AF2903 Road Construction and Maintenance

Asphalt Binder Characterization

Royal Institute of Technology,
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Highway and Railway Engineering

Asphalt Binder Characterization

- Introduction to the Binders
- Modified Binders
- Traditional Grading System
- Superpave (SHRP)

Standard Bitumen

- General
- Origin
- Production
- Test methods
- Properties
- Specifications
- Functional requirements

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General

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Bitumen

- The virtually in-volatile, adhesive and waterproofing material derived from crude petroleum, or present in natural asphalt, which is completely or nearly completely soluble in toluene, and very viscous or nearly solid at ambient temperatures. (EN 12597)

- Bitumen / Asphalt

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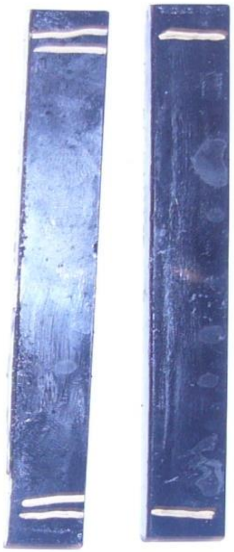
Bitumen is a visco-elastic material

- At low temperatures and/or high frequencies: **elastic solid material**
- With increasing temperature and/or decreasing loading rate: **more viscous**
- At sufficiently high temperature and/or long loading time: **like a fluid**



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Mixture of millions of chemical components...

- 90-95% C and H
- 5-10% heteroatoms (N, O, S)
- Trace metals
- Salt, mineral particles

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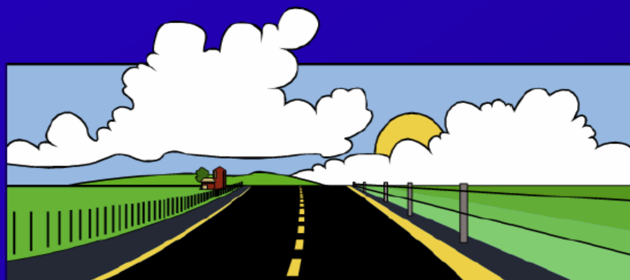
Bitumen chemically reacts with ……

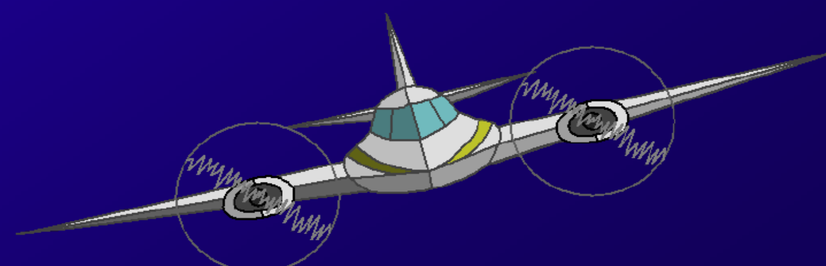
- Oxygen in the air?



- Water?

- Chemicals?

- Solubility?



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Origin

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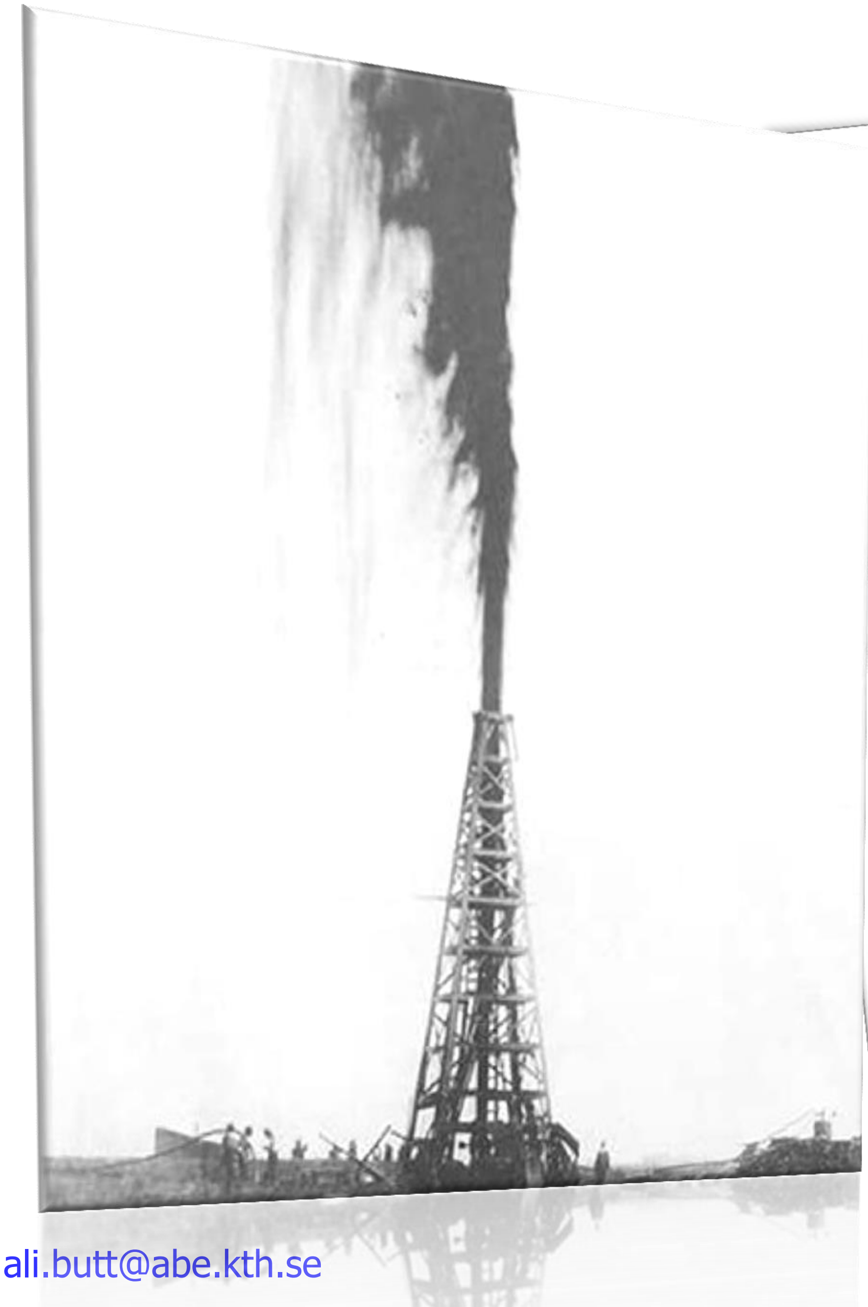
OIL GUSHER



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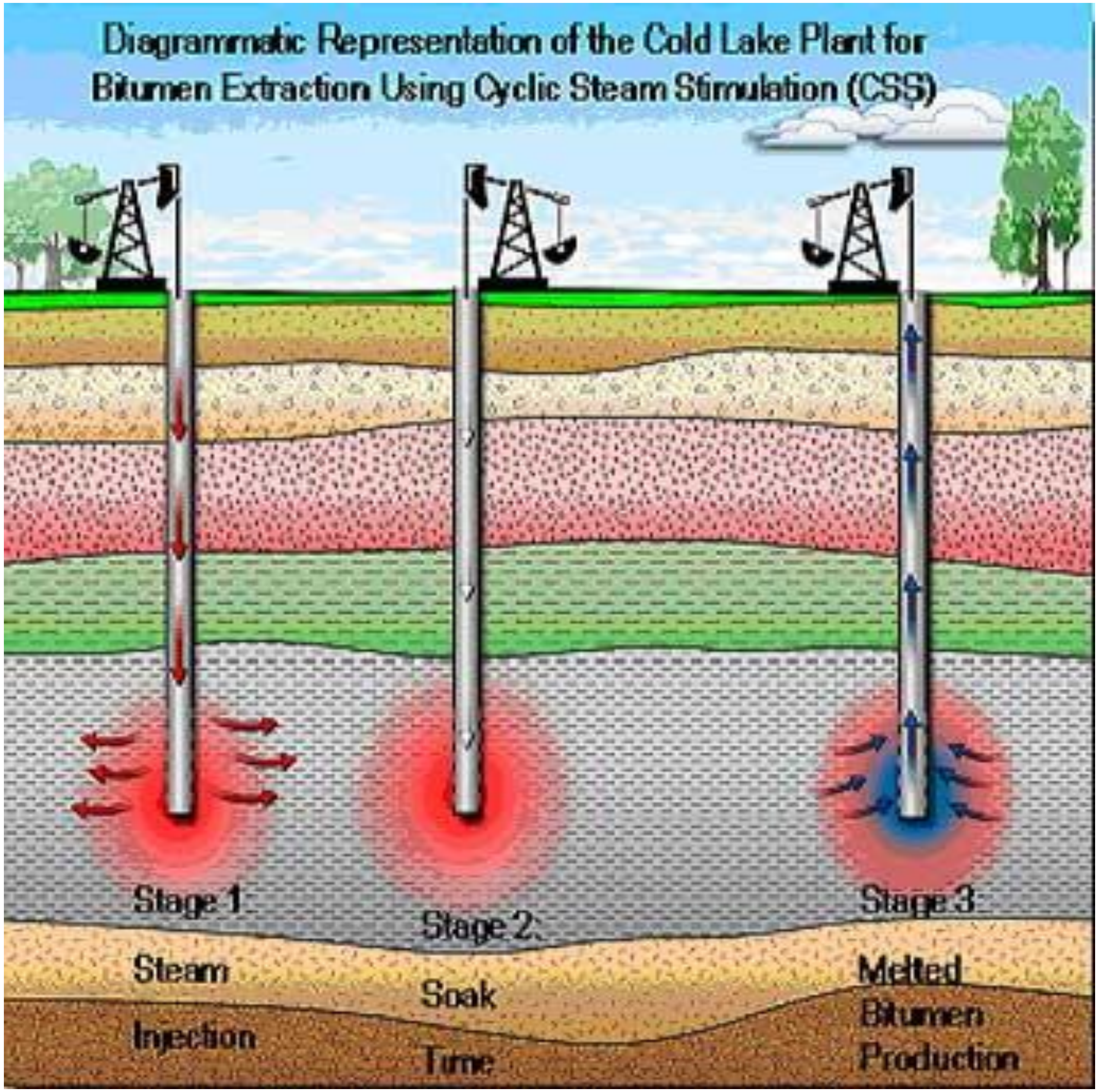
Cyclic Steam Stimulation (CSS)



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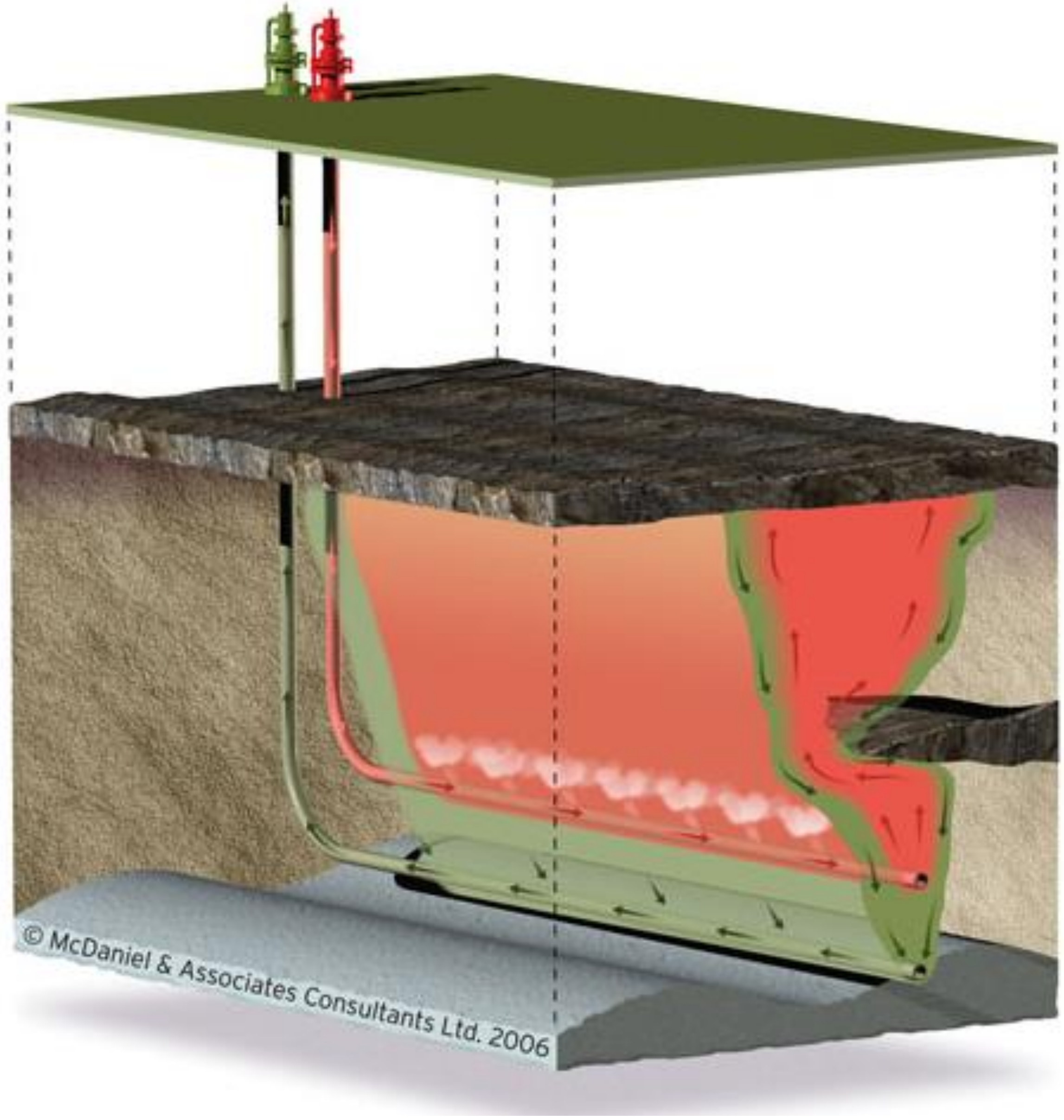
Steam Assisted Gravity Drainage



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Crude oil products

+3 000 million tons of crude oil per year are produced in the world today

- Aviation fuel (Kerosine)
- Gasoline
- Fuel and lubricating oils (Diesel)
- Paraffin wax
- Approximately 3 % will be bitumen

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Bitumen Markets

• World	80-90MT
• EU	20MT
• US	33MT
• CHINA	11MT
• UK	2MT
• Sweden	0,5MT

90% ROAD
10% Roofing, selant, etc

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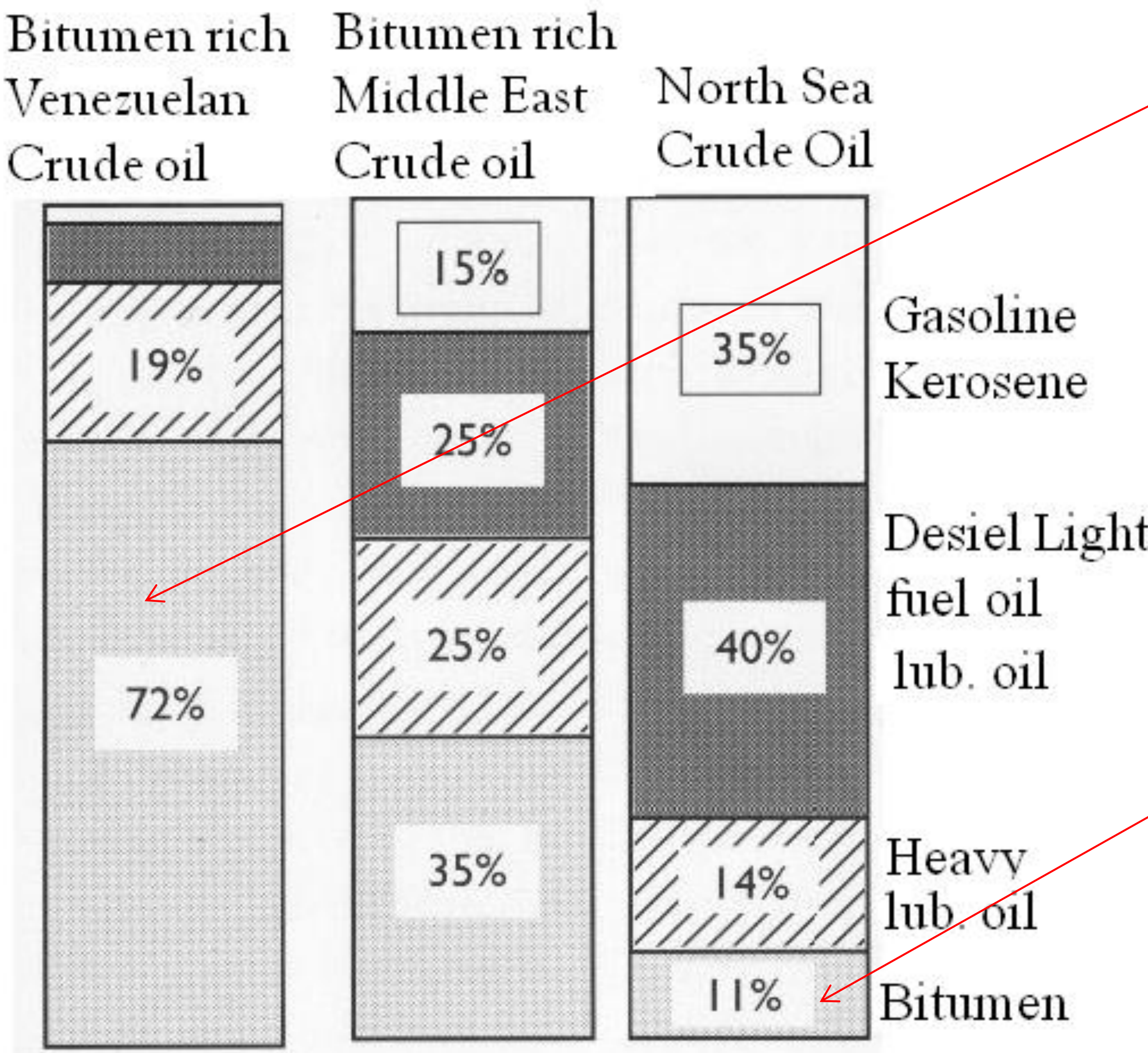
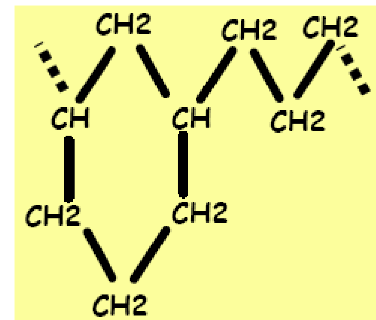
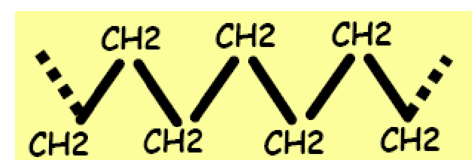
Different types of crude oil



