Asphalt Cement Grading

Asphalt Cement Performance

During its lifetime, asphalt cement must perform well over a range of temperatures from more than 300°F, where it behaves like a liquid, to below zero, where it behaves like an elastic solid.

At high temperatures—where the asphalt cement is mixed with aggregate, transported to the job site, and placed on the ground by a paver—it must be able to resist draining off the aggregate.

Asphalt Cement Performance

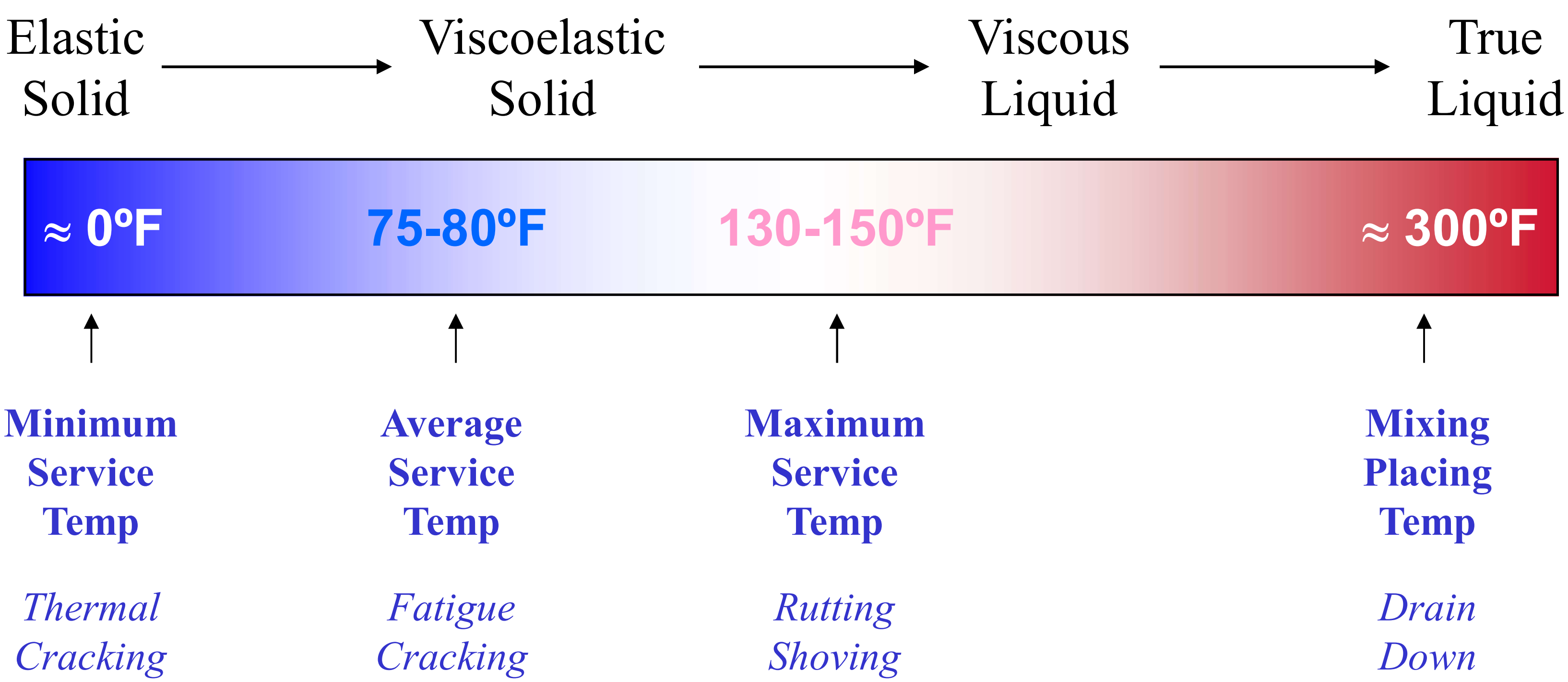
Once in service, the pavement can heat up to 150°F or more on a hot sunny day. The asphalt cement has to help resist rutting and shoving from wheel loads at those maximum service temperatures.

At around room temperature (which is the average service temperature for an asphalt pavement), the asphalt can become more brittle and prone to fatigue cracking as the result of repeated loading.

Asphalt Cement Performance

On a cold winter night, the asphalt cement behaves as a brittle elastic solid and is prone to cracking as a result of sudden drops in temperature. This is called thermal cracking.

Asphalt Cement Performance



Thermal Cracking

Thermal cracks can be initiated by a single low temperature event or by multiple cycles of warming and cooling. As the temperature drops the pavement tries to shrink but can't because of friction with the underlying roadbed. As a result, tensile stresses build to a point where a crack is formed. Because the pavement is much longer than it is wide, the highest stresses are in the longitudinal direction, so the cracks form perpendicular to the direction of travel.

Thermal Cracking

If you imagine a 1000-foot section of pavement that cools suddenly, the maximum tensile stress will be at the halfway point (500 feet) so that's where it cracks first. As the temperature drops more, each 500-foot section cracks in the middle, forming four 250-foot sections. Then those sections crack in the middle, and so on. The result is a series of equally spaced cracks.

Thermal Cracking

Fatigue Cracking

Fatigue cracking results from repeated applications of load to the pavement over time. In thin pavements, cracking initiates at the bottom of the asphalt layer where the tensile stress is the highest. In thick pavements, the cracks initiate from the top due to tire-pavement interaction and embrittlement of the asphalt near the surface where it is exposed to the air.

Fatigue Cracking

Fatigue cracks first appear at longitudinal cracks in the vehicle wheel paths. As the cracking gets worse, series of parallel cracks forms. These will eventually connect to each other, forming what is called alligator cracking because it resembles alligator skin.

Fatigue Cracking

Fatigue Cracking

Rutting

Rutting is a depression in the wheel path that may be accompanied by uplift along the sides of the rut as the material shears under loading. It may result from poor asphalt compaction during construction or from an improper mix design and is exacerbated by high temperatures.

Rutting

Rutting

Shoving

Shoving is one or a series of waves across the surface of the pavement perpendicular to the traffic direction. It is created by tire loads shearing the pavement when vehicles start, stop, or turn. It is caused by mix design problems and can be exacerbated by high pavement temperatures.

