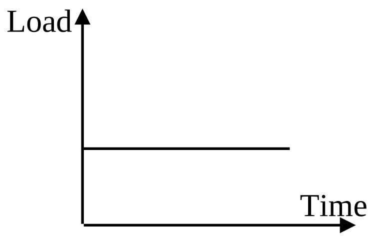
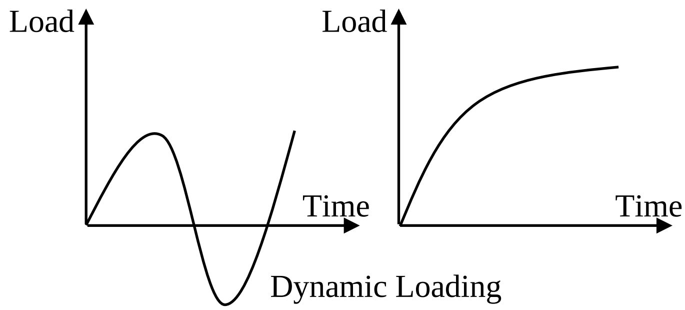
Dynamic Shear Rheometer: DSR

- Dynamic loading vs. static loading.

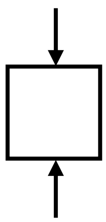


Static Loading

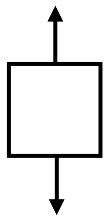


Dynamic Loading

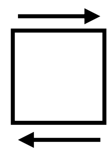
- Types of loading.



Compression, area is normal to load direction



Tension, area is normal to load direction

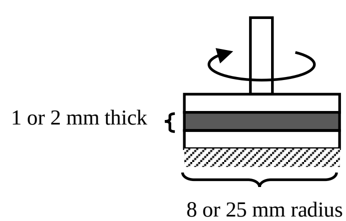


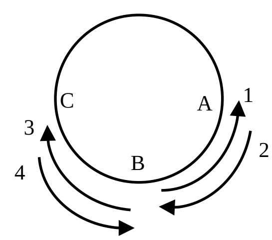
Shear, area is parallel to load direction

- Elasticity vs. viscosity:
  - Elastic solid: if load applied, deformation will happen, Length.
  - Viscous liquid: if load applied, flow will happen, length/time.
- Asphalt cement are viscoelastic, that means it behaves combination of liquid and solid (has deformation and flow properties).
- Asphalt cement behavior:
  - It behaves like elastic solid under rapid loading and cold temperature (deformation due to loading is recoverable – it is able to return to its original shape after a load is removed)
  - It behaves like viscous liquid under slow loading and high temperature (deformation due to loading is non-recoverable – it cannot return to its original shape after a load is removed).

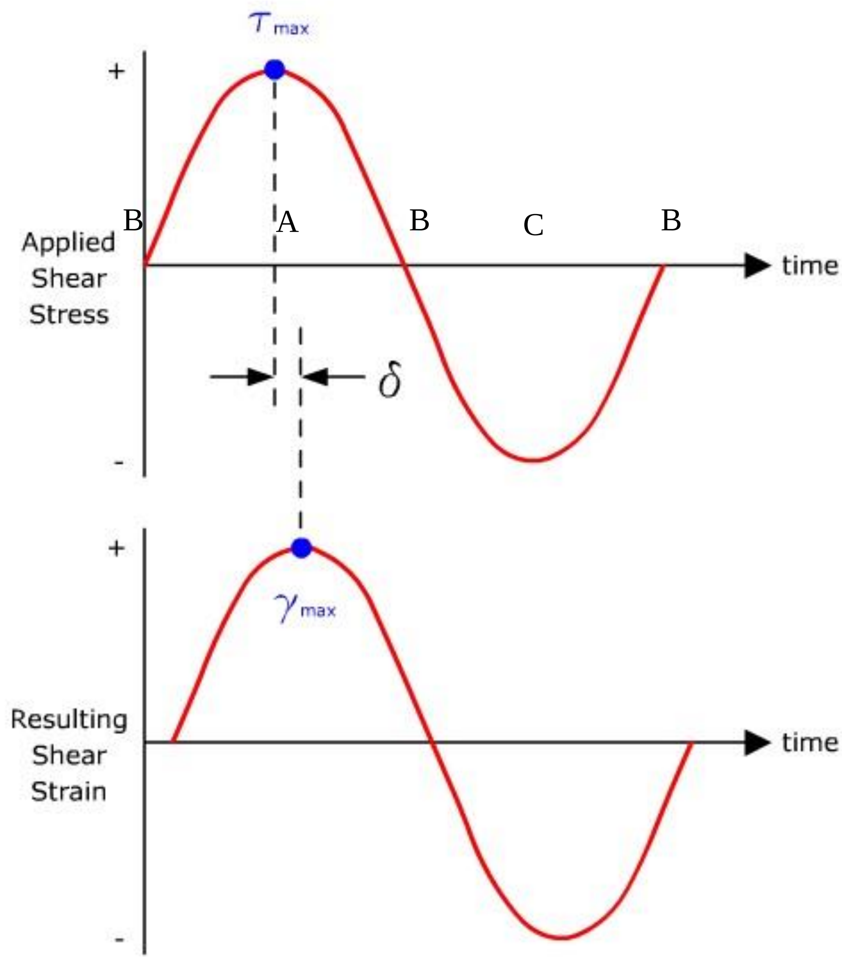
- The dynamic shear rheometer (DSR) is used to characterize the viscous and elastic behavior of asphalt.
- In other words, the DSR test is used to evaluate the asphalt cement's ability to resist permanent deformationand fatigue cracking. .

