COPPE UFRJ
Instituto Alberto Luiz Coimbra de Pós-Graduação e Pesquisa de Engenharia

PROJETO DNIT

DNIT
DEPARTAMENTO NACIONAL DE INFRAESTRUTURA DE TRANSPORTES

TED 680/2020

Parâmetros de desempenho de materiais asfálticos

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04 de junho de 2025

Objetivos

Indicadores de desempenho de ligantes aplicados a frio e a quente

- ❑ Aplicados a quente é a meta do TED 680/2020
- ❑ Aplicados a frio

Avaliação dos ligantes aplicados a quente

Visão da COPPE – escolha de parâmetros reológicos

- **Distinção dos ligantes modificados e não modificados;**
- **Permitir escolha adequada de materiais - MeDiNa;**
- **Correlações dos resultados de ensaios de ligantes e de misturas asfálticas para escolha dos parâmetros de especificação de ligantes;**
- **Verificação do enquadramento dos resultados de análises dos ligante quanto às especificações americanas e quanto a proposta de especificação da Petrobras;**
- **Análise dos ligantes quanto a parâmetros reológicos relacionados a trincamento por fadiga e deformação permanente;**

Materiais estudados

Código	Tipo
A1	50/70
A2	50/70
A3	50/70
A4	30/45
A5	50/70
A6	30/45
A7	50/70
A8	50/70
A9	50/70
A10	30/45
A11	50/70
A12	50/70

Tipo	Quantidade
30/45	3
50/70	9

Código	Tipo
B1	AB-8
B2	AB-8
B3	AB-8
B4	AB-22
B5	AB-8
B6	AB-22
B7	AB-8
B8	AB-8
B9	AB-8

Tipo	Quantidade
AB-8	7
AB-22	2

Código	Tipo
C1	76-28
C2	55/75
C3	60/85
C4	55/75
C5	HiMA
C6	65/90
C7	60/85
C8	55/75
C9	60/85
C10	55/75
C11	60/85
C12	60/85
C13	65/90
C14	60/85
C15	60/85
C16	60/85

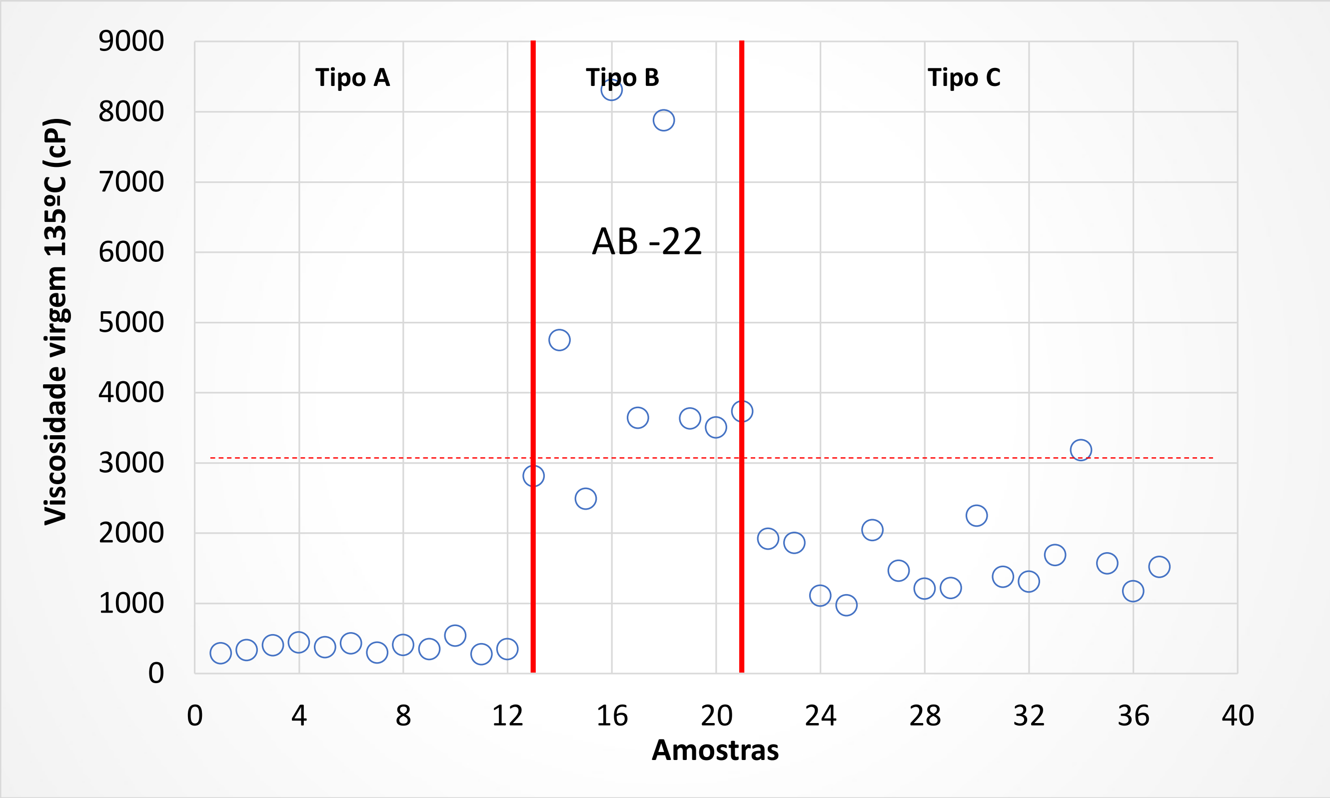
Tipo	Quantidade
Russo	1
55/75	4
60/85	8
65/90	2
HiMa	1

3 tipos de agregados

30 misturas asfálticas

Avaliação dos ligantes asfálticos quanto ao enquadramento das especificações SUPERPAVE

Viscosidade Brookfield a 135ºC, SP21, 20 RPM

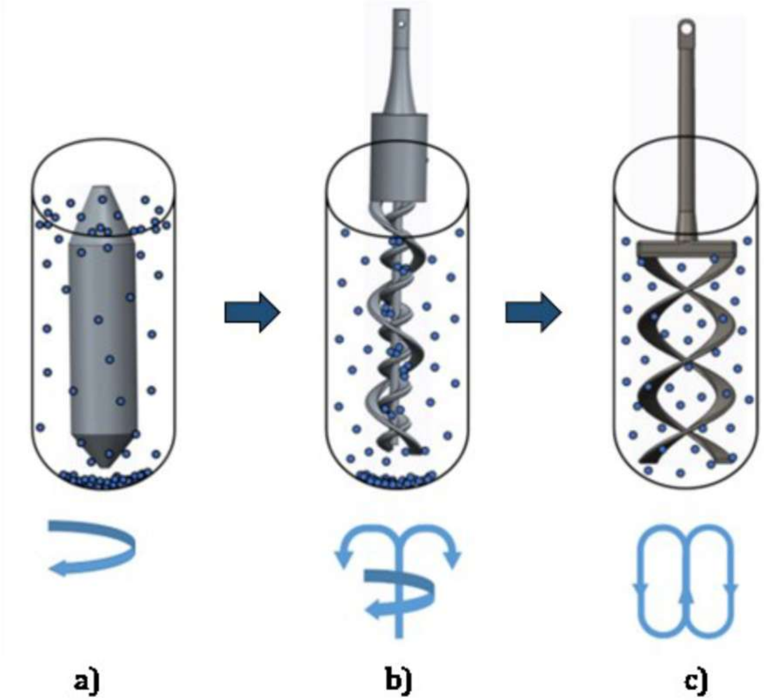


Viscosidade rotacional a 135ºC, SP21, 20 RPM	cP	≤ 3000

Lo Presti

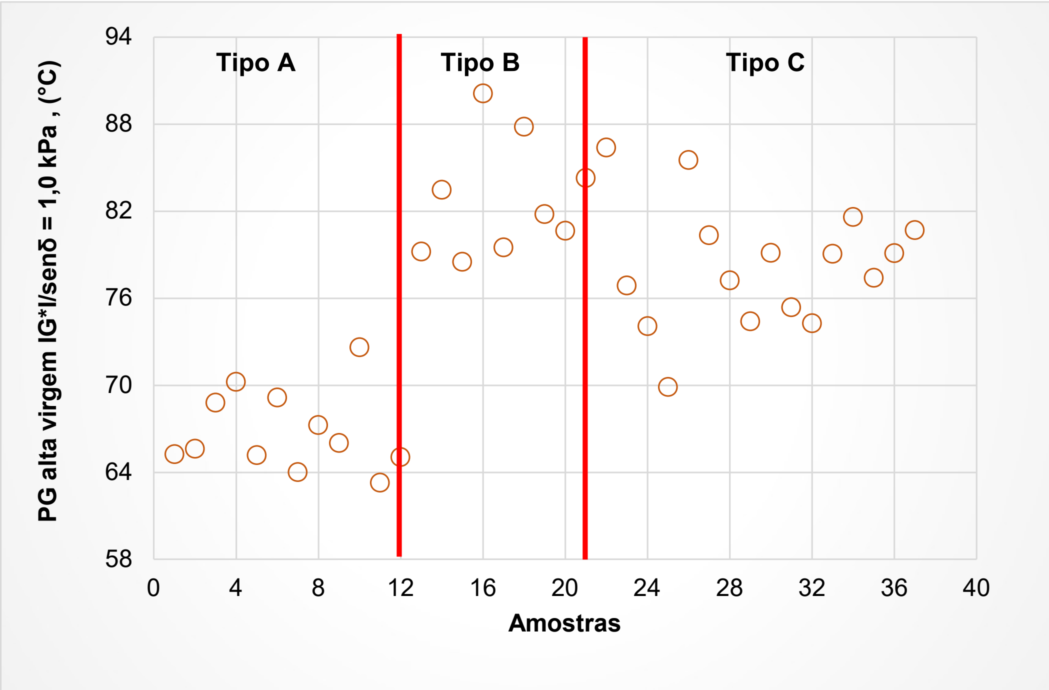
AB necessita de ensaio apropriado

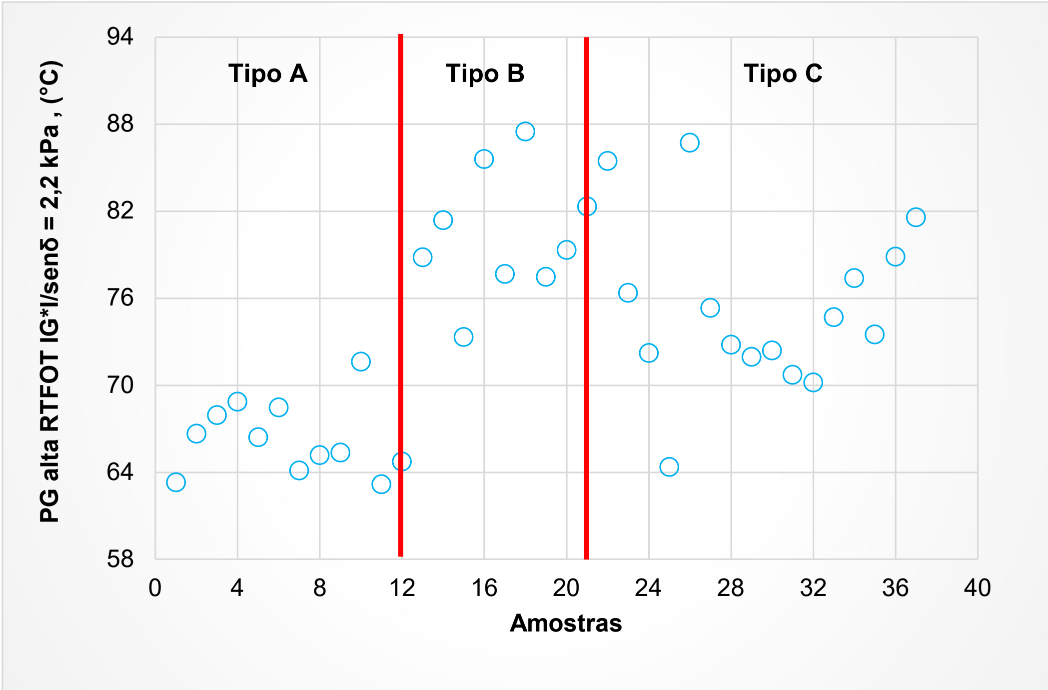
Are we correctly measuring the rotational viscosity of rubberized bituminous binder?
Conference Paper · October 2020



Distribuição das partículas de GTR dentro da câmara usando diferentes geometrias
a) standard spindle Sc-27,
b) dual helical impeller (DHI),
c) dual helical ribbon (DHR).

