
129.5	0.9299	0.9208	167.0	0.9077	0.8961	204.5	0.8860	0.8720	242.0	0.8647	0.8486
130.0	0.9296	0.9205	167.5	0.9075	0.8958	205.0	0.8857	0.8717	242.5	0.8644	0.8483
130.5	0.9293	0.9202	168.0	0.9072	0.8955	205.5	0.8854	0.8714	243.0	0.8641	0.8480
131.0	0.9290	0.9198	168.5	0.9069	0.8952	206.0	0.8851	0.8711	243.5	0.8638	0.8477
131.5	0.9287	0.9195	169.0	0.9066	0.8948	206.5	0.8849	0.8708	244.0	0.8636	0.8474
132.0	0.9284	0.9191	169.5	0.9063	0.8945	207.0	0.8846	0.8705	244.5	0.8633	0.8471
132.5	0.9281	0.9188	170.0	0.9060	0.8942	207.5	0.8843	0.8702	245.0	0.8630	0.8468
133.0	0.9278	0.9185	170.5	0.9057	0.8939	208.0	0.8840	0.8698	245.5	0.8627	0.8465
133.5	0.9275	0.9181	171.0	0.9054	0.8935	208.5	0.8837	0.8695	246.0	0.8624	0.8462
134.0	0.9272	0.9178	171.5	0.9051	0.8932	209.0	0.8835	0.8692	246.5	0.8622	0.8459
134.5	0.9269	0.9174	172.0	0.9048	0.8929	209.5	0.8832	0.8689	247.0	0.8619	0.8456
135.0	0.9266	0.9171	172.5	0.9046	0.8926	210.0	0.8829	0.8686	247.5	0.8616	0.8453
135.5	0.9263	0.9168	173.0	0.9043	0.8922	210.5	0.8826	0.8683	248.0	0.8613	0.8449
136.0	0.9260	0.9164	173.5	0.9040	0.8919	211.0	0.8823	0.8680	248.5	0.8610	0.8446
136.5	0.9257	0.9161	174.0	0.9037	0.8916	211.5	0.8820	0.8676	249.0	0.8608	0.8443
137.0	0.9254	0.9158	174.5	0.9034	0.8912	212.0	0.8817	0.8673	249.5	0.8605	0.8440
137.5	0.9251	0.9155	175.0	0.9031	0.8909	212.5	0.8815	0.8670	250.0	0.8602	0.8437
138.0	0.9248	0.9151	175.5	0.9028	0.8906	213.0	0.8812	0.8667	250.5	0.8599	0.8434
138.5	0.9245	0.9148	176.0	0.9025	0.8903	213.5	0.8809	0.8664	251.0	0.8596	0.8431
139.0	0.9242	0.9145	176.5	0.9022	0.8899	214.0	0.8806	0.8660	251.5	0.8594	0.8428
139.5	0.9239	0.9141	177.0	0.9019	0.8896	214.5	0.8803	0.8657	252.0	0.8591	0.8425
140.0	0.9236	0.9138	177.5	0.9017	0.8993	215.0	0.8800	0.8654	252.5	0.8588	0.8422
140.5	0.9233	0.9135	178.0	0.9014	0.8990	215.5	0.8797	0.8651	253.0	0.8585	0.8418
141.0	0.9230	0.9131	178.5	0.9011	0.8887	216.0	0.8794	0.8648	253.5	0.8582	0.8415
141.5	0.9227	0.9128	179.0	0.9008	0.8883	216.5	0.8792	0.8645	254.0	0.8580	0.8412
142.0	0.9224	0.9125	179.5	0.9005	0.8880	217.0	0.8789	0.8642	254.5	0.8577	0.8409
142.5	0.9222	0.9122	180.0	0.9002	0.8877	217.5	0.8786	0.8639	255.0	0.8574	0.8406
143.0	0.9219	0.9118	180.5	0.8999	0.8874	218.0	0.8783	0.8635	255.5	0.8571	0.8403
143.5	0.9216	0.9115	181.0	0.8996	0.8871	218.5	0.8780	0.8632	256.0	0.8586	0.8400
144.0	0.9213	0.9112	181.5	0.8993	0.8867	219.0	0.8778	0.8629	256.5	0.8566	0.8397
144.5	0.9210	0.9108	182.0	0.8990	0.8864	219.5	0.8775	0.8626	257.0	0.8563	0.8394
145.0	0.9207	0.9105	182.5	0.8988	0.8861	220.0	0.8772	0.8623	257.5	0.8560	0.8391
145.5	0.9204	0.9102	183.0	0.8985	0.8858	220.5	0.8769	0.8620	258.0	0.8557	0.8388
146.0	0.9201	0.9098	183.5	0.8982	0.8855	221.0	0.8766	0.8617	258.5	0.8554	0.8385
146.5	0.9198	0.9095	184.0	0.8979	0.8851	221.5	0.8763	0.8614	259.0	0.8552	0.8382
147.0	0.9195	0.9092	184.5	0.8976	0.8848	222.0	0.8760	0.8611	259.5	0.8549	0.8379
147.5	0.9192	0.9089	185.0	0.8973	0.8845	222.5	0.8758	0.8606	260.0	0.8546	0.8376
148.0	0.9189	0.9085	185.5	0.8970	0.8842	223.0	0.8755	0.8604	260.5	0.8543	0.8373
148.5	0.9186	0.9082	186.0	0.8967	0.8839	223.5	0.8752	0.8601	261.0	0.8540	0.8370
149.0	0.9183	0.9079	186.5	0.8964	0.8835	224.0	0.8749	0.8598	261.5	0.8538	0.8367
149.5	0.9180	0.9075	187.0	0.8961	0.8832	224.5	0.8746	0.8595	262.0	0.8535	0.8364
150.0	0.9177	0.9072	187.5	0.8959	0.8829	225.0	0.8743	0.8592	262.5	0.8532	0.8361
150.5	0.9174	0.9069	188.0	0.8956	0.8826	225.5	0.8740	0.8589	263.0	0.8529	0.8357
151.0	0.9171	0.9065	188.5	0.8953	0.8823	226.0	0.8737	0.8586	263.5	0.8526	0.8354
151.5	0.9168	0.9062	189.0	0.8950	0.8819	226.5	0.8735	0.8582	264.0	0.8524	0.8351
152.0	0.9165	0.9059	189.5	0.8947	0.8816	227.0	0.8732	0.8579	264.5	0.8521	0.8348
152.5	0.9163	0.9056	190.0	0.8944	0.8813	227.5	0.8729	0.8576	265.0	0.8518	0.8345
153.0	0.9160	0.9052	190.5	0.8941	0.8810	228.0	0.8726	0.8573	265.5	0.8515	0.8342
153.3	0.9157	0.9049	191.0	0.8938	0.8807	228.5	0.8723	0.8570	266.0	0.8512	0.8339
154.0	0.9154	0.9046	191.5	0.8935	0.8803	229.0	0.8721	0.8566	266.5	0.8510	0.8336
154.5	0.9151	0.9042	192.0	0.8932	0.8800	229.5	0.8718	0.8563	267.0	0.8507	0.8333
155.0	0.9148	0.9039	192.5	0.8930	0.8797	230.0	0.8715	0.8560	267.5	0.8504	0.8330
155.5	0.9145	0.9036	193.0	0.8927	0.8794	230.5	0.8712	0.8557	268.0	0.8501	0.8326
156.0	0.9142	0.9033	193.5	0.8924	0.8791	231.0	0.8709	0.8554	268.5	0.8498	0.8323
156.5	0.9139	0.9029	194.0	0.8921	0.8787	231.5	0.8707	0.8551	269.0	0.8496	0.8320
157.0	0.9136	0.9026	194.5	0.8918	0.8784	232.0	0.8704	0.8548	269.5	0.8493	0.8317
157.5	0.9133	0.9023	195.0	0.8915	0.8781	232.5	0.8701	0.8545	270.0	0.8490	0.8314
158.0	0.9130	0.9020	195.5	0.8912	0.8778	233.0	0.8698	0.8541	270.5	0.8487	0.8311
158.5	0.9127	0.9017	196.0	0.8909	0.8775	233.5	0.8695	0.8538	271.0	0.8484	0.8308
159.0	0.9124	0.9013	196.5	0.8906	0.8771	234.0	0.8693	0.8535	271.5	0.8482	0.8305
159.5	0.9121	0.9010	197.0	0.8903	0.8768	234.5	0.8690	0.8532	272.0	0.8479	0.8302
160.0	0.9118	0.9007	197.5	0.8901	0.8765	235.0	0.8687	0.8529	272.5	0.8476	0.8299
160.5	0.9115	0.9004	198.0	0.8898	0.8762	235.5	0.8684	0.8526	273.0	0.8473	0.8296
161.0	0.9112	0.9000	198.5	0.8895	0.8759	236.0	0.8681	0.8523	273.5	0.8470	0.8293
161.5	0.9109	0.8997	199.0	0.8892	0.8755	236.5	0.8678	0.8520	274.0	0.8468	0.8290
162.0	0.9106	0.8994	199.5	0.8889	0.8752	237.0	0.8675	0.8517	274.5	0.8465	0.8287

[a] Use column A factors for asphalts with specific gravity at 15° C of 0.967 or higher. Use column B factors for asphalts with specific gravity at 15° C of 0.850 to 0.966.

