DETERMINATION OF MIXING AND COMPACTION TEMPERATURE OF PG BINDERS USING A STEADY SHEAR FLOW TEST
STEWY SHEAR FLOW TEST (SSF)

• Using a 250 or 500 micron gap, 25 mm diameter plate we test at 76, 82, 88 & 94° C (we have settled on 500 µ as the most utilitarian; at 1000 µ material drills from between plates)

• We use a TA Instruments AR2000 with an environmental test chamber (air controlled), but any rheometer capable of performing steady shear flow should be able to perform the test.

• 0.5 to 1500 µN·m of torque (.16-489 Pa stress)

• Log mode 5 points per decade

• Maximum test time for each point of 12 minutes and test moves on to next torque level

• 3 consecutive points within 2% of each other and the test moves on to the next torque level
The following slide (slide 4) shows the results of a completed test on a PG 64-34 PMA binder. The data shows the viscosity decrease as test temperature increases and furthermore shows the decrease in viscosity at a given temperature as the shear stress increases.

Even though PG 64-34 is a fairly heavily modified binder this data shows that as shear stress increases at a given temperature the resulting apparent viscosity tends to a constant value. We have determined that by using these steady state values we can calculate realistic values for mixing and compaction temperature.
The comments which follow apply to the next 2 slides (6&7)

Slide 6 is a log-log plot of apparent viscosity versus shear stress. This material is well behaved and the data follows a classic pattern of a viscous plateau (zero shear or low shear viscosity value) at low shear stress and shear thinning region as the stress increases. If we could generate such well behaved data for all samples then zero shear viscosity could potentially be used as a basis for determining mixing and compaction temperature.

Slide 7 shows more typical data for a different PG 64-34. At the low shear rates the material has failed to reach steady state and it is impossible to know what the zero shear value would be.
Williamson
a: zero-rate viscosity: 2165 Pa.s
b: consistency: 110.4 s
c: rate index: 0.5112
standard error: 27.68
thixotropy: 0 Pa/s
normalised thixotropy: 0 1/s
End condition: Finished normally

Carreau
a: zero-rate viscosity: 1766 Pa.s
b: infinite-rate viscosity: 3.749E-3 Pa.s
c: consistency: 282.1 s
d: rate index: 0.4120
standard error: 4.457
thixotropy: 0 Pa/s
normalised thixotropy: 0 1/s
End condition: Finished normally
FHWA 64-34 KTR101 UNAGED, SSF for ZSV 76-94°C, 500gap AR2-0001f
MIXING AND COMPACTION TEMPERATURE DETERMINATION PROCEDURE

- Determine viscosity using a DSR Steady State Flow test at 76°, 82° C, 88° C, & 94° C as outlined in slide 2
  - Use plate-plate geometry and 500 micron gap
- Plot log viscosity (@ 409 Pa) versus log temperature and extrapolate the results to a temperature of 180° C
- Determine mixing temperature where viscosity = 150-190 centipoise (.15-.19 Pa.s)
- Determine compaction temperature where viscosity = 320-380 centipoise (.32-.38 Pa.s)
The following data plot (slide 10) shows a PG 58-28 tested over the range of 76° C to 94° C at a range of stress levels. Because the 58-28 is unmodified the viscosity very quickly achieves a nearly constant value at each temperature. (i.e. Newtonian)
Viscosity values at 409 Pascals

MIF 58-28 11-4-02 TK5, SSF FOR ZSV 76-94°C, 250 micron gap

shear stress (Pa)

viscosity (Pa.s)
The following data plot (slide 10) shows a PG 58-28 tested over the range of 76° C to 94° C at a range of stress levels. Because the 58-28 is unmodified the viscosity very quickly achieves a nearly constant value at each temperature, (i.e. Newtonian)

The next slide (slide 12) shows the DSR results, the extrapolated data and the Brookfield results. Note that for this material the Brookfield data and the extrapolated data overlay. This should be expected since the 58-28 is unmodified.
Log\(_{10}(Y) = 16.7304 - 6.70317\log_{10}(X)\)  
EMS = 2.2716e-005  
\(R^2 = 1.000\)

Log\(_{10}(Y) = 15.4452 - 6.10776\log_{10}(X)\)  
EMS = 5.15599e-006  
\(R^2 = 1.000\)