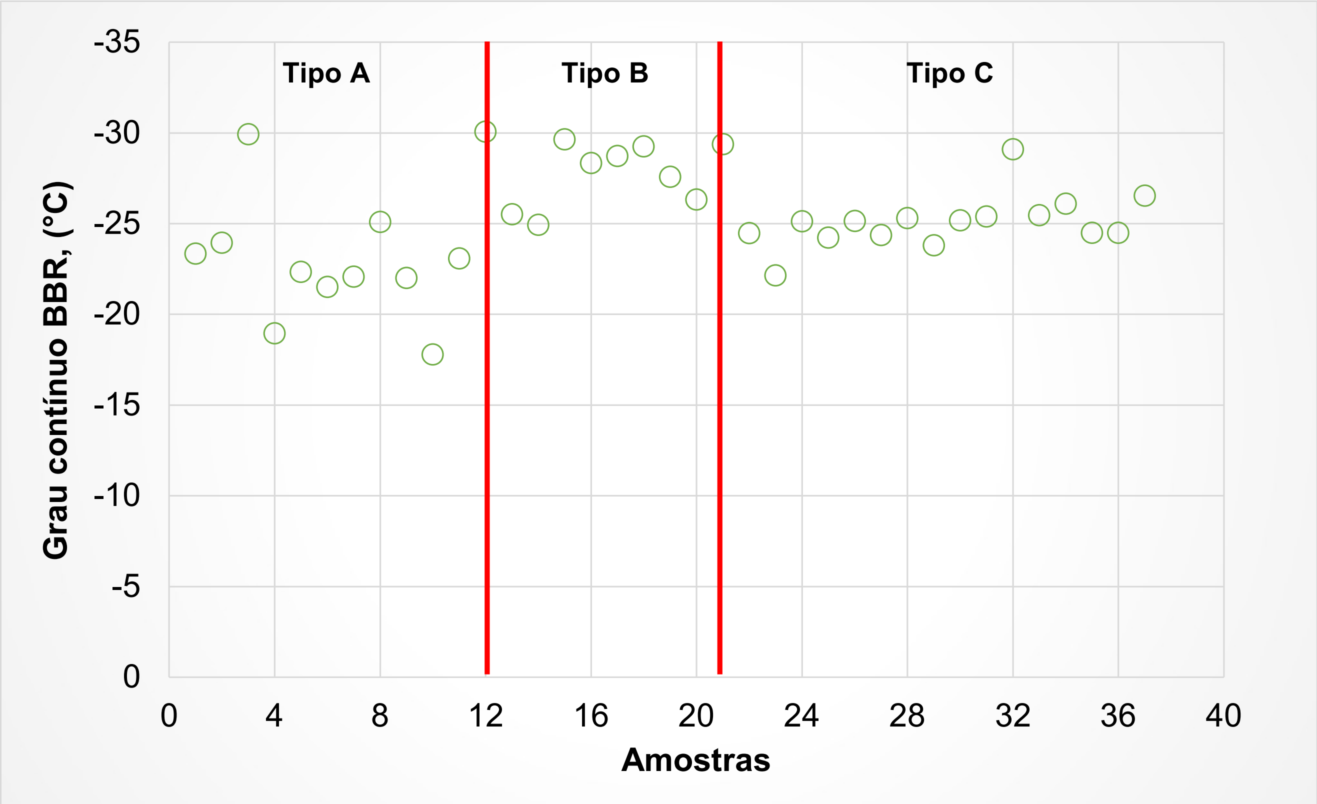
PG contínuo alta – virgem & RTFOT





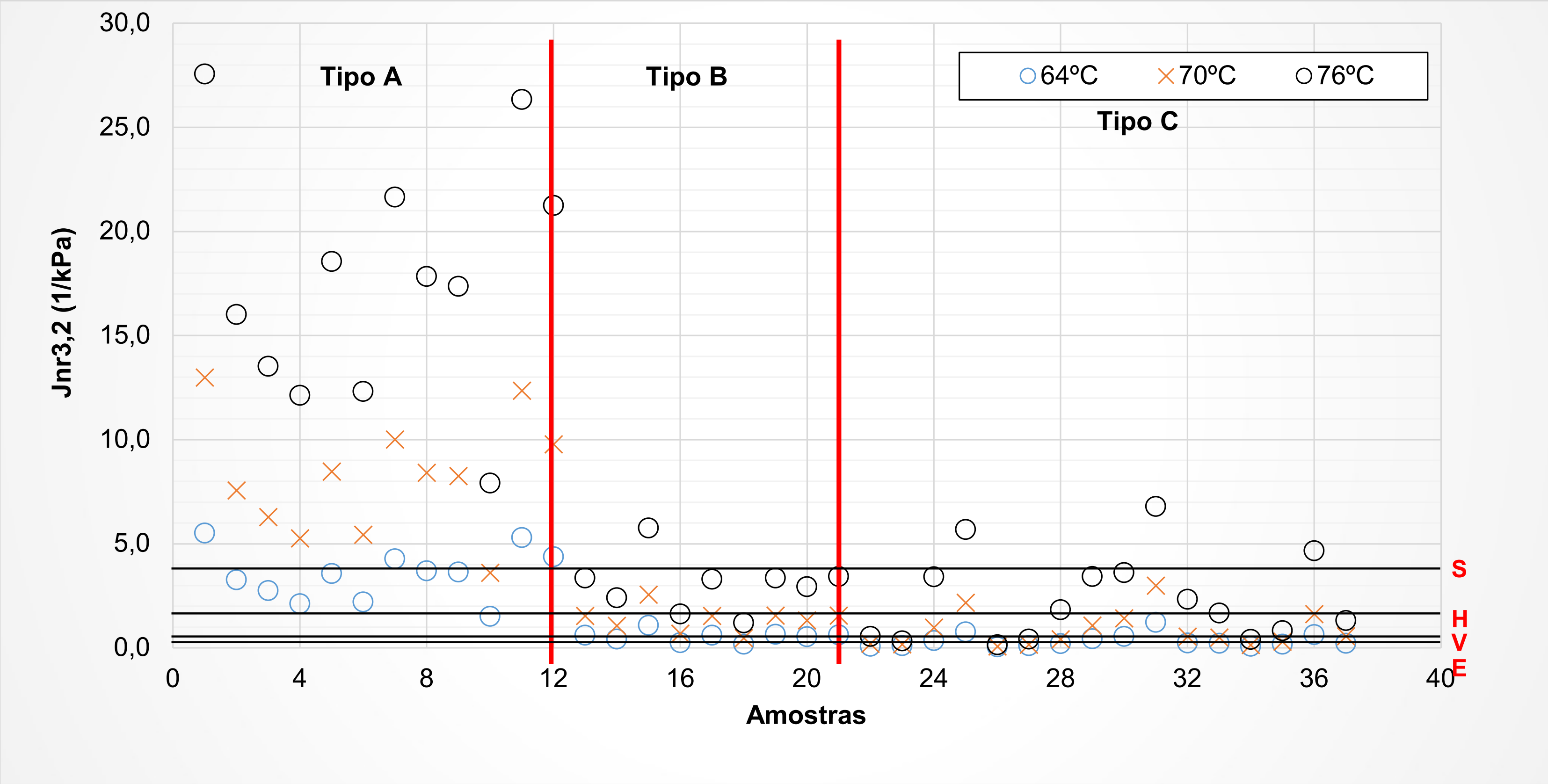
PG 58 a 88

PG baixa

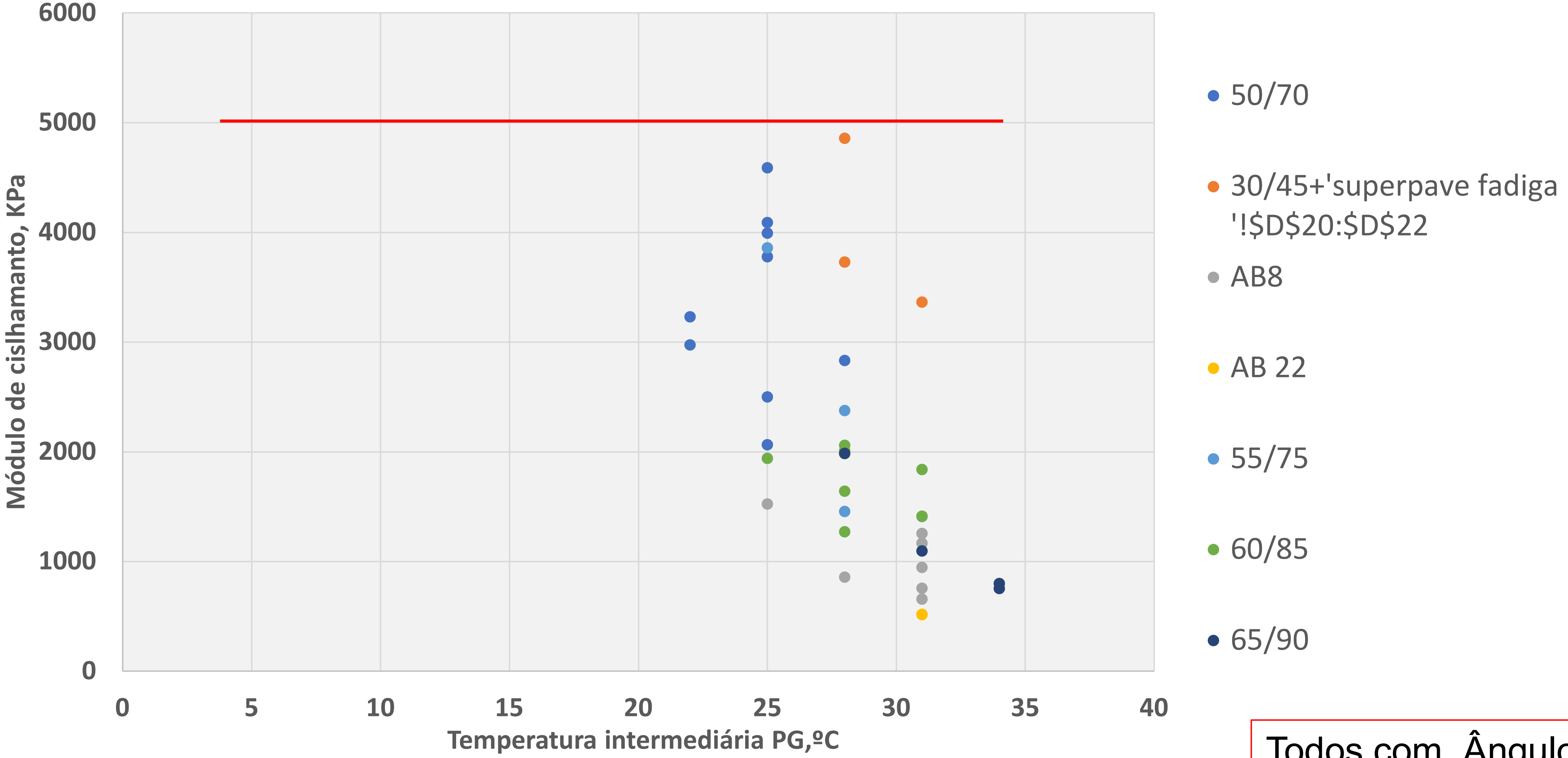


PG -28 a -16

MSCR – resistência a deformação permanente

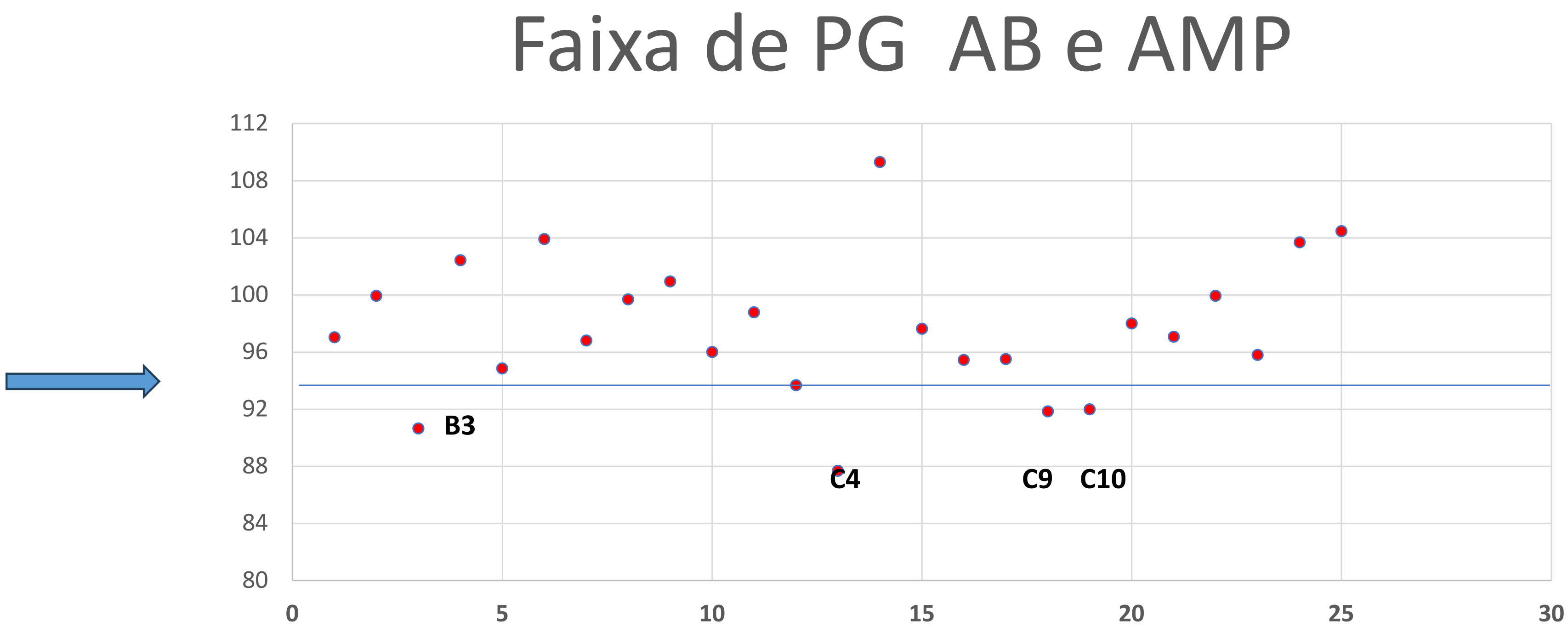


G*.senδ – resistência a trincas por fadiga



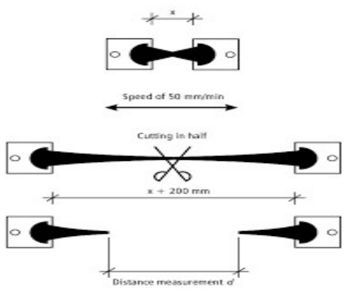
Todos com Ângulo de fase > 42

Faixa SUPERPAVE PG versus 92º (asfalto superior)

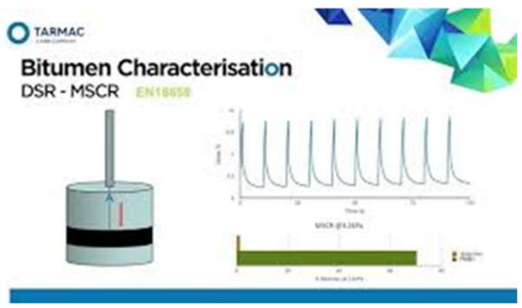


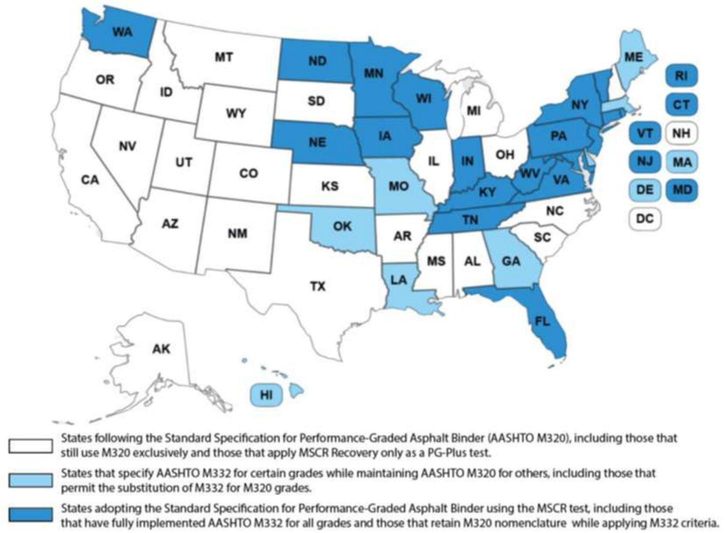
Ensaios plus com limites - DOT americanos

Retorno elástico (4 ou 25ºC)

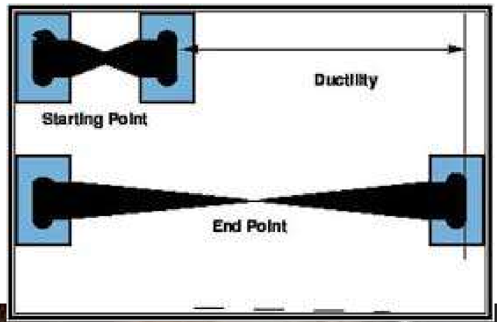


Recuperação elástica MSCR

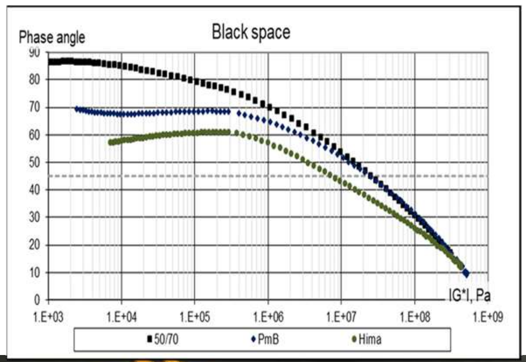




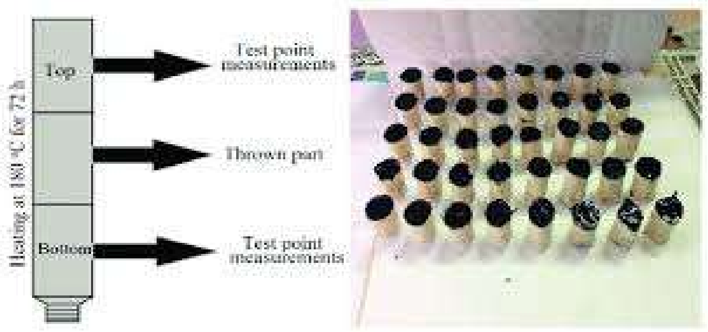
Ductilidade (4 ou 25ºC)



Ângulo de fase PG alta



Estabilidade a estocagem



África do Sul

Considerações importantes

- Viscosidade a 165°C alto cisalhamento;

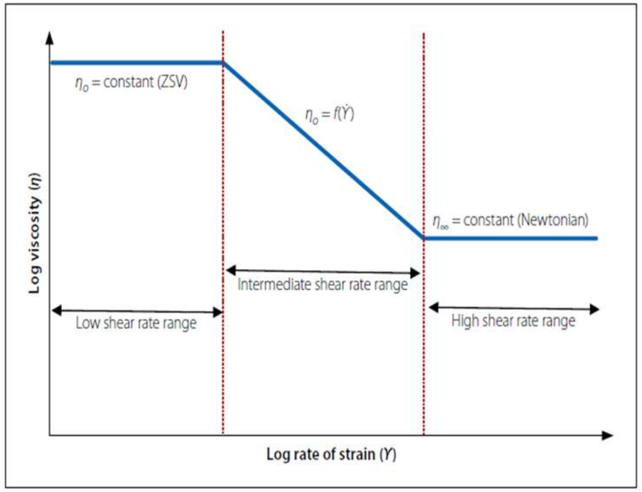


Figure 8 Schematic representation of viscosity ranges for bitumen

- Delta Tc;
- Estabilidade a estocagem a 180°C;
- Parâmetro de envelhecimento G*env/G*vir a T intermediária

(temperatura de 20 a 30°C) com índices semelhantes aos usados no passado para viscosidade a 60ºC.