- The basic DSR test uses a thin asphalt sample sandwiched between two circular plates. The lower plate is fixed while the upper plate oscillates back and forth across the sample to create a shearing action.
- DSR tests are conducted on unaged, RTFO aged and PAV aged asphalt binder samples.
- Test temperatures equal or greater than 46°C use a sample 1 mm thick and 25 mmin diameter (Unaged asphalt binder and RTFO residue).
- Test temperatures inclusively between 4°C and 40°C use a sample 2 mm thick and 8 mm in diameter (PAV residue).





- The DSR measures a specimen's complex shear modulus (G*) and phase angle (δ).
- The complex shear modulus (G*) can be considered the sample's total resistance to deformation when repeatedly sheared.
- The phase angle (δ), is the lag between the applied shear stress and the resulting shear strain.
- The larger the phase angle (δ), the more viscous the material.
- Phase angle (δ) limiting values are:
  - Purely elastic material: δ = 0 degrees.
  - Purely viscous material: δ = 90 degrees.

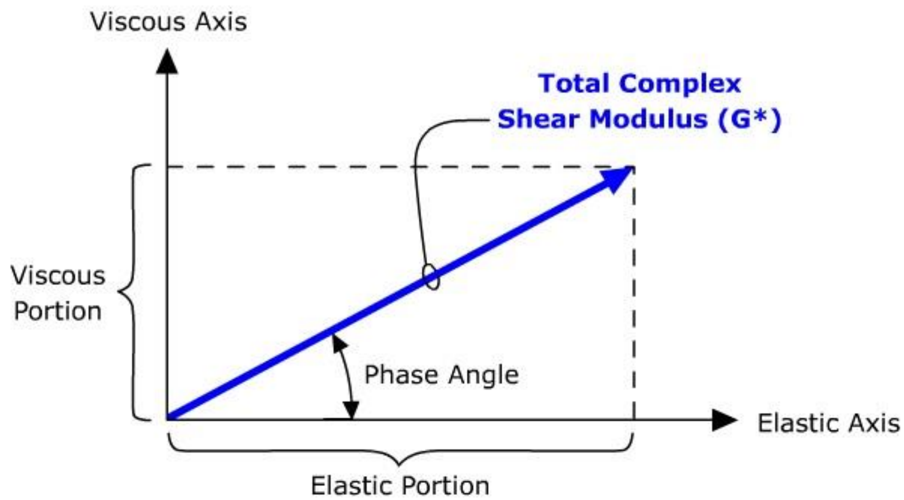


In this procedure, a disk of asphalt cement is placed between an oscillating spindle and the base plate. Since asphalt cement is a viscoelastic material, there is a time lag (δ) between the applied shear stress and the resulting shear strain. This is shown in Figure above. The maximum shear stress (τ_{max}) and the maximum shear strain (γ_{max}) are calculated using the following equations:

$$\tau_{max} = 2T/\pi f^3$$

$$\gamma_{max} = \theta r/h$$

where T is the maximum applied torque (Nm), r is the radius of specimen or plate (4 or 12.5 mm), θ is the deflection (rotation) angle, h is the specimen height (1 or 2 mm).