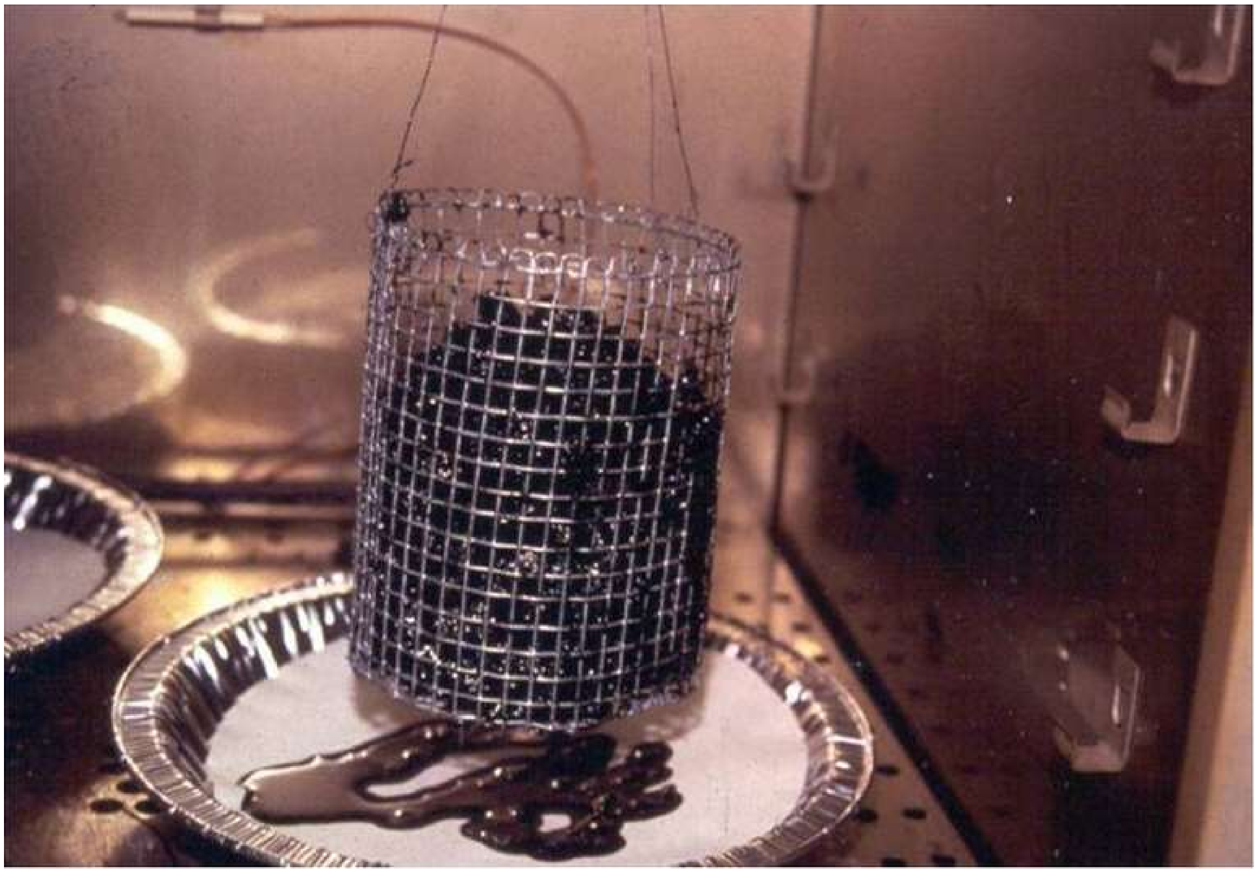
Shoving

Shoving

Drain Down

In hot-mix asphalt, the asphalt cement is heated to the point that its viscosity approaches that of water so it easily coats all of the aggregate. If the viscosity drops too low the asphalt cement simply drains off the aggregate and collects in a pool in the bed of the dump truck. In fact, one way to assess the tendency of an asphalt cement to drain down is to put a sample of asphalt concrete in an oven and see how large of a puddle is created after a certain amount of time.