Table 2.03 Temperature-Volume Corrections for Asphalt (continued)

Observed Temperature, °F	Volume Correction Factor to 60° F[1] A	Volume Correction Factor to 60° F[1] B	Observed Temperature, °F	Volume Correction Factor to 60° F[1] A	Volume Correction Factor to 60° F[1] B	Observed Temperature, °F	Volume Correction Factor to 60° F[1] A	Volume Correction Factor to 60° F[1] B	Observed Temperature, °F	Volume Correction Factor to 60° F[1] A	Volume Correction Factor to 60° F[1] B
0	1.0211	1.0241	70	0.9965	0.9950	140	0.9723	0.9686	210	0.9486	0.9418
1	1.0208	1.0237	71	0.9962	0.9956	141	0.9720	0.9682	211	0.9483	0.9414
2	1.0204	1.0233	72	0.9958	0.9952	142	0.9716	0.9678	212	0.9479	0.9410
3	1.0201	1.0229	73	0.9955	0.9948	143	0.9713	0.9674	213	0.9476	0.9407
4	1.0197	1.0225	74	0.9951	0.9944	144	0.9710	0.9670	214	0.9472	0.9403
5	1.0194	1.0221	75	0.9948	0.9940	145	0.9706	0.9666	215	0.9469	0.9399
6	1.0190	1.0217	76	0.9944	0.9936	146	0.9703	0.9662	216	0.9466	0.9395
7	1.0186	1.0213	77	0.9941	0.9932	147	0.9699	0.9659	217	0.9462	0.9391
8	1.0183	1.0209	78	0.9937	0.9929	148	0.9696	0.9655	218	0.9459	0.9388
9	1.0179	1.0205	79	0.9934	0.9925	149	0.9693	0.9651	219	0.9456	0.9386
10	1.0176	1.0201	80	0.9930	0.9921	150	0.9689	0.9647	220	0.9452	0.9380
11	1.0172	1.0197	81	0.9927	0.9917	151	0.9686	0.9643	221	0.9449	0.9376
12	1.0169	1.0193	82	0.9923	0.9913	152	0.9682	0.9639	222	0.9446	0.9373
13	1.0165	1.0189	83	0.9920	0.9909	153	0.9679	0.9635	223	0.9442	0.9369
14	1.0162	1.0185	84	0.9916	0.9905	154	0.9675	0.9632	224	0.9439	0.9365
15	1.0158	1.0181	85	0.9913	0.9901	155	0.9672	0.9628	225	0.9436	0.9361
16	1.0155	1.0177	86	0.9909	0.9897	156	0.9669	0.9624	226	0.9432	0.9358
17	1.0151	1.0173	87	0.9909	0.9893	157	0.9665	0.9620	227	0.9429	0.9354
18	1.0148	1.0168	88	0.9902	0.9889	158	0.9662	0.9616	228	0.9426	0.9350
19	1.0144	1.0164	89	0.9899	0.9885	159	0.9658	0.9612	229	0.9422	0.9346
20	1.0141	1.0160	90	0.9896	0.9881	160	0.9655	0.9609	230	0.9419	0.9343
21	1.0137	1.0156	91	0.9892	0.9877	161	0.9652	0.9605	231	0.9416	0.9339
22	1.0133	1.0152	92	0.9889	0.9873	162	0.9648	0.9601	232	0.9412	0.9335
23	1.0130	1.0148	93	0.9885	0.9869	163	0.9645	0.9597	233	0.9409	0.9331
24	1.0126	1.0144	94	0.9882	0.9865	164	0.9641	0.9593	234	0.9405	0.9328
25	1.0123	1.0140	95	0.9878	0.9861	165	0.9638	0.9589	235	0.9402	0.9324
26	1.0119	1.0136	96	0.9875	0.9857	166	0.9835	0.9585	236	0.9399	0.9320
27	1.0116	1.0132	97	0.9871	0.9854	167	0.9631	0.9582	237	0.9395	0.9316
28	1.0112	1.0128	98	0.9868	0.9850	168	0.9628	0.9578	238	0.9392	0.9313
29	1.0109	1.0124	99	0.9864	0.9846	169	0.9624	0.9574	239	0.9389	0.9309
30	1.0105	1.0120	100	0.9861	0.9842	170	0.9621	0.9570	240	0.9385	0.9305
31	1.0102	1.0116	101	0.9857	0.9838	171	0.9618	0.9566	241	0.9382	0.9301
32	1.0098	1.0112	102	0.9854	0.9834	172	0.9614	0.9562	242	0.9379	0.9298
33	1.0095	1.0108	103	0.9851	0.9830	173	0.9611	0.9559	243	0.9375	0.9294
34	1.0091	1.0104	104	0.9847	0.9826	174	0.9607	0.9555	244	0.9372	0.9290
35	1.0088	1.0100	105	0.9844	0.9822	175	0.9604	0.9551	245	0.9369	0.9286
36	1.0084	1.0096	106	0.9840	0.9818	176	0.9601	0.9547	246	0.9365	0.9283
37	1.0081	1.0092	107	0.9887	0.9814	177	0.9597	0.9543	247	0.9362	0.9279
38	1.0077	1.0088	108	0.9833	0.9810	178	0.9594	0.9539	248	0.9359	0.9275
39	1.0074	1.0084	109	0.9830	0.9806	179	0.9590	0.9536	249	0.9356	0.9272
40	1.0070	1.0080	110	0.9826	0.9803	180	0.9587	0.9532	250	0.9352	0.9268
41	1.0067	1.0076	111	0.9823	0.9799	181	0.9584	0.9528	251	0.9349	0.9264
42	1.0063	1.0072	112	0.9819	0.9795	182	0.9580	0.9524	252	0.9346	0.9260
43	1.0060	1.0068	113	0.9816	0.9791	183	0.9577	0.9520	253	0.9342	0.9257
44	1.0056	1.0064	114	0.9813	0.9787	184	0.9574	0.9517	254	0.9339	0.9253
45	1.0053	1.0060	115	0.9809	0.9783	185	0.9570	0.9513	255	0.9336	0.9249
46	1.0049	1.0056	116	0.9806	0.9779	186	0.9567	0.9509	256	0.9332	0.9245
47	1.0046	1.0052	117	0.9802	0.9775	187	0.9563	0.9505	257	0.9329	0.9242
48	1.0042	1.0048	118	0.9799	0.9771	188	0.9560	0.9501	258	0.9326	0.9238
49	1.0038	1.0044	119	0.9795	0.9767	189	0.9557	0.9498	259	0.9322	0.9234
50	1.0035	1.0040	120	0.9792	0.9763	190	0.9553	0.9494	260	0.9319	0.9231
51	1.0031	1.0036	121	0.9788	0.9760	191	0.9550	0.9490	261	0.9316	0.9227
52	1.0028	1.0032	122	0.9785	0.9756	192	0.9547	0.9486	262	0.9312	0.9223
53	1.0024	1.0028	123	0.9782	0.9752	193	0.9543	0.9482	263	0.9309	0.9219
54	1.0021	1.0024	124	0.9778	0.9748	194	0.9540	0.9478	264	0.9306	0.9216
55	1.0017	1.0020	125	0.9775	0.9744	195	0.9536	0.9475	265	0.9302	0.9212
56	1.0014	1.0016	126	0.9771	0.9740	196	0.9533	0.9471	266	0.9299	0.9208
57	1.0010	1.0012	127	0.9768	0.9736	197	0.9530	0.9467	267	0.9296	0.9205
58	1.0007	1.0008	128	0.9764	0.9732	198	0.9526	0.9463	268	0.9293	0.9201
59	1.0003	1.0004	129	0.9761	0.9728	199	0.9523	0.9460	269	0.9289	0.9197
60	1.0000	1.0000	130	0.9758	0.9725	200	0.9520	0.9456	270	0.9286	0.9194
61	0.9997	0.9996	131	0.9754	0..9721	201	0.9516	0.9452	271	0.9196	0.9190
62	0.9993	0.9992	132	0.9751	0.9717	202	0.9513	0.9448	272	0.9279	0.9186
63	0.9990	0.9988	133	0.9747	0.9713	203	0.9509	0.9444	273	0.9276	0.9182
64	0.9986	0.9984	134	0.9744	0.9709	204	0.9506	0.9441	274	0.9273	0.9179
65	0.9983	0.9980	135	0.9740	0.9705	205	0.9503	0.9437	275	0.9269	0.9175
66	0.9979	0.9976	136	0.9737	0.9701	206	0.9499	0.9433	276	0.9266	0.9171
67	0.9976	0.9972	137	0.9734	0.9697	207	0.9496	0.9429	277	0.9263	0.9168
68	0.9972	0.9968	138	0.9730	0.9693	208	0.9493	0.9425	278	0.9259	0.9164
69	0.9969	0.9964	139	0.9727	0.9690	209	0.9489	0.9422	279	0.9256	0.9160