- Rutting parameter = G* / sin δ
  - In order to resist rutting, an asphalt binder should be stiff and it should be elastic.
  - Therefore, the complex shear modulus elastic portion, G*/sinδ, should be large.
  - When rutting is of greatest concern (during an HMA early and mid-life), a minimum value for the elastic component of the G*is specified.
  - The higher the G* value, the stiffer the asphalt binder is.
  - the lower the δ value, the greater the elastic portion of G* is.
  - For fresh asphalt, G*/ sin δ ≥ 1.0 kPa
  - For RTFOT residue, G*/ sin δ ≥ 2.2 kPa
  - Prepared for the maximum pavement temperature in the field.
  - Measured in different temperatures, ± 6°C increments: 58°, 64°, 70°, 76°, and 82°.
  - ➔ Asphalt classification: PG 82, PG76, PG70, PG64, PG58.
  - e.g. PG70 ➔ no rutting until 70° C.

Example chart: for RTFOT residue

Temperature	G* / sin δ	Rutting?	Temperature	G* / sin δ	Rutting?
58°	2.6 kPa	No	76°	2.3 kPa	No
64°	2.5 kPa	No	82°	2.2 kPa	No
70°	2.4 kPa	No	88°	2.0 kPa	Yes

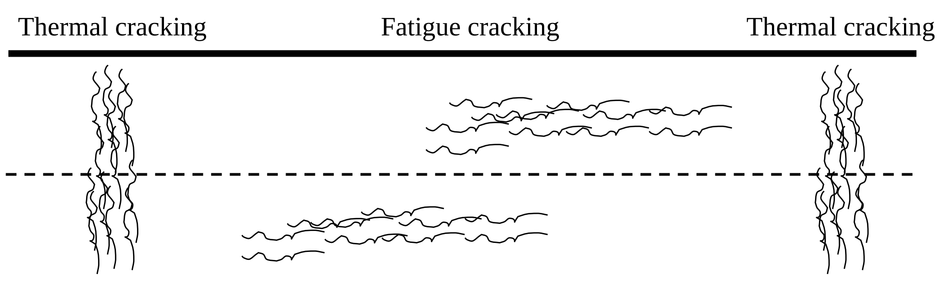
➔ PG 82

- Fatigue parameter = $G^* \times \sin \delta$
    - In order to resist fatigue cracking, an asphalt binder should be elastic but not too stiff.
    - Therefore, the complex shear modulus viscous portion, $G^*\times\sin\delta$, should be a minimum.
    - When fatigue cracking is of greatest concern (late in an HMA pavement's life), a maximum value for the viscous component of the complex shear modulus is specified.
    - Prepared for average pavement temperature in the field.
    - Fatigue parameter, $G^* \times \sin \delta \leq 5000$ kPa

- DSR replaces the penetration test and the softening point test.

Bending Beam Rheometer, BBR

- DSR or BBR:
  - To investigate rutting, use DSR at high temperature.
  - To investigate fatigue cracking, use DSR at intermediate temperature.
  - To investigate thermal cracking, use BBR at low temperature.



- As surrounding temperatures drop, pavements contract and build up internal stresses.
- If this contraction occurs fast enough, the pavement may crack because it does not have time to relax these stresses.
- This type of crack, typically called a “thermal crack”, or transverse crack.

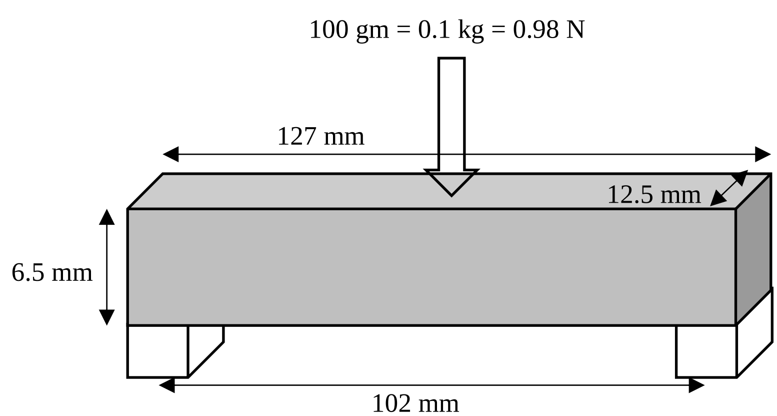
- Thermal crack can result from either of two related mechanisms:
    - Single thermal cycle below the critical temperature.