Drain Down



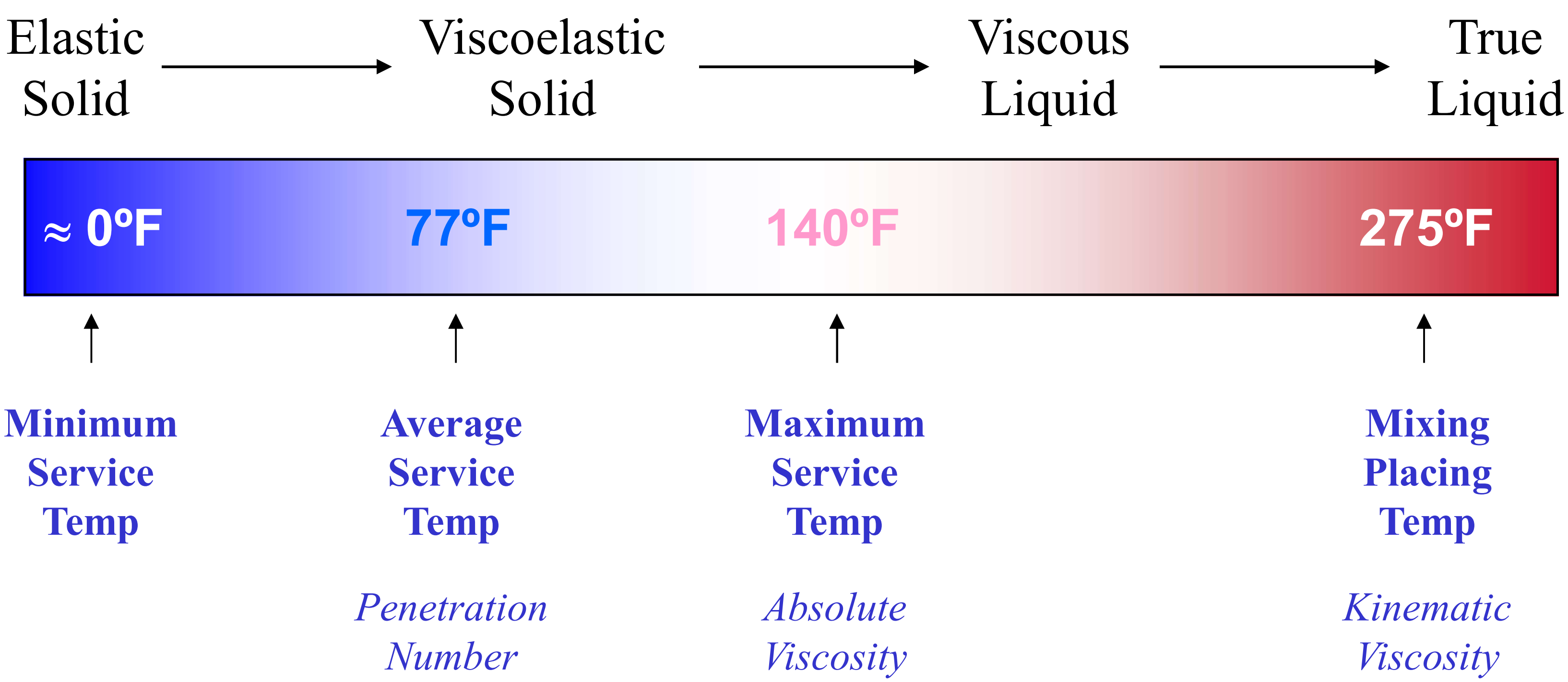
Asphalt Cement Grading

Some asphalt cements are better at resisting cracking at low temperatures; others are better at resisting rutting and shoving at high temperature. Some are better than others at resisting fatigue cracking. In order to select the best asphalt cement for the job, we need to know how it will perform in service. That is the idea behind asphalt cement ***grading***. It allows the pavement design to choose the right asphalt cement for the job.

Asphalt Cement Grading

Because the mechanical behavior of asphalt cement changes from a brittle solid at low temperature to a viscoelastic solid or viscous liquid at intermediate temperatures to a true liquid at high temperatures, it is impossible to create a single lab test to characterize the performance of the asphalt cement. So grading is based on several different tests the span the range of temperatures.

Asphalt Cement Grading



Asphalt Cement Grading

The original performance test was, believe it or not, the ***chew test***. The asphalt technician pinched off a bit of asphalt cement and popped it in his mouth! A good technician could estimate how well the asphalt cement would perform by its resistance to chewing.

Of course, this wasn't very accurate and the results varied greatly from one technician to the next. There was a need for an objective, repeatable test.

Penetration Test

In 1888, H.C. Bowen of the Barber Asphalt Paving Company invented the Bowen Penetration Machine. It's basic principle was to determine the depth to which a No. 2 sewing needle borrowed from his wife would penetrate an asphalt cement sample at room temperature in a given amount of time.

This test became known as the penetration test and was adopted as an ASTM standard.

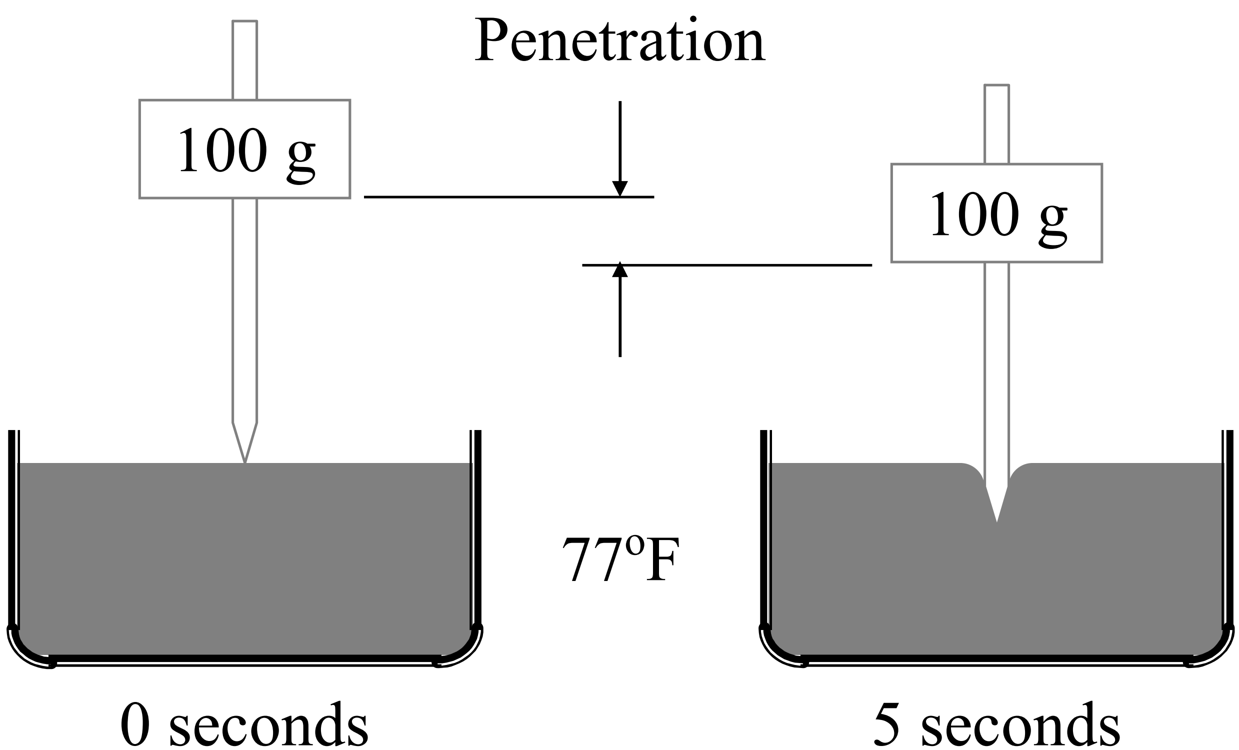
Penetration Test

The modern penetration test measures the penetration of a standard needle under the following conditions:

- Load = 100 grams
- Temperature = 25°C (77°F)
- Time = 5 seconds

Penetration depth is reported in 0.1-mm penetration units (pens). For example, if the needle sinks 8 mm in 5 seconds, it is an 80-pen asphalt cement.

Penetration Test



Penetration Number = Penetration in tenths of a millimeter

Asphalt Penetrometer

Penetration Grading

The penetration test formed the basis for the first asphalt cement grading system, which was developed in the early 1900s. The assumption was that “soft” asphalt cements with high penetration numbers are best suited for cold climates because they’ll resist thermal cracking while “hard” asphalt cements with low penetration numbers are best for warm climates because they’ll resist rutting and shoving.

Penetration Grading

The asphalt grades were assigned based on the pen number: 40-50, 60-70, 85-100, 120-150, 200-300.