Test Property	58S-22	58H-22	58V-22	58E-22	64S-16	64H-16	64V-16	64E-16	70S-10	70H-10	70V-10	70E-10	Test Method
Max pavement design temperature (°C) (T_{max})	58	58	58	58	64	64	64	64	70	70	70	70	
Minimum grading temperature (°C) (T_{min})	−22	−22	−22	−22	−16	−16	−16	−16	−10	−10	−10	−10	
G^* and δ at $[(T_{max} + T_{min})/2+4]$°C	Compulsory report only – see detail description of report only item												ASTM D7175
$G^*/\sin\delta$ @10rad/s (kPa) @ $T = T_{max}$ Report G^* and δ separately	Report only												ASTM D7175
Viscosity at 165°C (Pa.s) ≥ 30 sec^{-1}	≤ 0.9												ASTM D4402
Storage stability at 180°C (% diff in G^* at T_{max})	≤ 15												ASTM D7175
Flash Point (°C)	≥ 230												ASTM D92b
After RTFO Ageing													**ASTM D2872 / TG1 MB3**
G^* and δ at $[(T_{max} + T_{min})/2+4]$°C	Compulsory report only – see detail description of report only item												ASTM D7175
Mass change (% m/m)	≤ 0.3	≤ 1.0			≤ 0.3	≤ 1.0			≤ 0.3	≤ 1.0			ASTM D2872 / TG1 MB3
J_{NR} at T_{max} (kPa^{-1})	≤ 4.5	≤ 2.0	≤ 1.0	≤ 0.5	≤ 4.5	≤ 2.0	≤ 1.0	≤ 0.5	≤ 4.5	≤ 2.0	≤ 1.0	≤ 0.5	ASTM D7405
Ageing ratio $[G^*_{RTFO}/G^*_{Original}]$	≤ 3.0												ASTM D7175
After RTFO plus PAV Ageing													**ASTM D6521**
G^* and δ at $[(T_{max} + T_{min})/2+4]$°C	Compulsory report only – see detail description of report only item												ASTM D7175
Maximum creep stiffness tested at temperature (T_{min} + 10°C), MPa, [S (60s) ≤ 300 MPa]	−12°C				−6°C				0°C				ASTM D6648
Minimum m-value tested at temperature (T_{min} + 10°C), [m (60s) ≥ 0.300]	−12°C				−6°C				0°C				
ΔT_c (°C) = $T_{c,S} - T_{c,m}$	≥ −5												ASTM D7643
Ageing ratio $[G^*_{PAV}/G^*_{Original}]$	≤ 6.0												ASTM D7175

Conclusões – Superpave

O que pode ser melhorado

- **África do Sul emprega viscosidade a altas taxas de cisalhamento e alta temperatura para AMP;**
- **Necessidade de incluir ensaio de envelhecimento (Tint ou T alta) ?**
- **Inclusão de ensaio de estabilidade a estocagem;**
- **Incluir ângulo de fase para distinção de modificados dos não modificados;**
- **Inclusão de ensaios empíricos (DOT) ?**
- **AB necessita de desenvolvimento de ensaio de viscosidade com spindle helicoidal ?;**

Enquadramento das amostras

- **Superpave diferencia ligantes no MSCR e no PG de alta temperatura, mas não diferencia na resistência à fadiga;**
- **Alguns ligantes AMP não são vistos como modificados, segundo a faixa de PG 92;**

Proposta Petrobras

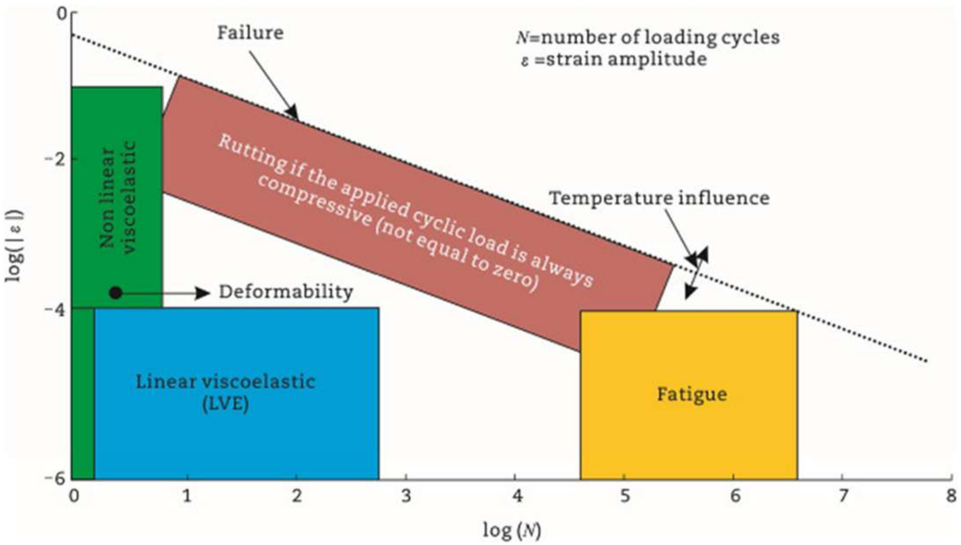
Avaliação dos ligantes asfálticos quanto ao enquadramento das especificações propostas pela Petrobras

Proposta Petrobras

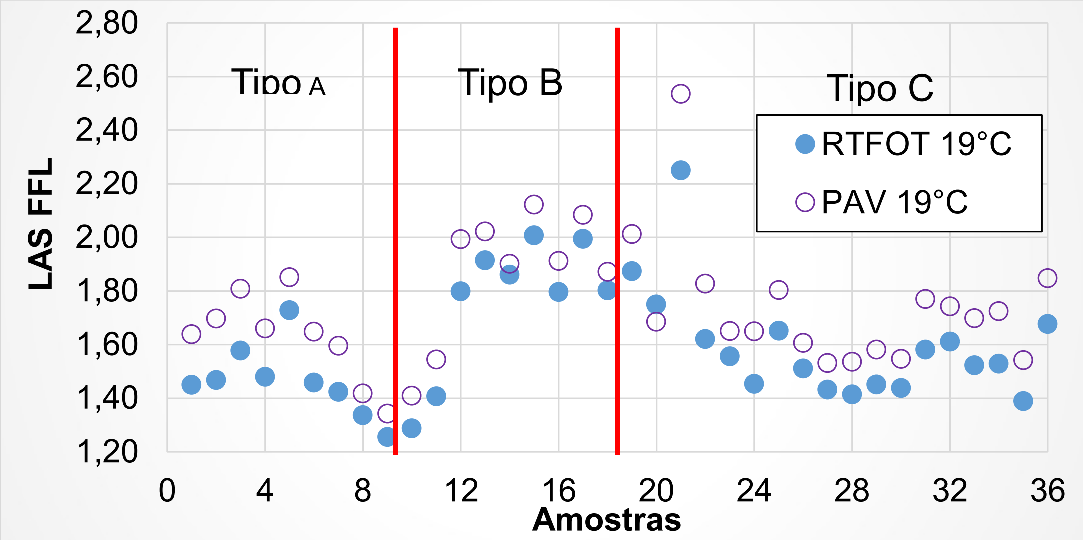
Característica	Unidade	Limites			
		CAP 5	CAP 10	CAP 25	CAP 40
		Ligante virgem			
$\|G^*\|/\text{sen}(\delta)$ a 64ºC e 1,59 Hz	kPa	$0,5 \leq \|G^*\|/\text{sen}(\delta) < 1,0$	$1,0 \leq \|G^*\|/\text{sen}(\delta) < 2,5$	$2,5 \leq \|G^*\|/\text{sen}(\delta) < 4,0$	$4,0 \leq \|G^*\|/\text{sen}(\delta) < 6,0$
Viscosidade rotacional a 135ºC, SP21, 20 RPM	cP	≤ 3000			
Viscosidade rotacional a 150ºC, SP21, 50 RPM	cP	≤ 2000			
Viscosidade rotacional a 177ºC, SP21, 100 RPM	cP	≤ 1000			
Ponto de fulgor	ºC	≥ 235			
Solubilidade em tricloroetileno	% massa	≥ 99,5 (apenas para ligantes não modificados)			
Ensaio de separação de fases	$R_{topo/fundo}$ [A]	$0,7 \leq R_{topo/fundo} \leq 1,4$ (apenas para ligantes modificados)			
		Ligante após RTFOT			
MSCR - J_{nr3200} a 64ºC	1/kPa	≤ 9,25	≤ 4,80	≤ 2,50	≤ 1,25
MSCR - $\%\gamma_{rec}$ a 64ºC	%	Se $\%\gamma_{rec}$ a 64ºC ≥ 29,371 x $[J_{nr3200}$ a 64ºC$]^{-0,2633}$ - E Se $\%\gamma_{rec}$ a 64ºC < 29,371 x $[J_{nr3200}$ a 64ºC$]^{-0,2633}$ - M (apenas para ligantes modificados)			
LAS – FFL_{PSE} a 19°C	log número de ciclos	≥ 1,31[B]	≥ 1,22		
LAS – $\|G^*\|_{ini}$ [C] a 19°C	MPa	≤ 25,00	≤ 40,00	≤ 55,00	≤ 75,00
Variação de massa	% massa	≤ 1,00			
		Classificação / denominação por desempenho			
Ligantes convencionais (não modificados)		CAP 5-D-F	CAP 10-D-F	CAP 25-D-F	CAP 40-D-F
Ligantes modificados		CAP 5-D-F-M	CAP 10-D-F-M	CAP 25-D-F-M	CAP 40-D-F-M
		Sendo: D = Classe de deformação permanente (tabela IX) F = Classe de fadiga (tabela VIII) M = Designação utilizada quando o ligante tiver qualquer tipo de modificação: E ou M conforme $\%\gamma_{rec}$ a 64ºC			

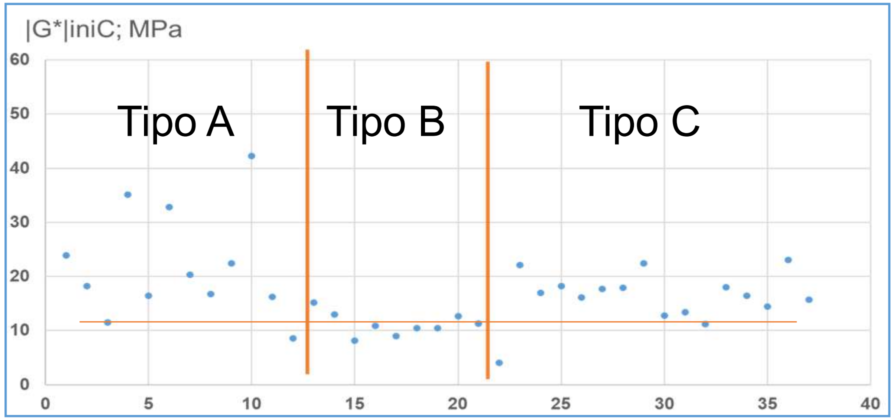
Vantagens do Ensaio LAS

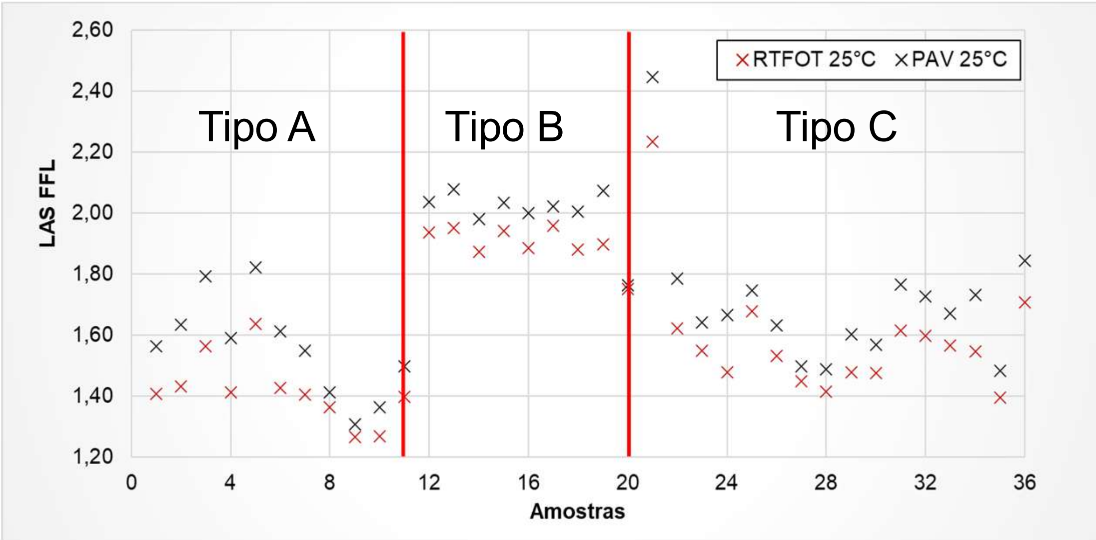
- Ser realizado fora da zona LVE, onde ocorre o dano;
- Correlação com ensaios de misturas asfálticas segundo experiencia brasileira ;
- Ensaio simples e rápido
- NCHRP - R e GRP (2022) são parâmetros LVE, sendo que R se correlaciona com LAS – FFL (PSE);



LAS / RTFOT & PAV







LAS, MSCR e R%

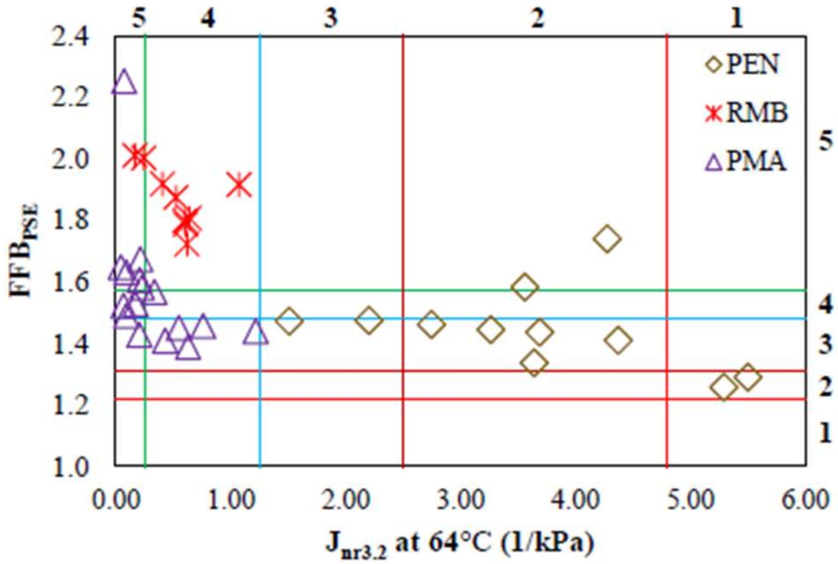
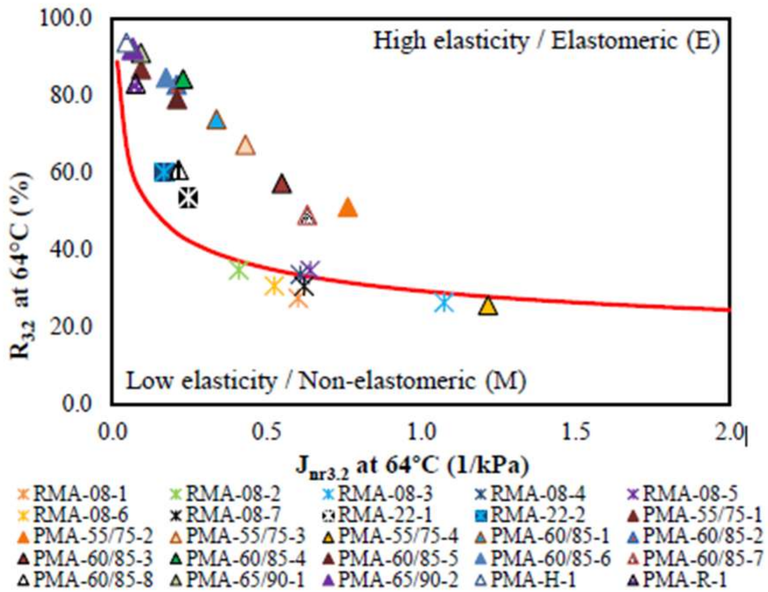