- Heavy bitumen rich crude oil of naphthenic type



- Light fuel rich crude oil of paraffinic type



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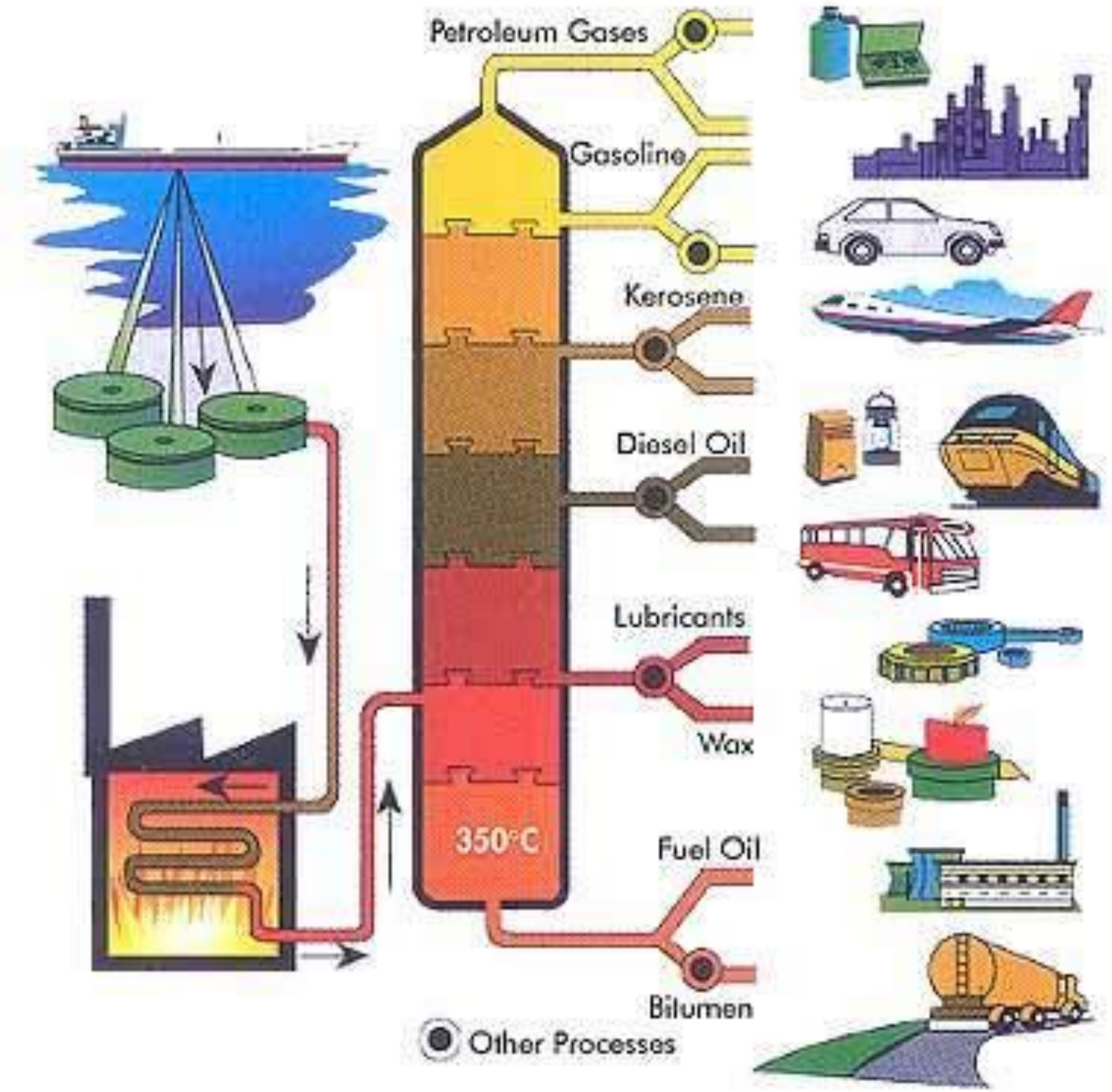
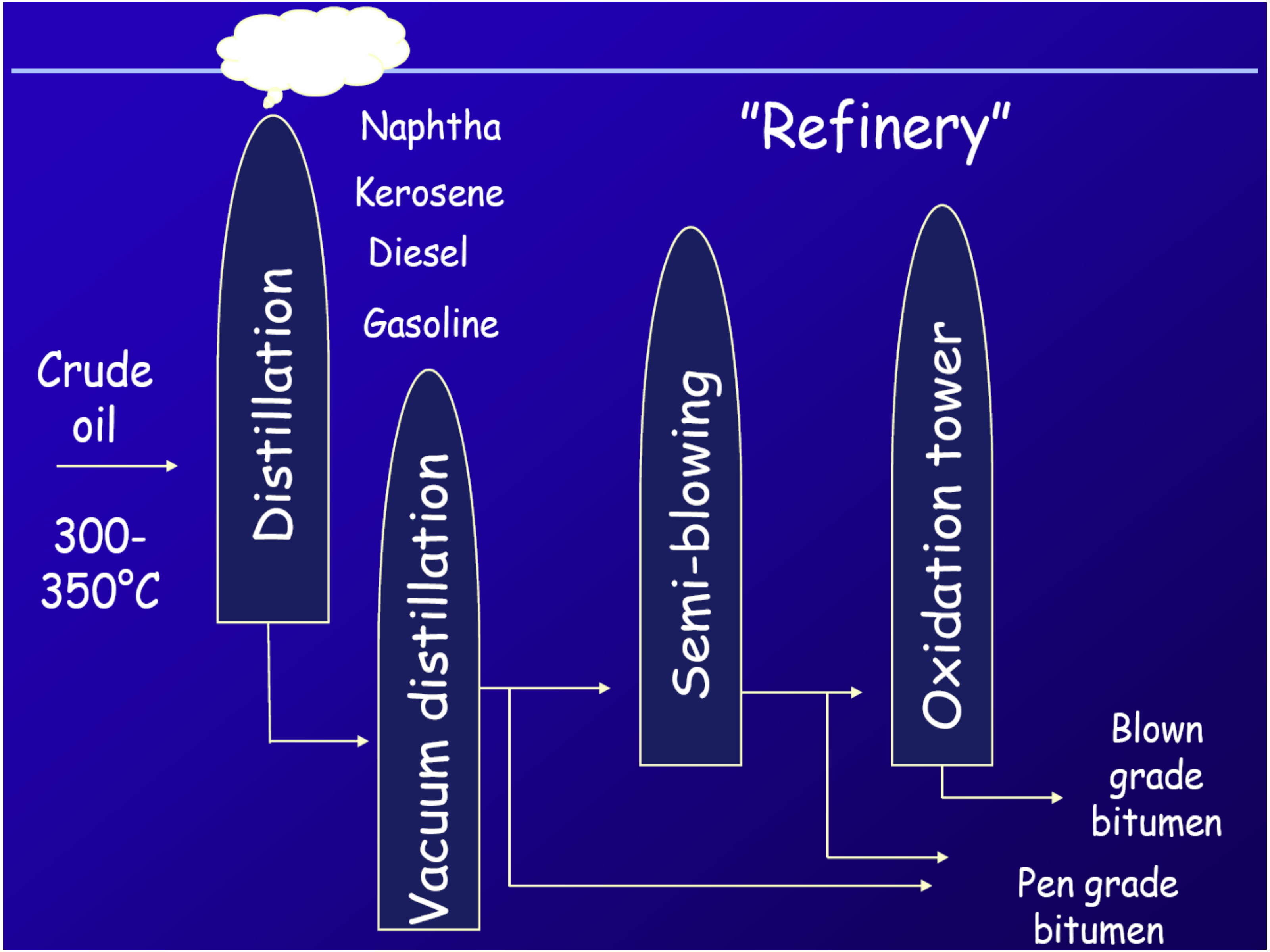
Production: Fractional distillation





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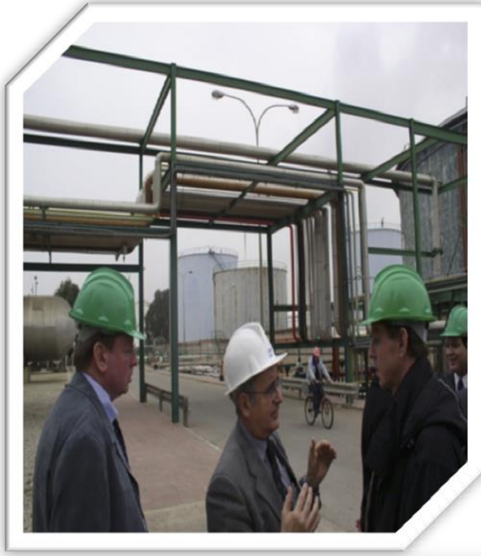
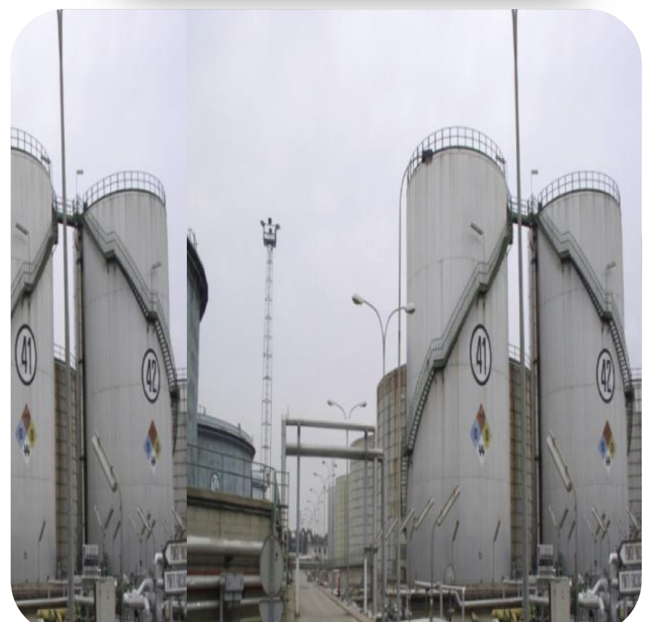
Refinery in Tarragona





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Test methods

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The state of bitumen is different at different temperatures.

- High Temperatures : **Viscous**
- Medium Temperatures : **Semi Solid**
- Low Temperatures : **Elastic Solid**
- Very Low Temperatures : **Glassy/Brittle**

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Standard specification tests

- Softening Point (EN 1427)
- Penetration (EN 1426)
- Elastic Recovery (EN 13398)
- Breaking Point, Fraass (EN 12593)
- Viscosity Brookfield (EN 13302)
- Storage Stability (EN 13399)

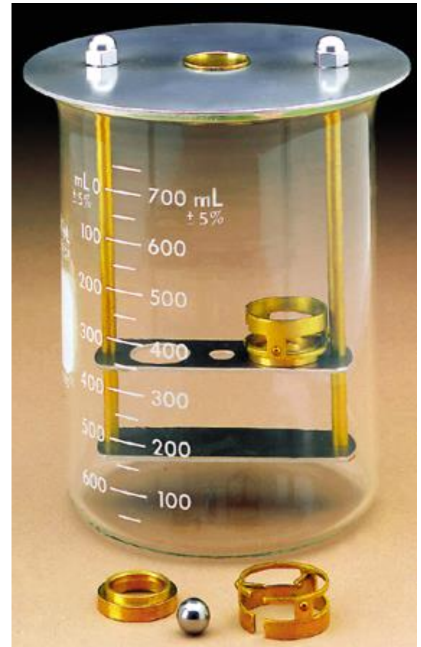
Penetration (EN 1426)

- Index test
- Material Property
- Classification

Softening point (EN 1427)

- Traditional way

- Change of state temperature measurment



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Elastic Recovery (EN 13398)

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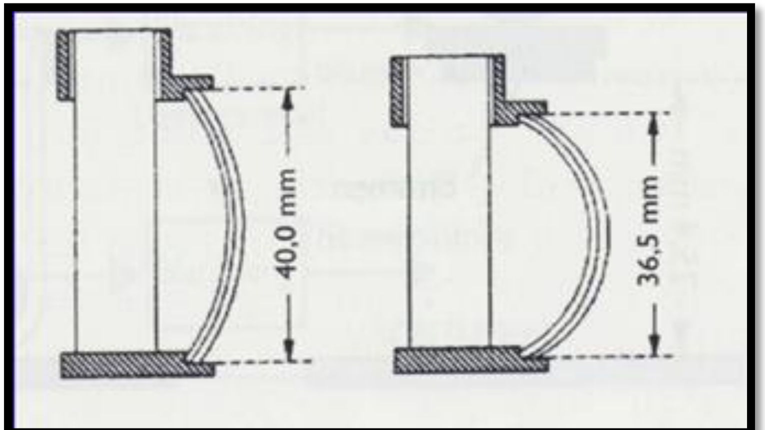
Breaking Point, Fraass (EN 12593)



To measure the temperature at which the bitumen cracks/fails at low temperatures in the glassy phase

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Viscosity Brookfield (EN13302)

Measure of viscosity of the bitumen at high temperatures

Mixing and compaction temperatures can be determined for a particular bitumen.