In Tennessee we're much more worried about high summertime temperatures than we are cold winter temperatures, so TDOT construction specifications called for asphalts with grades of 40-50 or 60-70 (the so-called "hard" asphalts).

Penetration Grading

Based on penetration index at 77°F:

Grade 40–50
Grade 60–70 } TDOT
Grade 85–100
Grade 120–150
Grade 200–300

Binders must also meet ductility, flashpoint, and retained penetration (aging) criteria.

Penetration Grading

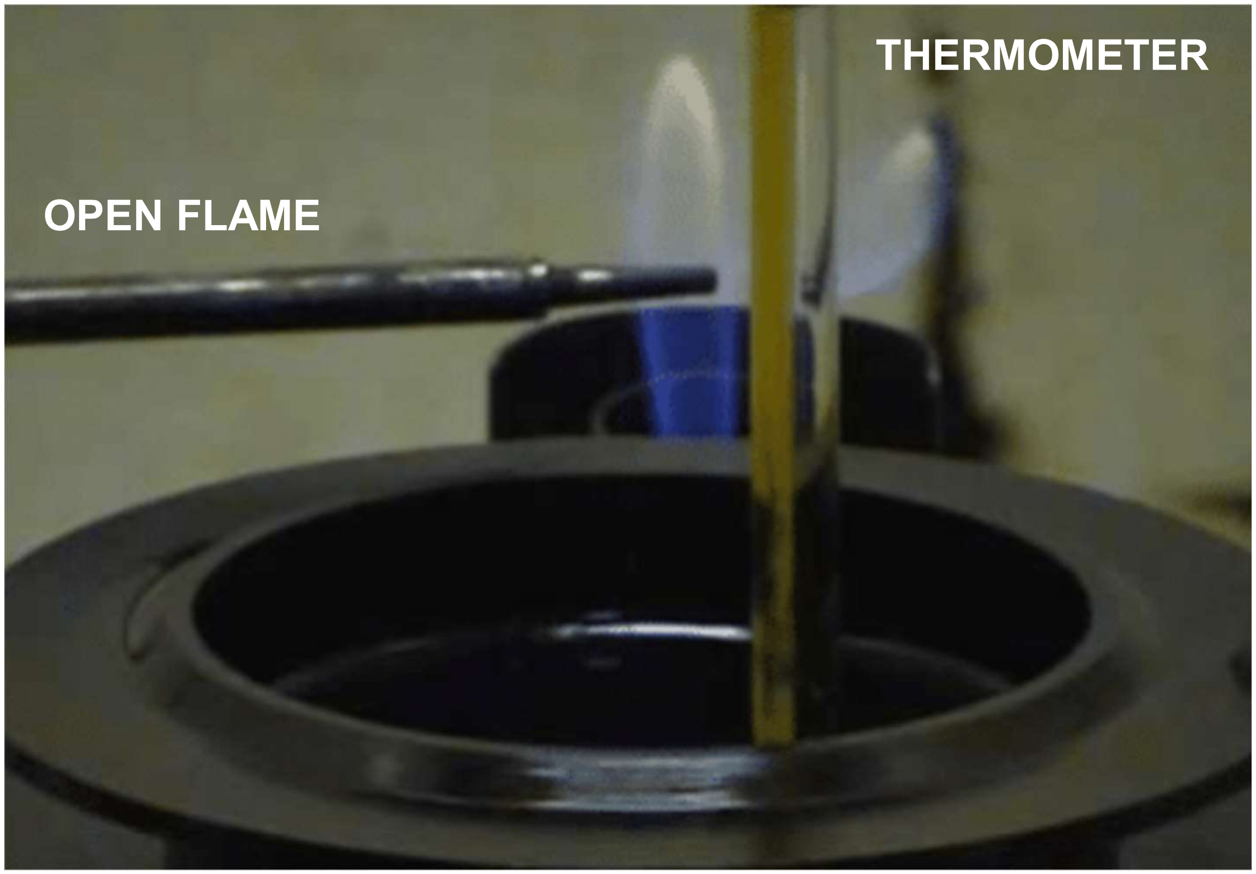
Table 6-1 Specifications for Penetration-Graded Asphalt Cements (ASTM D946) *

	Penetration Grade									
	40–50		*60–70*		*85–100*		*120–150*		*200–300*	
	Min	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*
Penetration at 77°F (25°C) 100 g, 5 s	40	50	60	70	85	100	120	150	200	300
Flash point, °F (Cleveland open cup)	450	—	450	—	450	—	425	—	350	—
Ductility at 77°F (25°C) 5 cm/min, cm	100	—	100	—	100	—	100	—	100	—
Retained penetration after thin-film oven test, %	55+	—	52+	—	47+	—	42+	—	37+	—
Ductility at 77°F (25°C) 5 cm/min, cm after thin-film oven test	—	—	50	—	75	—	100	—	100	—
Solubility in trichloroethylene, %	99.0	—	99.0	—	99.0	—	99.0	—	99.0	—

Penetration Grading

The grading system also includes tests to determine the purity of the asphalt cement (based on solubility in trichlorethylene), its flashpoint (the temperature at which it will ignite when exposed to an open flame), and its ductility (how far it can be stretched).