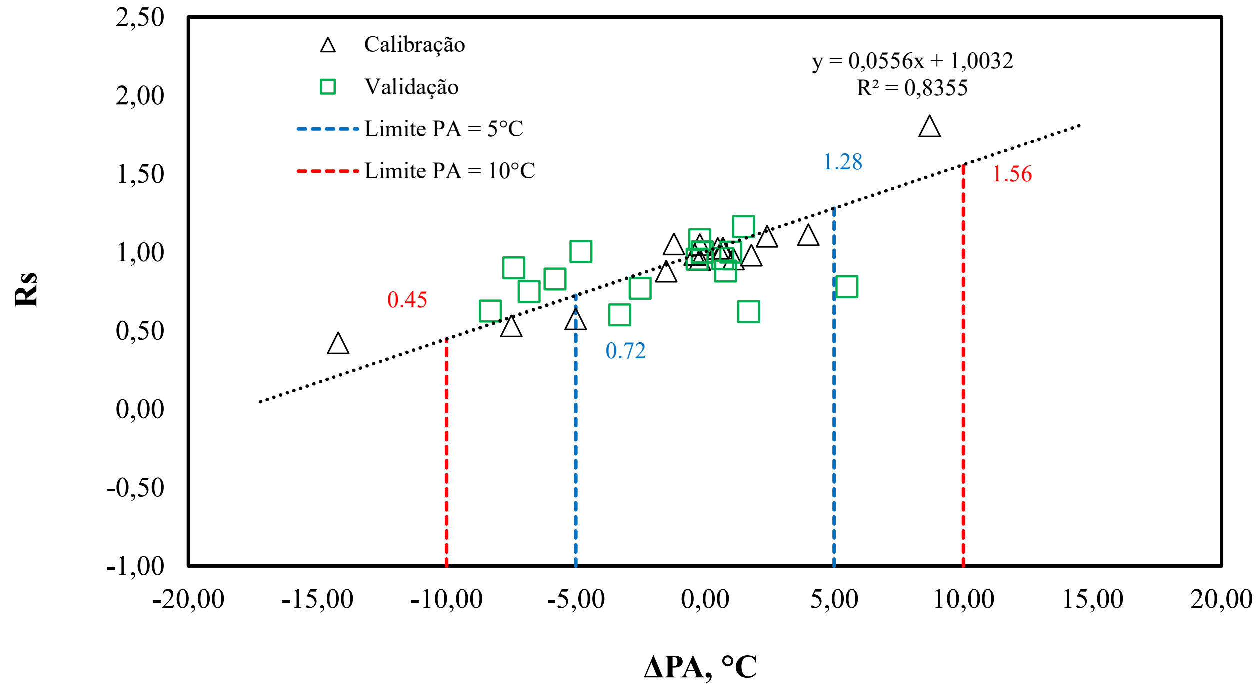
Figure 4.10 - Performance classification of asphalt binders based on Petrobras 2022 specification proposal for FFB_{PSE} at 19°C and $J_{nr3.2}$ at 64°C



Estabilidade a estocagem

- Rs para asfaltos polímeros seriam de 0,72 e 1,28
- Literatura (0,80-1,20)
- Proposta Petrobras de 0,7 a 1,4.

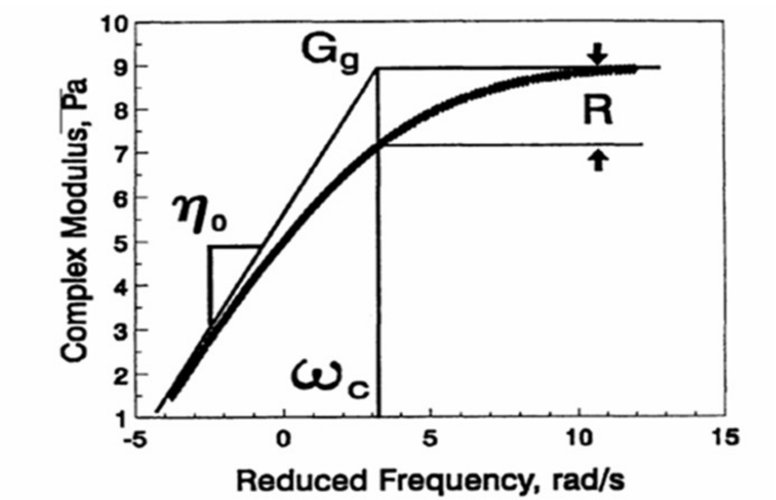
Asfalto borracha entre 0,4 e 1,6

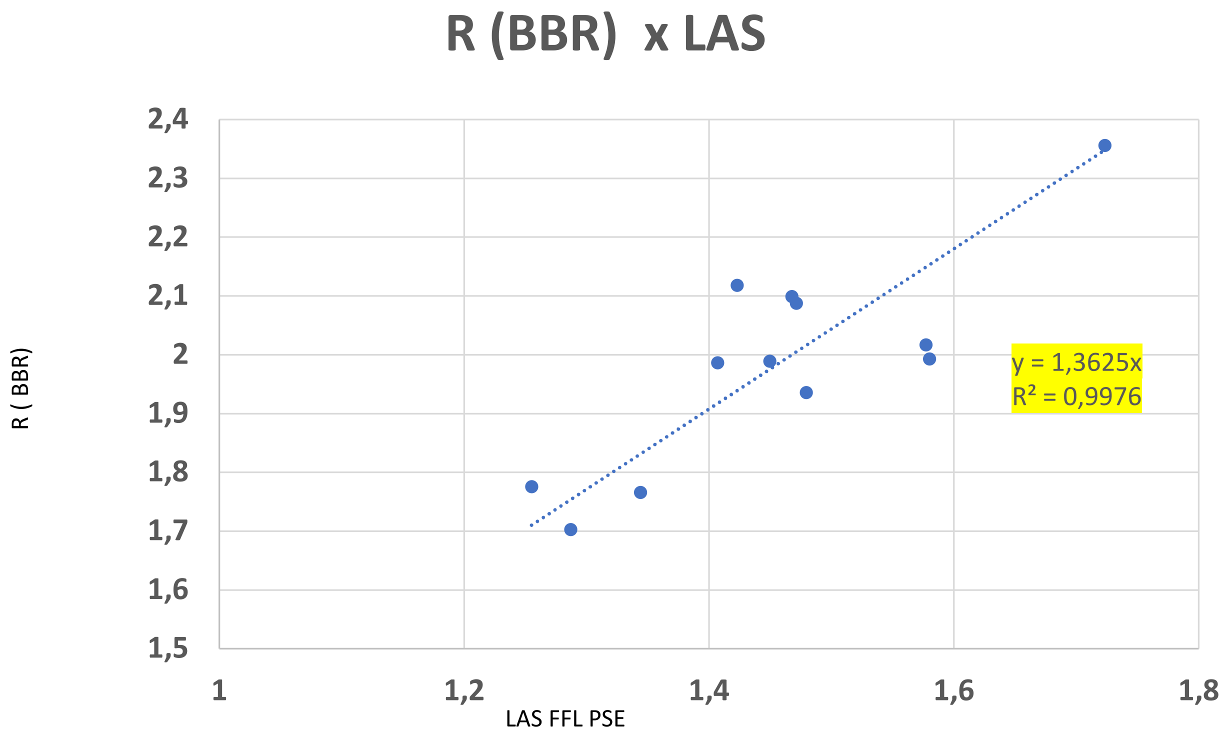


$$R_S = \frac{(|G^*|/s\,en\delta)_t}{(|G^*|/s\,en\delta)_b}$$

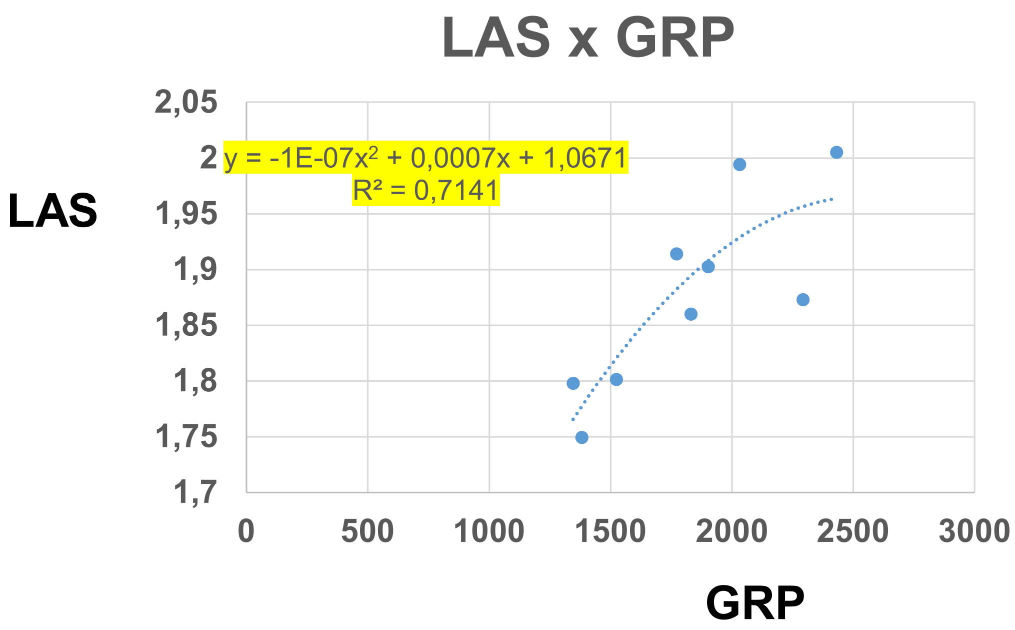
64ºC

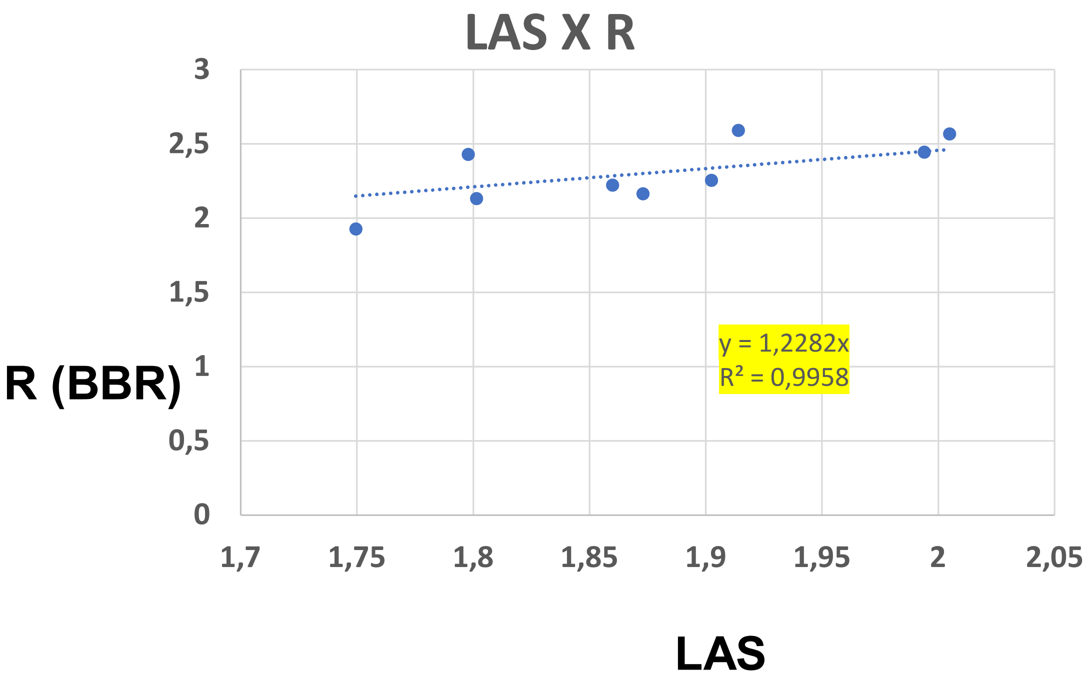
Correlações de índices de trincamento de CAP – LAS



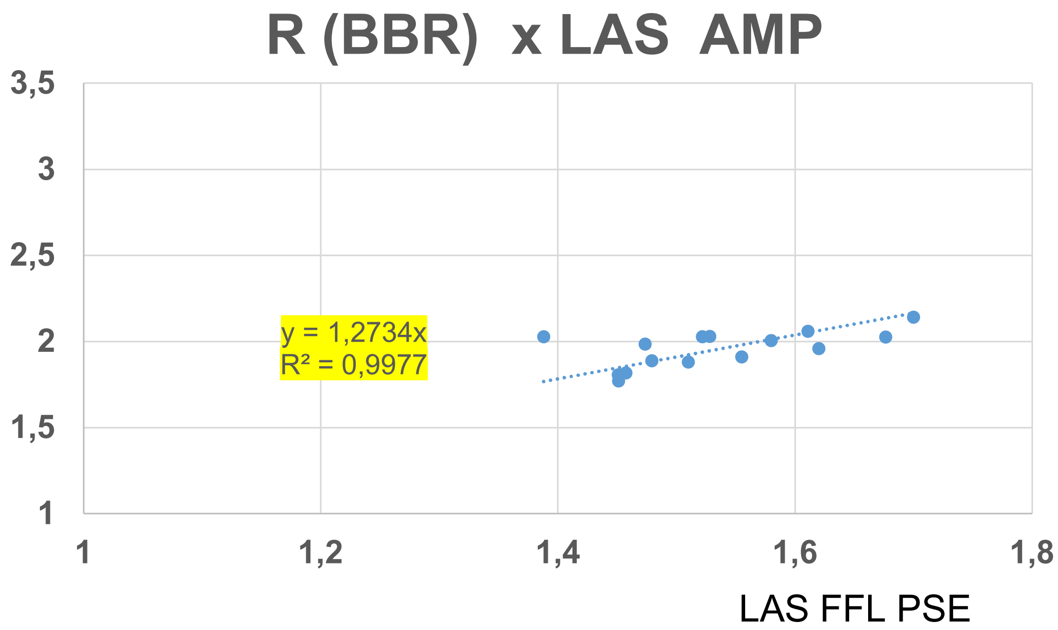


Correlações de índices de trincamento de AB – LAS





Correlações de índices de trincamento de AMP – LAS



Sem o AMP russo, apenas amostras ABEDA

Classificação proposta Petrobras

		DEF PERM	FADIGA
A1	50/70	1	3
A2	50/70	2	3
A3	50/70	2	5
A4	30/45	3	3
A5	50/70	2	5
A6	30/45	3	3
A7	50/70	2	3
A8	50/70	2	3
A9	50/70	2	2
A10	30/45	3	2
A11	50/70	1	3
A12	50/70	2	5

CAP
Nenhum com desempenho XX 4-4 nem XX 5-5, classe 3 para baixo

Classificação proposta Petrobras

		DEF PERM	FADIGA
B1	AB-8	4	5
B2	AB-8	4	5
B3	AB-8	4	5
B4	AB-22	5	5
B5	AB-8	4	5
B6	AB-22	5	5
B7	AB-8	4	5
B8	AB-8	4	5
B9	AB-8	4	5

AB
todos com desempenho entre XX 4-4 e XX 5-5

		DEF PERM	FADIGA
C1	76-28	5	5
C2	55/75	5	5
C3	60/85	4	4
C4	55/75	4	3
C5	HiMA	5	5
C6	65/90	5	4
C7	60/85	5	3
C8	55/75	4	3
C9	60/85	4	3
C10	55/75	4	3
C11	60/85	5	5
C12	60/85	5	5
C13	65/90	5	4
C14	60/85	5	4
C15	60/85	4	3
C16	60/85	5	5

AMP
A maioria com desempenho entre XX 4-4 e XX 5-5, apenas 6 amostras com 3 na resistência a fadiga

Conclusões - Proposta Petrobras

- Há diferenciação de asfaltos modificados e não modificados por meio do FFL-PSE
- Não tem parâmetro de envelhecimento;
- Diferencia asfalto elastomérico por meio da recuperação elástica;
- Inclui estabilidade à estocagem;
- Segundo a especificação, CAP podem ser classe 1, ou 2, ou 3, enquanto AB podem ser classe 4, ou 5 e AMP podem ser classe 3, ou 4 ou 5;
- Também foi verificado que determinados AMP tem desempenho semelhante ao CAP quanto a fadiga.

