Direct Tension Test - A Useful Tool in Evaluation of Polymer Modified Asphalt

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Outline

- Literature Background - The Low-temperature Performance of Asphalt Binder upon Polymer Modification
- Experimental Method
- Polymer Modified Asphalts for Colder Climates
- Polymer Modified Asphalts for Warmer Climates
- Polymer Modified Asphalts Black Max™
- Summary and Conclusions

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Literature Background

- The improvement of the performance of PMAs at low service temperature has been controversial.
- It was suggested that the presence of polymer allows the use of softer base asphalts - “sponge” theory
- Based on AASHTO MP1 using the BBR, the stiffness of the base asphalt either increases, remains unchanged or very marginally decreases upon polymer modification.
- An AASHTO MP1A method was developed.

Experimental Method

- The direct tension test (DTT) and the new parameter $T_{critical}$ were used to study the low-temperature behavior of selected groups of PMA.
- Three groups of PMA were studied -
  - PMA's for colder climates
  - PMA's for warmer climates

  (Laboratory prepared using two types of polymer)
  - Three grades of Black Max™ - commercial products of Husky Energy
- The sample preparation technique of DTT was developed at the University of Calgary

PMAs for Colder Climates

- The levels of polymer modification in this group of three PMAs were 1.0s, 1.5s and 2.5s where "s" is a unit of polymer.
- All three materials were tested according to the Superpave specification, including DTT and $T_{critical}$.
- An asphalt from Husky Energy was used as the base asphalt.

Level of Polymer Modification	1.0s	1.5s	2.5s
STANDARD TESTS			
Penetration at 25 °C, [dmm] (100g/5s)	175	159	120
Softening Point, [°C]	45.8	52.2	68.8
SUPERPAVE TESTS			
Original Binder Properties			
Viscosity at 135 °C, [mPa.s]	443	585	1411
Dynamic Shear (G*/sin δ), (Min. 1.0 kPa), [kPa]	1.14	1.03	1.03
Temperature, [°C]	60	64	75
RTFOT (T240)			
RTFOT Mass Loss, [%]	-0.692	-0.636	-0.710
Dynamic Shear (G*/sin δ), (Min. 2.20 kPa), [kPa]	2.30	2.28	2.21
Temperature, [°C]	61	63	73
Pressure Aging Vessel Residue			
PAV Aging Temperature, [°C]	100	100	100
Dynamic Shear [G*(sin δ)], (Max. 5000 KPa),[kPa]	2271	2068	808
Temperature, [°C]	16	16	22

PMAs for Colder Climates

Level of Polymer Modification	1.0s		1.5s		2.5s	
Creep Stiffness (S - max. 300 MPa) @ 60 s	276		291		267	
(m value - min. 0.300) @ 60 s	0.312		0.315		0.319	
Temperature, [°C]	-26.0		-28.0		-28.0	
MP1 Actual Grading	**PG60-36**		**PG63-38**		**PG73-38**	
MP1 ΔT	**96**		**101**		**111**	
MP1 Superpave Grading	**PG58-34**		**PG58-34**		**PG70-34**	
Direct Tension Failure Strain [%]	1.12	1.65	1.56	2.90	1.34	2.92
Direct Tension Failure Stress [MPa]	6.66	6.46	7.38	7.11	8.99	7.43
Direct Tension Test Temperature [°C]	-30.0	-27.0	-30.0	-27.0	-34.0	-28.0
$T_{critical}$ [°C]	-38.0		-39.4		-42.2	
$T_{critical}$ vs. Ts,m[°C]	-2.0		-1.4		-4.2	
MP1A Actual Grading	**PG60-38**		**PG63-39**		**PG73-42**	
MP1A ΔT	**98**		**102**		**115**	
MP1A Superpave Grading	**PG58-34**		**PG58-34**		**PG70-40**	

PMAs for Colder Climates

Level of Modification	1.0s	1.5s	2.5s
DT test temp. at 2.0% failure strain[°C]	-25	-28.5	-30.5
Failure s tress at 2.0% failure strain [MPa]	6.2	7.2	8.2
DT test temp. at 1.3% failure strain[°C]	-29	-31	-33
Failure s tress at 1.3% failure strain [MPa]	6.5	7.5	9.0