Flash Point



Ductility

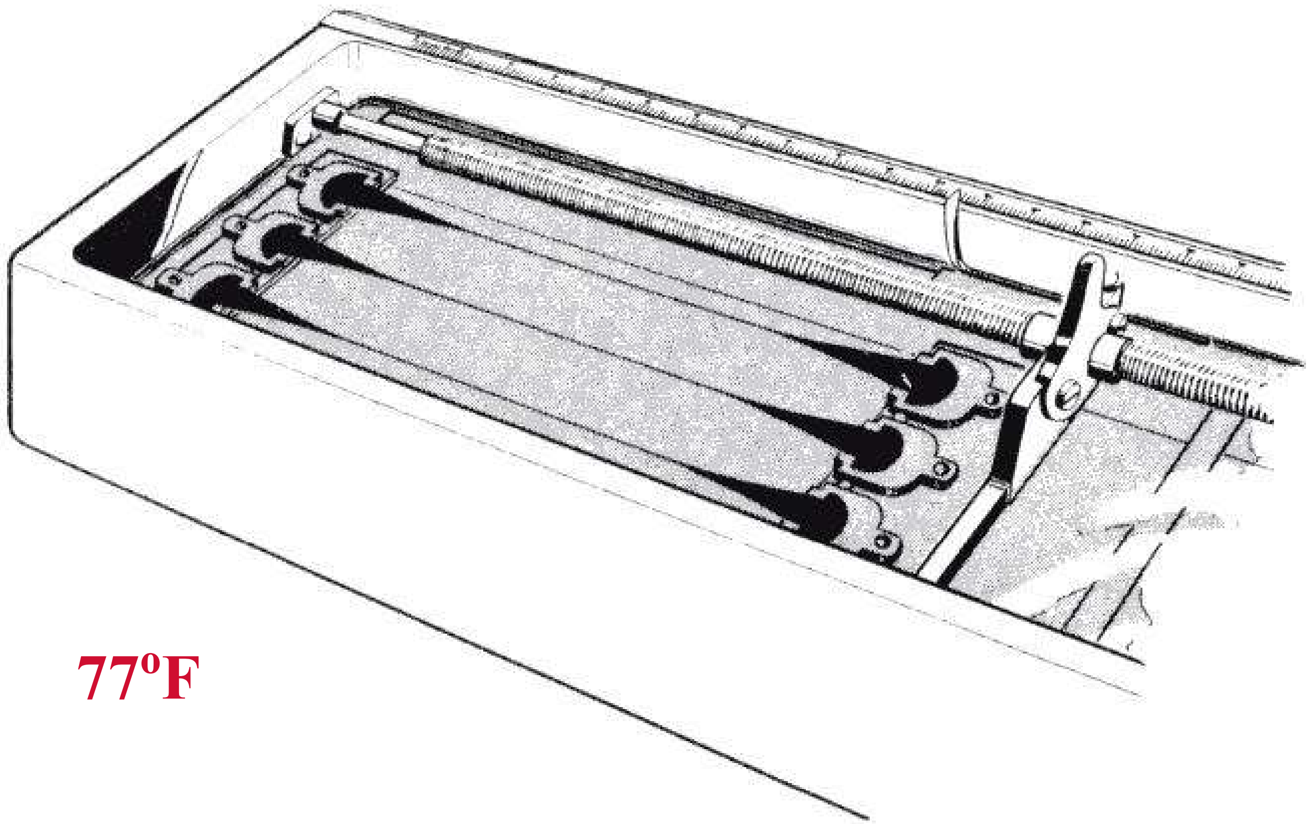
The ductility test measures asphalt binder ductility by stretching a standard-sized briquette of asphalt cement at room temperature to its breaking point. The stretched distance in centimeters at which the asphalt ribbon breaks is reported as the ductility.

The test is conducted in a water bath with the same density as the asphalt cement so it remains at neutral buoyancy and doesn’t sag under its own weight.

Ductility

Ductility

(Taken from The Asphalt Institute Manual ES-1, Second Edition)



77^oF

Retained Penetration

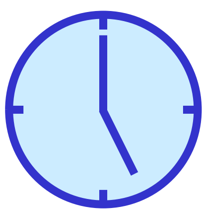
When asphalt cement is heated to high temperatures, the lighter organics volatilize, which means they turn into a vapor and escape. This hardens the asphalt and changes its grade. To measure this hardening, the asphalt cement is aged in a ***thin-film oven*** for several hours, then it is cooled to room temperature and its penetration is measured again. It must retain a certain percentage of its original penetration to be suitable.

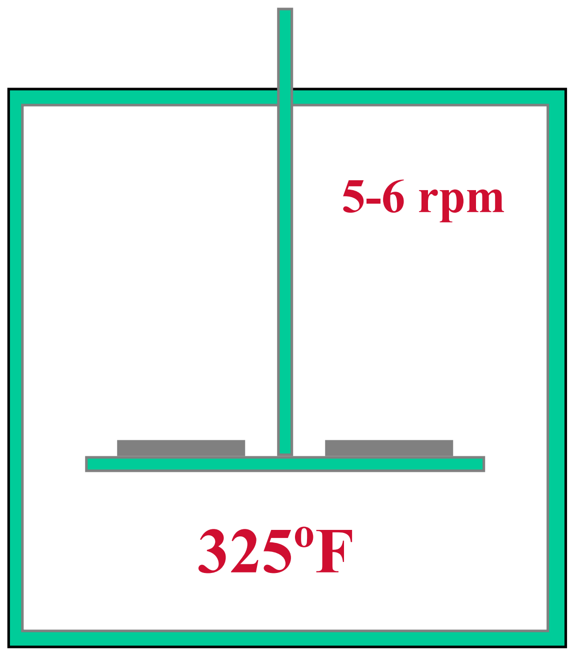
Thin-Film Oven

It's called a thin-film oven because the liquid asphalt cement is poured into shallow pans as a thin film to create as much surface area as possible in order to allow the volatile organics to easily escape. This is done to keep the test time as short as possible. The temperature in the oven is set at 325°F to approximate the temperatures it will be exposed to in the hot-mix asphalt plant.

Thin-Film Oven

5 hrs





sample pans

Simulates aging of asphalt cement during mixing and laydown

Thin-Film Oven

Penetration Grading

Penetration grading has several advantages:

1. The test is done at a temperature reasonably close to a typical pavement average temperature.
2. The test is quick and inexpensive; therefore, it can easily be used in the field.
3. The test is done at room temperature so special ovens or water baths aren't required.

Penetration Grading

Penetration grading also has several disadvantages:

1. The test is empirical; it provides a number, not a fundamental physical property.

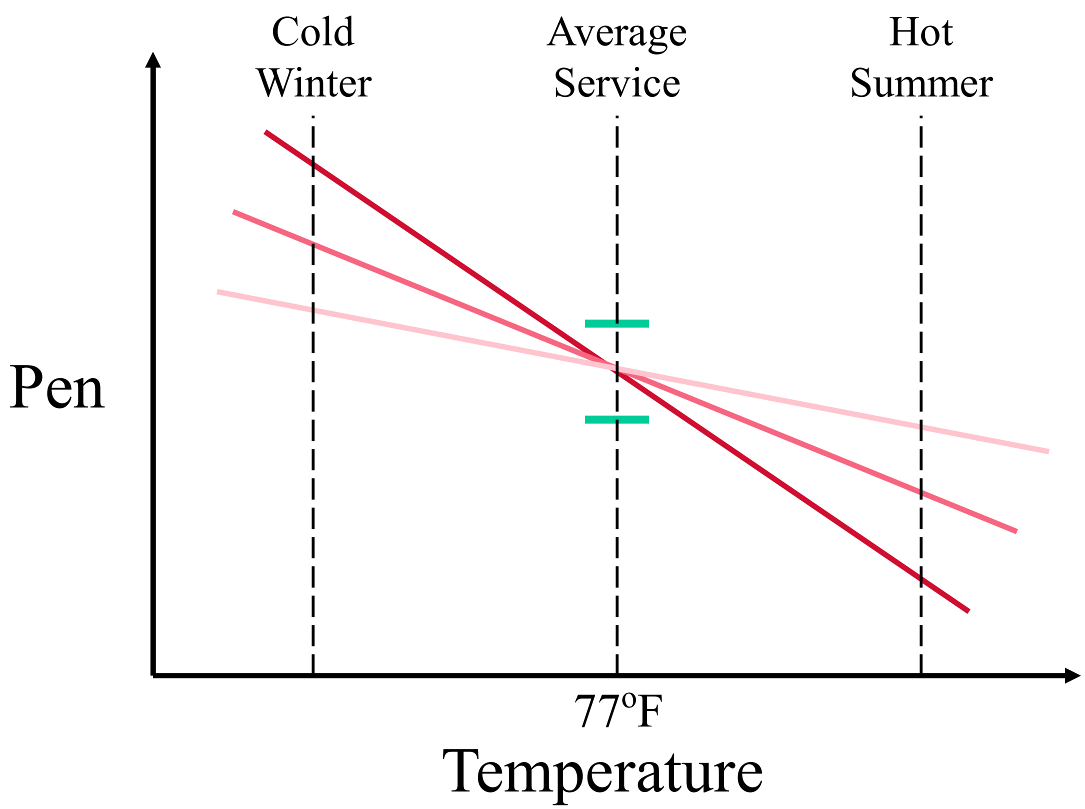
2. It doesn’t address long-term aging of the asphalt.

3. Temperature susceptibility (the change in asphalt behavior with temperature) cannot be determined by a single test at room temperature.

Penetration Grading

- PRO
  - Done at average service temperature
  - Easy test, inexpensive equipment
  - Test is done at room temperature
- CON
  - Empirical test
  - Doesn't specifically address aging
  - Doesn't capture temperature susceptibility

Penetration Grading



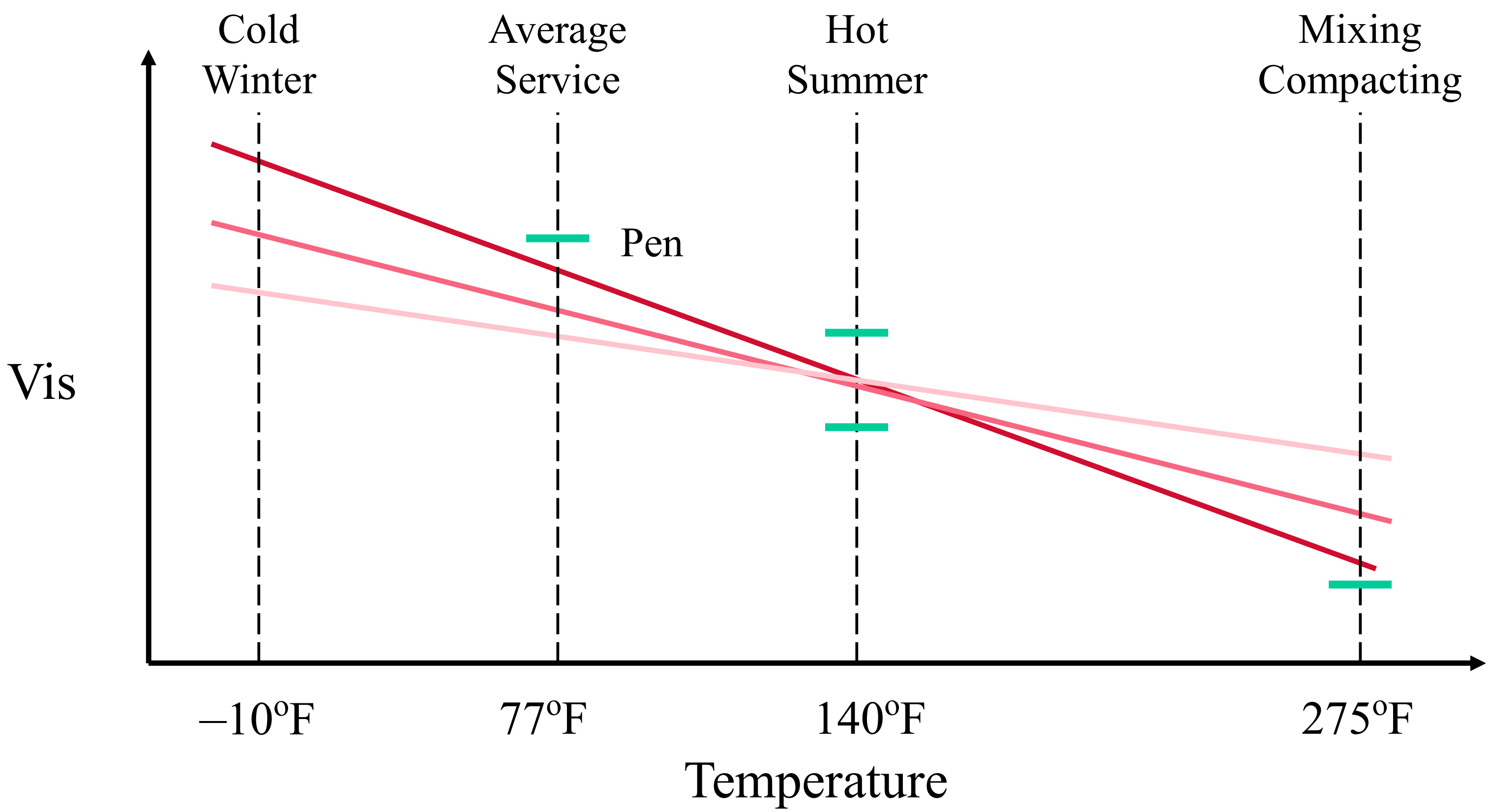
Penetration Grading

Temperature susceptibility is an important aspect of asphalt behavior. We ***assume*** a “hard” asphalt cement at room temperature will be hard on a sunny summer day and we ***assume*** a “soft” asphalt cement at room temperature will be soft on a cold winter night. But some asphalts stiffen or soften more than others as the temperature changes. This is called temperature susceptibility.