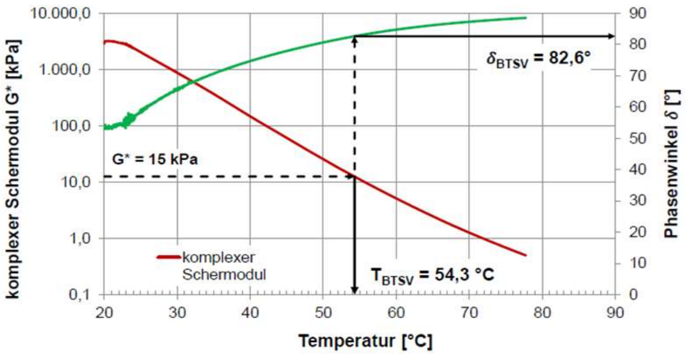
Avaliação dos ligantes asfálticos quanto aos índices reológicos

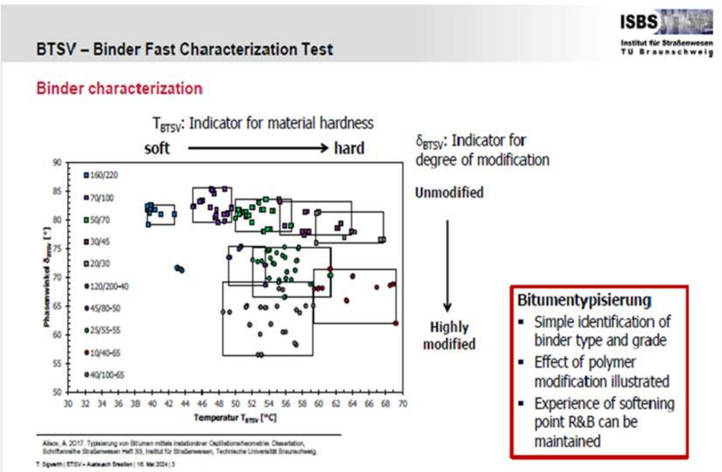
Alemanha

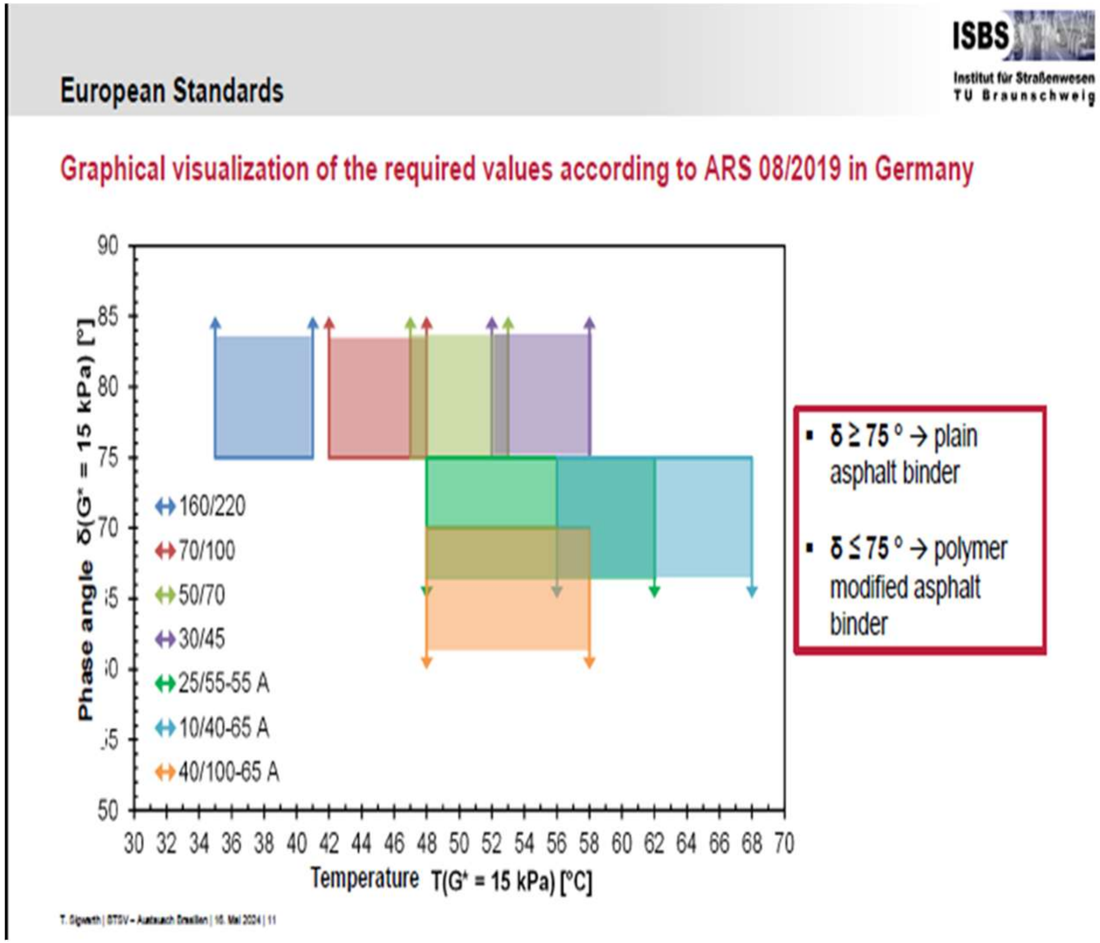
Test parameters

Binder-Fast-Characterization-Test (BTSV)

- Test geometry: 25 mm parallel-plate with a gap of 1 mm
- Test temperature: Starting temperature 20 °C, temperature rate 1.2 K/min
- Frequency: 1.59 Hz
- Shear stress: 500 Pa (oscillation)
- Characteristic values: Temperature T(BTSV) at G* = 15 kPa and associated phase angle δ(BTSV)
- Test time including pre-tempering: 1.5 h







Reologia nas especificações como Ensaios Plus com limites

Requirements of the regulations

ISBS Institut für Straßenwesen TU Braunschweig

Entwurf der TL Bitumen-StB, vom 15.09.2023

→ **Plain binder**

Tabelle 1a: Zusätzliche Anforderungen an die rheologischen Eigenschaften von Straßenbaubitumen

Merkmal oder Eigenschaft	Einheit	Prüfmethode	Sorten 20/30	30/45	50/70	70/100	160/220	250/330	
Äqui-Schermodultemperatur T(G*=15 kPa) bei 1,59 Hz	°C	TP Bitumen-StB Teil 3	55 bis 63	52 bis 60	46 bis 54	43 bis 51	35 bis 43	30 bis 38	Fresh binder
Phasenwinkel δ(G*=15 kPa) bei 1,59 Hz	°		≥ 75	≥ 75	≥ 75	≥ 75	≥ 75	≥ 75	
Beständigkeit gegen Verhärtung unter Einfluss von Wärme und Luft nach DIN EN 12607-1 bei 163 °C									
Zunahme der Äqui-Schermodultemperatur T(G*=15 kPa)	°C	TP Bitumen-StB Teil 3	≤ 8	≤ 8	≤ 9	≤ 9	≤ 11	≤ 11	Short-term aged binder
Abfall des Phasenwinkels δ(G*=15 kPa)	°		≤ 6	≤ 6	≤ 6	≤ 6	≤ 6	≤ 6	
Beständigkeit gegen Verhärtung unter Einfluss von Wärme und Luft nach DIN EN 12607-1 bei 163 °C und beschleunigter Langzeit-Alterung nach DIN EN 14769 bei 100 °C									
Zunahme der Äqui-Schermodultemperatur T(G*=15 kPa)	°C	TP Bitumen-StB Teil 3	≤ 18	≤ 18	≤ 18	≤ 18	≤ 18	≤ 18	long-term aged binder
Abfall des Phasenwinkels δ(G*=15 kPa)	°		≤ 12	≤ 12	≤ 12	≤ 12	≤ 12	≤ 12	
Verhalten bei tiefen Temperaturen im Biegebalkenrheometer T(S=300 MPa)	°C	TP Bitumen-StB Teil 4	≤ -3	≤ -6	≤ -9	≤ -12	≤ -15	≤ -18	
m(S=300 MPa)	-		IA	IA	IA	IA	IA	IA	

IA = Ist anzugeben. Für die Eigenschaft ist vom Hersteller ein Wertebereich zu deklarieren.

ENTWURF

Forschungsgesellschaft für Straßen- und Verkehrswesen
Arbeitsgruppe Asphaltbauweisen

FGSV

TL Bitumen-StB 25

Technische Lieferbedingungen
für Straßenbaubitumen
und gebrauchsfertige
Polymermodifizierte Bitumen

Ausgabe 2025

R1

Temperatura e ângulo de fase equivalentes a 15Pa, medidos no ligante virgem, após RTFOT a após RTFO+ PAV

Requirements of the regulations

ISBS Institut für Straßenwesen TU Braunschweig

Entwurf der TL Bitumen-StB, vom 15.09.2023

→ **Polymer modifed binder**

Tabelle 2a: Zusätzliche Anforderungen an die rheologischen Eigenschaften von Elastomermodifizierten Bitumen (PmB A)

Merkmal oder Eigenschaft	Einheit	Prüfmethode	Sorten 10/40-65 A	25/55-55 A	45/80-50 A	45/80-65 A	65/105-70 A	120/200-40 A	
Äqui-Schermodultemperatur T(G*=15 kPa) bei 1,59 Hz	°C	TP Bitumen-StB Teil 3	56 bis 68	48 bis 62	44 bis 56	48 bis 58	43 bis 53	36 bis 48	Fresh binder
Phasenwinkel δ(G*=15 kPa) bei 1,59 Hz	°		≤ 75	≤ 75	≤ 75	≤ 70	≤ 70	≤ 75	
Beständigkeit gegen Verhärtung unter Einfluss von Wärme und Luft nach DIN EN 12607-1 bei 163 °C									
Zunahme der Äqui-Schermodultemperatur T(G*=15 kPa)	°C	TP Bitumen-StB Teil 3	≤ 8	≤ 8	≤ 8	≤ 8	≤ 8	≤ 8	Short-term aged binder
Abfall des Phasenwinkels δ(G*=15 kPa)	°		≤ 6	≤ 6	≤ 6	≤ 6	≤ 6	≤ 6	
Beständigkeit gegen Verhärtung unter Einfluss von Wärme und Luft nach DIN EN 12607-1 bei 163 °C und beschleunigter Langzeit-Alterung nach DIN EN 14769 bei 100 °C									
Zunahme der Äqui-Schermodultemperatur T(G*=15 kPa)	°C	TP Bitumen-StB Teil 3	≤ 18	≤ 18	≤ 18	≤ 18	≤ 18	≤ 18	long-term aged binder
Abfall des Phasenwinkels δ(G*=15 kPa)	°		≤ 12	≤ 12	≤ 12	≤ 12	≤ 12	≤ 12	
Verhalten bei tiefen Temperaturen im Biegebalkenrheometer T(S=300 MPa)	°C	TP Bitumen-StB Teil 4	≤ -9	≤ -12	≤ -15	≤ -15	≤ -18	≤ -18	
m(S=300 MPa)	-		IA	IA	IA	IA	IA	IA	

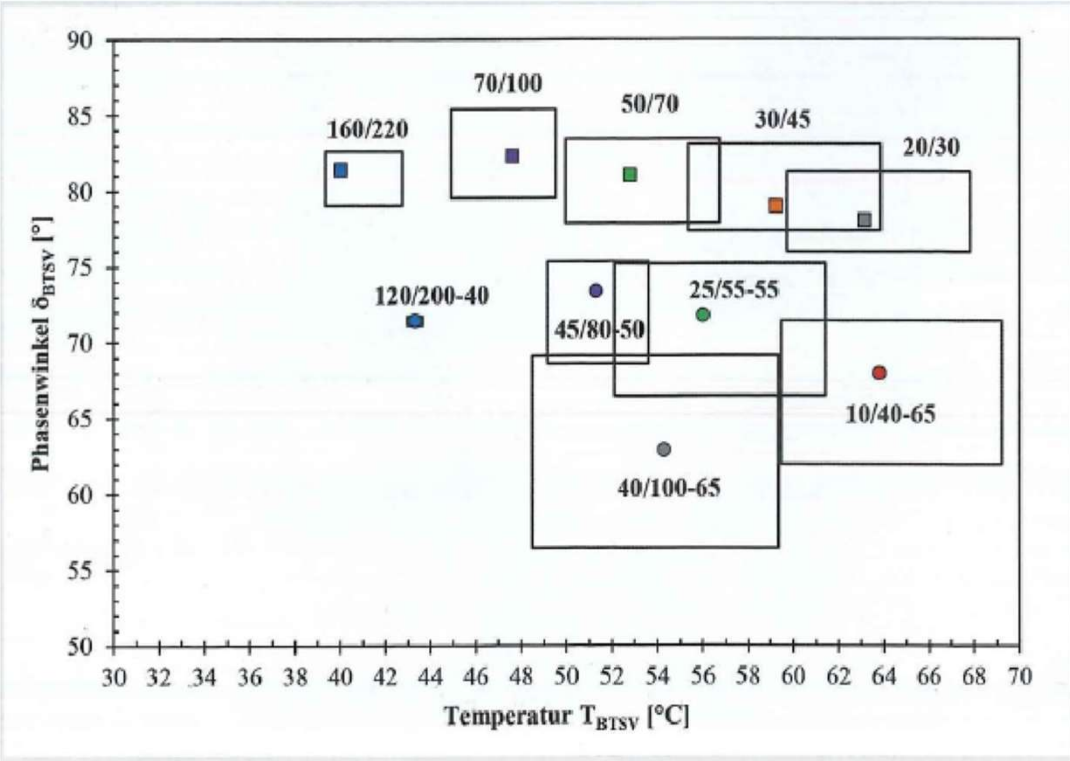
IA = Ist anzugeben. Für die Eigenschaft ist vom Hersteller ein Wertebereich zu deklarieren.