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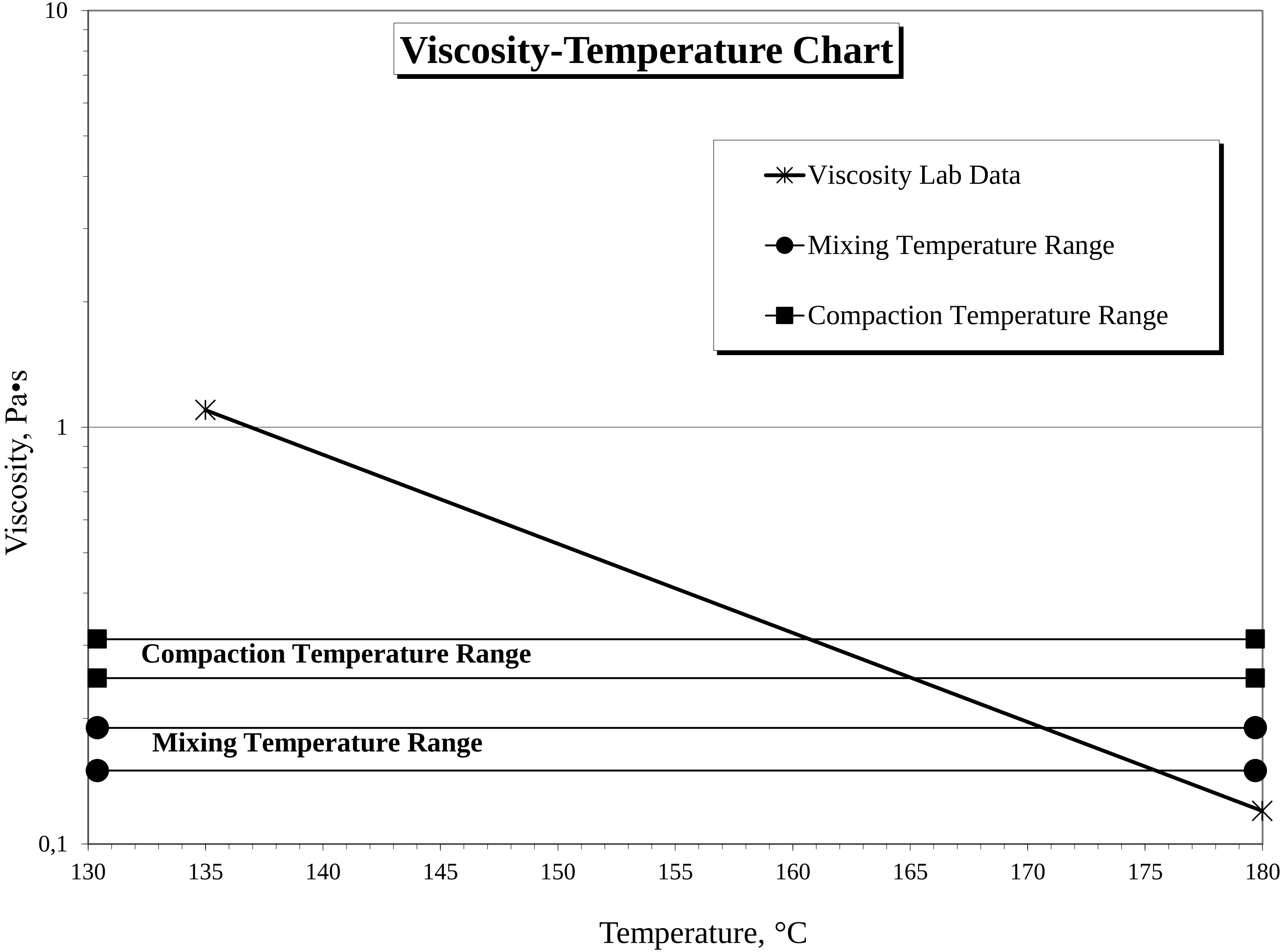

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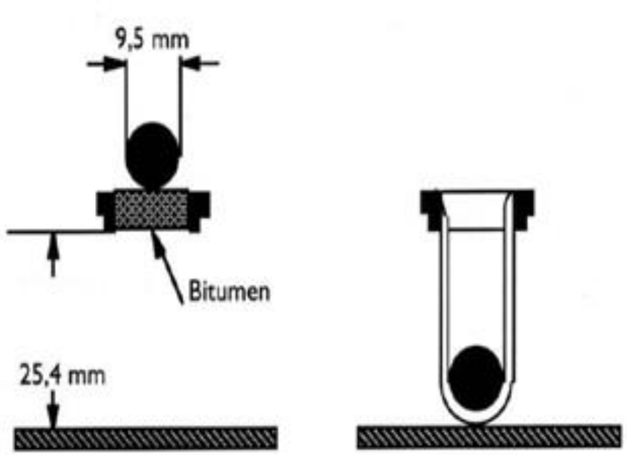
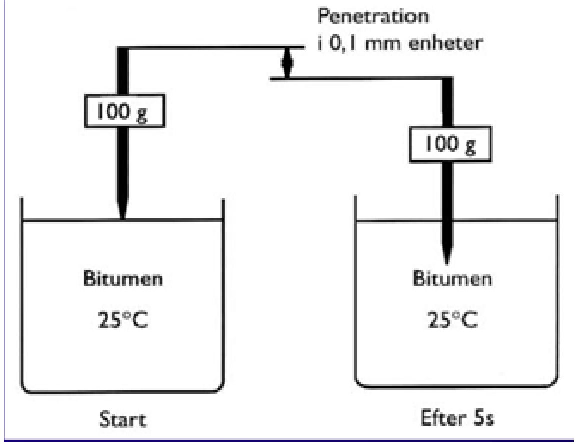
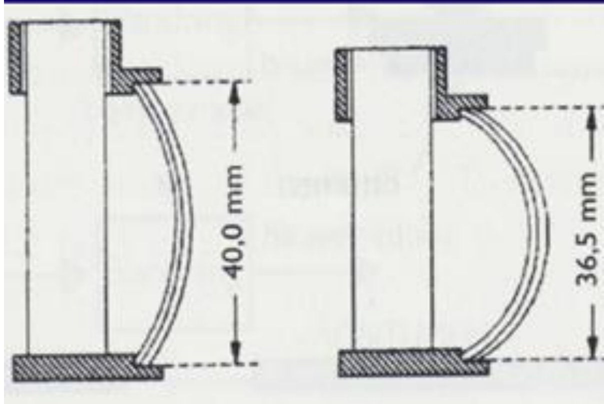
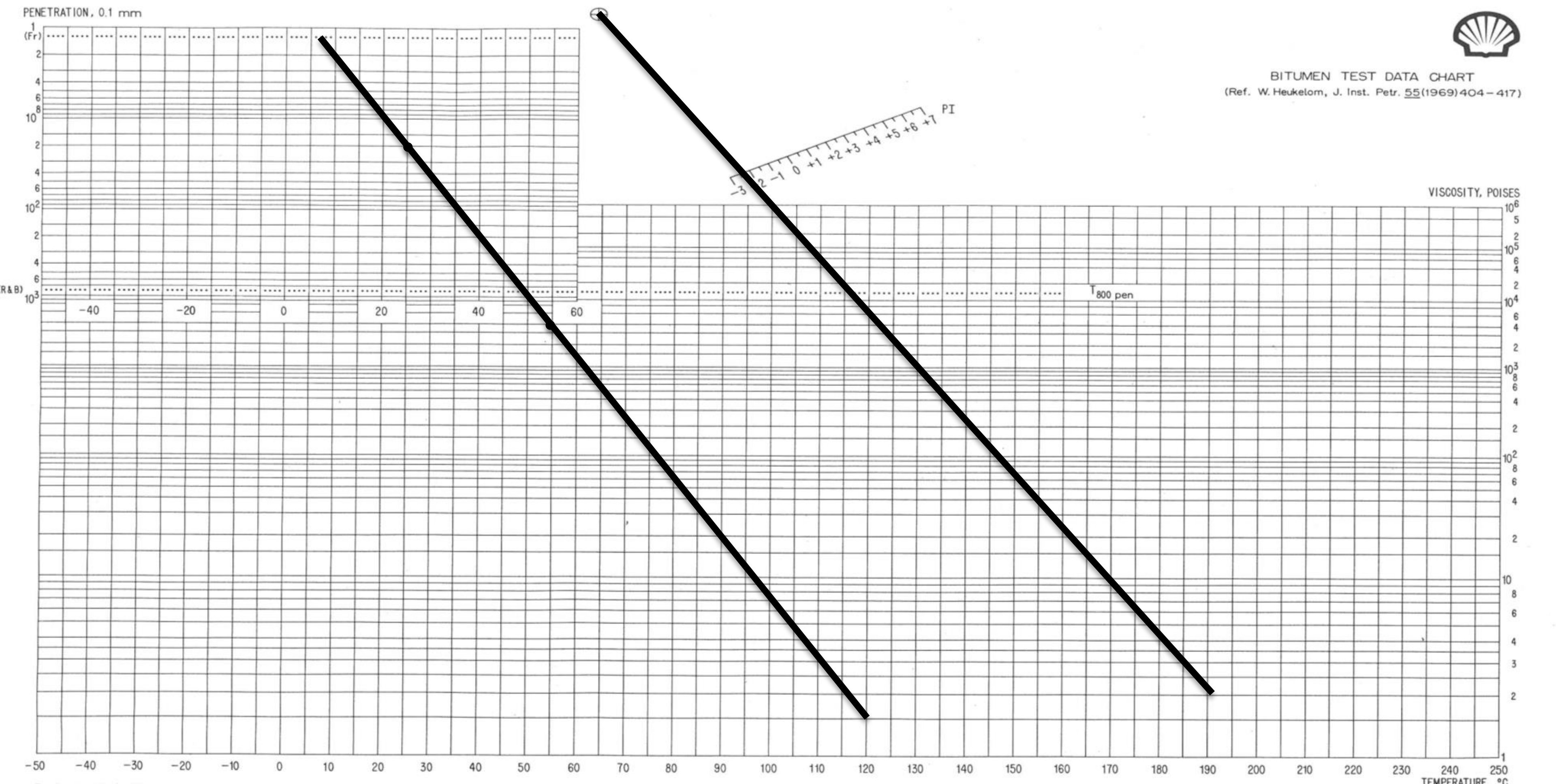
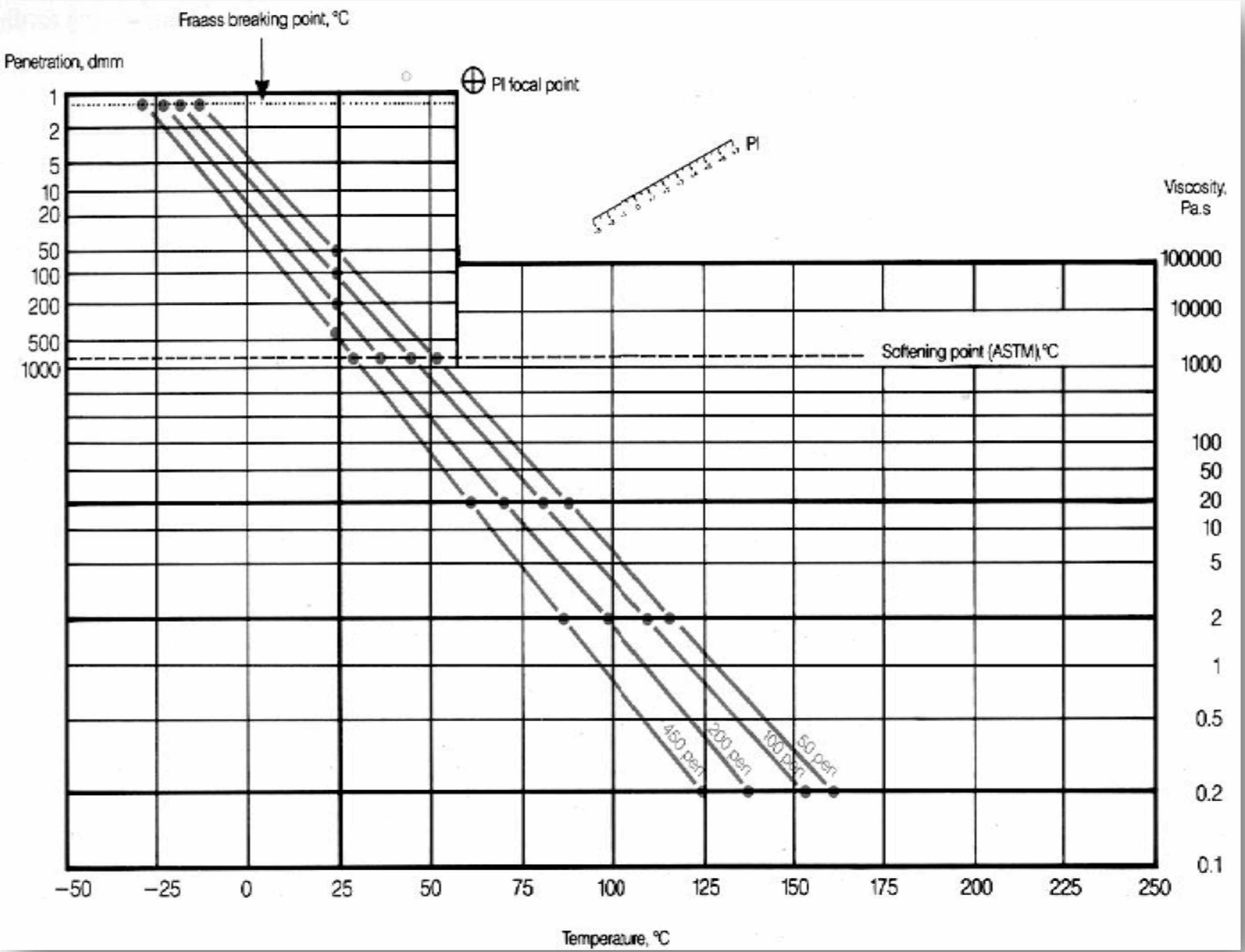

9,5 mm
Bitumen
25,4 mm


Penetration
i 0,1 mm enheter
100 g
100 g
Bitumen
25°C
Bitumen
25°C
Start
Efter 5s


40,0 mm
36,5 mm


PENETRATION, 0.1 mm
(Fr)
(R&B)
BITUMEN TEST DATA CHART
(Ref. W. Heukelom, J. Inst. Petr. 55(1969)404–417)
PI
VISCOSITY, POISES
$T_{800\ pen}$
TEMPERATURE, °C

Heukelom's diagram



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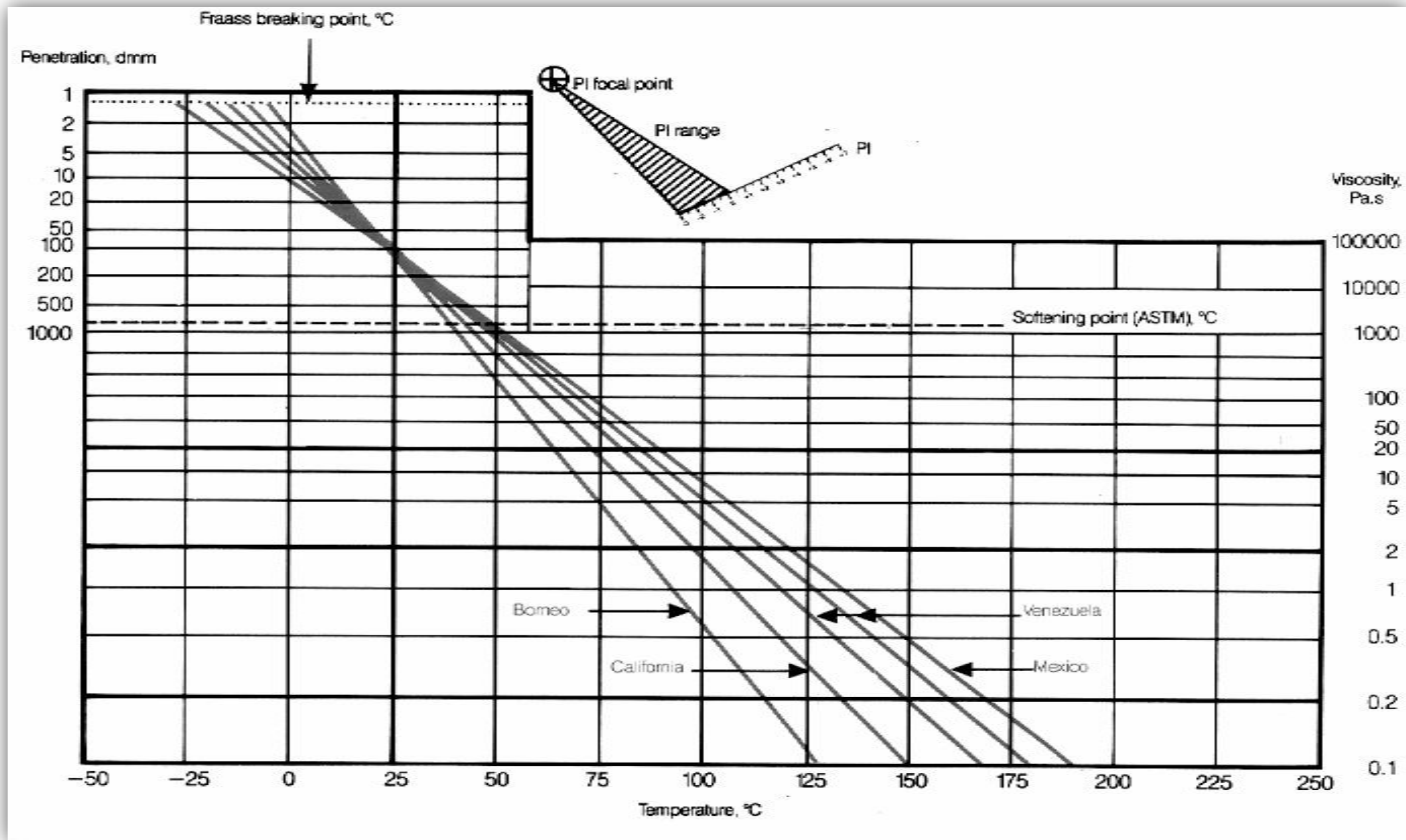
Same Bitumen Grade; different Source



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Rolling Thin Film Oven Test RTFOT