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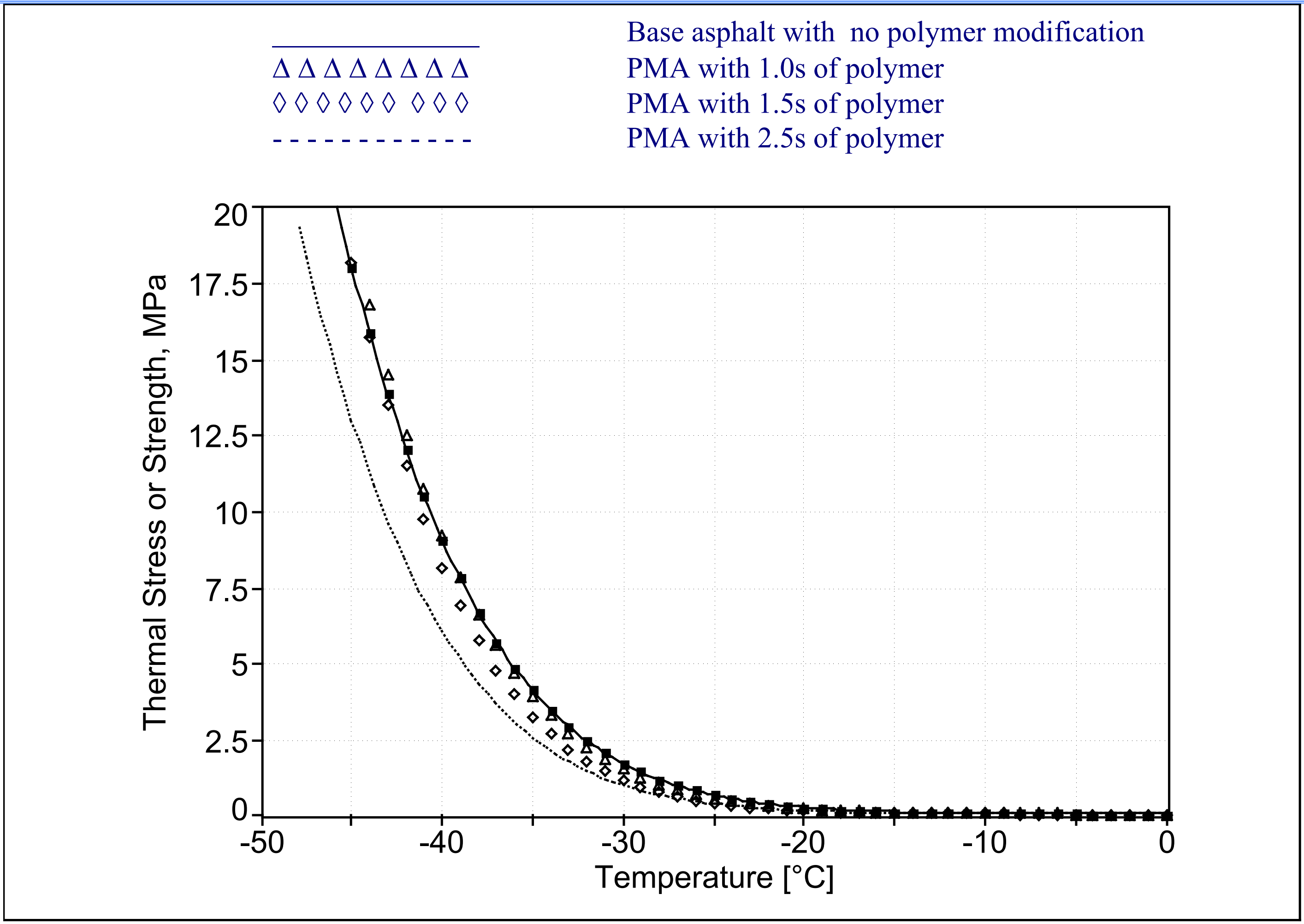
Figure 1. Thermal Stress versus Temperature – PMAs for Colder Climates



Impact of Polymer

The impact of polymer on the low-temperature performance of asphalt binder (except the indirect one that allows the use of softer base asphalt) can be at least two fold -

- Increase the tensile strength of the binder
- Decrease the thermal stress induced by the decreasing temperature

