Laboratory Mixing and Compaction Temperatures

For years, asphalt mix design procedures have used equiviscous temperature ranges for selecting laboratory mixing and compaction temperatures. The Asphalt Institute's Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types (MS-2) began recommending laboratory mixing and compaction temperature ranges based on viscosity as early as 1962. At that time, viscosity ranges were specified based on Saybolt-Furol viscosity. Beginning in 1974, the Asphalt Institute switched viscosity measurements to the more fundamental unit of centistokes. In 1974, the MS-2 manual recommended viscosity ranges of 170 ± 20 centistokes for mixing temperatures and 280 ± 30 centistokes for compaction temperatures when performing a Marshall mix design. Twenty years later, the same ranges have been recommended for Superpave mixture design, except that the units have been converted to metric (Pascal-seconds). The Asphalt Institute's Superpave Mix Design (SP-2) manual documents this change.

The purpose of using equiviscous mixing and compaction temperatures in laboratory mix design procedures is to normalize the effect of asphalt binder stiffness on mixture volumetric properties. In this manner, a particular asphalt mixture of the same aggregate gradation will exhibit very similar volumetric properties with a softer asphalt binder, such as an AC-10, as with a harder asphalt binder, such as an AC-40. The practice of normalizing the effect of binder stiffness on volumetric properties of the mixture comes from common production practices. A hot-mix plant that produces the asphalt mixture for placement on the road, increases the mix temperature with a stiffer asphalt binder to achieve the same coating and compaction obtained with a softer asphalt binder.

A major concern of many asphalt technologists is the appropriate mixing and compaction temperature ranges (viscosity ranges) for modified asphalt binders. The equiviscous ranges used in Marshall mix design, and now in Superpave mix design, were established for neat, or unmodified, asphalt binders. A national study, NCHRP 9-10, "Superpave Protocols for Modified Asphalt Binders", includes a task to recommend mixing and compaction temperatures for modified asphalt binders. This research is expected to be completed by 2000.

Mixing and compaction temperatures can be determined by measuring the asphalt binder viscosity at a minimum of two temperatures. In the past, absolute viscosity (60°C) and kinematic viscosity (135°C) measurements were used. The two measured data points were plotted on a graph of viscosity (log-log centistokes) versus temperature (log degrees Rankine) for the particular asphalt binder. For graphing purposes, the temperature is converted from Celsius to Rankine (°R = 1.8°C + 492). Since absolute viscosity is usually reported in poises, it is necessary to convert to kinematic viscosity using the following relationship:

\[ h_{\text{centistokes}} \ @ \ 60^\circ \text{C} = h_{\text{poises}} \ @ \ 60^\circ \text{C} \times 100 / (0.98 \times G_b) \]
where $G_b$ is the specific gravity of the asphalt binder at 15°C. With Superpave Performance Grade (PG) technology, the terminology has changed slightly. However, for convenience the viscosity range values remain at basically the same magnitude, but with different units. Using AASHTO MP1, Specification for Performance Graded Asphalt Binders, viscosity is measured with the rotational viscometer in units of centipoise. The viscosity is then reported in SI units, Pascal-seconds (Pa-s), using the following conversion:

$$1 \text{ poise} = 0.1 \text{ Pa-s} \text{ or } 1 \text{ centipoise} = 0.001 \text{ Pa-s}$$

$$h_{\text{Pa-s}} = h_{\text{centipoise}} \times \frac{0.001 \text{ Pa-s}}{1 \text{ centipoise}} \times \frac{\text{CF} \times G_b}{1}$$

where CF is a temperature-volume correction factor calculated as:

$$CF = 1.0135 - 0.0006 \times T_{\text{test}}; \text{ with } T_{\text{test}} \text{ in } ^\circ\text{C}.$$  

Assuming a binder specific gravity of 1.01 to 1.03, the product of the temperature-volume correction and the binder specific gravity varies from 0.92 to 0.96 at temperatures in the range of 135°C to 160°C. Since the product of the temperature-volume correction and the binder specific gravity (CF $\times$ $G_b$) is typically close to 1.0, most engineers assume:

$$h_{\text{Pa-s}} \approx 0.001 \times h_{\text{centistokes}}$$

Mixing and compaction temperatures are typically reported as ranges of approximately 5 to 7°C. In normal laboratory practice, mixing and compacting is performed at temperatures near the middle of these ranges. Therefore the above assumption should be adequate for achieving equiviscous temperature ranges. For this reason, Asphalt Institute's Superpave Level 1 Mix Design (SP-2) recommends these viscosity ranges: $0.17 \pm 0.02 \text{ Pa-s}$ for mixing temperatures and $0.28 \pm 0.03 \text{ Pa-s}$ for compaction temperatures in Superpave mix design.

In the Superpave system, the mixing and compaction temperature ranges are also typically determined by measuring an asphalt binder's viscosity at two temperatures. To meet the requirements of AASHTO MP1, the rotational viscosity is determined at 135°C. This measurement establishes one point on the temperature-viscosity graph. To establish the second point, the temperature in the Rotational Viscometer (RV) can be increased to 165°C and additional measurements can be made. The time necessary to reset the temperature, allow the sample to achieve temperature equilibrium, and take the measurements should be less than 30 minutes.
As an alternate method, the complex dynamic shear viscosity, or $\gamma^*$, can also be found using the Dynamic Shear Rheometer (DSR) measurement and the following equation:

$$\gamma^*_{Pa-s} = \frac{G^*}{w}$$

where, $w$ is the angular velocity. In Superpave PG specification measurements, $w$ is specified to be 10 radians per second.