Short term aging

*EN 12607-1

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Pressure Aging Vessel PAV

Long term aging

*EN 14769

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FTIR Spectroscopy

Identify effect on different groups in a bitumen due to aging

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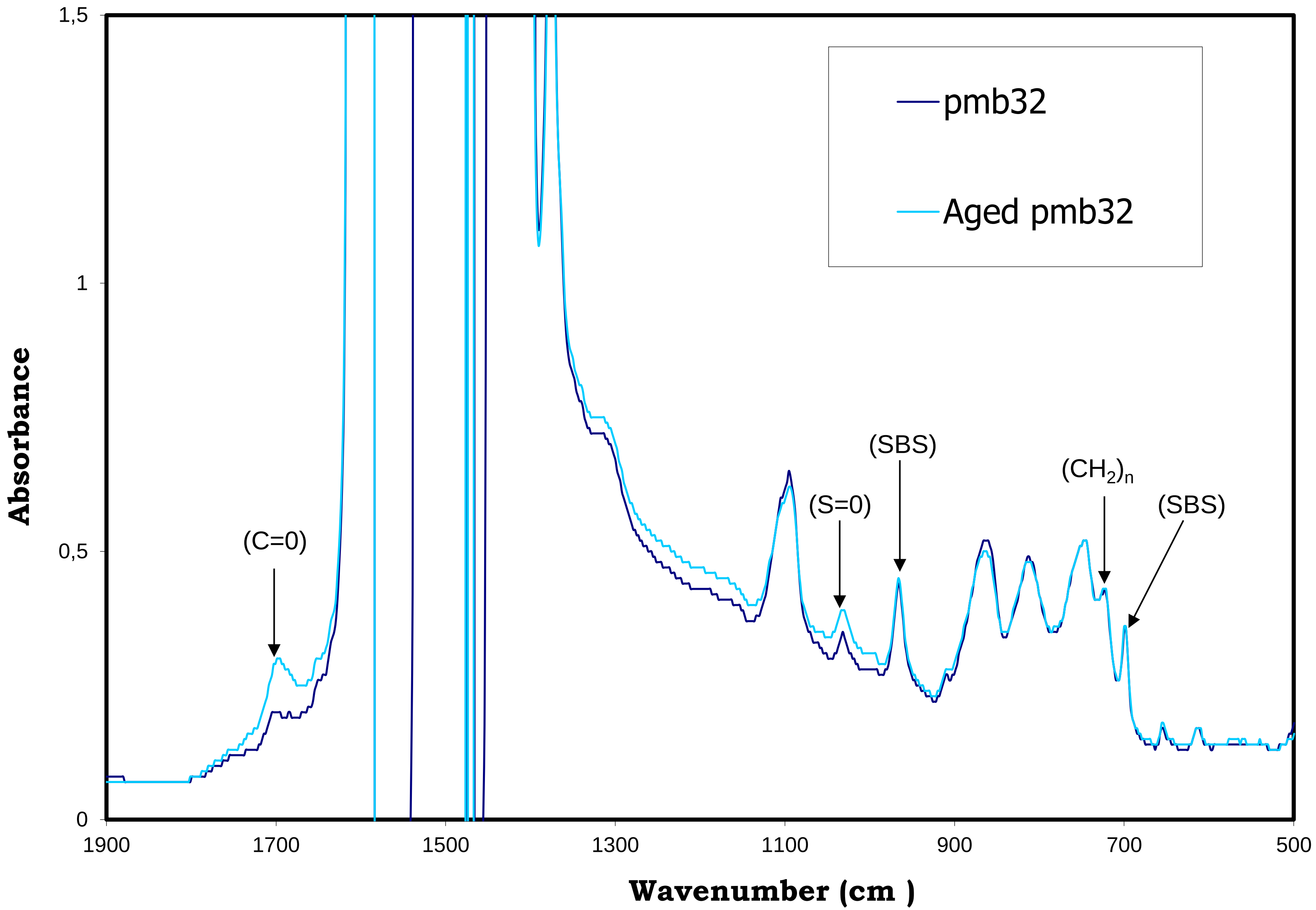
FTIR Spectroscopy



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Specifications

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Penetration grade

Egenskaper	Enhet	Testmetod SS-EN	Kvalitet				
			50/70	**70/100**	**100/150**	**160/220**	**330/430**
Penetration vid 25 C	x 0,1mm	1426	50-70	70-100	100-150	160-220	330/430
Penetration vid 15 C	x 0,1mm	-	-	-	-	-	90-170
Kinematisk viskositet vid 135 C, minimum	mm2/s	12595	295	230	175	135	85
Dynamisk viskositet vid 60 C, minimum	Pa s	12596	200	120	80	43	15
Mjukpunkt	C	1427	46-54	43-51	39-47	35-43	-
Brytpunkt Fraass, maximum	C	12593	-8	-10	-12	-15	-18
Löslighet, minimum	% (m/m)	12592	99,0	99,0	99,0	99,0	99,0
Flampunkt, minimum	C	22592 b)	230	230	230	220	-
Flampunkt, minimum	C	22719	-	-	-	-	180
Densitet	kg/m3	SS EN ISO 3838 c)	-	-	-	-	-
Viktförändring efter upphettning 163 C, maximum	%	12607-1 -3 a)	0,5	0,8	0,8	1,0	1,0
Mjukpunkt efter upphettning 163 C, minimum	C	1427 d)	48	45	41	37	-
Bibehållen penetration efter upphettning 163 C, minimum	%	1426 d)	50	46	43	37	-
Mjukpunktsökning efter upphettning 163 C, maximum	C	1427 d)	9	9	10	11	-
Viskositetskvot för viskositet vid 60 C, maximum		12596 d)	-	-	-	-	4,0

***ATB VÄG 2005 / VVTBT**

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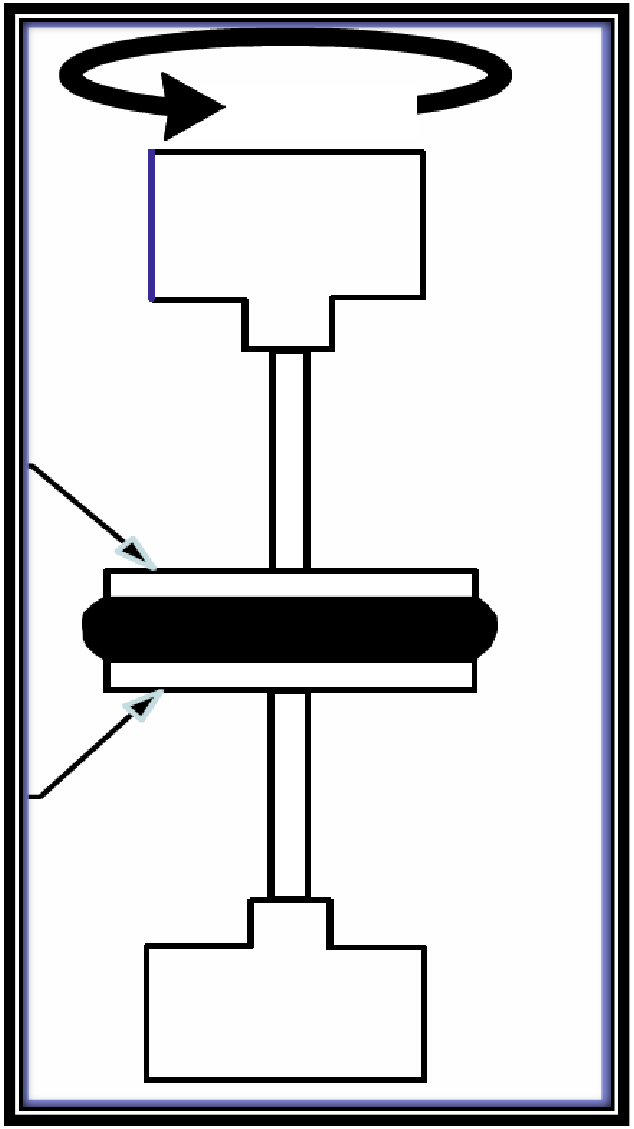
DSR (Dynamic Shear Rheometer)

Shearing between oscillating spindle and fix plate

Measures:

Complex modulus G*, total shear resistance

Phase angle δ, relationship between elastic and viscous part



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Complex modulus

$$\tau_{\max} = \frac{2T}{\pi r^3}$$

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

$$G^* = \frac{\tau_{\max}}{\gamma_{\max}}$$

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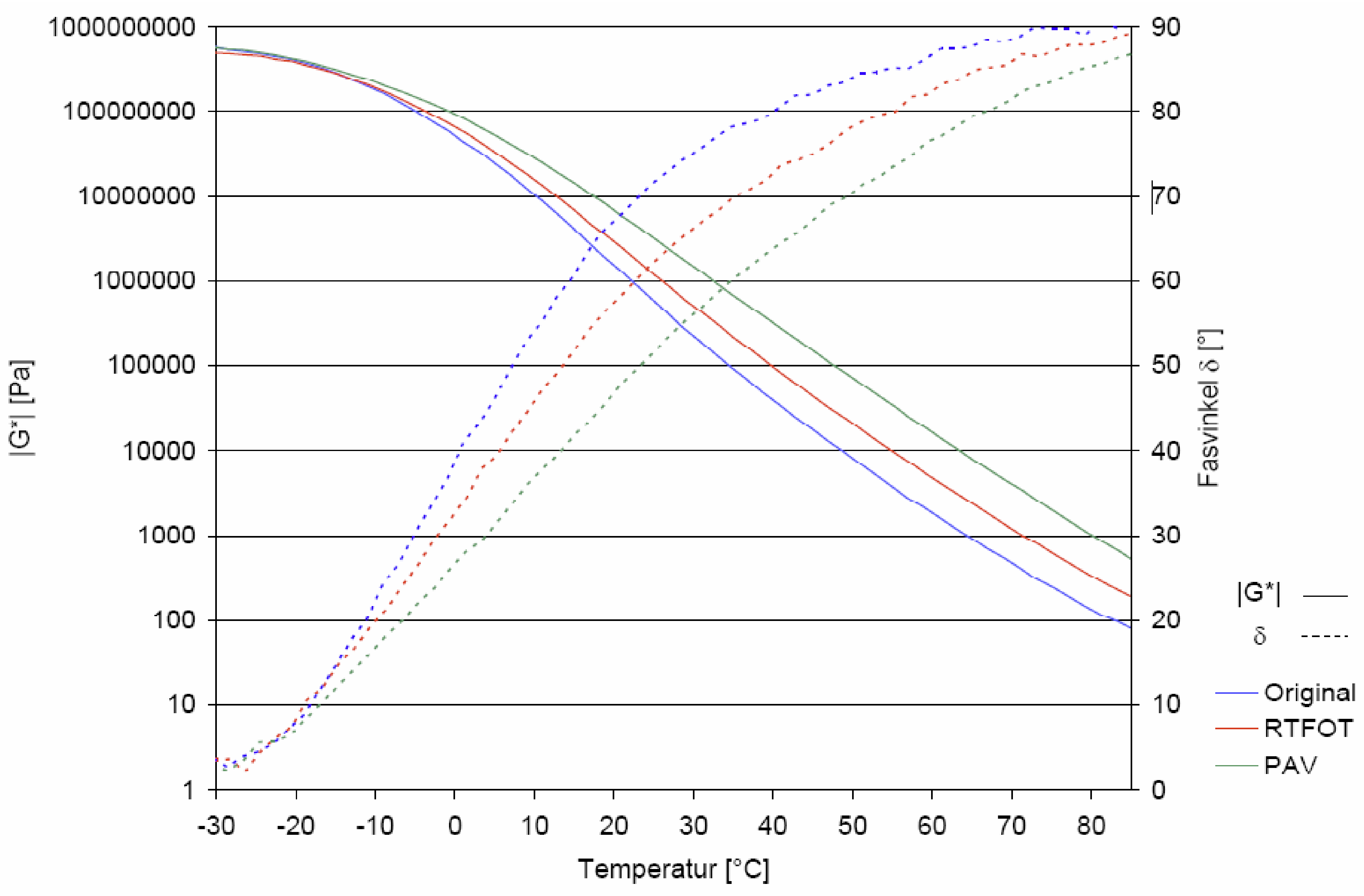
OUTPUT from DSR



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Binder Modification

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Uses of binder Modification

Mitigate both traffic- and environmentally induced HMA pavement distresses

Rutting resistance

- Stiffer asphalt binders at warm temps

Thermal cracking

- Inhibit crack propagation
- Internal elastic network (polymers)

Most common modifiers

- Polymers
  - Rubber
  - Styrene-Butediene-Styrene (SBS)

- Waxes
  - Montan
  - Paraffin
  - Sasobit

- Fillers
  - Limestone

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Modifier's effects

Bitumen	Penetration (dmm)	Softening point (°C)	Brookfield viscosity (mPa s)		Forced ductility at 10 °C (Nm)	Penetration index
			At 135 °C	At 165 °C		
Unmodified 70/100	81	46	345	101	1.38	−1.1
+4% wax AB	52	85	263	82	3.54	5.1
+4% wax FT	45	89	270	80	4.03	5.2

*Das et al 2012

TESTS		PMB32	PMB32+ 4% WAX
Softening Point	°C	75	93
Penetration	dmm	53	45
Breaking Point Fraass	°C	-14	-11
Elastic recovery at 10 °C	%	72,5	53,4
Brookfield visc at 135 °C @20RPM	mPas	1544	1394
Brookfield visc at 180 °C @50RPM	mPas	258	192

*Butt et al 2009

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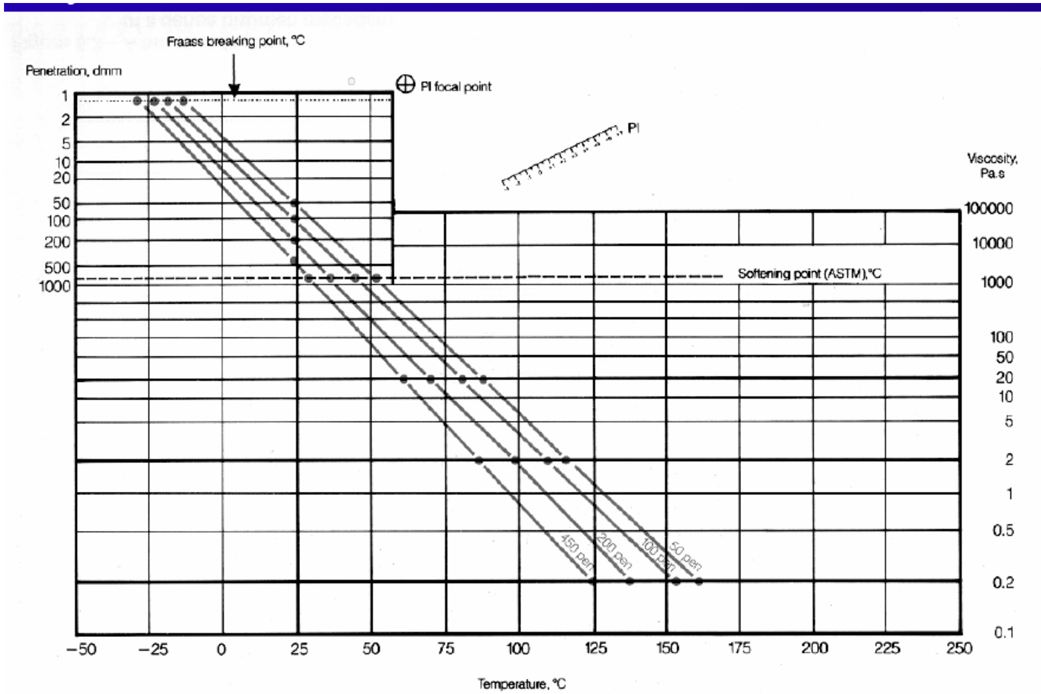
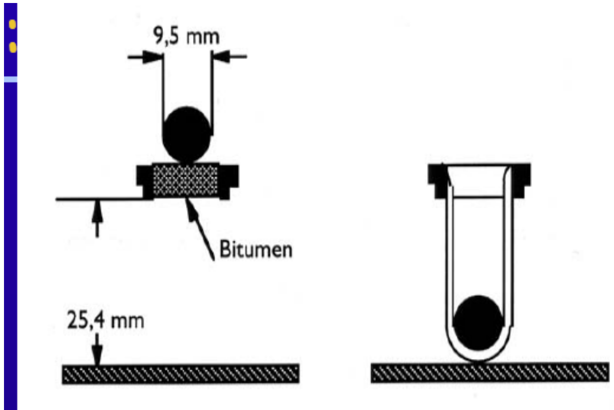
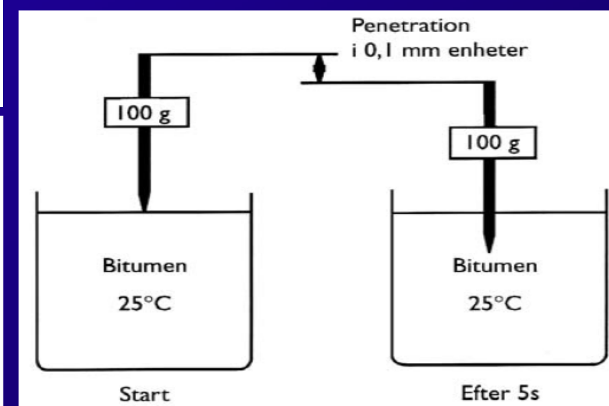
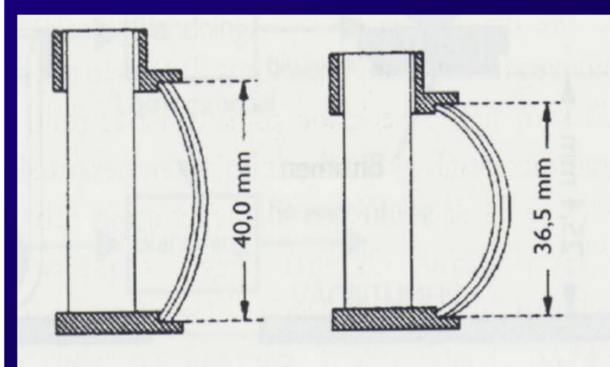
Activities in the afternoon









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SHRP-Strategic Highway Research Program

The largest SHRP asphalt research program ($53 million) (FHWA, 1998), had three primary objectives:

- WHAT?