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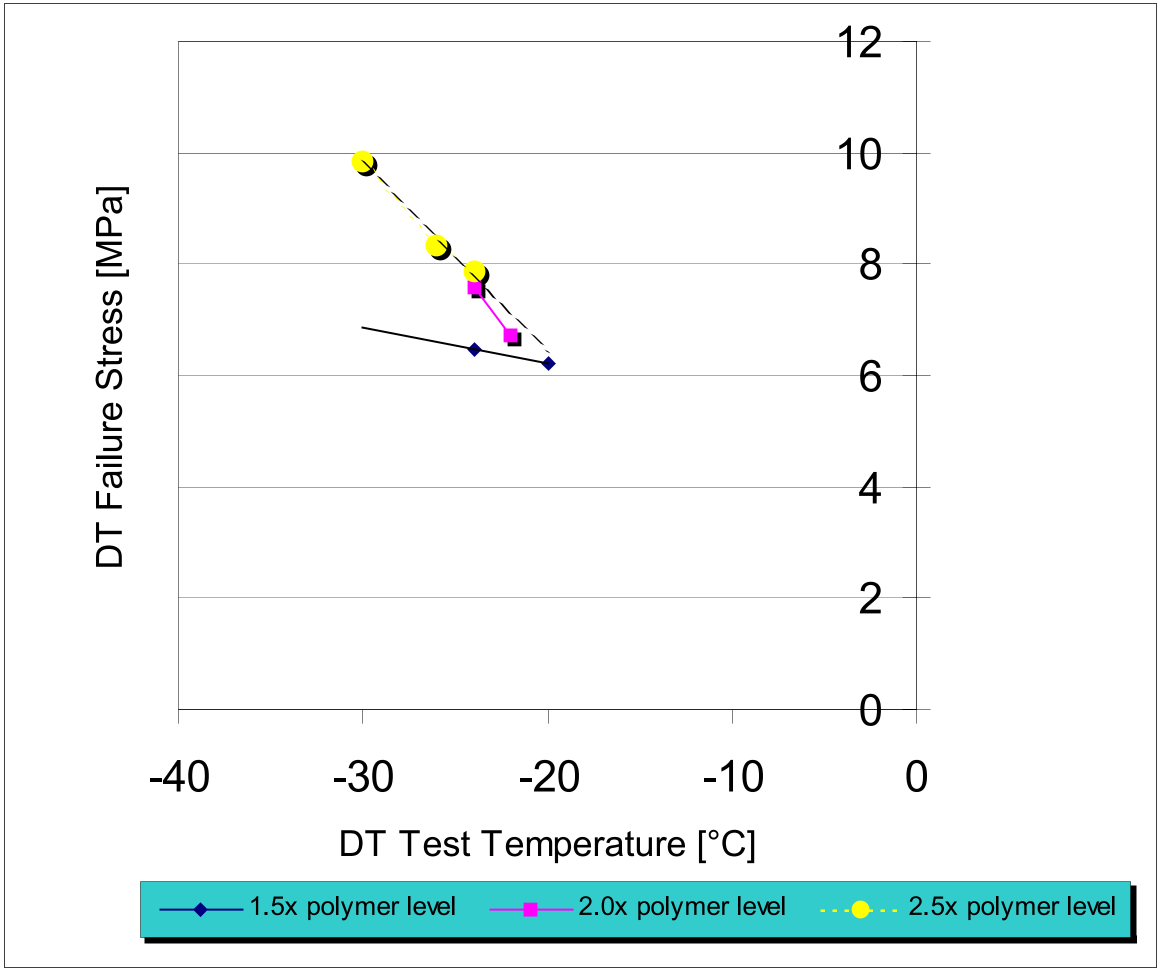
PMAs for Warmer Climates

- The level of polymer modification in this group of three PMAs were 1.5x, 2.0x and 2.5x where "x" is a unit of polymer.
- All three materials were tested according to the Superpave specification, including DTT and $T_{critical}$.
- A different asphalt from Husky Energy was used as the base asphalt.