Table 2.03 Temperature-Volume Corrections for Asphalt (continued)

Observed Temperature, °F	Volume Correction Factor to 60° F [1] A	B	Observed Temperature, °F	Volume Correction Factor to 60° F [1] A	B	Observed Temperature, °F	Volume Correction Factor to 60° F [1] A	B	Observed Temperature, °F	Volume Correction Factor to 60° F [1] A	B
280	0.9253	0.9157	335	0.9073	0.8956	390	0.8896	0.8760	445	0.8721	0.8567
281	0.9250	0.9153	336	0.9070	0.8952	391	0.8892	0.8756	446	0.8718	0.8564
282	0.9246	0.9149	337	0.9066	0.8949	392	0.8889	0.8753	447	0.8715	0.8560
283	0.9243	0.9146	338	0.9063	0.8945	393	0.8886	0.8749	448	0.8714	0.8557
284	0.9240	0.9142	339	0.9060	0.8942	394	0.8883	0.8746	449	0.8709	0.8554
285	0.9236	0.9138	340	0.9057	0.8938	395	0.8880	0.8742	450	0.8705	0.8550
286	0.9233	0.9135	341	0.9053	0.8934	396	0.8876	0.8738	451	0.8702	0.8547
287	0.9230	0.9131	342	0.9050	0.8931	397	0.8873	0.8735	452	0.8699	0.8543
288	0.9227	0.9127	343	0.9047	0.8927	398	0.8870	0.8731	453	0.8696	0.8540
289	0.9223	0.9124	344	0.9044	0.8924	399	0.8867	0.8728	454	0.8693	0.8536
290	0.9220	0.9120	345	0.9040	0.8920	400	0.8864	0.8724	455	0.8690	0.8533
291	0.9217	0.9116	346	0.9037	0.8917	401	0.8861	0.8721	456	0.8687	0.8529
292	0.9213	0.9-113	347	0.9034	0.8913	402	0.8857	0.8717	457	0.8683	0.8526
293	0.9210	0.9109	348	0.9031	0.8909	403	0.8854	0.8717	458	0.8680	0.8522
294	0.9207	0.9105	349	0.9028	0.8906	404	0.8851	0.8710	459	0.8677	0.8519
295	0.9204	0.9102	350	0.9024	0.8902	405	0.8848	0.8707	460	0.8674	0.8516
296	0.9200	0.9098	351	0.9021	0.8899	406	0.8845	0.8703	461	0.8671	0.8512
297	0.9197	0.9094	352	0.9018	0.8895	407	0.8841	0.8700	462	0.8668	0.8509
298	0.9194	0.9097	353	0.9015	0.8891	408	0.8838	0.8696	463	0.8665	0.8505
299	0.9190	0.9087	354	0.9011	0.8888	409	0.8835	0.8693	464	0.8661	0.8502
300	0.9187	0.9083	355	0.9008	0.8884	410	0.8832	0.8689	465	0.8658	0.8498
301	0.9186	0.9080	356	0.9005	0.8881	411	0.8829	0.8686	466	0.8655	0.8495
302	0.9181	0.9076	357	0.9002	0.8877	412	0.8826	0.8682	467	0.8652	0.8492
303	0.9177	0.9072	358	0.8998	0.8873	413	0.8822	0.8679	468	0.8649	0.8488
304	0.9174	0.9069	359	0.8995	0.8870	414	0.8819	0.8675	469	0.8646	0.8485
305	0.9171	0.9065	360	0.8992	0.8866	415	0.8816	0.8672	470	0.8643	0.8481
306	0.9167	0.9061	361	0.8989	0.8863	416	0.8813	0.8668	471	0.8640	0.8478
307	0.9164	0.9058	362	0.8986	0.8859	417	0.8810	0.8665	472	0.8636	0.8474
308	0.9161	0.9054	363	0.8982	0.8856	418	0.8806	0.8661	473	0.8633	0.8471
309	0.9158	0.9050	364	0.8979	0.8852	419	0.8803	0.8658	474	0.8630	0.8468
310	0.9154	0.9047	365	0.8976	0.8848	420	0.8800	0.8654	475	0.8627	0.8464
311	0.9151	0.9043	366	0.8973	0.8845	421	0.8797	0.8651	476	0.8624	0.8461
312	0.9148	0.9039	367	0.8949	0.8841	422	0.8794	0.8647	477	0.8621	0.8457
313	0.9145	0.9036	389	0.8966	0.8838	423	0.8791	0.8644	478	0.8618	0.8454
314	0.9141	0.9032	369	0.8963	0.8834	424	0.8787	0.8640	479	0.8615	0.8451
315	0.9138	0.9028	370	0.8960	0.8831	425	0.8784	0.8637	480	0.8611	0.8447
316	0.9135	0.9025	371	0.8957	0.8827	426	0.8781	0.8633	481	0.8608	0.8444
317	0.9132	0.9021	372	0.8953	0.8823	427	0.8778	0.8630	482	0.8605	0.8440
318	0.9128	0.9018	373	0.8950	0.8820	428	0.8775	0.8626	483	0.8602	0.8437
319	0.9125	0.9014	374	0.8947	0.8816	429	0.8772	0.8623	484	0.8599	0.8433
320	0.9122	0.9010	375	0.8944	0.8813	430	0.8768	0.8619	485	0.8596	0.8430
321	0.9118	0.9007	376	0.8941	0.8809	431	0.8765	0.8616	486	0.8593	0.8427
322	0.9115	0.9003	377	0.8937	0.8806	432	0.8762	0.8612	487	0.8590	0.8423
323	0.9112	0.9000	378	0.8934	0.8802	433	0.8759	0.8609	488	0.8587	0.8420
324	0.9109	0.8996	379	0.8931	0.8799	434	0.8756	0.8605	489	0.8583	0.8416
325	0.9105	0.8992	380	0.8928	0.8795	435	0.8753	0.8602	490	0.8580	0.8413
326	0.9102	0.8989	381	0.8924	0.8792	436	0.8749	0.8599	491	0.8577	0.8410
327	0.9099	0.8985	382	0.8921	0.8988	437	0.8746	0.8595	492	0.8574	0.8406
328	0.9096	0.8981	383	0.8918	0.8784	438	0.8743	0.8592	493	0.8571	0.8403
329	0.9092	0.8978	384	0.8915	0.8781	439	0.8740	0.8588	494	0.8568	0.8399
330	0.9089	0.8974	385	0.8912	0.8777	440	0.8737	0.8585	495	0.8565	0.8396
331	0.9086	0.8971	386	0.8908	0.8774	441	0.8734	0.8581	496	0.8562	0.8383
332	0.9083	0.8967	387	0.8905	0.8770	442	0.8731	0.8578	497	0.8559	0.8389
333	0.9079	0.8963	388	0.8902	0.8767	443	0.8727	0.8574	498	0.8556	0.8386
334	0.9076	0.8960	389	0.8899	0.9763	444	0.8724	0.8571	499	0.8558	0.8383
									500	0.8549	0.8379

[1] Use column A for factors asphalts with API gravity at 60°F of 14.9° or less, or with specific gravity 60/60°F of 0.967 or higher. Use column B factors for asphalts with API gravity at 60°F from 15.0° to 34.9° or with specific gravity 60/60°F from 0.850 to 0.966.

Class	Type	Family
Sedimentary	Calcareous	Limestone Dolomite
	Siliceous	Shale Sandstone Chert Conglomerate[1] Breccia[1]
Metamorphic	Foliated	Gneiss Schist Amphibolite Slate
	Nonfoliated	Quartzite Marble Serpentinite
Igneous	Intrusive (coarse-grained)	Granite[2] Syenite[2] Diorite[2] Gabbro Periodotite Pyroxenite Hornblendite
	Extrusive (fine-grained)	Obsidian Pumice Tuff Rhyolite[2,3] Trachyte[2,3] Andesite[2,3] Basalt[2] Diabase

Table 2.04 Aggregate Classifications

[1] May also be composed partially or entirely of calcareous materials.
[2] Frequently occurs as a porphyritic rock.
[3] Included in general term "felsite" when constituent minerals cannot be determined quantitatively.