PG 58-28

EXTRAPOLATION BASED ON DSR DATA
BROOKFIELD DATA
STEADY SHEAR VIS DATA AT 409 Pascal STRESS

MID POINT OF MIXING TEMP RANGE = 146 C /295 F
MID POINT OF COMPACTION RANGE = 131 C/268 F

BROOKFIELD RESULTS
MIX TEMP = 343 F
COMPACTION TEMP = 321.6 F

PG 58-28

MID POINT OF MIXING TEMP RANGE = 146 C /295 F
MID POINT OF COMPACTION RANGE = 131 C/268 F
The following data plot (slide 14) shows a PG 64-34 tested over the range of 82°C to 94°C at a range of stress levels. Because the 64-34 is polymer modified the viscosity at low stress levels is quite high and then begins to level off at high applied stress levels.

The zoomed scale slide (slide 15) shows that even at 409 Pascals the viscosity is not quite constant.
SBS MODIFIED 64-34, Unaged, SSF FOR ZSV 82°C-94°C, 500gap-0001f-2

ZOOMED SCALE

Shear stress (Pa)

Viscosity (Pa.s)
The following data plot (slide 14) shows a PG 64-34 tested over the range of 82° C to 94° C at a range of stress levels. Because the 64-34 is polymer modified the viscosity at low stress levels is quite high and then begins to level off at high applied stress levels.

The zoomed scale slide (slide 15) shows that even at 409 Pascals the viscosity is not quite constant.

The next slide (slide 17) shows the mixing and compaction temperature results based on extrapolated data and the values that the Brookfield would predict. As we would expect there is significant difference between these results.
Log10(Y) = 27.5527 - 11.6067Log10(X)
EMS = 9.03714e-005
R² = 1.000

PG 64-34 SBS POLYMER MODIFIED

BROOKFIELD MIXING >195 C/383 F
BROOKFIELD COMPACTION = 185 C/365 F

DSR EXTRAPOLATED RESULT
MID POINT OF RANGE
MIXING TEMP 152.6 C/306 F
COMPAC TION TEMP = 143 C/289 F
The next slide (slide 19) shows mixing and compaction results for a PG 64-34 which we tested using both a 250 µ and 500 µ gap. As you can see from these data, the results are nearly identical. The only reason for ultimately choosing a 500 µ gap was because of the very high viscosity of some highly modified binders and because some PMA’s can have dispersed particles with diameters approaching 60 µ (1/4 the value of 250 µ).
Log10(Y) = 25.8352 - 10.7708Log10(X)
EMS = 0.000587813
R² = 0.998

Log10(Y) = 25.5676 - 10.668Log10(X)
EMS = 0.000300143
R² = 0.999

Log10(Y) = 17.8247 - 6.93041Log10(X)
EMS = 0.00067418
R² = 0.994

PG 64-34 ELVALOY POLYMER

MIX AND COMPACTION RANGE
USING SSF @ 500 µ
MIXING = 309°–315°F
COMPACTION = 290°–297°F

BROOKFIELD RESULT
MIXING = 347°–358°F
COMPACTION = 326°–334°F

BROOKFIELD RESULTS FOR 64-34 ELVALOY BINDER
DSR SSF RESULTS USING 250 µ GAP
DSR SSF RESULTS USING 500 µ GAP
Slides 21-23 show mixing and compaction results for several different polymer modified binders. These are just examples showing the range of results than are possible depending on the type of polymer, the PG grade produced and the base asphalt employed. Because all of these factors will ultimately affect the final mixing and compaction values, trying to arrive at “typical” values for each PG grade will at best be an approximation.
Log10(Y) = 20.4759 - 8.16534Log10(X)
EMS = 1.15886e-005
R² = 1.000

PG 70-28 POLYMER

MIXING RANGE 336-345 F
COMPACTION RANGE 310-320 F
Log10(Y) = 18.9617 - 7.59698Log10(X)
EMS = 0.00011372
R² = 0.999

PG 64-34 POLYMER

MIXING RANGE 314-323 F
COMPACTION RANGE 288-298 F

PG 64-34 WITH SBS

PG 64-34 POLYMER MIXING RANGE 314-323 F COMPACTION RANGE 288-298 F

VISCOSITY IN CPS

TEMPERATURE IN DEG C
Log10(Y) = 18.5756 - 7.39438Log10(X)
EMS = 1.47328e-005
R² = 1.000

PG 64-28 SENT TO UW MADISON

MIXING RANGE 320-329 F
COMPACTION RANGE 292-303 F

EXTRAPOLATION BASED ON DSR DATA