Level of Polymer Modification	1.5x	2.0x	2.5x
STANDARD TESTS			
Penetration at 25 °C, [dmm] (100g/5s)	74	76	67
Softening Point, [°C]	54.8	57.7	60.9
SHRP TESTS			
Original Binder Properties			
Viscosity at 135 °C, [mPa.s]	983	1169	1601
Dynamic Shear (G*/sin δ), (Min. 1.0 kPa), [kPa]	1.10	1.16	1.11
Temperature, [°C]	73	74	78
RTFOT (T240)			
RTFOT Mass Loss, [%]	-0.268	-0.390	-0.255
Dynamic Shear (G*/sin δ), (Min. 2.20 kPa), [kPa]	2.27	2.31	2.3
Temperature, [°C]	71	73	76
Pressure Aging Vessel Residue			
PAV Aging Temperature, [°C]	100	100	100
Dynamic Shear [G*(sin δ)], (Max. 5000 kPa),[kPa]	1980	2118	1200
Temperature, [°C]	25	25	28

Level of Polymer Modification	1.5x	2.0x	2.5x
Creep Stiffness (S - max. 300 MPa) @ 60 s	272	255	258
(m value - min. 0.300) @ 60 s	0.302	0.297	0.290
Temperature, [°C]	-20.0	-21.0	-21.0
MP1 Actual Grading	**PG71-30**	**PG73-30**	**PG76-30**
MP1 ΔT	**101**	**103**	**106**
MP1 Superpave Grading	**PG70-28**	**PG70-28**	**PG76-28**
Direct Tension Failure Strain [%]	1.17 2.11	1.75 2.14	1.39 1.75 2.17
Direct Tension Failure Stress [MPa]	6.47 6.21	7.57 6.71	9.85 8.35 7.86
Direct Tension Test Temperature [°C]	-24.0 -20.0	-24.0 -22.0	-30.0 -26.0 -24.0
$T_{critical}$ [°C]	-31.8	-33.7	-34.1
$T_{critical}$ vs. Ts,m[°C]	-1.8	-3.7	-4.1
MP1A Actual Grading	**PG71-31**	**PG73-33**	**PG76-34**
MP1A ΔT	**102**	**106**	**110**
MP1A Superpave Grading	**PG70-28**	**PG70-28**	**PG76-34**

Figure 3. Failure Stress versus Test Temperature in DTT for PMAs for Warmer Climates