- End products of chemical action or evaporation (salt, gypsum).
- Combinations of these types of materials.

Two terms often applied to sedimentary rocks are *siliceous* and *calcareous*. Siliceous sedimentary rocks are those which contain a high percentage of silica. Rocks containing a high percentage of calcium carbonate (limestone) are called calcareous.

Igneous Igneous rocks consist of molten material (magma) that has cooled and solidified. There are two types of igneous rock: *extrusive* and *intrusive*.

Extrusive igneous rock is formed from material that has poured out onto the earth's surface during a volcanic eruption or similar geologic activity. Because exposure to the atmosphere allows the material to cool quickly, the resulting rock has a glass-like appearance and structure. Rhyolite, andesite and basalt are examples of extrusive rock.

Intrusive rock forms from magma trapped deep within the earth's crust. Trapped in the earth, the magma cools and hardens slowly, allowing a crystalline structure to form. Examples of igneous rock are: granite, diorite and gabro. Earth movement and erosion processes bring intrusive rock to the earth's surface where it is quarried and used.

Metamorphic Metamorphic rock is generally sedimentary or igneous rock that has been changed by intense pressure and heat within the earth. Because such formation processes are complex, it is often difficult to determine the exact origin of a particular metamorphic rock.

Many types of metamorphic rock have a distinct characteristic feature: the minerals are arranged in parallel planes or layers. Splitting the rock along its planes is much easier than splitting it in other directions. Metamorphic rock that exhibits this type of structure is termed *foliated*. Examples of foliated rock are gneisses, schists (formed from igneous material) and slate (formed from shale, a sedimentary rock).

Not all metamorphic rock is foliated. Marble (formed from limestone) and quartzite (formed from sandstone) are common types of metamorphic rock without foliation.

➤➤Aggregate Sources

Aggregates for HMA are generally classified according to their sources. They include natural aggregates, processed aggregates and synthetic or artificial aggregates.

Natural Aggregates Natural aggregates are those used with little or no processing. They are made up of particles produced by natural erosion and degradation, such as the action of wind, water, moving ice and chemicals. The shape of individual particles is largely a result of erosion. Glaciers, for example, often produce rounded boulders and pebbles. Similarly, flowing water produces smoothly rounded particles.

The two major types of natural aggregates used in pavement construction are *gravel* and *sand*. Gravel is usually defined as particles 6.35 mm (1/4 in.) or larger in size. Sand is defined as particles smaller than 6.35 mm but larger than .075 mm (No. 200). Particles smaller than .075 mm are considered mineral filler.

Gravels and sands are further classified by their source. Materials quarried from an open pit and used without further processing are referred to as pit-run materials. Similarly, materials taken from stream banks are referred to as bank-run materials.

Gravel deposits vary widely in composition, but usually contain some sand and silt. Sand deposits ordinarily contain some clay and silt. Beach sands (some of which are now far inland) consist of fairly uniform size particles, while river sand often contains a variety of gravel, silt and clay.

Processed Aggregates Processed aggregates have been quarried, crushed and/or screened in preparation for use. There are two basic sources of processed aggregates: natural gravels that are crushed to make them more suitable for use in HMA, and fragments of bedrock and large stones that must be reduced in size.

Rock is crushed for three reasons:

- To reduce the size and improve the distribution and range (gradation) of particle sizes.
- To change the surface texture of the particles from smooth to rough.
- To change particle shape from round to angular.

Screening the materials after crushing classifies the particles into specific gradation ranges. Maintaining specific aggregate gradation is a critical element in producing quality HMA. Proper control of the crushing operation determines whether the resulting aggregate gradation meets job requirements.

Crushing some types of rocks, such as limestone, produces substantial quantities of smaller particles. In most operations these fractions are separated from all particles 6.35 mm (1/4 in.) in diameter or larger, and are used as crushed sand or processed further to a maximum particle size of 0.60 mm (No. 30).

Synthetic Aggregates Synthetic or artificial aggregates are the product of chemical or physical processing of materials. Some are by-products of industrial production processes such as ore refining. Others are produced specifically for use as aggregate by processing raw materials.

Blast-furnace slag is the most commonly used by-product aggregate. It is a nonmetallic substance that rises to the surface of molten iron during the smelting process. When drawn off the surface of the iron, the slag is reduced into small particles, either by quenching it immediately in water or crushing it after is has cooled.

Manufactured synthetic aggregates are relatively new in the HMA industry. They are manufactured by firing clay, shale, processed diatomaceous earth, volcanic glass, slag and other materials. The end products are typically lightweight and have unusually high resistance to wear. Synthetic aggregates have been used in bridge-deck and roof-deck paving, as well as pavement surface layers where maximum skid resistance is required.

➤➤Aggregate Production, Stockpiling, Handling and Sampling

Most contracting agencies do not specify handling and stockpiling procedures. Instead, they specify aggregate gradations and quality requirements. However, handling and stockpiling practices affect aggregate suitability. Therefore, sampling and testing are performed to verify that specifications are met. Correct sampling and testing procedures must be followed to ensure the samples selected are representative and are tested properly.

Production of Aggregates Special care must be taken removing soil overburden. This is particularly important where the overburden contains clay, vegetation or other materials that can adversely affect pavement performance. Some overburden material may provide an acceptable filler; however, it should be removed and processed separately.

Operations in pits and quarries must often work around clay lenses, shale seams and other deposits of unsuitable material embedded in the rock formation. To avoid contamination and ensure uniform aggregate gradation, excavation may have to be done along a horizontal bench, or from top to bottom of the formation's vertical face.

It is essential to thoroughly evaluate aggregates after crushing and screening to ensure they meet quality and gradation requirements. At commercial production facilities, where aggregate production can be continuous throughout the paving season, one or two quality evaluations per season may be satisfactory. Where an operation is starting up for the first time, evaluations of aggregate prior to their use in paving mixtures should be done regularly.

Stockpiling Good stockpiling procedures are crucial to HMA production. Properly stockpiled aggregates retain their gradation. Poorly stockpiled aggregates segregate (separate by size) and gradation varies within the stockpile.

Clean, well drained surfaces should be used for stockpiling aggregates. Precautions should be taken to keep stockpiles separated to maintain proper gradation. This is achieved by keeping stockpiles widely spaced; by using bulkheads between stockpiles; or by storing aggregate in bins. Bulkheads should extend to the full depth of the stockpiles.

Sands, crushed fine aggregate, and aggregates consisting of a single-size particle (especially small particles) can be stockpiled by almost any method with very little segregation. However, materials containing a range of particle sizes require certain stockpiling precautions. Segregation of graded aggregates can be minimized if coarse and fine material are separated at the site and blended in proper proportion prior to the mixing operation.

If not separated, certain stockpiling guidelines should be followed. The first guideline is to control the shape of the stockpile. When aggregate containing both coarse and fine materials is heaped into a stockpile with sloped sides, the coarse particles tend to roll down the slope and accumulate at the bottom.

The best method of stockpiling aggregates consisting of a range of different-size particles is to build the stockpile in layers. Such layers minimize segregation caused by gravity. If the aggregate is delivered by truck, loads should be placed close together over the surface of the stockpile. The volume of each truckload determines the thickness of each layer. When a crane is used to stockpile aggregate, each bucketload should be carefully placed to ensure uniform layer thickness.

Mineral fillers are usually stored in bins, silos or bags to prevent them from blowing away and being exposed to moisture. More details on aggregate stockpiling are provided in Chapter 4.

Handling All handling degrades individual aggregate particles to some extent. This can cause particle segregation where different-size aggregate particles are involved. Therefore, handling should be minimized to prevent degradation and segregation that could make the aggregate unsuitable for use.

Necessary handling includes removing aggregate from stockpiles for further processing or mixing in the hot mix facility. There are no set rules for this operation, but one general guideline is usually applicable: use a front-end loader or clamshell to remove material from a near-vertical face of the stockpile. Having a bulldozer or other tracked vehicle working on top of the stockpile increases the probability of serious degradation.

Sampling During the process of producing, stockpiling and handling aggregates, good quality control procedures:

- Ensure that only satisfactory material is used in the HMA.
- Provide a permanent record as evidence that the materials meet job specifications.