Investigate why some pavements perform well, while others do not.

- HOW?

Develop tests and specifications for materials that will out-perform and outlast the pavements being constructed today.

- WHERE?

Work with highway agencies and industry to have the new specifications put to use.

SHRP-Strategic Highway Research Program

The final product of this research program was a new system referred to as "Superpave", which stands for SUperior PERforming asphalt PAVEments.

Superpave, in its final form consists of three basic components:

- *An asphalt binder specification*. This is the PG asphalt binder specification.
- *A design and analysis system based on the volumetric properties of the asphalt mix*. This is the Superpave mix design method.
- *Mix analysis tests and performance prediction models*. This area is not yet complete. Test development and evaluation is on-going.

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Focus on:

Binder Grading Systems

1. Background
2. Methods and Equipment
3. Use and Evaluation

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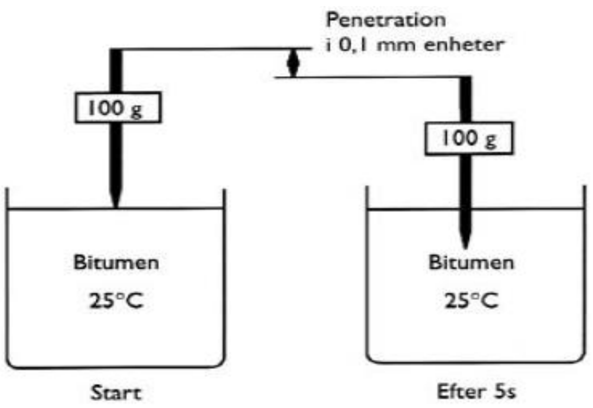
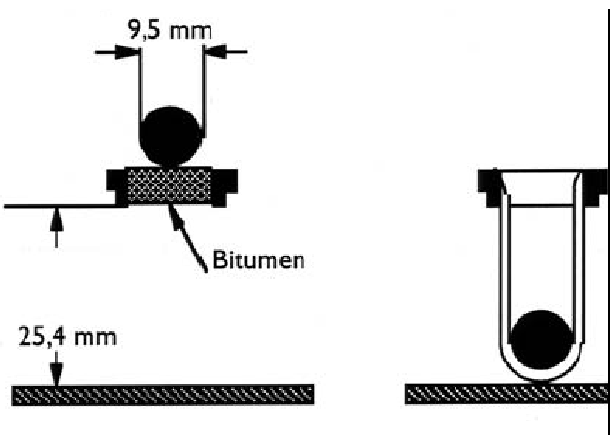
Standard Paving Grade –EN 12591 (1999)





Penetration at 25 °C, 0,1 mm	EN-1426	70-100
Kinematic viscosity at 135 °C, mm^2/s	EN-12595	Min. 230
Dynamic viscosity at 60 °C, Pa s	EN-12596	Min. 120
Softening point, °C	EN-1427	43-51
Fraass breaking point, °C	EN-12593	Max. -10
Solubility, %	EN-12592	Min. 99,0
Flash point, °C	EN-22592	Min. 230
Density at 25 °C, kg/m^3	EN-ISO-3838	measure
After RTFOT		
Change of mass, %	EN-12607-1	Max. 0,8
Softening point, °C	EN-1427	Min. 45
Retained penetration, %	EN-1426	Min. 46
Increase in softening point, °C	EN-1427	Max. 9

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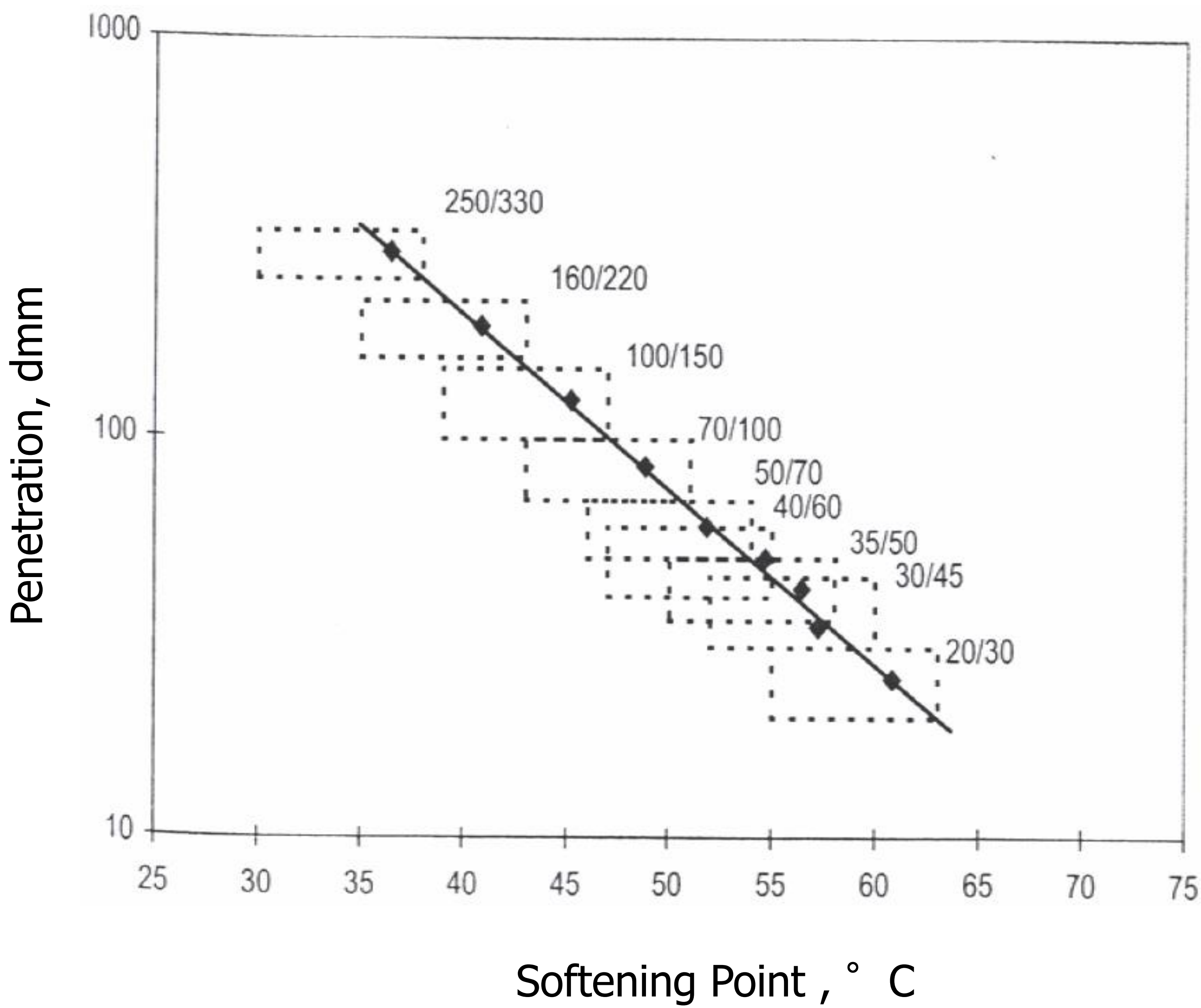
Penetration and Softening Point for CEN-Specifications



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Pmb 100/150 - 75

Pmb	100/150	75
• Polymer modified bitumen	• Penetration	• Softening point

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Soft bitumen V **1500**

Viscosity

Emulsion BE **60** R 160/220

Bitumen content %

Penetration

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- **General**
- **Equipments**
- **Test methods**
- **Specifications**

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Performance Grade

PG 76 - 22

Tmax

- **The highest measured 7-day temperature 20 mm under the pavement surface (average7-day max pavement design temp)**

Tmin

- **The lowest measured temperature in the pavement surface (min pavement design temp)**

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Superpave Binder Grades

Temp $_{max}$ Temp $_{min}$

PG46					-34	-40	-46
PG52	-10	-16	-22	-28	-34-	-40	-46
PG58	-10	-16	-22	-28	-34	-40	
PG64	-10	-16	-22	-28	-34	-40	
PG70	-10	-16	-22	-28	-34	-40	
PG76	-10	-16	-22	-28	-34		
PG82	-10	-16	-22	-28	-34		

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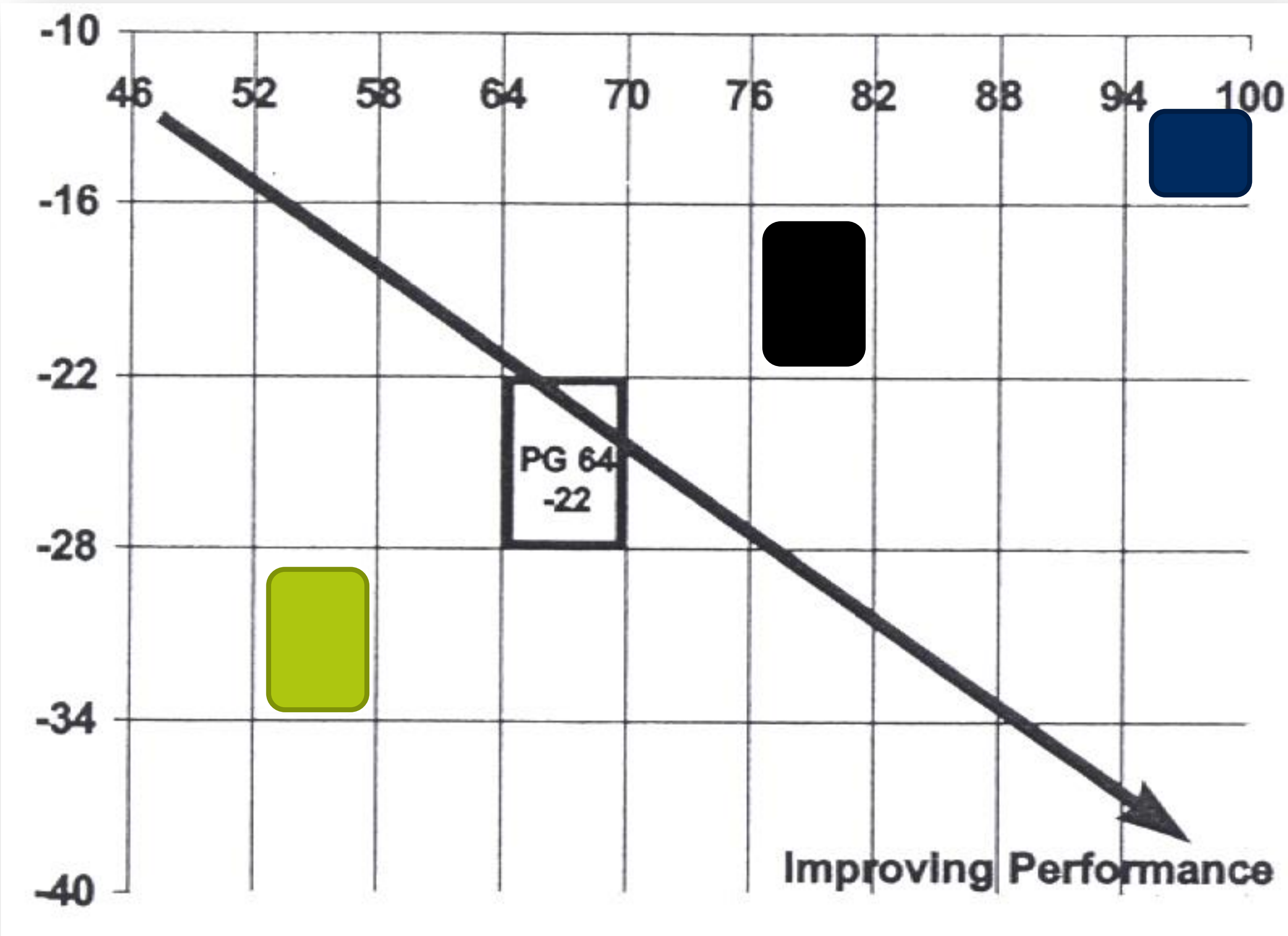
Performance according to Superpave



Northern Sweden

Southern Sweden

Middle East

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Performance Grades (PG)

Climate conditions

Rutting

Fatigue

Brittle Fracture

Performance Graded Asphalt Binder Specifications (from AASHTO, 2001)

Performance Grade	PG 46			PG 52							PG 58					PG 64					
	34	40	46	10	16	22	28	34	40	46	16	22	28	34	40	10	16	22	28	34	40
Average 7-day Maximum Pavement Design Temperature, °C[a]	< 46			< 52							< 58					< 64					
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
ORIGINAL BINDER																					
Flash Point Temp, T 48, Minimum (°C)	230																				
Viscosity, ASTM D 4402:[b] Maximum, 3 Pa*s, Test Temp, °C	135																				
Dynamic Shear, TP 5:[c] G*/sinδ[f], Minimum, 1.00 kPa Test Temp @ 10 rad/s, °C	46			52							58					64					
ROLLING THIN FILM OVEN RESIDUE (T 240)																					
Mass Loss, Maximum, percent	1.00																				
Dynamic Shear, TP 5: G*/sinδ[f], Minimum, 2.20 kPa Test Temp @ 10 rad/s, °C	46			52							58					64					
PRESSURE AGING VESSEL RESIDUE (PP 1)																					
PAV Aging Temperature, °C[d]	90			90							100					100					
Dynamic Shear, TP 5: G*/sinδ[f], Maximum, 5000 kPa Test Temp @ 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
Physical Hardening[e]	Report																				
Creep Stiffness, TP 1 Determine the critical cracking temperature as described in PP 42	-24	-30	-36	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30
Direct Tension, TP 3 Determine the critical cracking temperature as described in PP 42	-24	-30	-36	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30

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PAV - Pressure Aging Vessel

Simulates long term aging

RTFO - Rolling Thin Film Oven

Simulates short term aging

RV- Rotational Viscosity

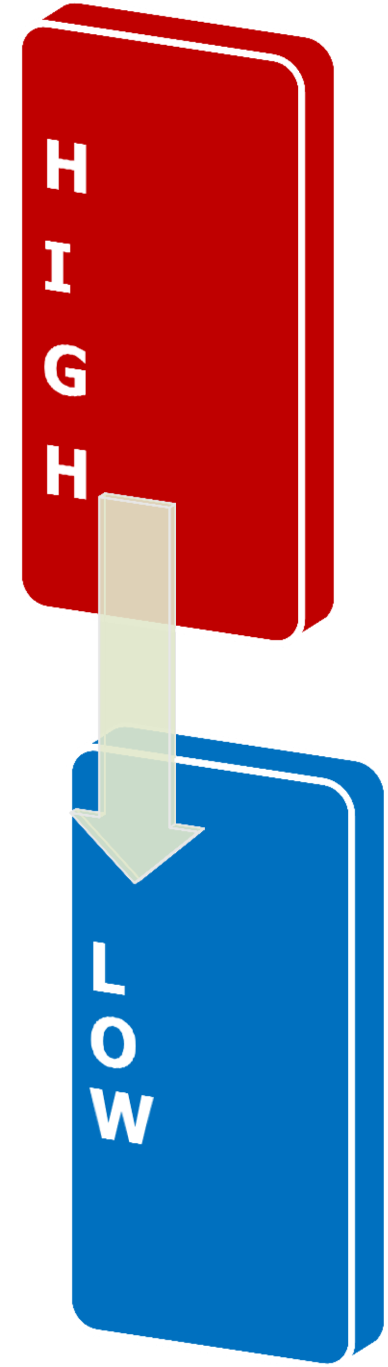
Measures performance at high temperatures