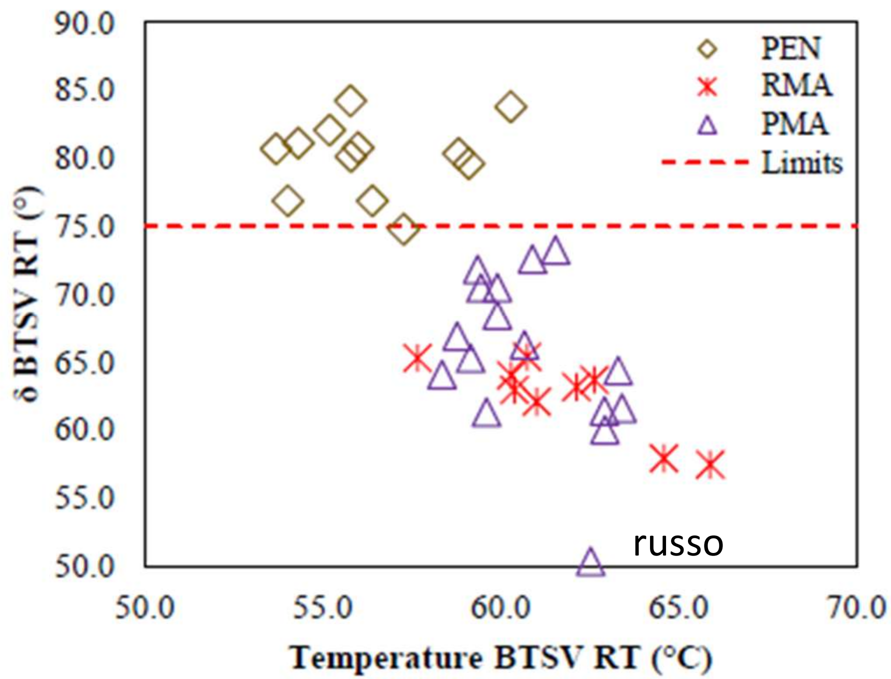
ENTWURF

BTSV

Os 37 ligantes do projeto DNIT

➢ Parâmetro de alta temperatura intermediária – especificado na Alemanha

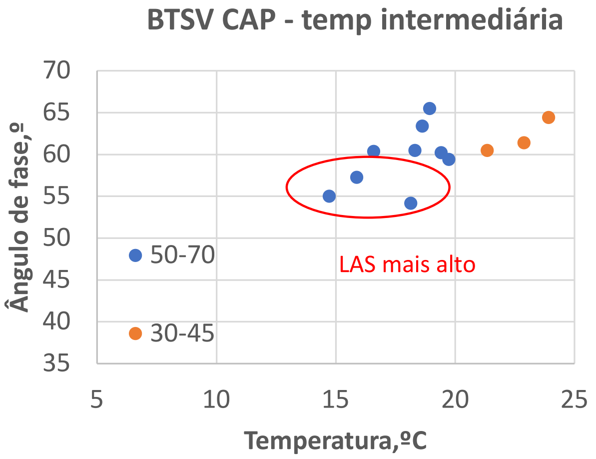


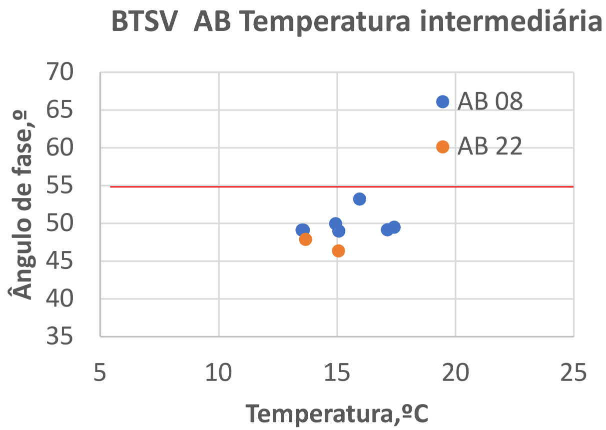


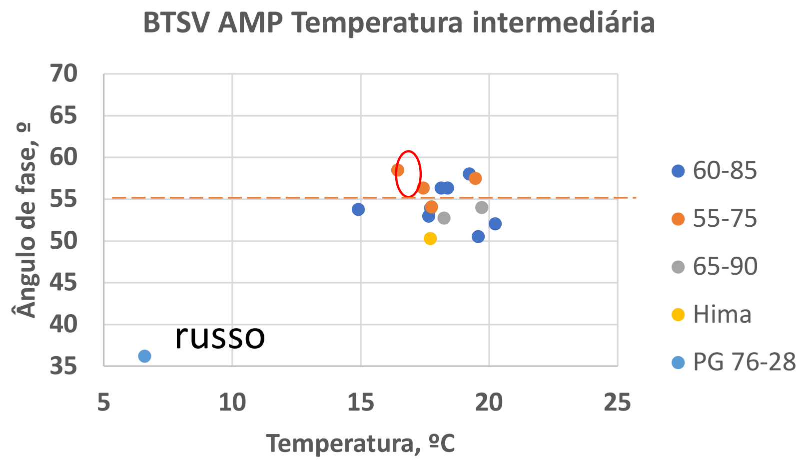
COPPE UFRJ
Instituto Alberto Luiz Coimbra de Pós-Graduação e Pesquisa de Engenharia

➢Parâmetro de temperatura intermediária em estudo

Linha de boa resistência a fadiga em angulo de fase de 55º







Acima de 55º são os piores valores de LASFFL, menor que 1,5 para AMP 55-75 e alguns 60-85

Índices reológicos dos EUA - FADIGA

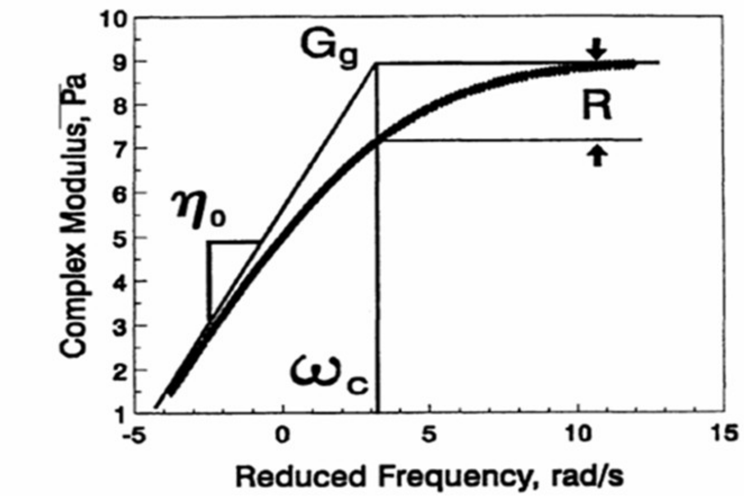
NCHRP 09-59 (2022) - R e GRP com limites

$$R = \log(2)\frac{\log\left(\frac{S}{3.000}\right)}{\log(1-m)}$$

Resultados do BBR

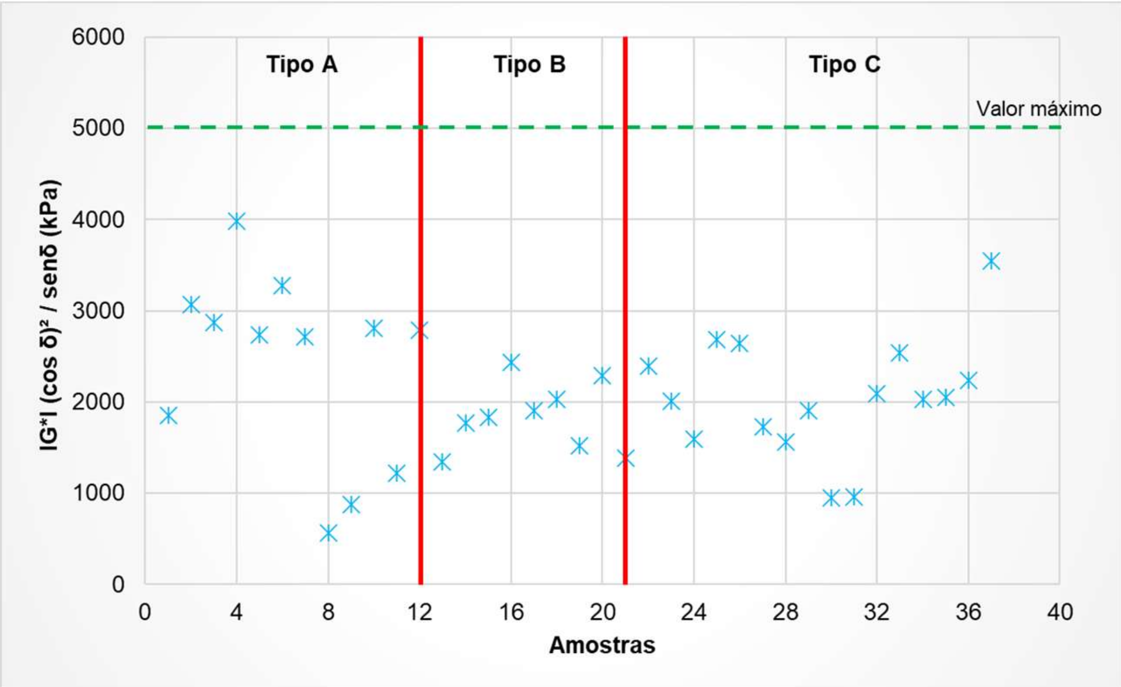
Limites de 1,5 a 2,5 (20h PAV)

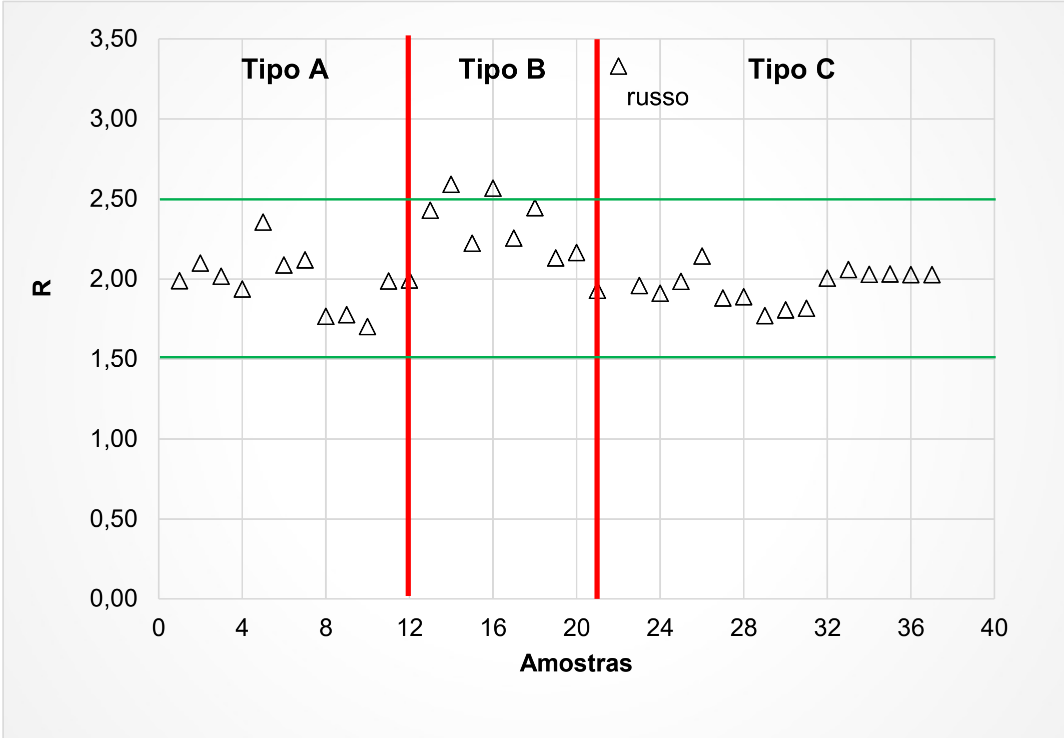
PG de baixa temperatura	temperaturas de ensaio propostas (ºC)
-46	15
-30	17
-34	19
-28	22
-22	25
-16	27
-10	29



O requisito |G*| senδ deve ser substituído pelo parâmetro Glover-Rowe (GRP = |G*| cos2 δ/sen δ), devendo ser determinado na frequência de 10 rad/s. O valor máximo para GRP após envelhecimento no RTFOT seguido do PAV 20 horas deve ser 5.000 kPa.

GRP e R (NCHRP 9-59) - 2022





Delta Tc – índice de trincamento

$$T_{c,S} = T_1 + \left(\frac{(T_1 - T_2) * (\text{Log } 300 - \text{Log } S_1)}{\text{Log } S_1 - \text{Log } S_2}\right) - 10$$

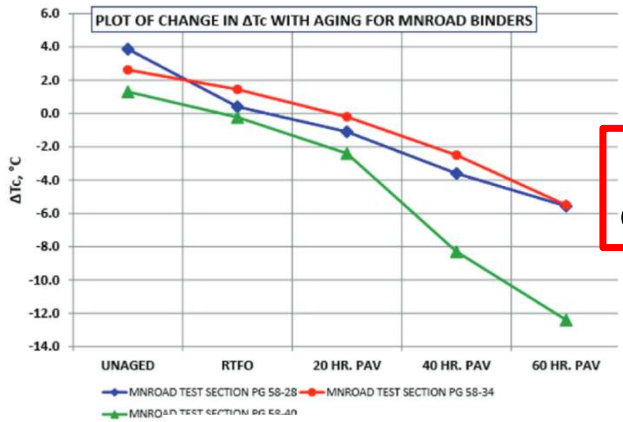
$$T_{c,m} = T_1 + \left(\frac{(T_1 - T_2) * (0.300 - m_1)}{m_1 - m_2}\right) - 10$$

where,

S_1 = creep stiffness at T_1, MPa,
S_2 = creep stiffness at T_2, MPa,
m_1 = creep rate at T_1,
m_2 = creep rate at T_2,
T_1 = temperature at which S and m passes, °C
T_2 = temperature at which S and m fails, °C.

Therefore, the equation for ΔT_C becomes:

$\Delta T_C = T_{C,S} - T_{C,m}$.



Delta Tc ≥ -5 ou -2,5
dependente do tempo de PAV

➤Unmodified, Polymer-modified, ReOB-modified, SDA, PPA-modified, Biophalt, Oxidized, Airblown, Visbroken.

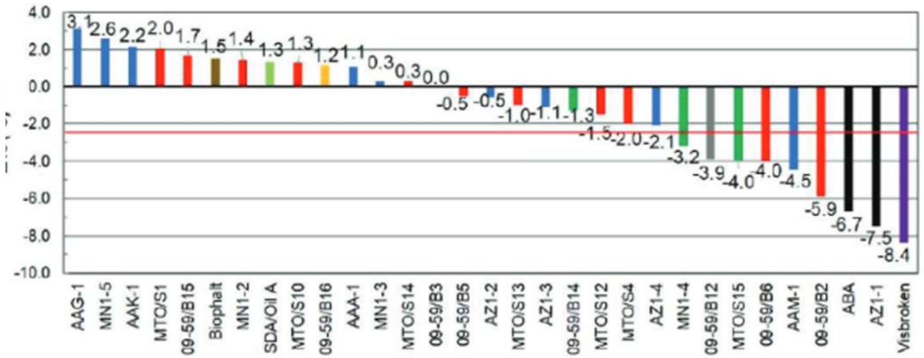
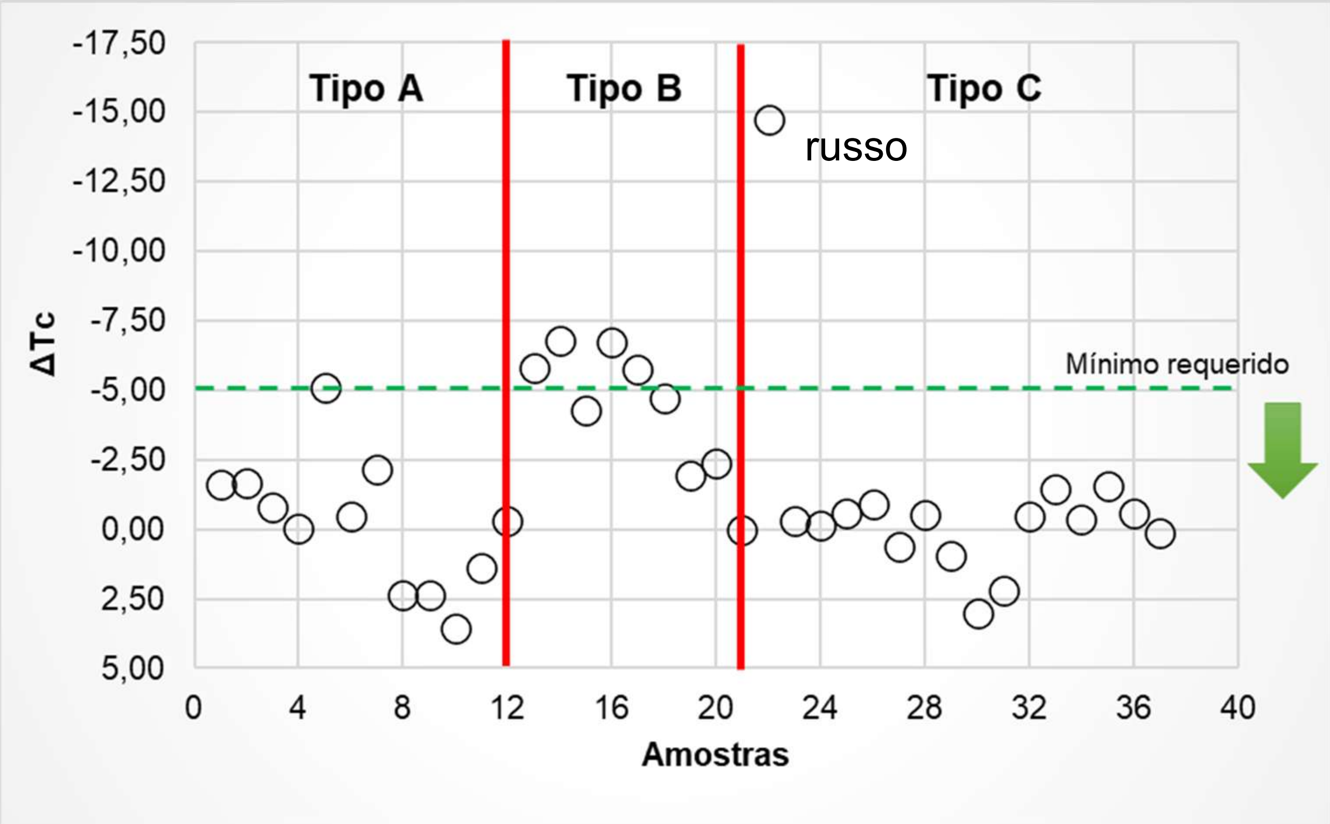