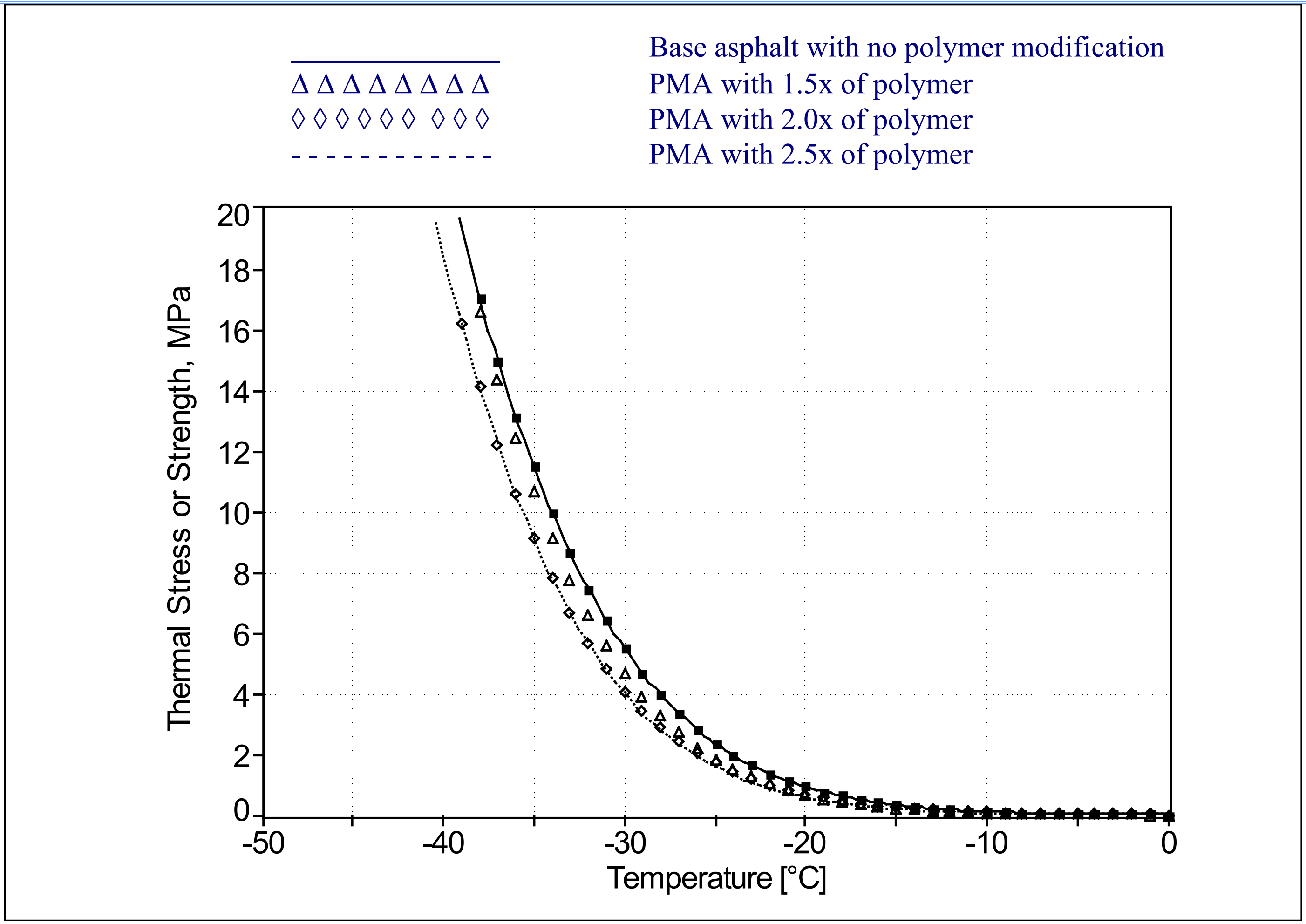


PMAs for Warmer Climates

Level of Modification	1.5x	2.0x	2.5x
DT test temp. at 2.0% failure strain[°C]	-20	-22	-24
Failure s tress at 2.0% failure strain [MPa]	6.2	6.7	7.9
DT test temp. at 1.75% failure strain[°C]	-22	-24	-26
Failure s tress at 1.75% failure strain [MPa]	6.4	7.6	8.4

If 1.3% DT failure strain were used as a criterion for passing a certain grade, the PMA with 2.5x level of polymer modification would have passed -40.0°C for the low-temperature grading.

Figure 2. Thermal Stress versus Temperature – PMAs for Warmer Climates



Questions to be answered -

The following questions should be answered by future studies :

- Should the inclusion of failure strain values in DTT evaluation of asphalt materials be reconsidered?
- Should the stiffness and m-value from BBR be excluded as the low temperature parameter for evaluation of asphalt binder, especially the PMAs?

Polymer Modified Asphalts Black Max^{TM}

- Three commercially available Black Max^{TM} PMAs produced by Husky Energy were also studied.
- All three materials were tested according to the Superpave specification, including DTT and $T_{critical}$.

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Husky PMA	Black Max™ I	Black Max™ II	Black Max™ III
Dynamic Shear (G*/sin δ), (Min. 1.0 kPa), [kPa]	1.02	1.01	1.01
Temperature, [°C]	62	70	75
RTFOT (T240)			
Dynamic Shear (G*/sin δ), (Min. 2.20 kPa), [kPa]	2.27	2.46	2.27
Temperature, [°C]	62	68	75
Pressure Aging Vessel Residue			
PAV Aging Temperature, [°C]	100	100	100
Dynamic Shear [G*(sin δ)], (Max. 5000 KPa),[kPa]	4180	1459	1303
Temperature, [°C]	7	19	22

Husky PMA	Black Max™ I	Black Max™ II	Black Max™ III
Creep Stiffness (S - max. 300 MPa) @ 60 s	296	255	198
(m value - min. 0.300) @ 60 s	0.319	0.302	0.308
Temperature, [°C]	-30.0	-27.0	-24.0
MP1 Actual Grading	**PG62-40**	**PG68-37**	**PG75-34**
MP1 ΔT	**102**	**105**	**109**
MP1 Superpave Grading	**PG58-40**	**PG64-34**	**PG70-34**
Direct Tension Failure Strain [%]	1.36 2.97	1.27 2.01	1.61 2.60 3.60
Direct Tension Failure Stress [MPa]	8.25 7.25	8.53 8.04	9.65 7.79 7.28
Direct Tension Test Temperature [°C]	-35.0 -30.0	-34.0 -30.0	-34.0 -29.0 -28.0
$T_{critical}$ [°C]	-43.2	-41.3	-40.3
$T_{critical}$ vs. Ts,m[°C]	-3.2	-4.3	-6.3
MP1A Actual Grading	**PG62-43**	**PG68-41**	**PG75-40**
MP1A ΔT	**105**	**109**	**115**
MP1A Superpave Grading	**PG58-40**	**PG64-40**	**PG70-40**