DSR – Dynamic Shear Rheometer

Measures performance at medium and normal temperatures

BBR – Bending Beam Rheometer

Measures performance at low temperatures



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Bitumen aging

Oxidation

-Irreversible chemical reaction

-Formation of functionalities containing oxygen

Evaporation

-Loss of volatile components

Exudation
-Loss of oily components due to exudation of bitumen into the mineral aggregate

Physical hardening
-Molecular association (steric hardening)

-Low temperature physical hardening

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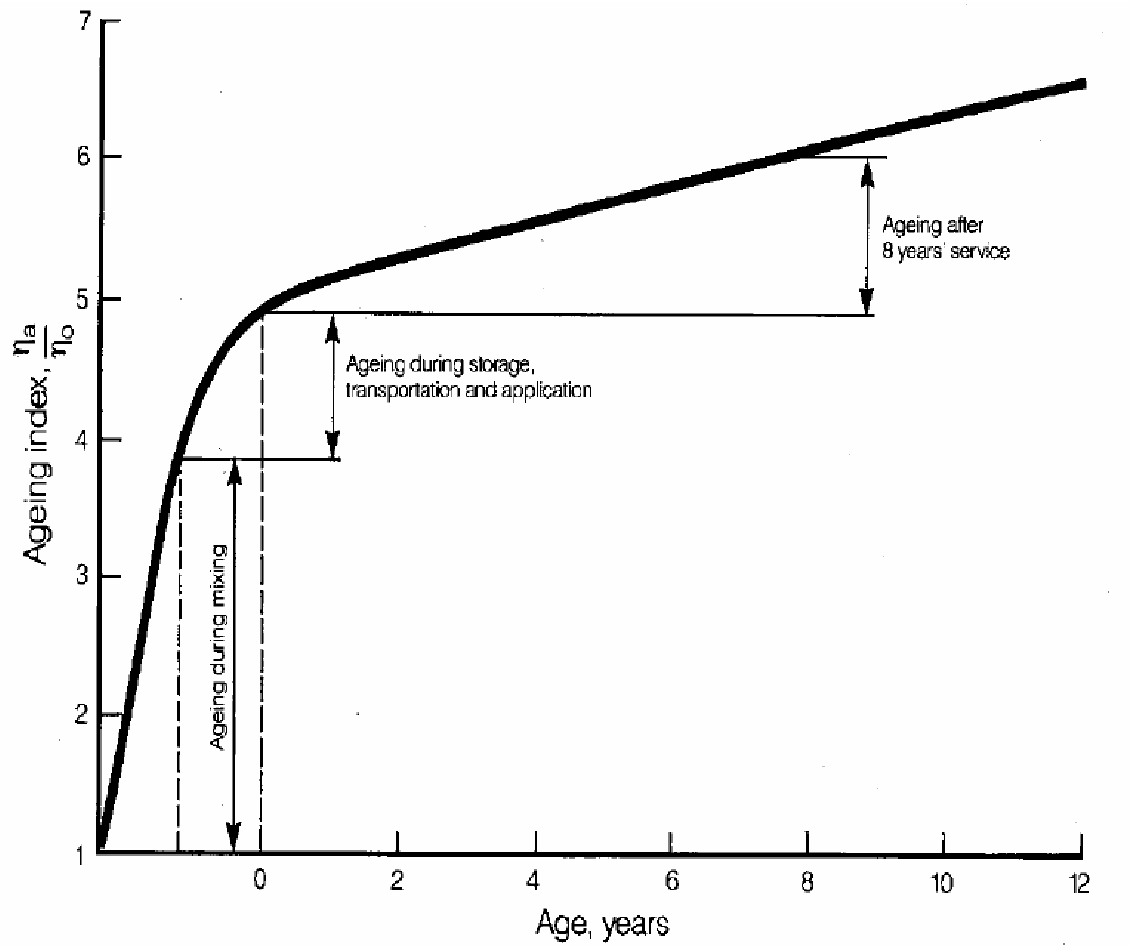
Bitumen aging -When?

Most during production;

Storage transport and laying;

In the pavement.



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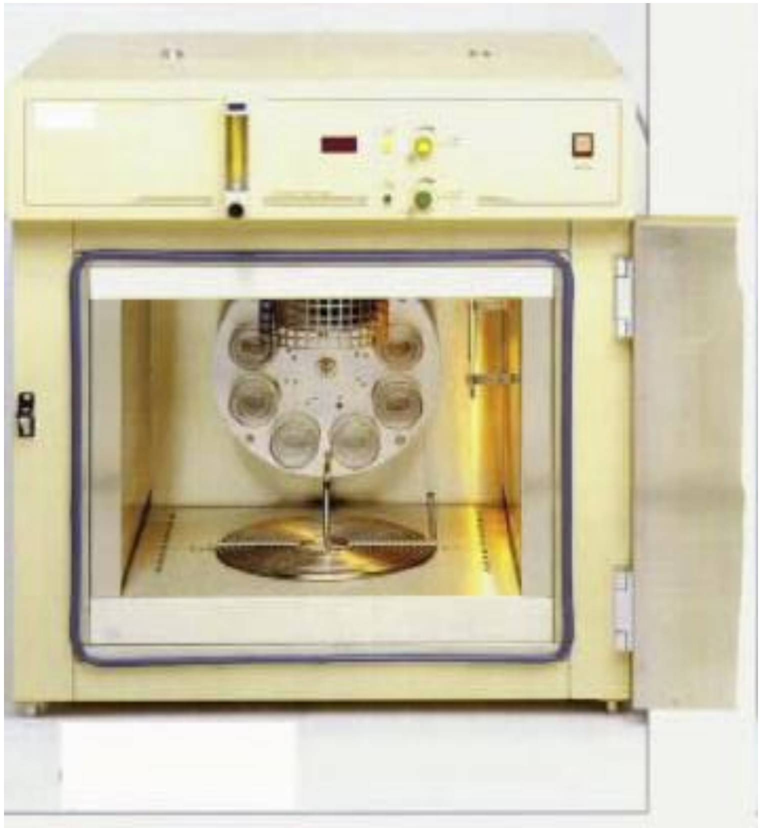
Aging

Binder aged in
RTFO (Rolling Thin Film Oven)



Binder aged in
PAV (Pressure Aging Vessel)

RTFO – Rolling Thin Film Oven

- RTFO simulates aging of the binder during mixing and laying of an asphalt mix (short time aging).
- Aging in rotating bottles, 85 min/163° C.
- Weight loss is determined.
- DSR analysis.
- The main part of the aged bitumen sample will then be further aged in PAV.

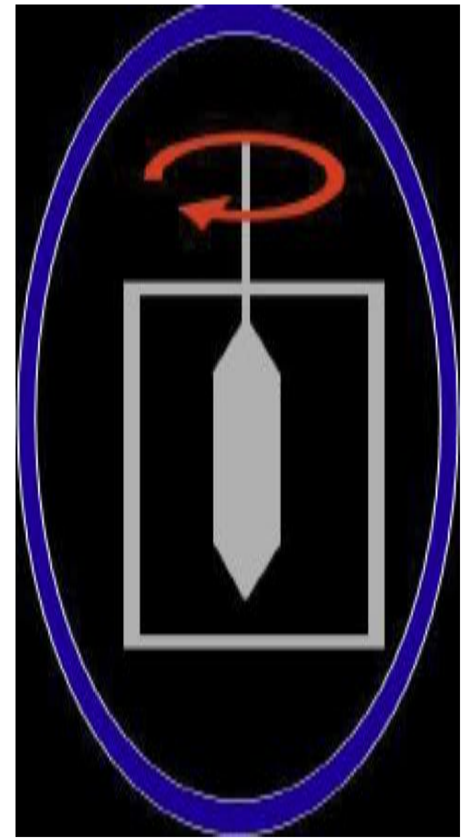
PAV - Pressure Aging Vessel

- PAV simulates long time aging on the road (long term aging).
- Aging under high pressure (2070 KPa) at 90, 100 or 110° C/20 hours.
- DSR (G*sinδ) and BBR (S and m) and possibly DTT.

RV - Rotational Viscometer

- Rotational Viscometer (Brookfield) for evaluating the workability at higher temperatures (production, mixing, transport and laying)

- The dynamic viscosity is measured at 135° C < **3 Pas**



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DSR - Dynamic Shear Rheometer

- Shearing between oscillating spindle and fix plate
- Frequency: 10 rad/s (1.57 Herz) at particular temperature.

Measures:

- Complex modulus G*, total shear resistance
- Phase angle δ, relationship between elastic and viscous part.
- Shear strain: 1 - 12%
- Temp range: 4 to 85° C (G* between 0.1 and 10 000 KPa)

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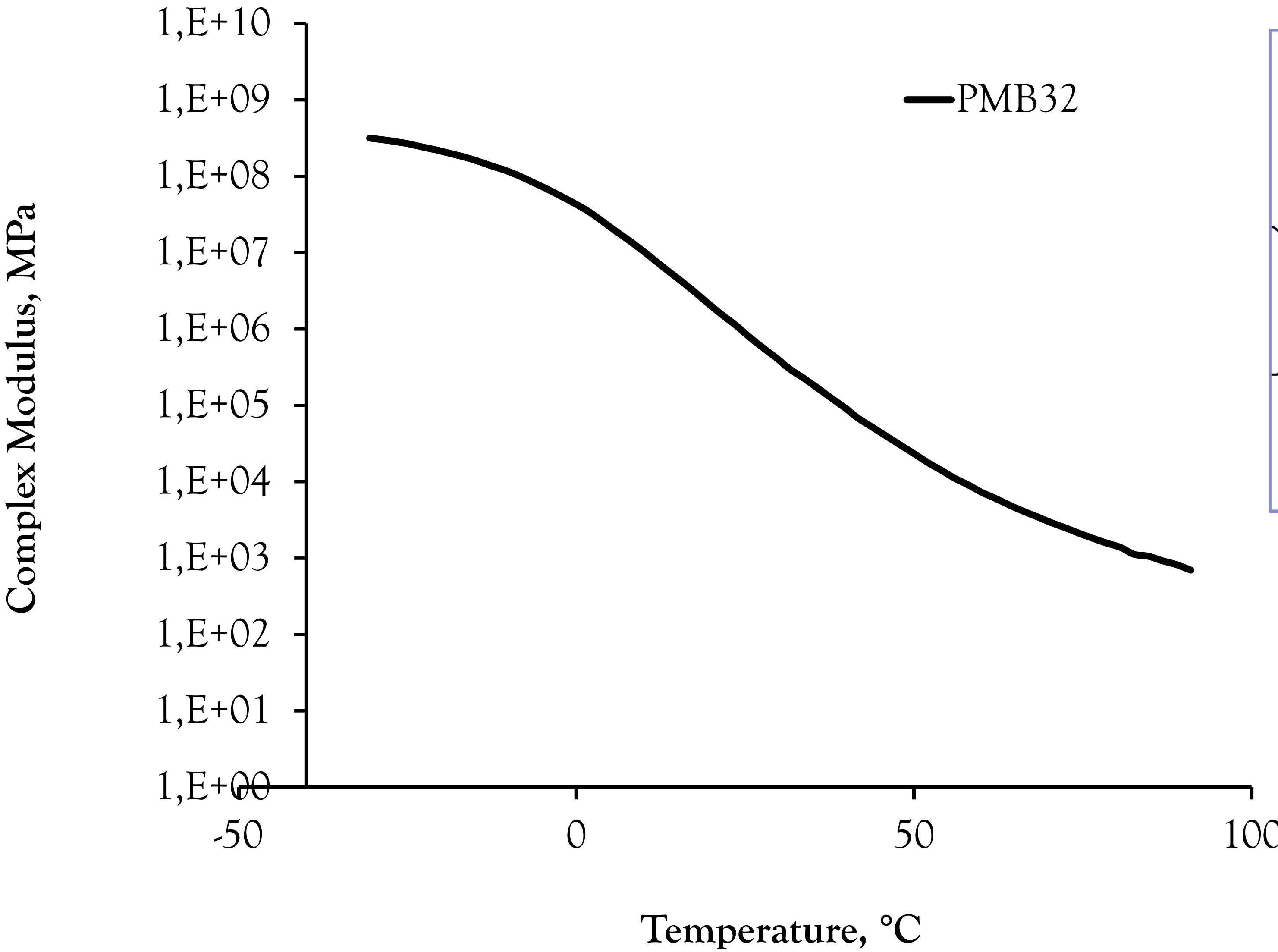
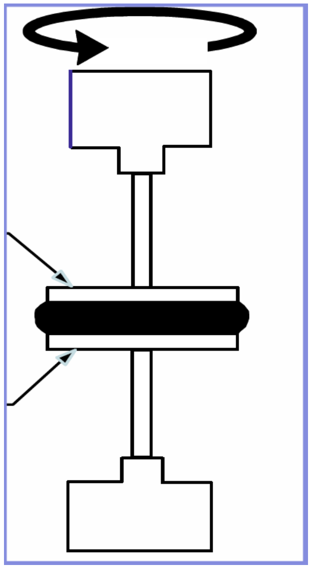
Complex modulus *Versus Temperature*





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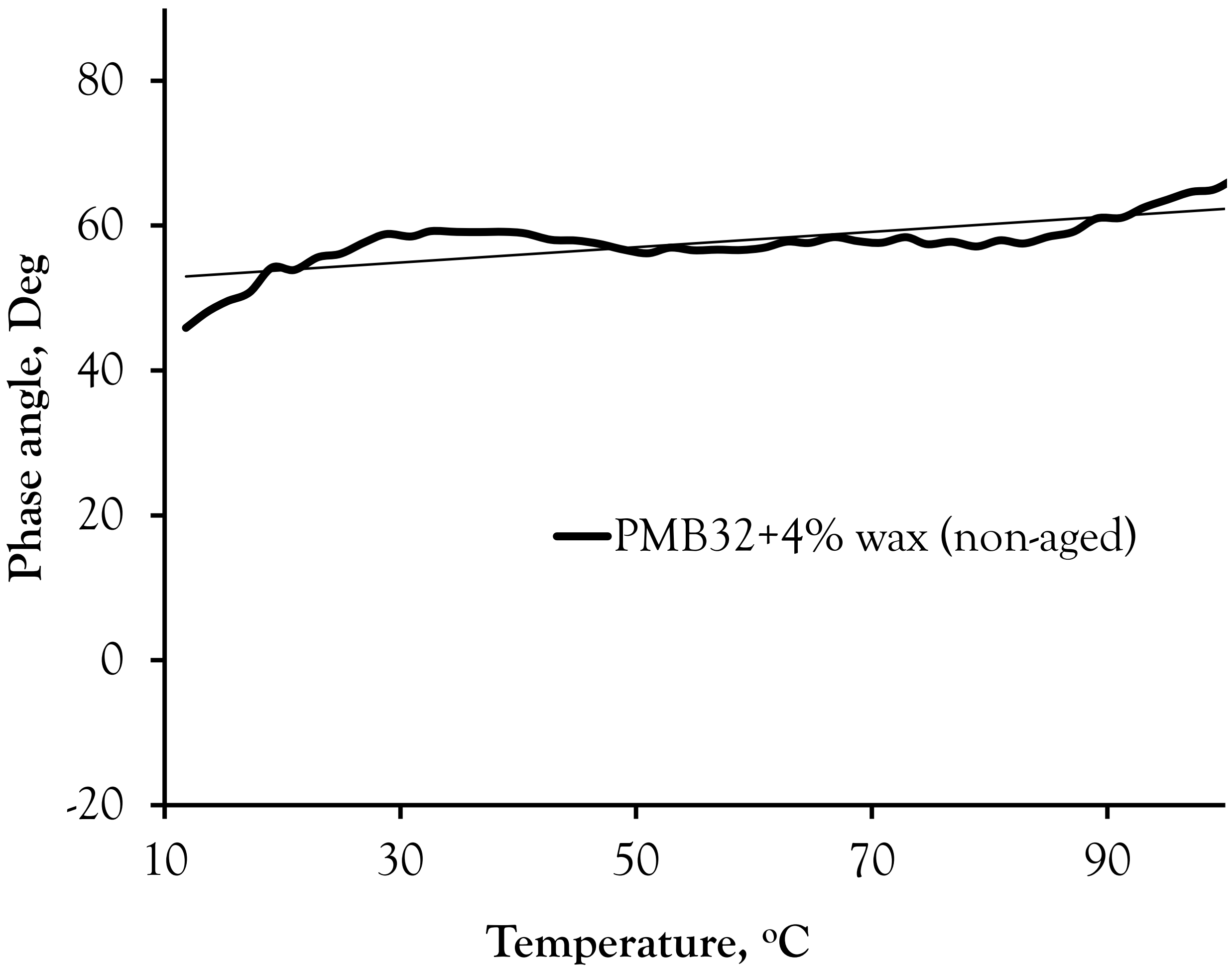
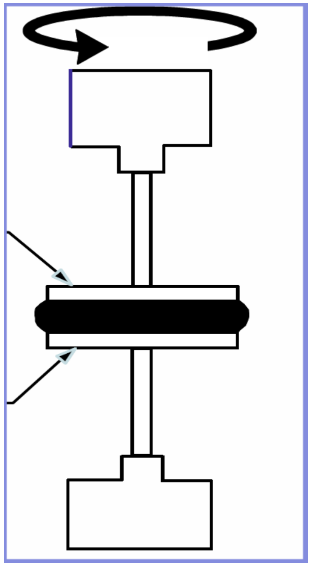
Phase angle *Versus Temperature*