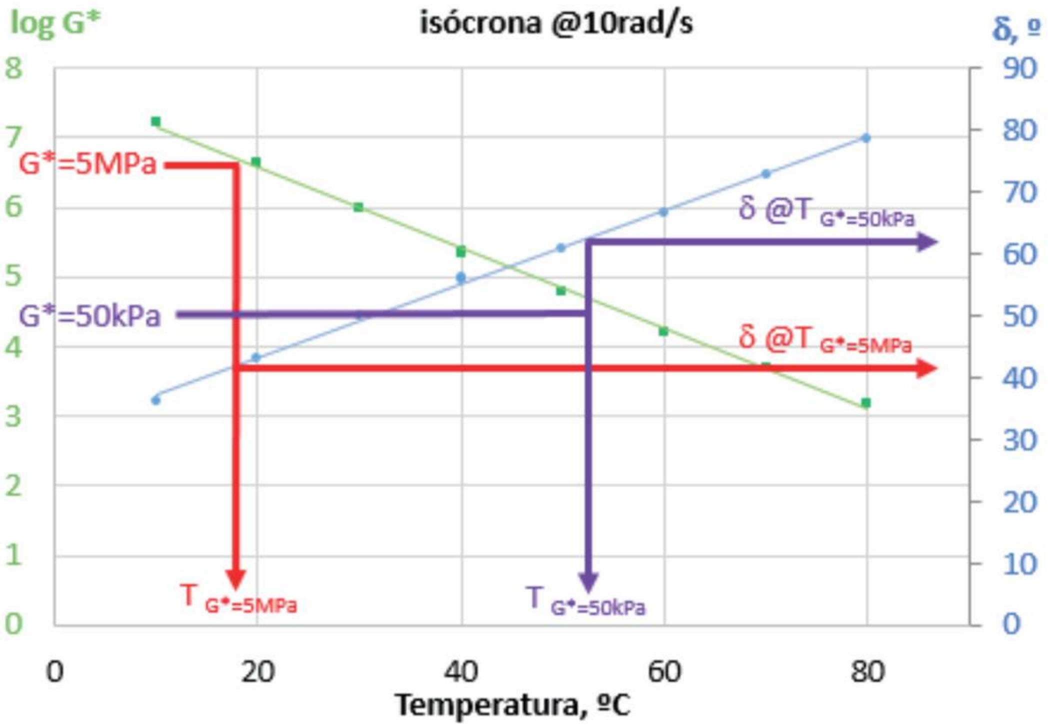
Figure 11. ΔT_c (PAV20) of Various Binders from NCHRP 9-60 Research Project Database (4)

Delta Tc



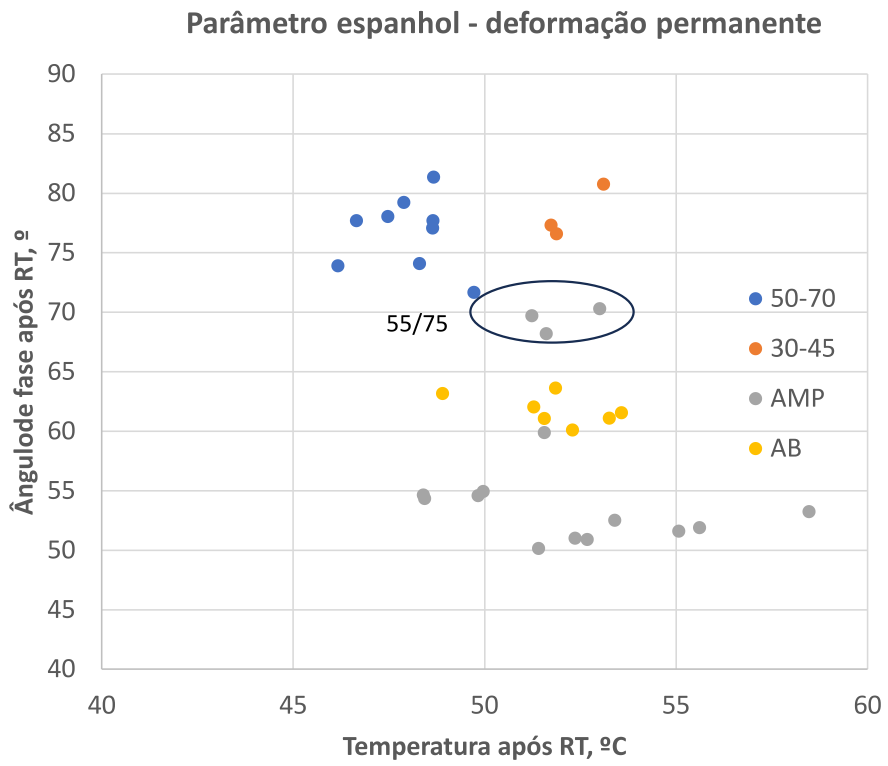
Tipo A
Tipo B
Tipo C
russo
Mínimo requerido
ΔTc
Amostras
-17,50
-15,00
-12,50
-10,00
-7,50
-5,00
-2,50
0,00
2,50
5,00
0
4
8
12
16
20
24
28
32
36
40

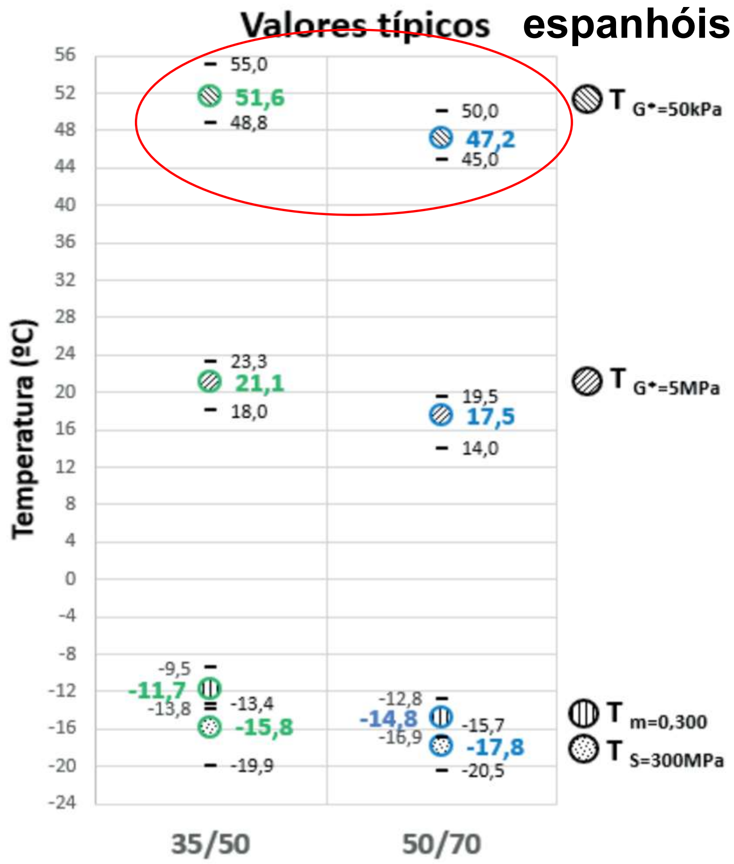
Parâmetros espanhóis – fadiga e deformação permanente



El ensayo DSR descrito en la norma EN 14770, se basa en aplicar un esfuerzo cortante constante oscilatorio a una muestra de ligante colocada entre dos platos metálicos paralelos. El ensayo se realiza a temperaturas de 10ºC a 80ºC) a frecuencias entre 0,1 Hz y 10 Hz. **Las temperaturas a las cuales G*= 5 MPa y G*= 50 kPa se obtienen mediante interpolación logarítmica en la isócrona a una frecuencia de 1,59** Hz, de G* vs T. Los ángulos de fase correspondientes se obtienen por interpolación lineal de las temperaturas obtenidas en la curva de d vs. T a dicha frecuencia.

Parâmetros espanhóis CAP deformação permanente





G* a 15ºC a 10Hz

Propiedad	Unidad	Método de ensayo	Dato
TS= 300 MPa, medida por el BBR(a)	ºC	EN 14771	TBR
Tm=0,3, medida por el BBR(a)	ºC	EN 14771	TBR
G* a 15 ºC y 10 Hz medido mediante DSR(b)	MPa	EN 14770	TBR
TG*/senδ = 1 kPa a 1,6 Hz medido mediante DSR(b)	ºC	EN 14770	TBR

a BBR = Reómetro de Flexión.
b DSR = Reómetro de corte dinámico (Dynamic Shear Rheometer) o cualquier otro reómetro capaz de medir un módulo complejo.

TABLE 9/8: (05/18) **Binder Characteristics to be Reported**

Characteristic	Test Method	Unit	Binder for EME2	FPC frequency		
				AS	STA	LTA
Brookfield Viscosity T 200cP	EN 13302	°C	TBR	A		
T 2000cP		°C	TBR		A	
T 5000cP		°C	TBR		A	
G* and Phase Angle	BS EN 14770	Pa, degrees	TBR	A	A	A
VET temperature, G'=G", at 0.4 Hz		°C	TBR	A	A	A
G* at the VET temperature		Pa	TBR	A	A	A
G' and G" Mastercurves 80°C to 0°C	Graphical Output	Graphical Output	TBR	A	A	A
G" and Phase Angle at 15°C, 10Hz and 20°C, 1Hz		Pa, degrees	TBR	A	A	A
$T_{S=300\ MPa}$, by BBR	BS EN 14771	°C	TBR	A	A	A
$T_{m=0.3}$, by BBR		°C	TBR	A	A	A
Pendulum Cohesion, min	BS EN 13588	J/cm²	TBR	A	A	A
Fraass breaking point, min	EN 12593	°C	TBR		A	

Notes:

AS = As Supplied; STA = After EN 12607-1 (RTFOT) * LTA = After PAV85 *

* An ageing profile determined in accordance with clause 955 is an acceptable alternative to STA and PAV85.

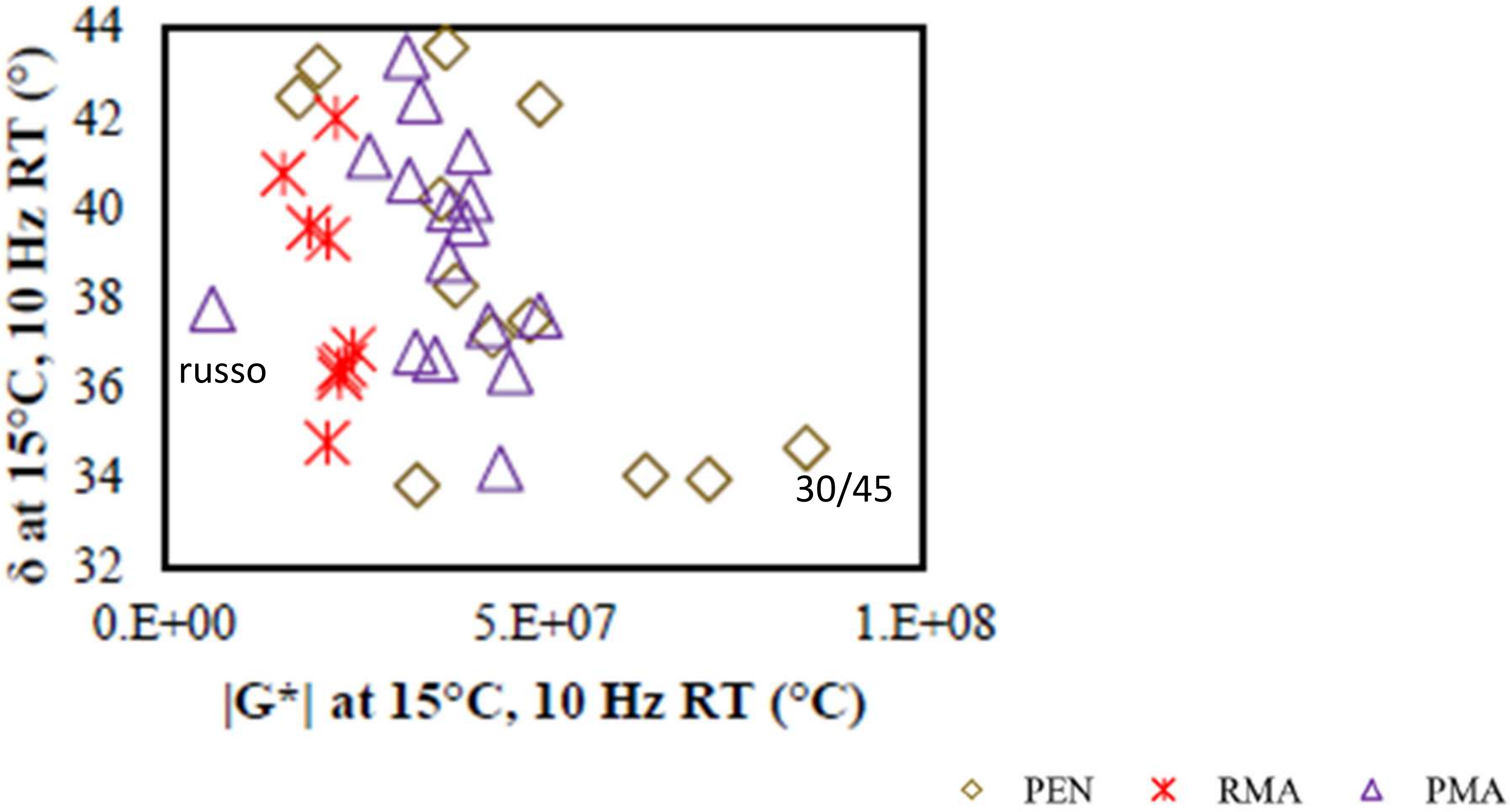
All tests to be carried out on sub-samples of a single bulk sample of binder.
Minimum test frequency : A = Annually.

(Indicated frequencies apply only if product is in regular supply.)