Obviously, it is not practical to test all the aggregate being produced or to test all the contents of a stockpile. It is feasible only to test samples of these materials. For test results to be accurate, the selected sample must be truly representative of the stockpile. Proper sampling techniques are very important (see Chapter 4).

➤➤ *Aggregate Properties and Evaluation*

Aggregate makes up 90-95 percent by weight of HMA. This makes the quality of the aggregate a critical factor in pavement performance. In addition to quality, there are other criteria that influence aggregate selection for a particular project such as cost and availability. An aggregate that meets cost and availability requirements must still have certain properties to be considered suitable for use in quality HMA. These properties include:

- Maximum particle size
- Specific Gravity
- Toughness
- Absorption
- Aggregate gradation
- Cleanliness, or clay content
- Particle shape
- Moisture susceptibility

Another characteristic of aggregate that affects mixture behavior is surface texture. However, since there is no standard method for evaluating surface texture directly, it is not generally specified. A rough surface texture increases pavement strength because it prevents particles from moving easily past one another. A non-polishing surface texture will maintain a higher coefficient of friction and provide a more skid-resistant surface for safer traffic operation. In addition, asphalt films cling more readily to rough surfaces than to smooth ones.

Maximum Particle Size All HMA specifications require aggregate particles to be within a certain range of sizes and for each size of particle to be present in a certain proportion. This distribution of various particle sizes within the aggregate used is called the aggregate, or mix, gradation. To determine whether or not an aggregate gradation meets specifications requires an understanding of how particle size and gradation are measured.

Because specifications list a maximum particle size for each aggregate used, the size of the largest particles in the sample must be determined. There are two designations for maximum particle size:

- *Nominal maximum particle size* is designated as one sieve size larger than the first sieve to retain more than 10 percent in a standard series of sieves.
- *Maximum particle size* is defined as one sieve size larger than the nominal maximum particle size. Typically, this will be the smallest sieve through which 100 percent of the aggregate particles pass.

To illustrate the difference between the two designations, consider this example:

A sample of aggregate to be used in a paving mixture is put through a sieve analysis. All of the material passes through the 25 mm (1 in.) sieve and falls into the 19 mm (3/4 in.) sieve directly below. The 19 mm (3/4 in.) sieve retains 4 percent of the aggregate particles. The 12.5 mm (1/2 in.) sieve, directly below the 19 mm (3/4 in.) sieve, retains a total of 18 percent of the aggregate particles. In this case, the *nominal maximum* size is 19 mm (3/4 in.), and the *maximum* size is 25 mm (1 in.).

HMA is classified according to either its maximum size or its nominal maximum size (as in Superpave mixtures). Therefore, according to the maximum size of the aggregate described in the example, the mix would be termed a 25 mm (1 in.) mix. According to its nominal maximum size, the mixture would be a 19 mm (3/4 in.) mix.

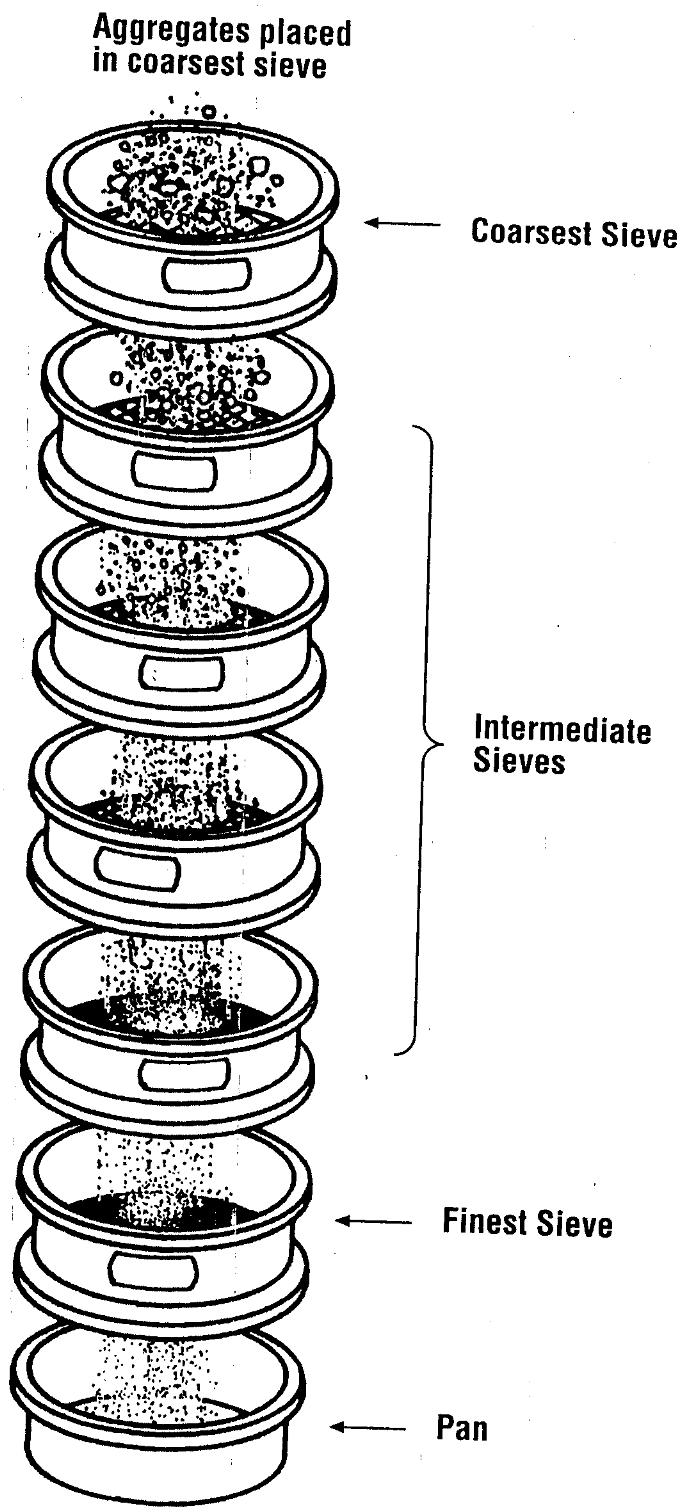

Figure 2.18 Sieve Analysis

Table 2.05 Typical Composition of Hot Mix Asphalt

Sieve Size	Mix Designation and Nominal Maximum Size of Aggregate				
	37.5 mm (1½ in.)	25.0 mm (1 in.)	19.0 mm (¾ in.)	12.5 mm (½ in.)	9.5 mm (⅜ in.)
	Total Percent Passing (by weight)				
50 mm (2 in.)	100	–	–	–	–
37.5 mm (1½ in.)	90 to 100	100	–	–	–
25.0 mm (1 in.)	–	90 to 100	100	–	–
19.0 mm (¾ in.)	56 to 80	–	90 to 100	100	–
12.5 mm (½ in.)	–	56 to 80	–	90 to 100	100
9.5 mm (⅜ in.)	–	–	56 to 80	–	90 to 100
4.75 mm (No. 4)	23 to 53	29 to 59	35 to 65	44 to 74	55 to 85
2.36 mm (No. 8)*	15 to 41	19 to 45	23 to 49	28 to 58	32 to 67
1.18 mm (No. 16)	–	–	–	–	–
0.60 mm (No. 30)	–	–	–	–	–
0.30 mm (No. 50)	4 to 16	5 to 17	5 to 19	5 to 21	7 to 23
0.15 mm (No. 100)	–	–	–	–	–
0.075 mm (No. 200)**	0 to 5	1 to 7	2 to 8	2 to 10	2 to 10
Asphalt Binder, weight percent of Total Mixture†	3 to 8	3 to 9	4 to 10	4 to 11	5 to 12
	Suggested Coarse Aggregate Sizes				
	4 and 67 or 4 and 68	5 and 7 or 57	67 or 68 or 6 and 8	7 or 78	8

* In considering the total grading characteristics of an asphalt paving mixture, the amount passing the 2.36 mm (No. 8) sieve is a significant and convenient field control point between fine and coarse aggregate. Gradings approaching the maximum amount permitted to pass the 2.36 mm (No. 8) sieve will result in pavement surfaces having comparatively fine texture, while gradings approaching the minimum amount passing the 2.36 mm (No. 8) sieve will result in surfaces with comparatively coarse texture.

** The material passing the 0.075 mm (No. 200) sieve may consist of fine particles of the aggregates or mineral filler, or both. It shall be free from organic matter and clay particles and have a plasticity index not greater than 4 when tested in accordance with Method D 423 and Method D 424.