Viscosity Grading

Viscosity grading corrects some of the flaws with penetration grading. It still uses the penetration test to characterize the asphalt at the average service temperature, but it also uses the absolute viscosity at 140°F (the maximum service temperature) and the kinematic viscosity at 275°F (the mixing and placing temperature). This places limits on the temperature susceptibility of the asphalt.

Viscosity Grading



Viscosity Grading

In viscosity grading, the asphalt cement is assigned a grade based on its absolute viscosity at 140°F in units of 100 poise. So asphalt cement with a grade of AC-20 has a viscosity of $20 \times 100 = 2000$ poise.

TDOT construction specifications called for asphalts with grades of AC-20 or AC-30. In this case, the higher the number, the <u>stiffer</u> the asphalt.

Viscosity Grading

Based on the absolute viscosity at 140^{o}F:

AC-2.5
AC-5
AC-10
TDOT $\left\{\begin{array}{l}\text{AC-20}\\\text{AC-30}\end{array}\right.$
AC-40

Numbers correspond to absolute viscosity in hundreds of poise

Must also meet ductility, penetration (77^{o}F), kinematic viscosity (275^{o}F), and aging criteria

Viscosity Grading

ASTM later adopted SI units for all of its tests and the units for absolute viscosity changed from poise to Pa·s. Fortunately, this just means moving the decimal place because 1 poise = 0.1 Pa·s.

So asphalt cement with a grade of AC-20 now has a viscosity of 2000 poise × 0.1 Pa·s/poise = 200 Pa·s.

Viscosity Grading

Based on 2013 ASTM Specification

D3381/D3381M – 13

TABLE 1 Requirements for Asphalt Cement, Viscosity Graded at 60°C [140°F] Based on Original Asphalt

Test	Viscosity Grade					
	AC-2.5	AC-5	AC-10	AC-20	AC-30	AC-40
Viscosity, 60°C [140°F], Pa·s	25 ± 5	50 ± 10	100 ± 20	200 ± 40	300 ± 60	400 ± 80
Viscosity, 135°C [275°F], min, mm^2/s	80	110	150	210	250	300
Penetration, 25°C [77°F], 100 g, 5 s, min	200	120	70	40	30	20
Flash point, Cleveland open cup, min,°C [°F]	165 [325]	175 [350]	220 [425]	230 [450]	230 [450]	230 [450]
Solubility in trichloroethylene,[A] min, %	99.0	99.0	99.0	99.0	99.0	99.0
Tests on residue from thin-film oven test:						
Viscosity, 60°C [140°F], max, Pa·s	125	250	500	1000	1500	2000
Ductility, 25°C [77°F], 5 cm/min, min, cm	100[B]	100	50	20	15	10

[A] Solubility in N-Propyl Bromide can be an alternate method to Solubility in TCE.
[B] If ductility is less than 100, material will be accepted if ductility at 15°C [60°F] is 100 minimum at a pull rate of 5 cm/min.

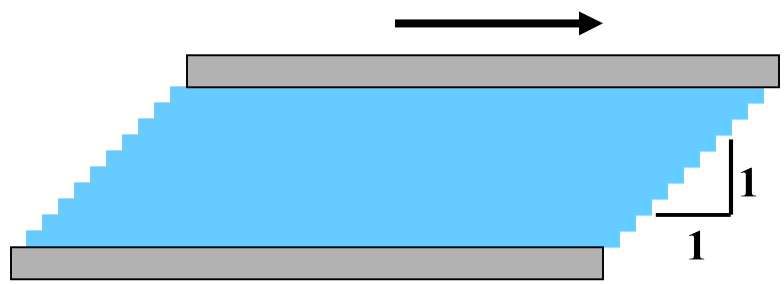
1 Pa·s = 10 poise = 1000 centipoise

Absolute Viscosity

Absolute viscosity has units of shear stress divided by shear strain rate. In SI units, the shear stress is measured in pascals (Pa). Shear strain rate has units of strain per second. Since strain has no units, strain rate actually has units of s^{-1}. So the units of viscosity are $Pa/s^{-1} = Pa \cdot s$.

Absolute Viscosity

- If a fluid with a viscosity $\mu = 1$ Pa·s is placed between two plates and one plate is pushed sideways with a shear stress $\tau = 1$ Pa it will move a distance equal to the thickness of the layer in one second.



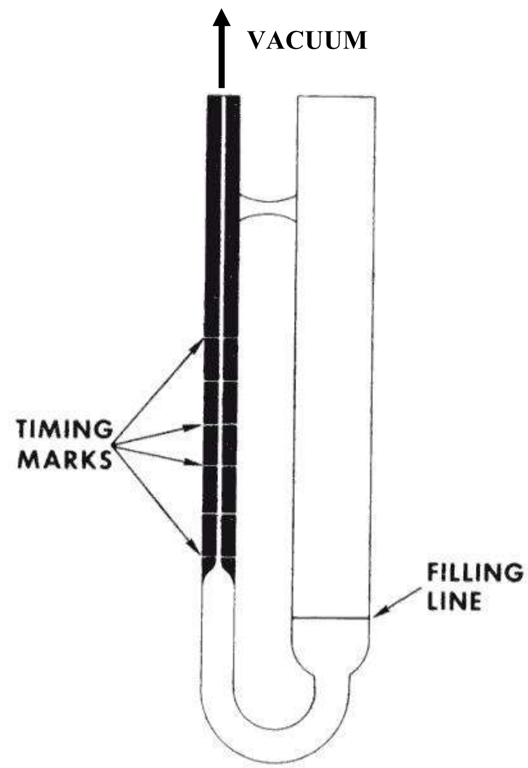
Absolute viscosity of water at 20ºC is
0.001 Pa·s = 0.01 poise = 1 centipoise