By definition, the coefficient of viscosity, or simply viscosity, is actually the ratio of shear stress to rate of shear; it is a measure of the resistance of a liquid to flow. The complex shear modulus, or $G^*$, measured in the DSR is the ratio of peak shear stress to peak shear strain. The equations for shear stress, $t$, and shear strain, $g$, are as follows:

$$t_{max} = \frac{2 \, T_{max}}{r^3} \text{ and } g_{max} = \frac{\phi_{max}}{r}$$

where,

- $T_{max}$ is the maximum applied torque (N-m),
- $r$ is the specimen radius (m),
- $\phi_{max}$ is the maximum rotation angle (radians), and
- $h$ is the specimen height (m).

$$G^* = \frac{t_{max}}{g_{max}}$$, in units of N/m$^2$, or Pa, at the peak angle in radians.

Therefore, by dividing the measured $G^*$, in Pa, by the $w$ of 10 radians per second, the viscosity can be determined in Pa-s. For most practical purposes, $G^* @ G^*/\sin \phi$ at the normal high DSR operating temperatures (e.g. 58, 64, and 70°C) where $\phi$ is high (> 82°, almost purely viscous) and $\sin \phi$ is about 0.99. This is a useful assumption, since the determination of $G^*/\sin \phi$ is already required for the original binder to be classified using AASHTO MP1.

The results of the high temperature DSR test can then be converted directly to viscosity units by dividing by the angular velocity (10 rad/s). This conversion provides one point on the temperature viscosity graph. The second point is established from the rotational viscosity at 135°C, also required by AASHTO MP1.

For example, if the measured $G^*/\sin \phi$ of an asphalt binder is 1.212 kPa at 64°C, then this is equal to 1212 Pa. To convert to viscosity units, the complex shear modulus is divided by 10 rad/s. In this case, the viscosity is calculated to be approximately 121.2 Pa-s.
The resulting graph of the viscosity-temperature relationship is usually assumed to be linear when viscosity is plotted on a double log scale (Pa-s) and temperature is plotted on a log scale (°C). This assumption can be verified by making measurements at other temperatures and adding data points to the graph. Some modified asphalt binders may not exhibit a linear trend. An example Superpave temperature-viscosity graph is shown.

If the plot of these viscosities produces a mixing temperature higher than 175°C, it may indicate that the asphalt is modified. Because of their distinctive characteristics, modified asphalts can frequently be mixed and compacted at higher viscosities than conventional binders. While this is generally true, many modified asphalt binders may be successfully mixed at temperatures much lower than 175°C. It should be noted that temperatures above 175°C may lead to binder thermal degradation and should not be used. The binder supplier should be consulted for recommendations on appropriate mixing and compaction temperatures for modified binders for the laboratory and the field.

In summary, two methods may be used to develop the temperature-viscosity graph and determine mixing and compaction temperatures:

(1) RV measurements at 135°C and 165°C, or
(2) RV measurement at 135°C and DSR measurement at the highest PG temperature where the original binder meets the specification.

The advantages of Method (1) are the following:
- The temperature differential between the two viscosity readings is 30°C, approximately one-half of the temperature differential of the alternate method. The assumption of linearity made when developing the temperature-viscosity graphs is more appropriate within a smaller temperature range.
- The temperatures selected for viscosity measurements, 135°C and 165°C, represent a range where most asphalt mixtures will be mixed and compacted during production.

The advantages of Method (2) are the following:
- The two tests (DSR at high PG temperature and RV at 135°C) do not require any additional testing.
- The temperatures for these viscosity measurements represent a range that is similar to the absolute and kinematic viscosity measurements used previously.
A blank copy of the viscosity-temperature chart is attached for duplication and use as desired.

**Note**
Set printer to print in landscape mode.

The temperatures determined using the procedures discussed in this bulletin are not intended for field production. Depending on the gradation (fines content) of the mixture, the type of plant and the mixing time, the appropriate field mixing temperature for proper coating may be 10 to 30°C lower than the laboratory temperature determined by this method. The field compaction temperature is affected by several factors: air temperature, base temperature, wind speed, haul distance, roller type, and lift thickness. The field compaction temperature, usually in the same range as the laboratory compaction temperature, controls all of the plant operations for the project. The field mixing temperature is often adjusted to compensate for one or more of these factors affecting compaction.

For modified asphalt binders, the field mixing temperature for proper coating is usually higher than that for unmodified binders. Mixes with modified binders can also be expected to support the roller passes at a higher temperature. In addition, the cessation temperature of mixes with modified binders, where all rolling should be completed, is also usually higher and reached more quickly. Higher frequencies of vibration and heavier rollers may facilitate the compaction sequence. However, some modified mixtures have been successfully constructed with no changes from the standard compaction sequence. Field mixing temperatures for these mixes should not be increased to super-elevated temperatures to provide more rolling time.