      A single severe drop in temperature that causes stress to build up quickly to a critical point that causes cracking.
    - Thermal cycling above the critical temperature.

      Repeated thermal contraction and expansion that occurs above the critical temperature can cause stresses to build up and eventually cause cracking.

- The BBR test provides a measure of low temperature stiffness and relaxation properties of asphalt binders.
- These parameters give an indication of an asphalt binder's ability to resist low temperature cracking.
- The BBR is used in combination with the DTT to determine an asphalt binder's low temperature PG grade.

- The basic BBR test uses a small asphalt beam that is simply supported and immersed in a cold liquid bath.
- A load is applied to the center of the beam and its deflection is measured against time.
- Creep stiffness is calculated based on measured deflection and standard beam properties.
- A measure of how the asphalt binder relaxes the load induced stresses is also measured.
- BBR tests are conducted on PAV aged asphalt binder samples.

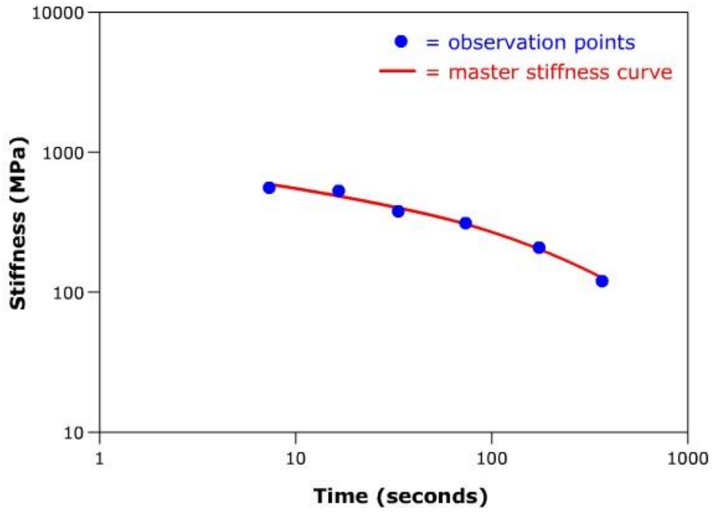


- Properties Measured:
  - Stiffness, S, at 8, 15, 30, 60, 120, and 240 seconds

    S at 60 seconds at test temperature simulates two hours at the field temperature.

    $S \leq 300$ MPa
  - Rate of change of stiffness, m-value, at 8, 15, 30, 60, 120, and 240 seconds.

    M-value ≥ 0.3



- Classic beam theory is used to calculate the flexural beam stiffness:

$$S(t) = \frac{P(L^3)}{4bh^3\delta(t)}$$

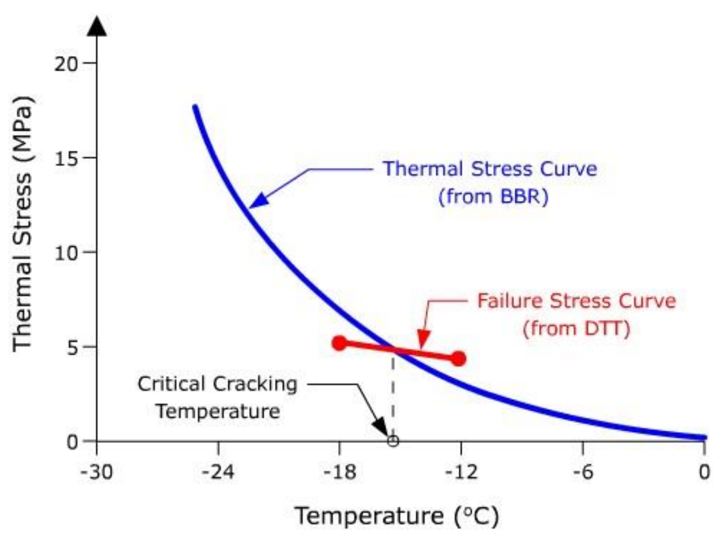
- where S(t) is the creep stiffness (at time 60 sec), P is the applied constant load (980 mN), L is the distance between beam supports (102 mm), b is the beam width (12.5 mm), h is the beam thickness (6.25 mm), and d(t) is the deflection (at time 60 sec).
- A maximum stiffness of 300 MPa and minimum m-value of 0.300 are required to minimize lowtemperature cracking. If both these criteria are met, there is no need for additional testing. If the maximum stiffness is between 300 and 600 MPa and the m-value is greater than 0.300, then the direct tension test may be conducted to check for compliance with the PG specifications for that grade of asphalt cement.