† The quantity of asphalt binder is given in terms of weight percent of the total mixture. The wide difference in the specific gravity of various aggregates, as well as a considerable difference in absorption, results in a comparatively wide range in the limiting amount of asphalt binder specified. The amount of asphalt required for a given mixture should be determined by appropriate laboratory testing or on the basis of past experience with similar mixtures, or by a combination of both.

Aggregate Gradation Particle gradation is determined by a sieve (or gradation) analysis of aggregate samples. A sieve analysis involves running the sample through a series of sieves, each of which has openings of specific sizes (Figure 2.18). Sieves are designated by the size of their openings. Coarse particles are retained on the upper sieves. Medium-size particles pass through to the mid-level sieves, and fine particles pass through to the lowest sieves.

The aggregate gradation is normally expressed as the percentage (by weight) of the total sample that passes through each sieve. It is determined by weighing the contents of each sieve

Table 2.06 Typical Sieve Sizes

Coarse Aggregate Sieve Designation		Fine Aggregate Sieve Designation	
Metric	U.S. Customary	Metric	U.S. Customary
63 mm	2½ in.	2.36 mm	No. 8
50 mm	2 in.	1.18 mm	No. 16
37.5 mm	1½ in.	0.60 mm	No. 30
25.0 mm	1 in.	0.30 mm	No. 50
19.0 mm	¾ in.	0.15 mm	No. 100
12.5 mm	½ in.	0.075 mm	No. 200
9.5 mm	⅜ in.		
4.75 mm	No. 4		

Table 2.07 Sieve Analysis Data Converted to Aggregate Gradation

Sieve Size	Retained Each Sieve (grams)	Passing Each Sieve (grams)	Total Percent Passing	Total Percent Retained	Passing-Retained,* Percent
9.0mm (¾ in.)	0	1135	100	0	5
12.5 mm (½ in.)	56	1079	95	5	15
9.5 mm (⅜ in.)	171	908	80	20	23
4.75 mm (No. 4)	262	646	57	43	18
2.36 mm (No. 8)*	203	443	39	61	16
0.60 mm (No. 30)	182	261	23	77	6
0.30 mm (No. 50)	68	193	17	83	5
0.15 mm (No. 100)	57	136	12	88	4.5
0.075 mm (No. 200)	51	85	7.5	92.5	7.5
Pan	85			100	

Total Weight = 1135 grams
* Passing designated sieve, retained on next smaller size.

following the sieve analysis and then calculating the percentage passing each sieve by one of several mathematical procedures. One method is to subtract the weight of the contents of each sieve from the weight of the material passing the previous sieve, resulting in the total weight passing each sieve. These weights are then converted to the percentage of the total sample passing each sieve.

HMA is graded by the percentages of different-size aggregate particles it contains. Table 2.05 illustrates five different HMA gradations. Sieves generally used in grading aggregate for HMA are shown in Table 2.06.

Certain terms are used in referring to aggregate fractions:

- *Coarse aggregate* – Material retained by the 2.36 mm (No. 8) sieve.
- *Fine aggregate* – Material passing the 2.36 mm (No. 8) sieve.

- *Mineral filler* – Fraction of fine aggregate that passes 0.60 mm (No. 30) sieve.
- *Mineral dust* – Fraction of fine aggregate passing the 0.075 mm (No. 200) sieve.

Mineral filler and mineral dust occur naturally with many aggregates and are produced as a by-product of crushing many types of rock. They are essential for producing a mixture that is dense, cohesive, durable, and resistant to water penetration. However, small changes in the amount or character of the mineral filler or dust can make significant changes in the quality and performance of HMA. Consequently, the type and amount of filler or dust used in any asphalt paving mixture must be carefully controlled.

The two methods for determining aggregate gradation are dry sieve analysis and wet sieve analysis. Dry sieve analysis alone is often used for coarser graded aggregate. When aggregate particles are coated with dust or silt-clay material, however, a washed sieve analysis should be performed.

Dry Sieve Analysis (ASTM C 136/AASHTO T 27)

- Sample for analysis is reduced by mechanical splitter or by quartering.
- Sample is dried to a constant weight.
- Sample is sieved into fractions.
- Weights of the fractions retained in each sieve and in the pan beneath the sieves are determined.

Washed-Sieve Analysis (ASTM C 117/AASHTO T 11)

- Sample for washed-sieve analysis is reduced, dried and weighed.
- Sample is then washed thoroughly to remove dust and silt-clay material (that which passes the .075 mm [No. 200] sieve).
- After washing, the sample is again dried and weighed. The difference between the weight before washing and the weight after washing determines the amount by weight of dust and silt-clay material in the original sample.
- Dry sieve analysis is performed on the washed sample (AASHTO T 27).

The method of determining the percentages of various-size particles from the weights of fractions obtained by sieve analysis is illustrated in Table 2.07. Gradations are usually expressed as a total percent passing each sieve (the total percent by weight of aggregate sample that passes through each sieve).

Graduations are sometimes expressed by two other methods:

- Total percent retained (the total percent by weight of aggregate sample retained by a given sieve).
- Total passing and retained (the total percent by weight of aggregate sample that passes through a given sieve, and is retained on the next smaller sieve).

After being calculated, aggregate gradation is often plotted as a grading curve. Two types of gradation charts are in general use: the semi-log chart (Figure 2.19) and the 0.45 power chart (Figure 2.20). The percent passing each sieve is recorded as a point on the appropriate vertical line. When one point is plotted for each sieve and its percent passing, the points are connected by a continuous line. The line represents the gradation curve of the aggregate analyzed.

Aggregate gradation specifications for a given job can also be presented graphically. On Figure 2.21, the specifications for the particular job are represented by the region between the