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DSR (Dynamic Shear Rheometer)

Requirements

Permanent deformation is controlled by:

- $G^*/\sin\delta$ for non aged binder > 1.00 KPa
- $G^*/\sin\delta$ for RTFO aged binder > 2.20 KPa

DSR (Dynamic Shear Rheometer)

Requirements

Fatigue is controlled by:

- $G^*\sin\delta$ for RTFOT/PAV aged material = max 5 MPa

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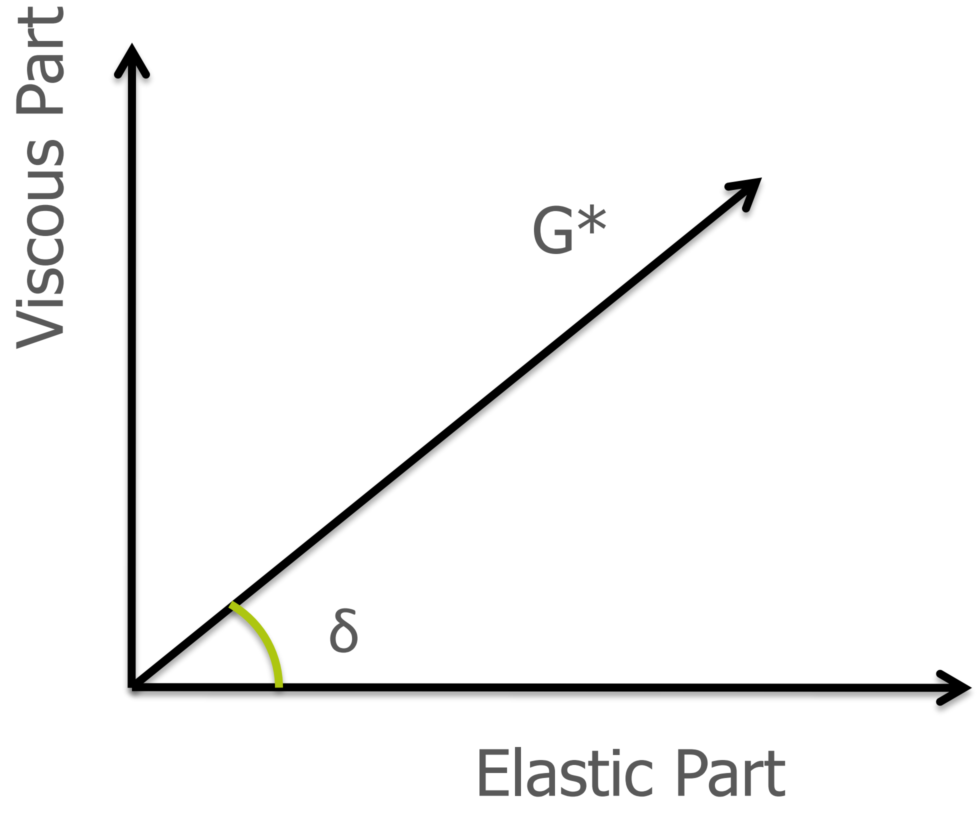
Visco-Elasticity Concept



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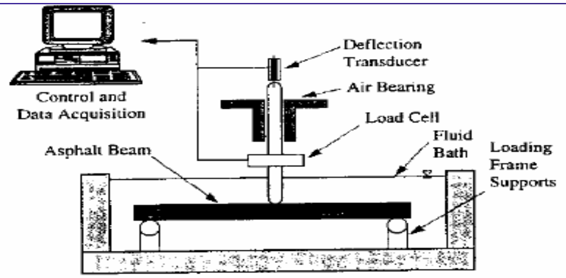
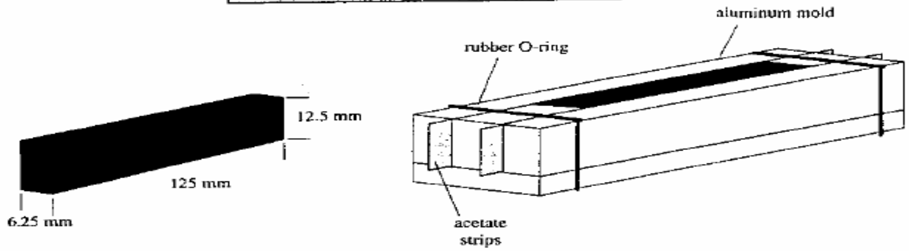
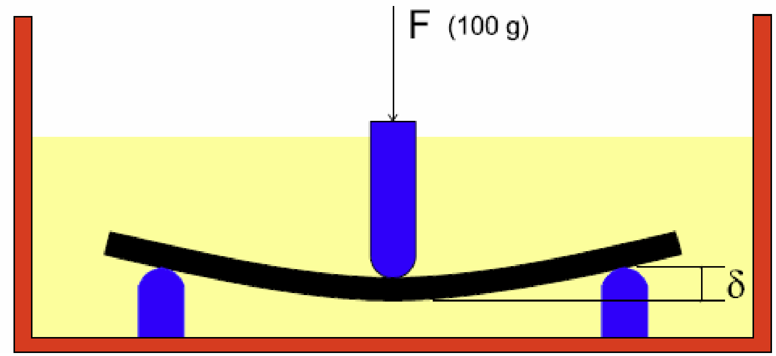
BBR (Bending Beam Rheometer)







- For testing at low temperatures where bitumen is very stiff.

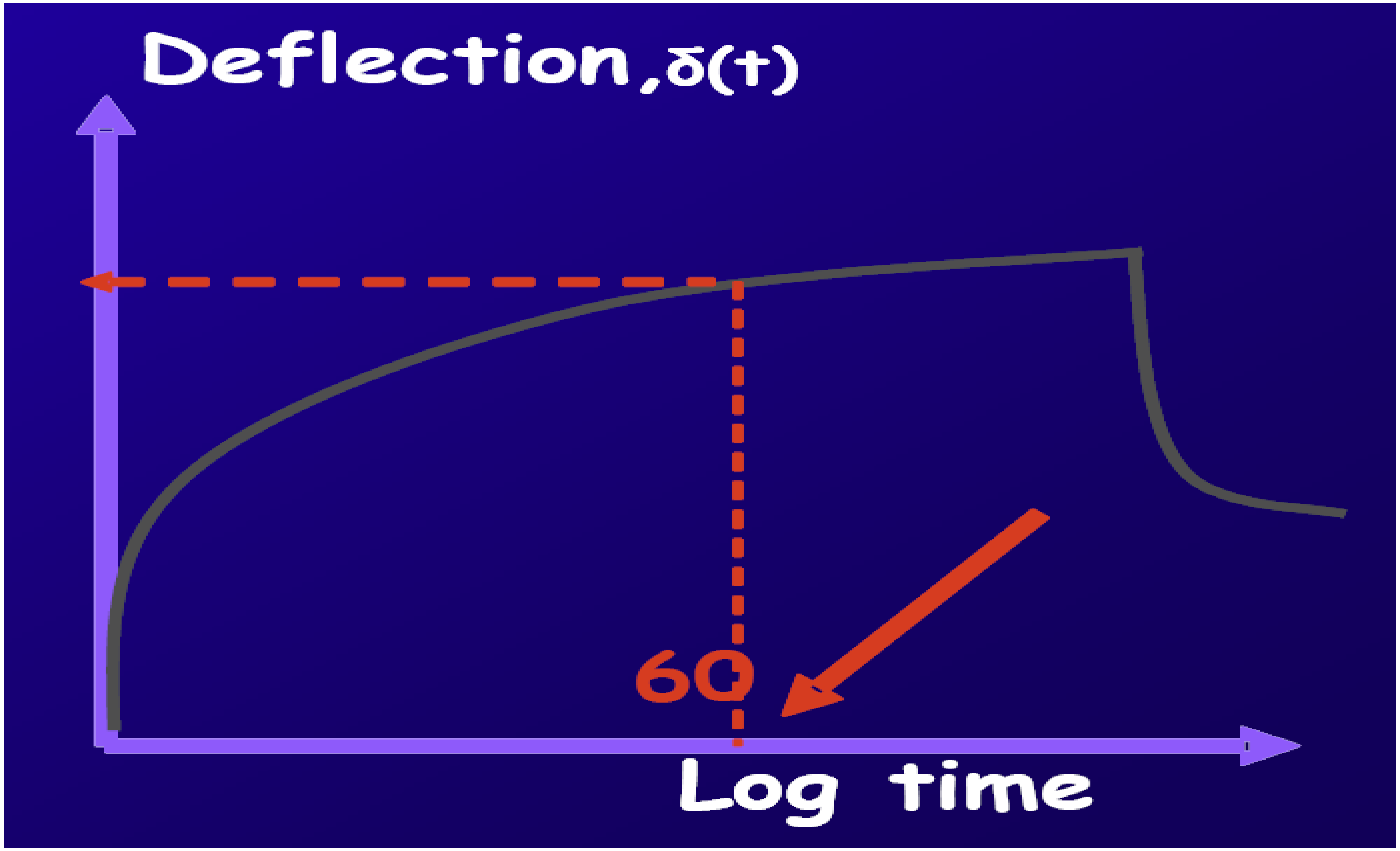
- A small beam of binder is loaded to simulate stresses built up at falling temperature in a pavement.

- The midpoint deflection of the beam versus time (4 minutes) is measured.

- Flexural creep stiffness S and m-value under creep loading.

BBR (Bending Beam Rheometer)

- The test is performed at a temperature 10° C higher than the expected lowest pavement temperature.
- The requirement of <300 MPa corresponds to the stiffness after 2 hours loading. Increasing the test temperature leads to a shorter testing time of **60sec.**



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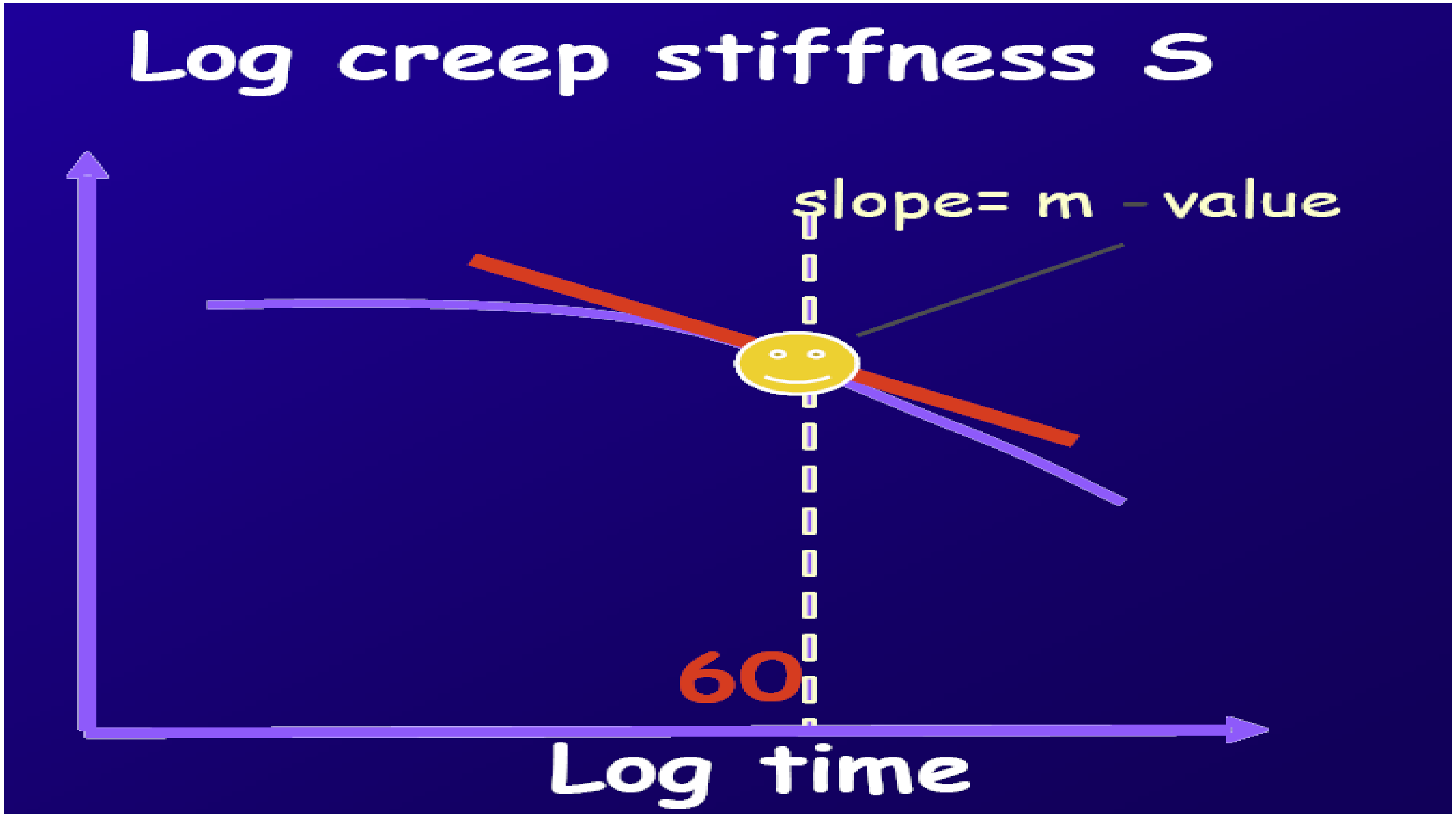
BBR (Bending Beam Rheometer)

$S(t) = PL^3/4bh^3\delta(t)$

*Equation and registered deflection give the stiffness S at 60 sec.

m-value is the slope of the stiffness and time on the log-log scale.

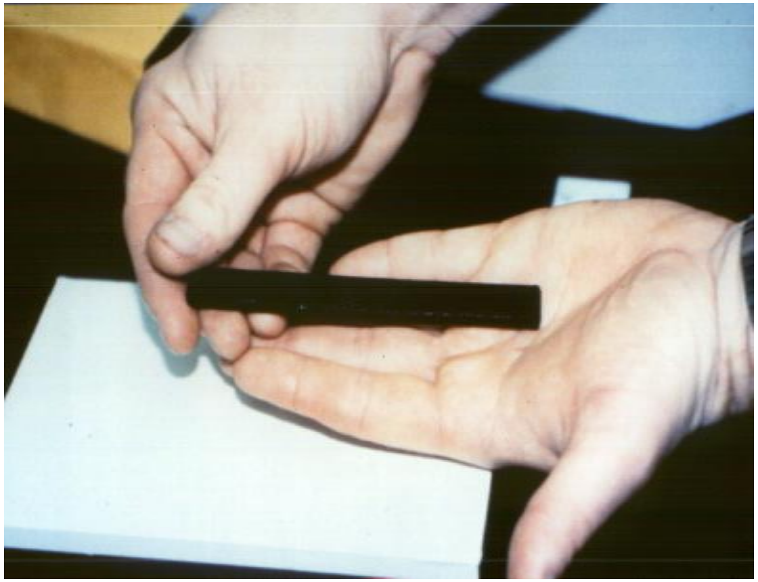


BBR (Bending Beam Rheometer)

Requirements

Cracking at low temperature is controlled by:

- S for RTFO/PAV aged binder < 300 MPa
- m-value for RTFO/PAV aged binder > 0.300