Direct Tension Test, DTT

- If S ≥ 300 MPa we have to check strain at failure, if it is ≥ 1% then the binder is OK.
- The basic DTT test measures the stress and the strain at failure of a specimen of asphalt binder pulled apart at a constant rate of elongation.
- Test temperatures are such that the failure will be from brittle or brittle-ductile fracture.
- The test is of little use at temperatures where the specimen fails by ductile failure.
- DTT tests are conducted on PAV aged asphalt binder samples.

- Critical Cracking Temperature:
  - The DTT is used in combination with the BBR to determine an asphalt binder's low temperature PG grade.
  - Convert the master stiffness curve to thermal stress curve and compare it to the failure stress from the DTT.
    - Two DTT test temperatures are used and a line is drawn between these two results.

    - The point at which this DTT curve intersects the BBR thermal stress curve is defined as the critical cracking temperature of a pavement.



Performance Grading of Asphalt PG

- The 7-day average maximum air temperature and the 1-day minimum air temperature are required for determining the high and low temperature conditions that should be used for design:
  - Rutting parameter is compared with maximum pavement temperature.
  - Critical temperature is compared with minimum pavement temperature.
- The 7-day average maximum air temperature is defined as the average highest air temperature for a period of 7 consecutive days within a given year.
- The 1-day minimum temperature is defined as the lowest air temperature recorded in a given year.
- However, the PG binder selection is based on pavement temperatures, not air emperatures.
- The high pavement design temperature is the temperature at a depth of 20 mm below the pavement surface.

$$T_{20mm} = (T_{air} - 0.00618Lat^2 + 0.2289Lat + 42.2)(0.9545) - 17.78$$

where $T_{20\ mm}$ is the high pavement design temperature, T_{air} is the 7-day average maximum air temperature, and Lat is the geographical latitude of the project in degrees.

- The low design pavement temperature is the temperature at the surface of the pavement surface.
- The low pavement design temperature at the pavement surface is the same as the 1-day minimum temperature since the air temperature is the same as the pavement surface temperature.

Example:

- Consider Riyadh where the latitude is 24.7136°. The 7-day average maximum air temperature is 45°C and the 1-day minimum air temperature is -3°C. By calculating the high pavement design temperature, we find it 67.3°C. The low pavement design temperature is the 1-day minimum air temperature -3°C. At these conditions, a (PG70 – 10) asphalt cement would be sufficient.