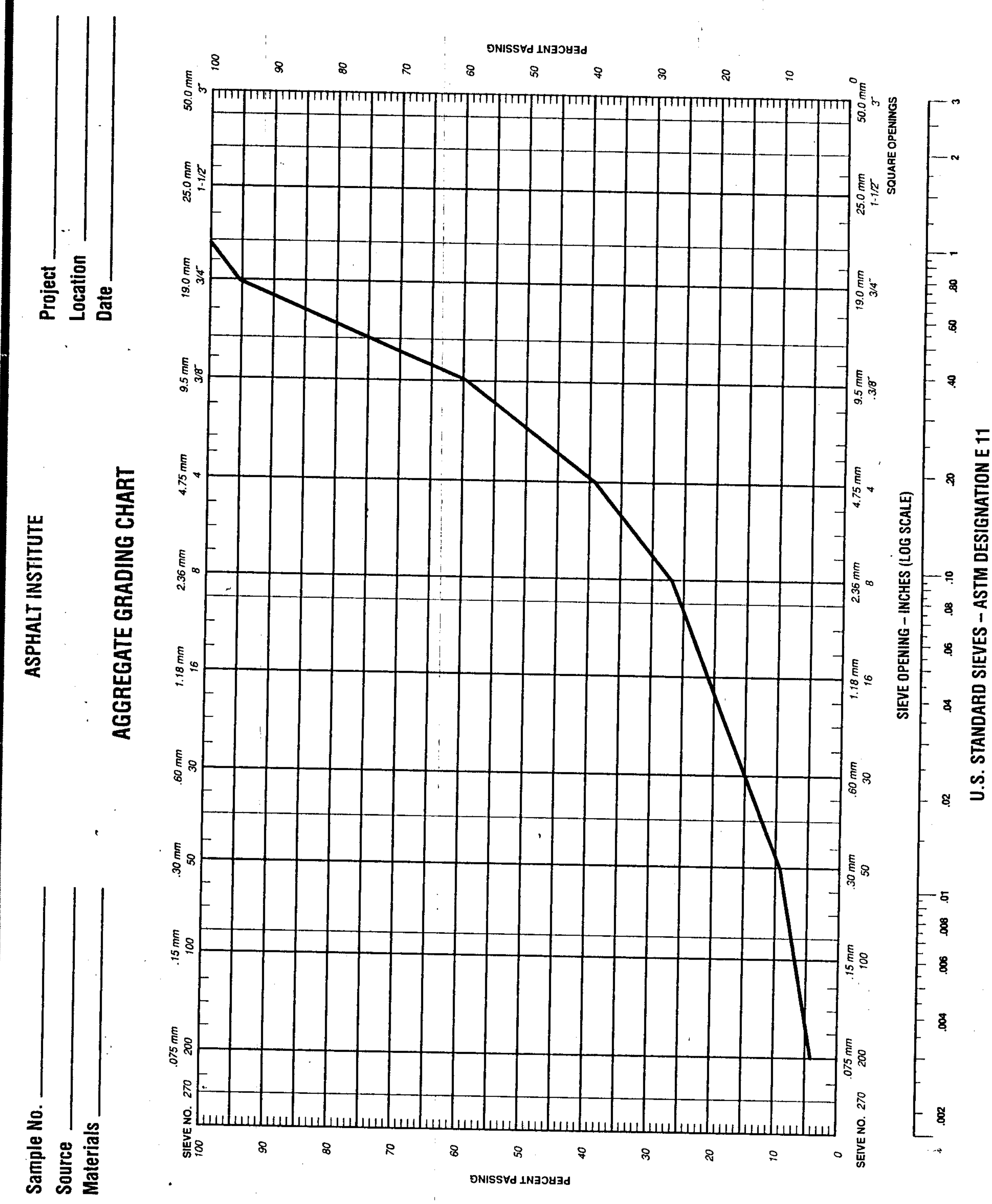

Figure 2.19 Semi-Log Chart

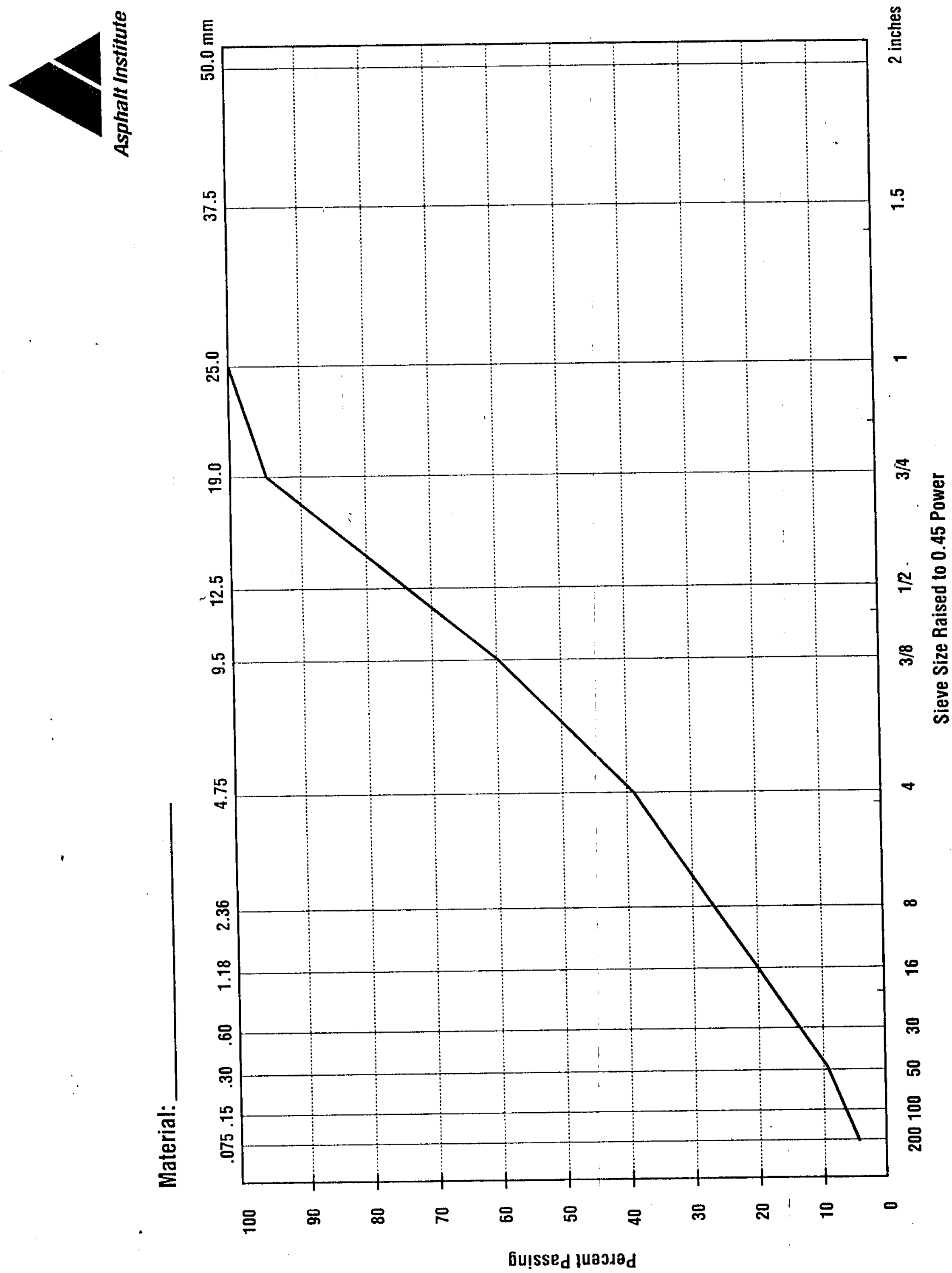

Figure 2.20 0.45 Power Chart

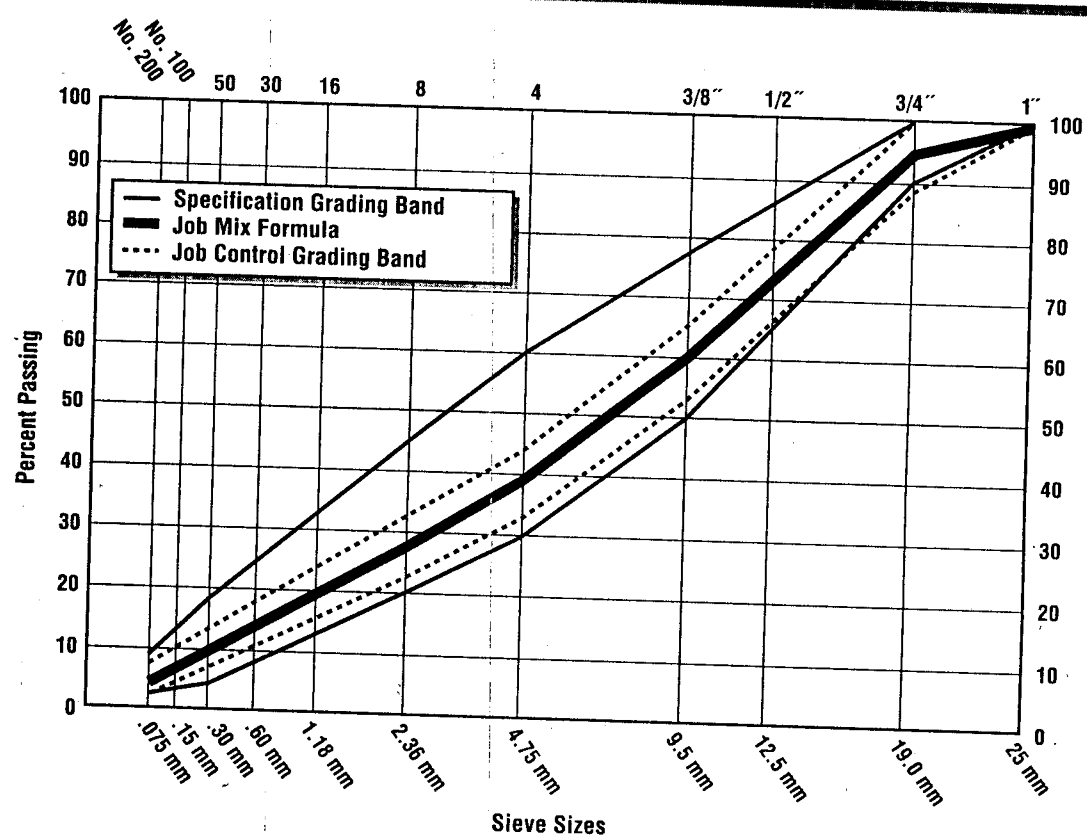

Figure 2.21 Typical 0.45 Power Chart and Example of Grading Band

thin solid lines. The paving mixture formula (job mix formula) is represented by the heavy solid line. The job control gradation band – established as the target for gradation control on the project – lies within the region bounded by the dotted lines. By plotting aggregate gradation along with the curves of the gradation specifications, one can tell immediately if the aggregate gradation falls within those specifications and targets.

Using Figure 2.21, we can examine what a gradation chart tells us. Taking the 9.5 mm (3/8-in.) sieve as an example, we see that the job control grading band permits between 54 percent and 66 percent of the aggregate to pass through. The job mix formula calls for 60 percent of the aggregate to pass through the 9.5 mm (3/8-in.) sieve. During mixing and construction, however, between 54 percent and 66 percent passing is the range used. A gradation chart helps to understand the gradations required by the specification gradation band, the job mix formula, and the job control gradation band.

The analysis of aggregate gradations and the combining of aggregates to obtain a desired gradation are important steps in HMA design. In combining aggregates, precise proportions of each must be determined to meet the target gradation. The aggregate gradation must meet the project specifications and yield a mix that meets the mix design criteria. The aggregate will normally be the most economical material available, provided that it complies with all of the quality requirements.