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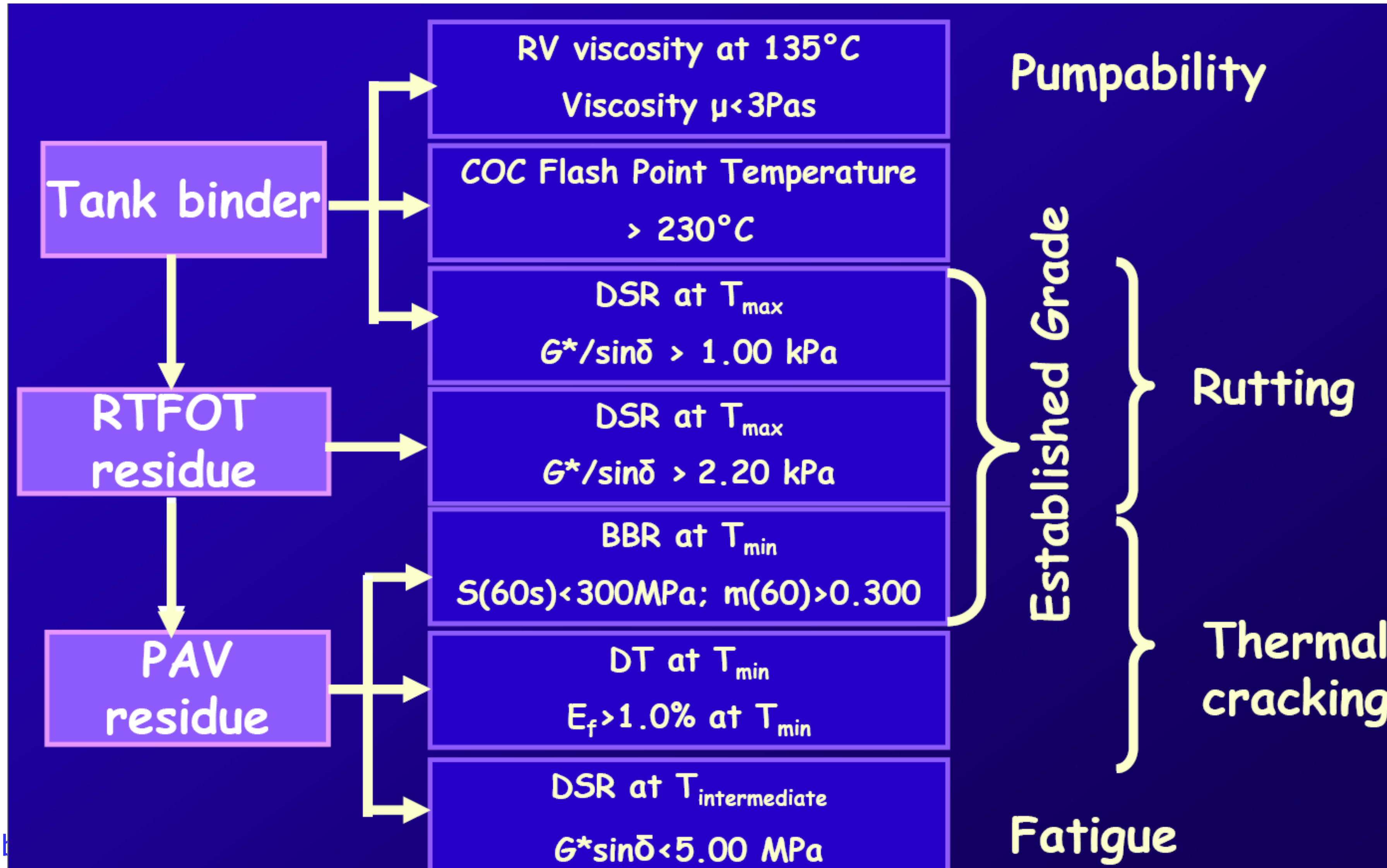
Modified binders and Superpave Plus Specifications

- The current Superpave binder specification does not appear to adequately determine the performance characteristics of modified binders.

- Many Highway agencies have included additional tests to the existing Superpave binder specification to assure a desired modifier is included in the binder.

- In the near future we will have the answers ………Until that time, the Highway agencies will have to use engineering judgement in specifying modified asphalt binders.

Flow Chart for PG-qualities According to Superpave



Performance Grades

Avg 7-day Max, °C	PG 46	PG 52	PG 58	PG 64	PG 70	PG 76	PG 82
1-day Min, °C	-34 -40 -46 (-28 -34)	-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
ORIGINAL							
≥ 230 °C	(Flash Point) **FP**						
≤ 3 Pa·s @ 135 °C	(Rotational Viscosity) **RV**						
≥ 1.00 kPa	(Dynamic Shear Rheometer) **DSR** G*/sin δ						
	46	52	58	64	70	76	82
(ROLLING THIN FILM OVEN) RTFO Mass Loss ≤ 1.00 %							
≥ 2.20 kPa	(Dynamic Shear Rheometer) **DSR** G*/sin δ						
	46	52	58	64	70	76	82
(PRESSURE AGING VESSEL) PAV							
20 Hours, 2.07 MPa	90	90 100	100	100 (110)	100 (110)	110 (110)	
≤ 5000 kPa	(Dynamic Shear Rheometer) **DSR** G* sin δ						
	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
S ≤ 300 MPa m ≥ 0.300	(Bending Beam Rheometer) **BBR** "S" Stiffness & "m"-value						
	-24 -30 -36 (-18 -24)	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
Report Value	(Bending Beam Rheometer) **BBR** Physical Hardening						
≥ 1.00 %	(Direct Tension) **DT**						
	-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

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Permanent Deformation

Addressed by high temp stiffness;

- G*/sin δ on unaged binder >1.00 KPa
- G*/sin δ on RTFO aged binder >2.20 KPa

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Fatigue Cracking

Addressed by intermediate temperature stiffness;

- G*sin δ on RTFO & PAV aged binder <5000 kPa

Low Temperature Cracking

Addressed by low temperature stiffness and m - value;

- S for RTFO/PAV aged binder < 300 Mpa
- m-value for RTFO/PAV aged binder > 0.300

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Conformance Testing and Classification Testing

- Conformance testing: Does this binder sample meet all specification requirements of a certain performance grade (such as PG64-28)?

- Classification testing: What performance grade (or grades) does this binder sample meet? A series of tests are performed to classify an unknown binder, using a trial and error process.

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Bitumen conforming to PG 64-28

Binder property / Test		Results	Unit	Requirement
Original				
Flashpoint (Cleveland open cup)		**293**	[°C]	230 min
Viscosity at 135 °C (Brookfield)		**0.3**	[Pas]	3 max
DSR $\lvert G* \rvert / \sin\delta$ at 64 °C		**1.31**	[kPa]	1.00 min
After RTFOT				
Weight loss after RTFOT		**0.32**	[%]	1.00
DSR: $\lvert G* \rvert / \sin\delta$ at 64 °C		**2.63**	[kPa]	2.20 min
After RTFOT + PAV (100 °C)				
DSR: $\lvert G* \rvert \cdot \sin\delta$ at 22 °C		**4517**	[kPa]	5000 max
BBR at -18 °C after 60 sec	Stiffness m-value	**274** **0.346**	[MPa] [ ]	300 max 0.300 min
BBR at -18 °C After 24 h	Stiffness m-value	**0.350** **0.300**	[MPa] [ ]	To be reported

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SUPERPAVE Binder Conformance testing

ORIGINAL BINDER

Flash point: 340 ° C
Viscosity: 0.42 Pas

Modulus (G*/sinδ) at;

64° C :	**70° C:**
1.61 KPa	0.72 KPa

RTFOT

Change in mass: 0.08 %

Modulus (G*/sinδ) at;

58° C :	**64° C:**
7.28 KPa	3.24 KPa

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PAV

Modulus (G*sinδ) at;

25° C :	22° C:	19° C:	16° C:
1943 kPa	2917 kPa	4047 kPa	5442 kPa

BBR

Creep stiffness/m-value at;

-6° C:	-12° C :	-18° C:
46.3 MPa	107 MPa	229 MPa
0.411	0.350	0.305

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PG 64-28

Binder property / Test		Results	Unit	Requirement
Unaged				
DSR $\|G*\|/\sin\delta$ at 58 °C			[kPa]	1.00 min
DSR $\|G*\|/\sin\delta$ at 64 °C		**1.61**	[kPa]	1.00 min
DSR $\|G*\|/\sin\delta$ at 70 °C		**0.72**	[kPa]	1.00 min
After RTFOT				
DSR: $\|G*\|/\sin\delta$ at 58 °C		**7.28**	[kPa]	2.20 min
DSR: $\|G*\|/\sin\delta$ at 64 °C		**3.24**	[kPa]	2.20 min
DSR: $\|G*\|/\sin\delta$ at 70 °C			[kPa]	2.20 min
After RTFOT + PAV (100 °C)				
DSR: $\|G*\|\cdot\sin\delta$ at 13 °C			[kPa]	5000 max
DSR: $\|G*\|\cdot\sin\delta$ at 16 °C		**5445**	[kPa]	5000 max
DSR: $\|G*\|\cdot\sin\delta$ at 19 °C		**4047**	[kPa]	5000 max
DSR: $\|G*\|\cdot\sin\delta$ at 22°C		**2917**	[kPa]	5000 max
DSR: $\|G*\|\cdot\sin\delta$ at 25°C		**1943**	[kPa]	5000 max
DSR: $\|G*\|\cdot\sin\delta$ at 28°C			[kPa]	5000 max
DSR: $\|G*\|\cdot\sin\delta$ at 31°C			[kPa]	5000 max
DSR: $\|G*\|\cdot\sin\delta$ at 34°C			[kPa]	5000 max
BBR at -6 °C after 60 sec	Stiffness m-value	**46.3** **0.411**	[MPa] [ ]	300 max 0.300 min
BBR at -12 °C after 60 sec	Stiffness m-value	**107** **0.350**	[MPa] [ ]	300 max 0.300 min
BBR at -18 °C after 60 sec	Stiffness m-value	**229** **0.305**	[MPa] [ ]	300 max 0.300 min
BBR at -24 °C after 60 sec	Stiffness m-value		[MPa] [ ]	300 max 0.300 min

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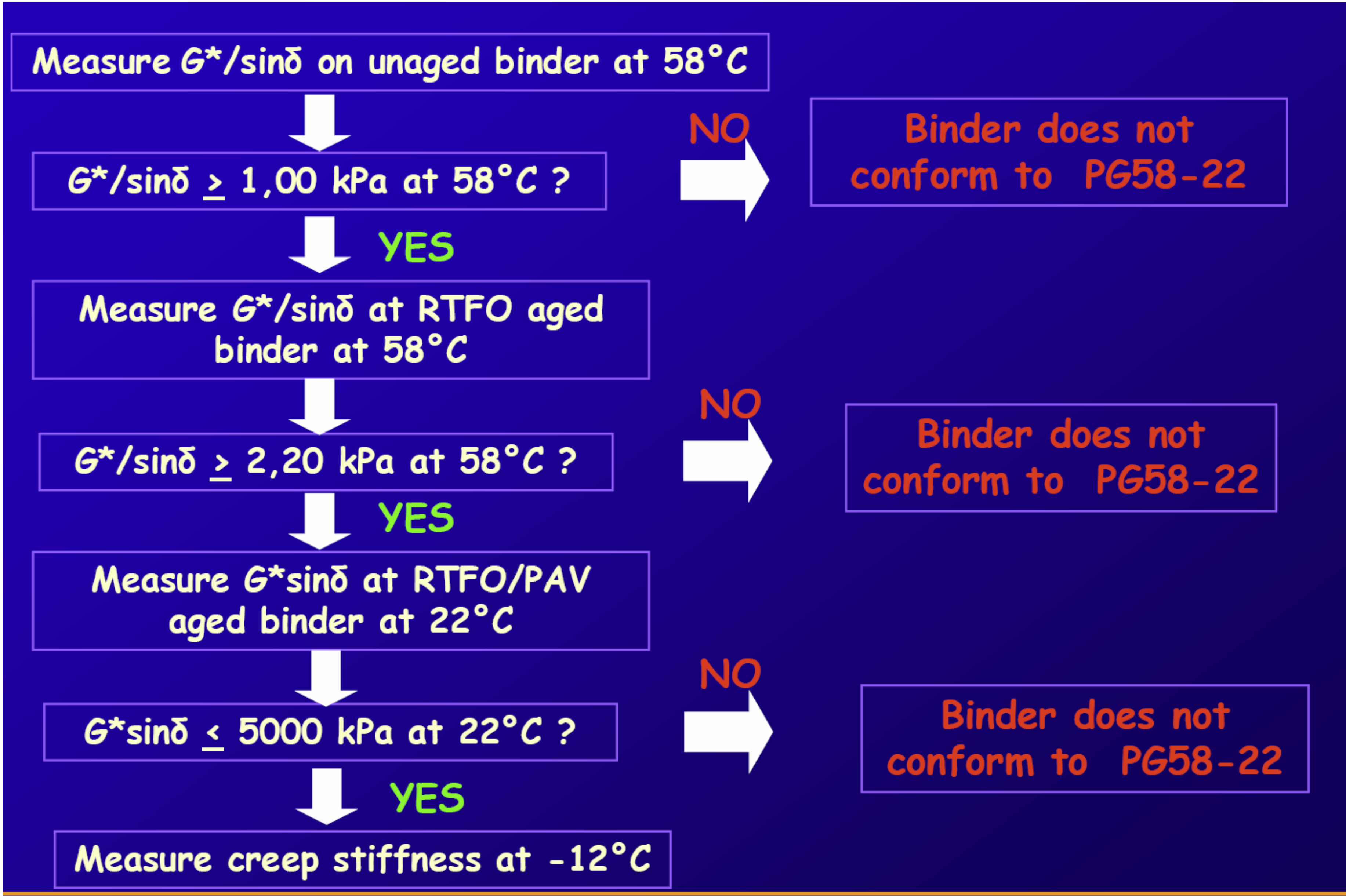
PG 58 – 22 ???



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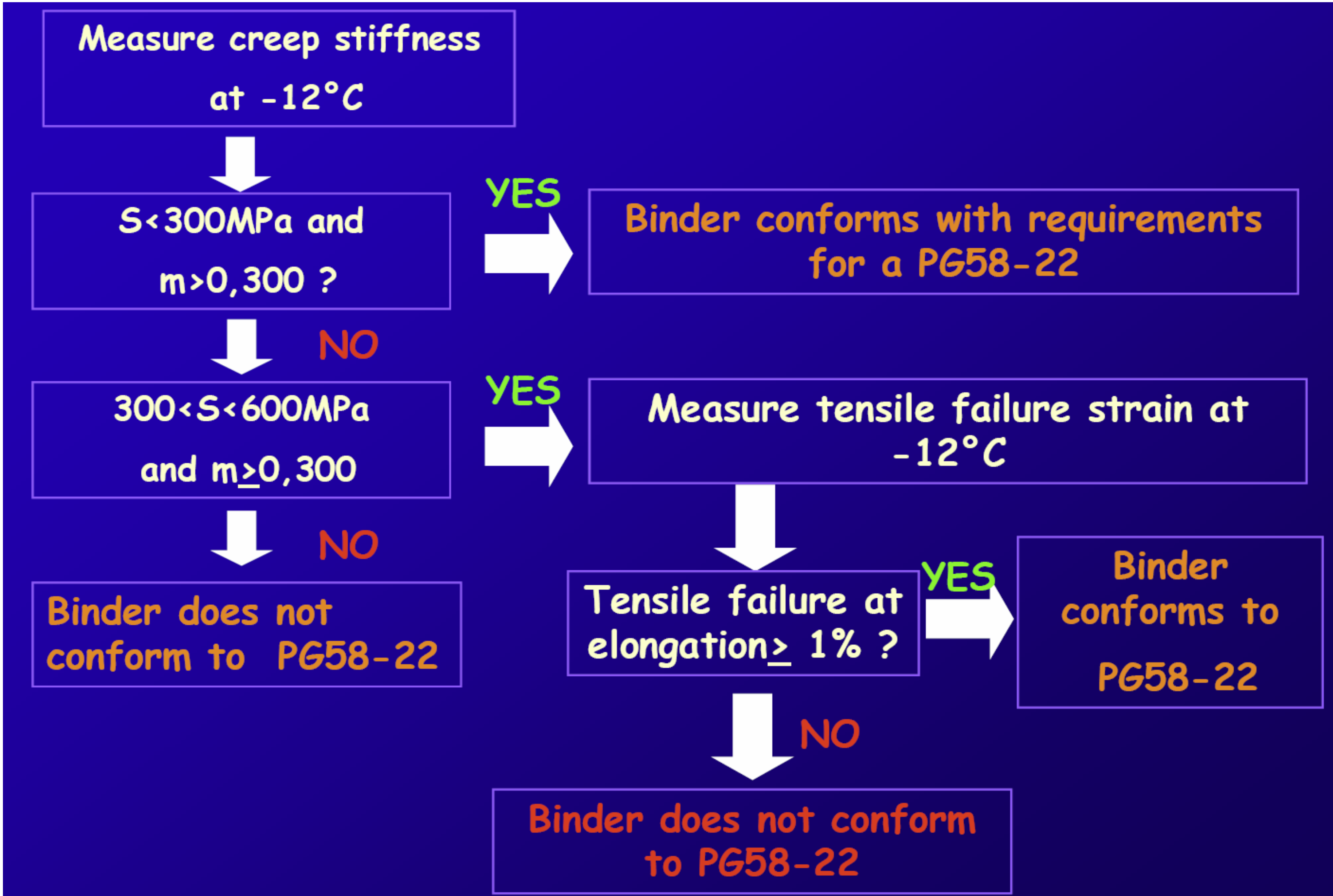
PG 58 – 22 ???



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Break for Lunch