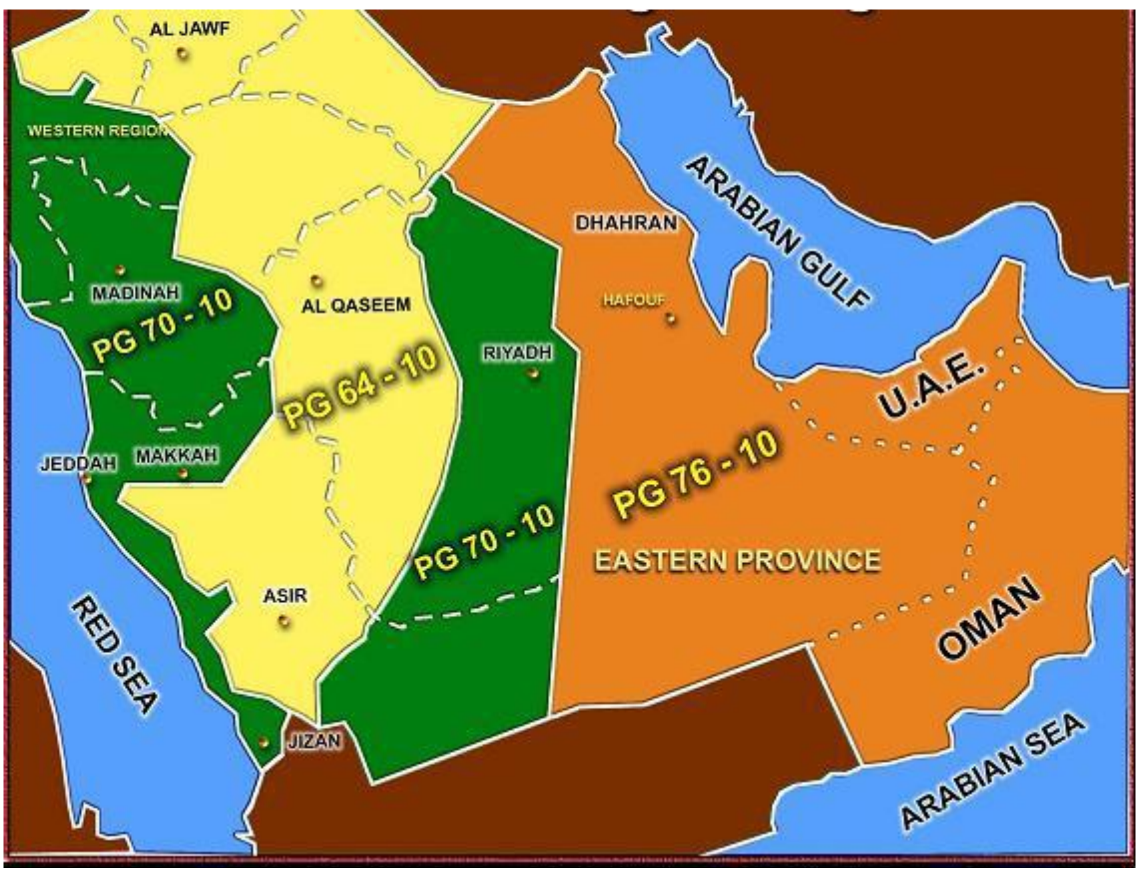
PG 70 – 10

PG = Performance Grade.

70 = Average 7-day max. pavement temperature (20 mm below surface)

– 10 = Min pavement temperature (on the surface)

- Ministry of Transport has established PG zones



Performance Grade	PG 46			PG 52							PG 58					PG 64						PG 70						PG 76					PG 82				
	-34	-40	-46	-10	-16	-22	-28	-34	-40	-46	-16	-22	-28	-34	-40	-10	-16	-22	-28	-34	-40	-10	-16	-22	-28	-34	-40	-10	-16	-22	-28	-34	-10	-16	-22	-28	-34
Average 7-day maximum Pavement Design Temperature, °C	< 46			< 52							< 58					< 64						< 70						< 76					< 82				
Minimum Pavement Design Temperature, °C[A]	> -34	> -40	> -46	> -10	> -16	> -22	> -28	> -34	> -40	> -46	> -16	> -22	> -28	> -34	> -40	> -10	> -16	> -22	> -28	> -34	> -40	> -10	> -16	> -22	> -28	> -34	> -40	> -10	> -16	> -22	> -28	> -34	> -10	> -16	> -22	> -28	> -34
Original Binder																																					
Flash Point Temp., D92: min °C	230																																				
Viscosity, D4402: max. 3 Pa.s Test Temp, °C	135																																				
Dynamic Shear, P246: [C] G*/sinδ, min. 1.00 kPa 25 mm Plate, 1 mm Gap Test Temp. at 10 rad/s, °C	46			52							58					64						70						76					82				
Rolling Thin Film Oven Test (Test Method D2872)																																					
Mass Loss, max. percent	1.00																																				
Dynamic Shear, P246: [C] G*/sinδ, min. 2.20 kPa 25 mm Plate, 1 mm Gap Test Temp. at 10 rad/s, °C	46			52							58					64						70						76					82				
Pressure Aging Vessel Residue (AASHTO PP1)																																					
PAV Aging Temperature, °C[D]	90			90							100					100						100 (110)						100 (110)					100 (110)				
Dynamic Shear, P246: G*sinδ, max. 5000 kPa 8 mm Plate, 2 mm Gap Test Temp. at 10 rad/s, °C	10	7	4	25	22	19	16	13	10	7	25	22	19	16	13	31	28	25	22	19	16	34	31	28	25	22	19	37	34	31	28	25	40	37	34	31	28
Creep Stiffness, P245: [E] S, max. 300 Mpa, m-value, min. 0.300 Test Temp. at 60s, °C	-24	-30	-36	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	0	-6	-12	-18	-24
Direct Tension, P252: [E] Failure strain, min. 1.0% Test Temperature at 1.00 mm/min., °C	-24	-30	-36	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	0	-6	-12	-18	-24