Specific Gravity The specific gravity of an aggregate is the ratio between the weight of a given volume of the aggregate and the weight of an equal volume of water. Specific gravity provides a means of expressing the weight-volume characteristics of materials. These characteristics are especially important in manufacturing pavement mixtures because the aggregate and asphalt in a mixture are proportioned by weight.

A ton of aggregate with a low specific gravity has a greater volume than a ton of aggregate with a higher specific gravity. Consequently, more asphalt must be added to a ton of aggregate with a low specific gravity in order to coat all the aggregate particles, than to a ton of aggregate with a high specific gravity.

Another critical reason for knowing the specific gravity of the aggregate is to aid in calculating the volumetric properties of the compacted mixtures. HMA must include a certain percentage of air spaces or voids (Chapter 3). These spaces perform important functions in the finished pavement. The percentage of air voids in compacted HMA specimens at various asphalt contents is calculated by a formula using the bulk specific gravities of the compacted mix and its maximum specific gravities at various asphalt contents. Maximum specific gravity is calculated using effective specific gravity of the aggregate along with the specific gravity of the asphalt.

All aggregates are porous to varying degrees. Because porosity affects the amount of asphalt needed to coat aggregate particles, as well as the percentage of air voids in the final mixture, three types of specific gravity measurements have been developed to take the porosity of an aggregate into consideration (Figure 2.22):

- Bulk specific gravity
- Apparent specific gravity
- Effective specific gravity

Bulk specific gravity is the specific gravity of a sample when the aggregate volume includes all pores in the sample.

Apparent specific gravity does not include pores and capillaries that would fill with water during soaking as part of the aggregate volume.

Effective specific gravity excludes from the aggregate's volume all pores and capillaries that absorb asphalt.

In an asphalt-aggregate mixture, the bulk specific gravity calculation of an aggregate would assume that no asphalt is absorbed into the aggregate pores. Calculating for apparent specific gravity would require an assumption that all of the pores are filled with asphalt. Except in rare cases, neither of these assumptions is true. Therefore, effective specific gravity, which takes into account the amount of asphalt absorbed into the pores, is the most nearly correct value for calculating the maximum specific gravity of the mix.

Cleanliness, or Clay Content Job specifications usually place a limit on the types and amounts of unsuitable material (vegetation, shale, soft particles, lumps of clay, etc.) permitted in the aggregate, particularly if the aggregate is known to contain quantities of such material. Excessive amounts of such material can have an adverse effect on pavement performance.

Aggregate cleanliness can be determined often by visual inspection, but a washed sieve analysis gives an accurate measurement of the percentage of unsuitable material finer than .075 mm (No. 200). The sand-equivalent test (ASTM D 2419/AASHTO T 176) is a method of determining the relative proportion of detrimental fine dust and clay-like material in the fraction (portion) of aggregate passing the 4.75 mm (No. 4) sieve.

Toughness Aggregates must be able to resist abrasion and degradation during manufacture, placing, compaction of the HMA and under actual traffic. Aggregates at or near the pavement

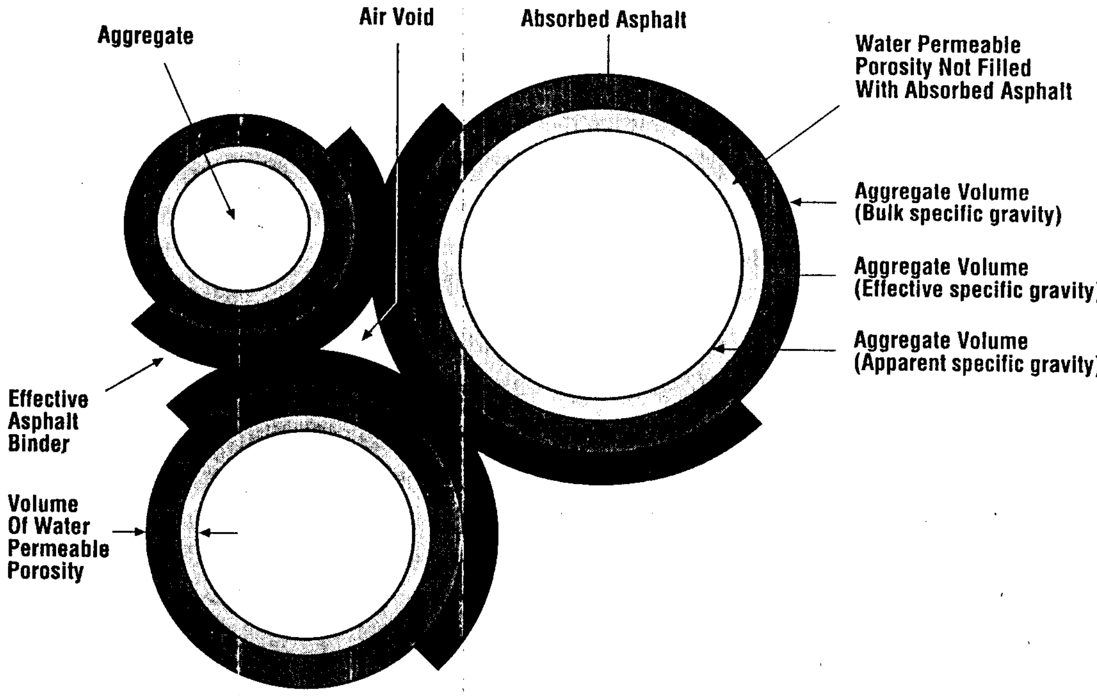

Figure 2.22 Various Types of Aggregate Specific Gravities

Figure 2.23 Los Angeles Abrasion Machine

Figure 2.24 Aggregate of Various Shapes and Surface Textures

surface must be tougher (more resistant to abrasion) than aggregates used in the lower layers of the pavement structure. This is because upper pavement layers receive more stress and wear from traffic loads.

The Los Angeles Abrasion Test (ASTM C 131 or C 535/AASHTO T 96) measures an aggregate's resistance to wear or abrasion. The test equipment is illustrated in Figure 2.23.

Particle Shape Particle shape (Figure 2.24) influences the workability of HMA during placement, as well as, the amount of force necessary to compact the mixture to the required density. During pavement life, particle shape influences the strength of the pavement structure. Aggregates at or near the surface must be of optimum shape.

Because angular particles tend to interlock when compacted, they usually resist displacement in the finished pavement. Particle interlocking is generally obtained with sharp-cornered, cubical-shaped particles. The term "crushed faces" has long been used to describe particle shape of coarse aggregates.

The Superpave asphalt mix design system adopted two procedures to quantify particle shape: coarse aggregate angularity (ASTM D 5821) and fine aggregate angularity (AASHTO T 304).

Absorption All aggregates are porous. Porosity determines how much liquid an aggregate particle absorbs when soaked.

The capacity of an aggregate to absorb water (or asphalt) is important information. If an aggregate is highly absorptive, it will continue to absorb asphalt after initial mixing at the plant, leaving less asphalt on its surface to bond aggregate particles together. Because of this, a porous aggregate requires significantly more asphalt to make a suitable mixture than a less porous aggregates does. Asphalt absorption is calculated during mix design (Chapter 3).

Highly porous, highly absorptive aggregates are not normally used unless they possess other characteristics that make them desirable. Blast furnace slag and other synthetic or manufactured aggregates are examples of highly porous, yet abrasion-resistant and skid-resistant material.

Moisture Susceptibility Stripping is a phenomenon in which the asphalt cement coating does not adhere to the aggregate after placement in the pavement structure. *Moisture susceptibility* is the term used to describe a mixture's tendency toward stripping. Why certain aggregates are moisture susceptible is not clearly understood.

Limestone, dolomite, and traprock have high affinities for asphalt and are also hydrophobic because they resist the efforts of water to strip asphalt from them. Hydrophilic aggregates have low affinities for asphalt. Consequently, they tend to separate from asphalt films when exposed to water. Siliceous aggregates (e.g., quartzite and some granites) are examples of aggregates that are prone to stripping and must be used cautiously.

Several test methods have been developed for determining moisture susceptibility. In one such test, the uncompacted aggregate-asphalt mixture is soaked in water and evaluated visually. In several other tests, two sets of mixture specimens are prepared and compacted. One is conditioned in water and the other is not. Both are then tested for indirect tensile strength. The ratio of the average strength of the conditioned samples to the unconditioned samples is considered to be an indicator of the aggregate's susceptibility to stripping. The Superpave asphalt mix design system adopted one of these strength comparison methods (AASHTO T 283) to evaluate HMA moisture susceptibility.