Viscosity Grading

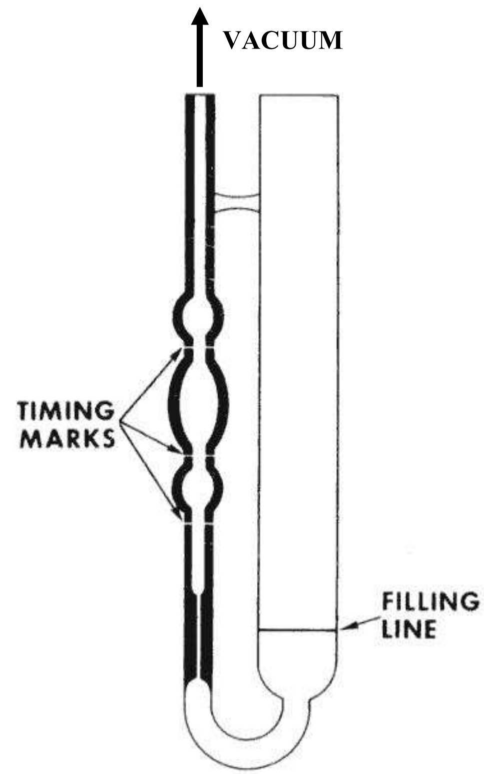
The absolute viscosity of asphalt cement at 140°F is measured in a ***viscometer*** submerged in a water bath. A vacuum is applied to suck the viscous asphalt up through a capillary tube past a series of timing marks. The time it takes to pass through the timing marks is inversely proportional to the viscosity. The vacuum provides the shear stress and the velocity measures the corresponding shear strain rate.

Absolute Viscosity

(Taken from The Asphalt Institute Manual ES-1, Second Edition)



Asphalt Institute Viscometer



Cannon Manning Viscometer

Viscosity of Common Materials

Water		1 centipoise
Cream		20 centipoise
Vegetable Oil		100 centipoise
Tomato Juice		200 centipoise
Honey	AC @ 275°F	2000 centipoise
Chocolate Syrup		10000 centipoise
Sour Cream		20000 centipoise
Ketchup		50000 centipoise
Peanut Butter	AC @ 140°F	150000 centipoise
Vegetable Shortening		1000000 centipoise

Kinematic Viscosity

Viscous liquids flow under their own weight, like molasses being poured out of a jar. Since the weight of the liquid provides the shear stress, a liquid that is twice as dense produces twice the shear stress, so it flows twice as fast as the lighter liquid, even if both have the same viscosity. Kinematic viscosity takes care of this. It's calculated as the absolute viscosity divided by the density of the fluid.

Kinematic Viscosity

$$\text{Kinematic Viscosity} = \frac{\text{Absolute Viscosity}}{\text{Fluid Density}}$$

$$1\ \text{stoke} = \frac{1\ \text{poise}}{1\ \text{g}/\text{cm}^3}$$

Kinematic viscosity of water at 20ºC is
0.01 stoke = 1 centistoke

Kinematic Viscosity

The traditional units of kinematic viscosity are stokes. A stoke is 1 poise divided by 1 g/cm^3 of density.

In SI units it gets a bit messier. 1 $Pa{\cdot}s = 1\ N{\cdot}s/m^2$ and $1\ N = 1\ kg{\cdot}m/s^2$, so $1\ Pa{\cdot}s = 1\ kg/m{\cdot}s$. The density is in kg/m^3, so 1 $Pa{\cdot}s$ divided by 1 kg/m^3 gives units of m^2/s for the kinematic viscosity.

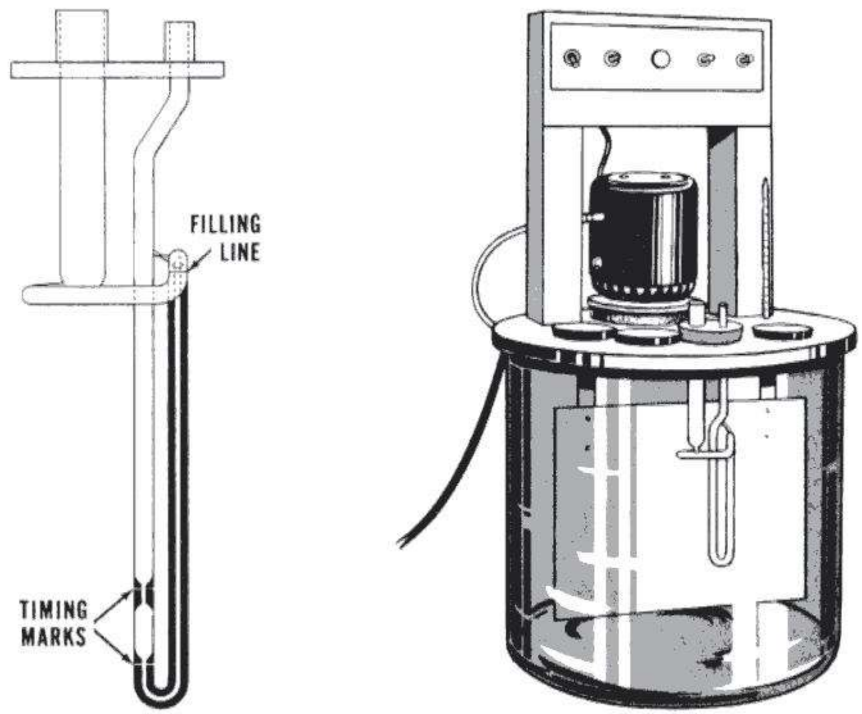
Since this is often a really small number, units of mm^2/s may be used instead.

Kinematic Viscosity

The kinematic viscosity of asphalt cement at 325°F is measured in a slightly different ***viscometer*** that sits in an oil bath. Because of the higher temperature, the asphalt cement is much more liquid, so it is allowed to flow past the timing marks under its own weight.

Kinematic Viscosity

(Taken from The Asphalt Institute Manual ES-1, Second Edition)



Zeitfuchs Cross-Arm Viscometer

Viscosity Grading

As with penetration grading, viscosity and ductility testing is done on both virgin and aged asphalt cement to address the effects of short-term aging (volatilization) on the asphalt cement.

Viscosity Grading

Viscosity grading improves on penetration grading by addressing the rheology at average service temperatures, high service temperatures and mixing and placing temperatures.

It also improves on penetration grading by using a fundamental material property (viscosity) instead of an empirical test.

Viscosity Grading

However, viscosity grading doesn't address asphalt behavior at low service temperatures and it doesn't address long-term aging due to oxidation. Oxidation over time causes the asphalt to become brittle. This exacerbates the formation of top-down fatigue cracks over time.

Viscosity Grading

- PRO
  - Fundamental material property
  - Done at maximum service temperature
  - Includes high & average temperature criteria
- CON
  - Harder to run, more expensive equipment
  - Doesn't specifically address long-term aging
  - Doesn't consider low-temperature cracking