Figure 4. DT Failure Stress – Strain Curve of Black Max™ III Tested at –34.0°C

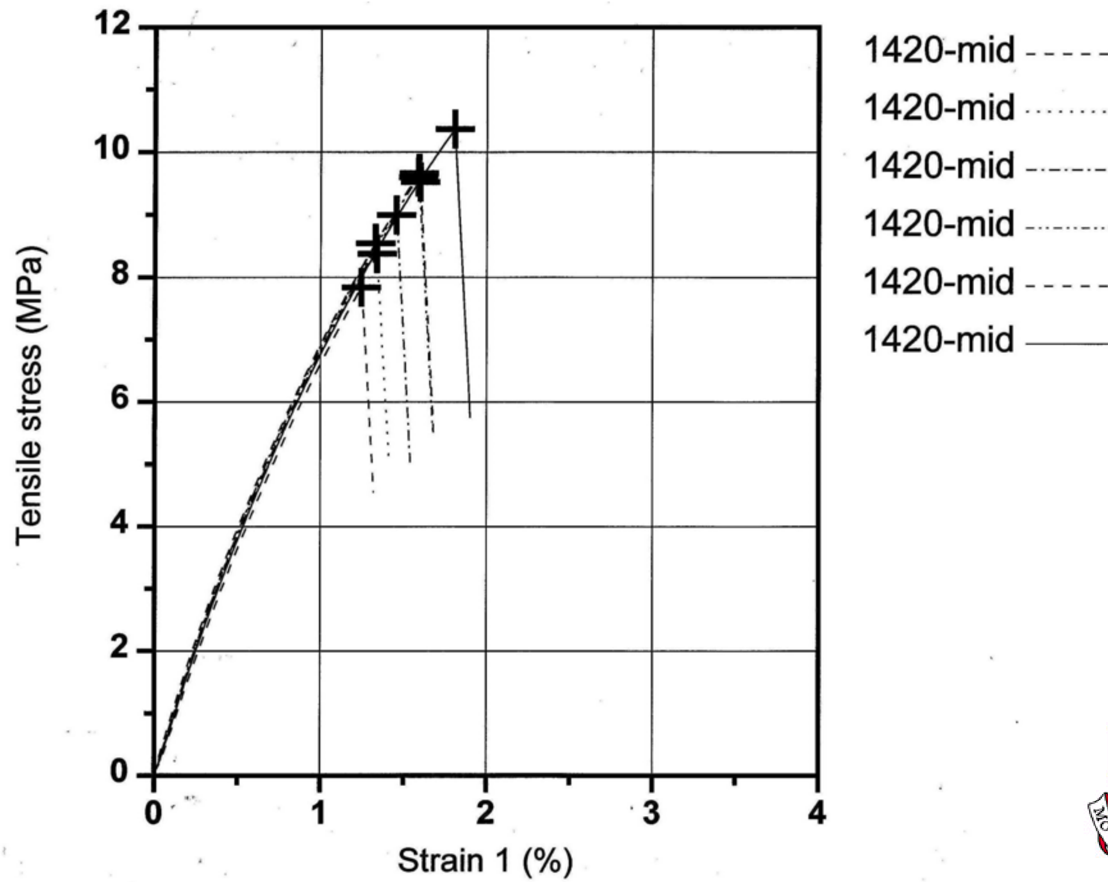

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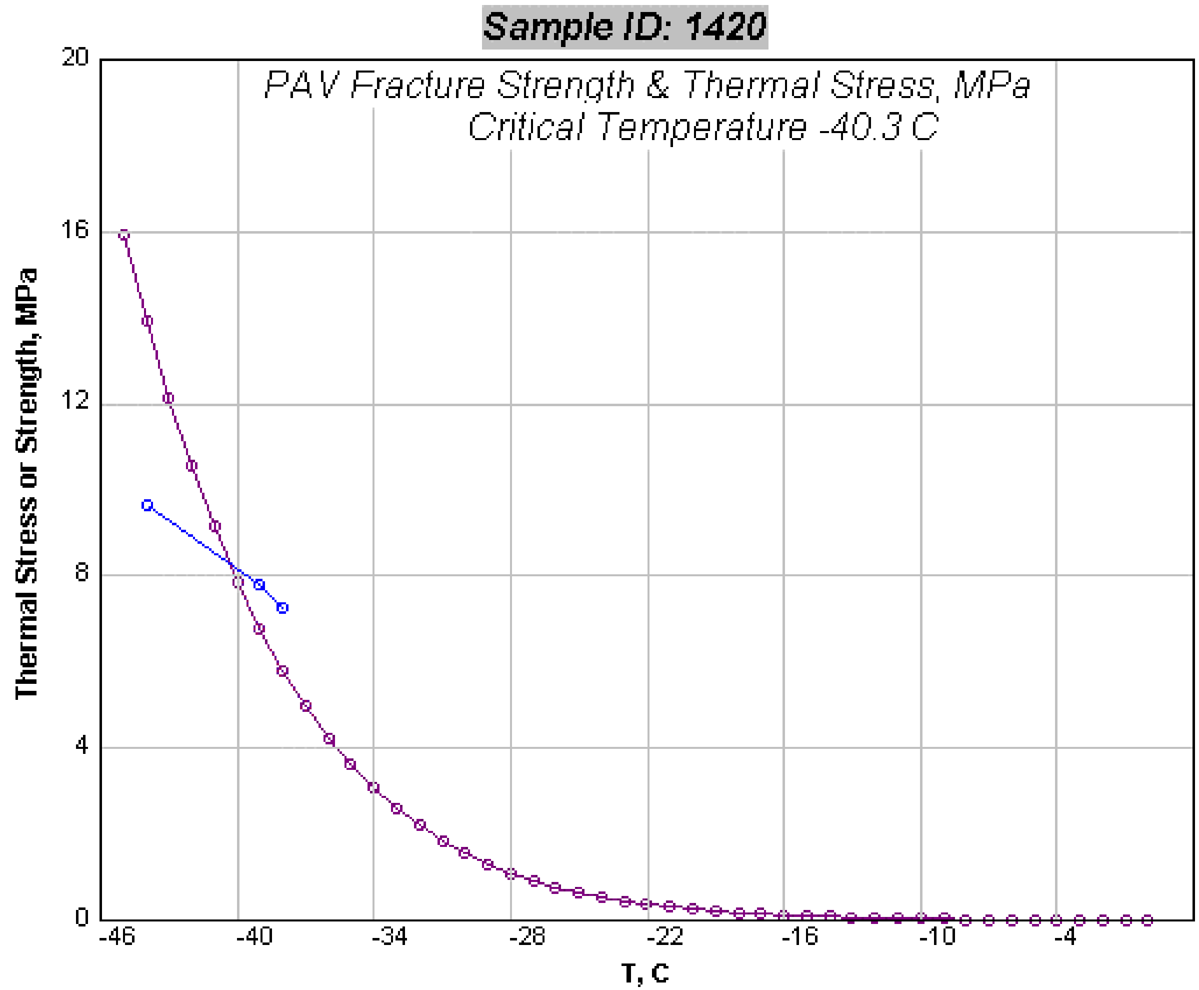
Figure 5. Fracture Strength and Thermal Stress Curve of Black Max^{TM} III with a Linear Fit



Summary and Conclusions

Test Methodology

- The MP1 passing temperature parameter was not able to differentiate between the low-temperature performances of different PMAs. The passing temperature based on stiffness and m-value should be questioned.
- The $T_{critical}$ was able to differentiate among the low temperature performance of different PMAs and to recognize the increasing amount of polymer in PMA.
- The data obtained from DTT can be used for deeper analysis of the low-temperature behavior of asphalt binders. The failure strain might be utilized to obtain a better understanding of the low-temperature behavior.

Summary and Conclusions

Character of Polymer Modified Asphalt

- We used to think that the positive impact of polymers on the low-temperature performance of PMAs to be only indirect - allowing the use of softer base asphalt. The MP1 passing temperature parameter showed that increased amount of polymer in PMA in most cases increased the stiffness and decreased the m-value.
- The analysis of data from DTT and BBR as performed by TSAR™ indicated that the improvement of the low temperature performance of asphalt modified by polymers can actually be threefold -

Three Fold Impact of Polymer in PMA

- Indirect improvement by allowing the use of softer asphalt base as recognized previously.
- Improvement caused by the increase in the DTT failure stress of asphalt binder by increasing the amount of polymer.
- Improvement caused by the decrease in the thermal stress in the asphalt binder by increasing amount of polymer.

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