Proposta espanhola e inglesa BS

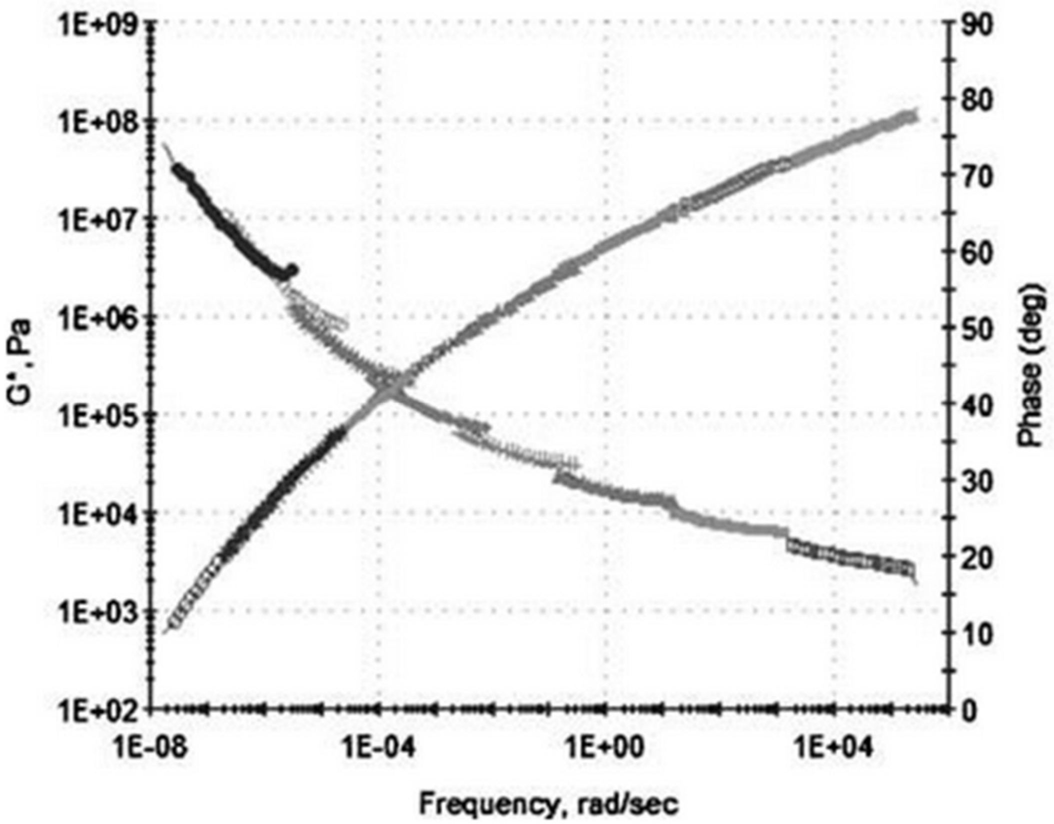
Binder for EME2				FPC frequency		
Characteristic	**Test method**	**Unit**		**AS**	**STA**	**LTA**
Brookfield viscosity T200cP	BS EN 13302	°C	TBR	A		
T2000cP		°C	TBR		A	
T5000cP		°C	TBR		A	
G* and phase angle	BS EN 14770 see Clause 956 Graphical output	Pa, degrees	TBR	A	A	A
VET temperature, G'=G'', at 0.4 Hz		°C	TBR	A	A	A
G* at the VET temperature		Pa	TBR	A	A	A
G' and G'' mastercurves 80°C to 0°C		Graphical output	TBR	A	A	A
G'' and phase angle at 15°C, 10Hz and 20°C, 1Hz		Pa, degree	TBR	A	A	A
Ts=300MPa by BBR	BS EN 14771	°C	TBR	A(Q)	A(Q)	A(Q)
Tm=0.3, by BBR		°C	TBR	A(Q)	A(Q)	A(Q)

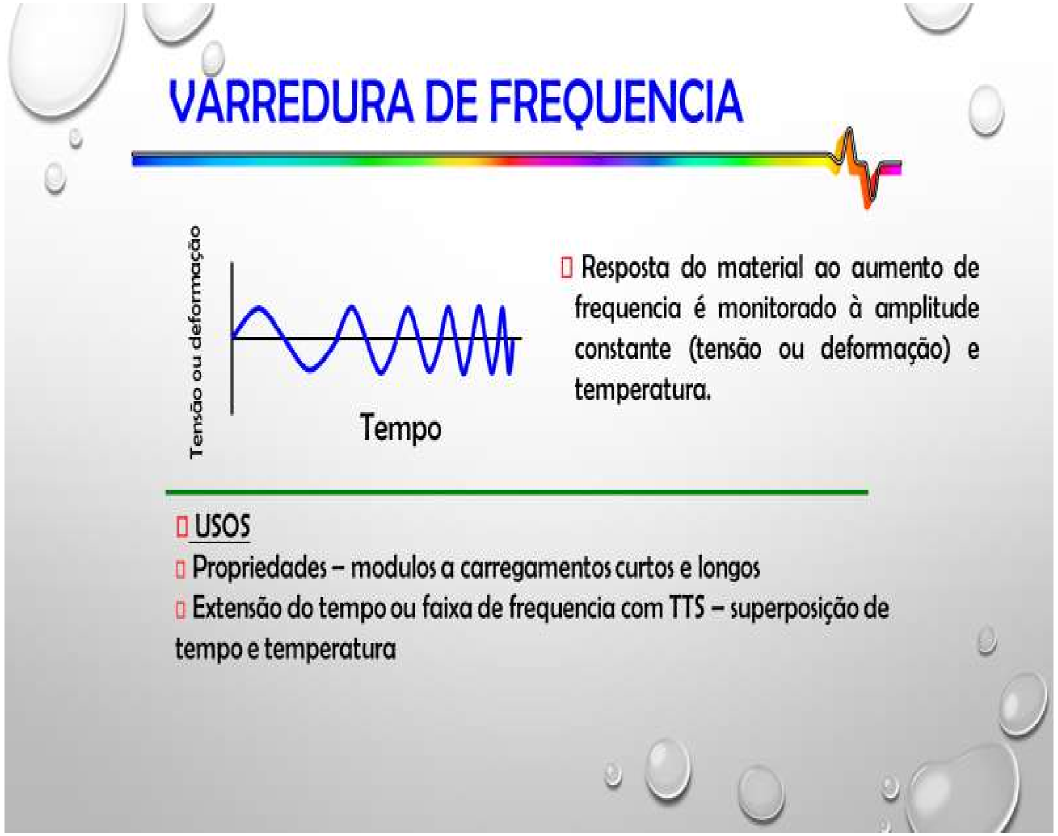
G* a 15°C


44
42
40
38
36
34
32
δ at 15°C, 10 Hz RT (°)
russo
30/45
0.E+00
5.E+07
1.E+08
|G*| at 15°C, 10 Hz RT (°C)
PEN
RMA
PMA

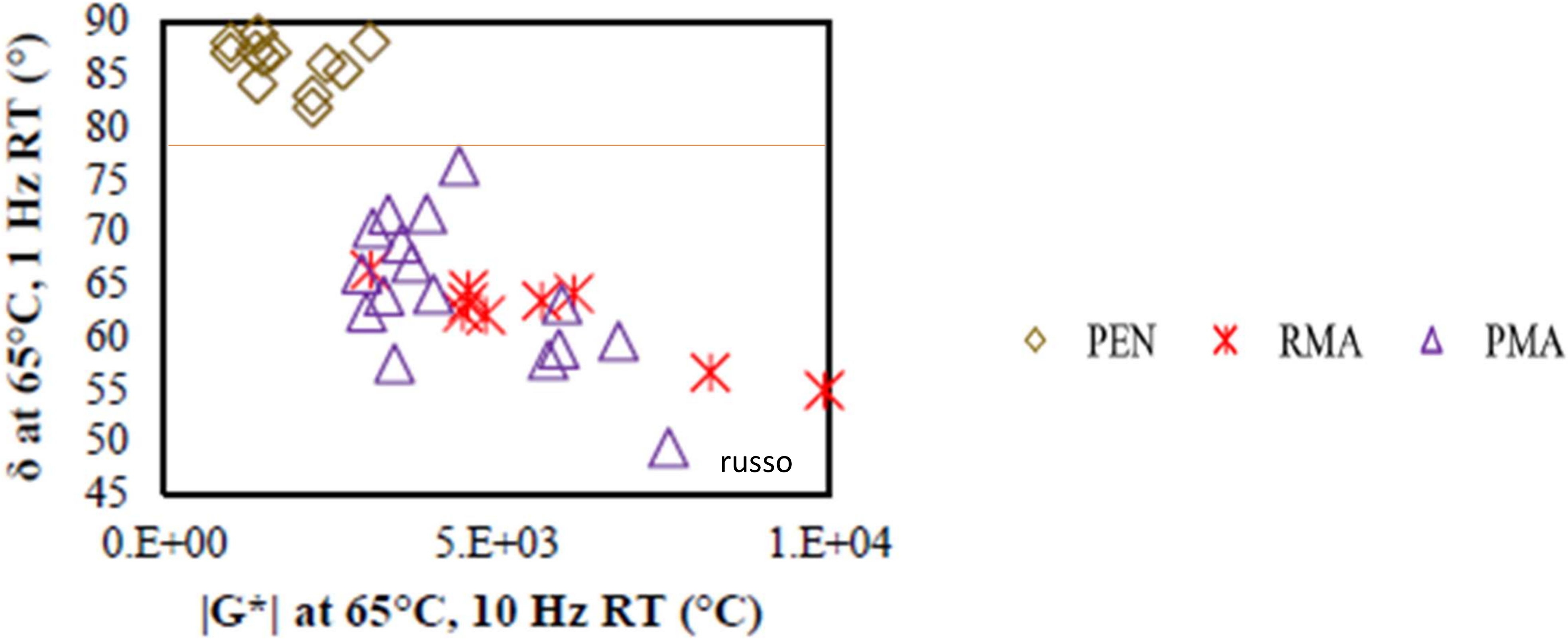
Curva mestre

Varredura de frequência





AF a 65°C, 1Hz após RT x G* a 65°C, 10 Hz após RT



Conclusões - Ensaios reológicos

Índices que distinguem ligantes modificados dos não modificados

- BTSV;
- AF a 65°C, 1 Hz após RT X G* a 65°C a 10 Hz após RT;
- Parâmetro espanhol AF e Temperatura após RT (50 KPa);
- Asfalto russo é sempre visto como outlier;
- G* a 15°C a 10 Hz;
- R, GRP e delta Tc não parecem ser interessantes de ser explorados

Outros ensaios para misturas quentes

Especificação australiana – parâmetro de resistência a deformação permanente
Asfalto modificado 2020

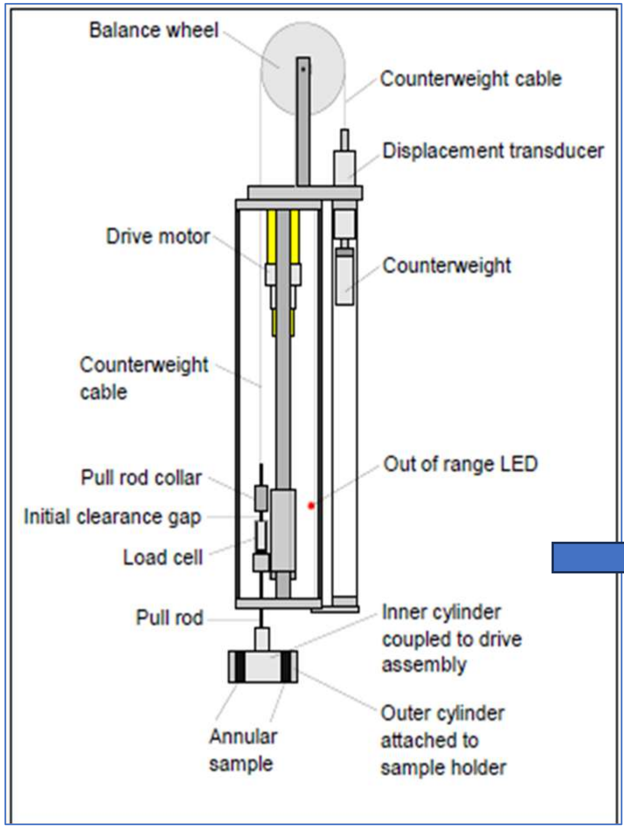
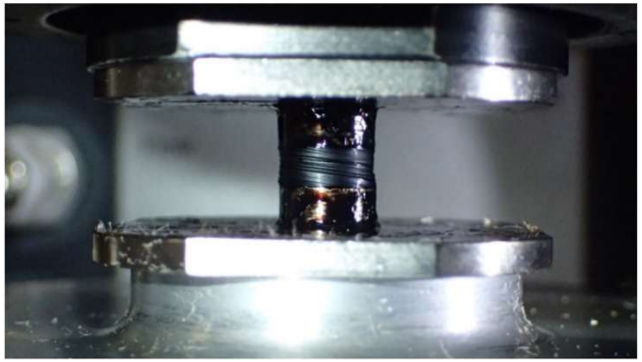


Table 8.2: Properties of Polymer Modified Binders for Asphalt Applications

Test method	Class / Binder property	A35P	A25E	A20E	A15E	A10E
AS/NZS 2341.4 or AGPT/T111(1)	Viscosity at 165 °C (Pa.s) max.(1)	0.6	0.6	0.6	0.9	1.1
AGPT/T122	Torsional recovery at 25 °C, 30 s (%)	6–21	17–30	38–70	55–80	60–86
AGPT/T131	Softening point (°C)	62–74	52–62	65–95	82–105	88–110
AGPT/T125	Stress ratio at 10 °C min.	TBR(2)	TBR	TBR	TBR	TBR
AGPT/T121	Consistency 6% at 60 °C (Pa.s) min.(3)	1000	400	500	900	1000
AGPT/T121	Stiffness at 25 °C (kPa) max.	120	45	35	30	30
AGPT/T108	Segregation (%) max.	8	8	8	8	8
AGPT/T112	Flash point (°C) min.	250	250	250	250	250
AGPT/T103	Loss on heating (% mass) max.	0.6	0.6	0.6	0.6	0.6

Razão de tensão= Tensão (10 def.)/Tensão (3 def.)

Figure 9.1: Distressed binder after testing



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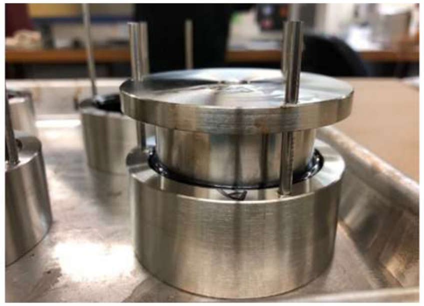
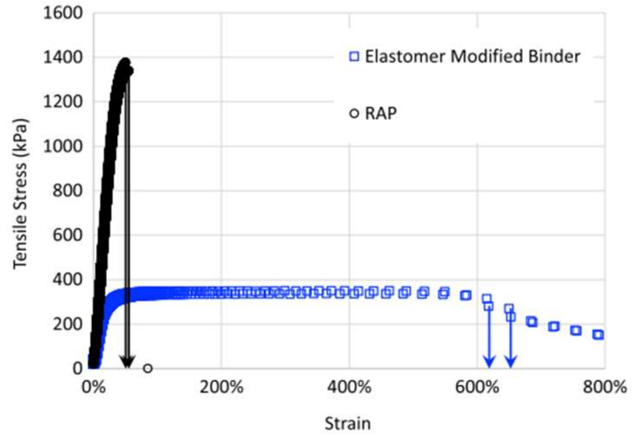
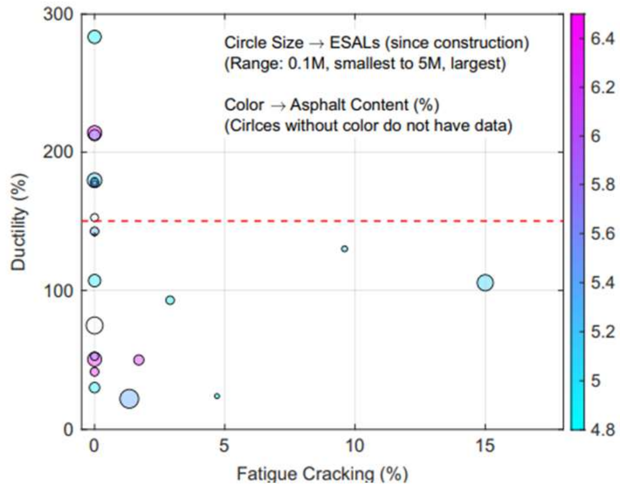
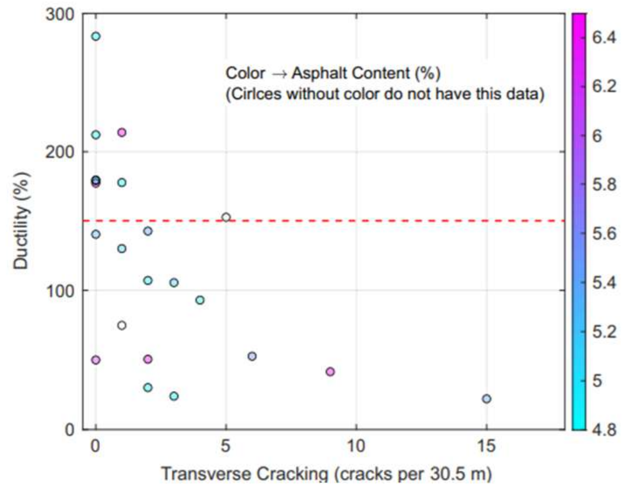
AGPT/T131	Softening point (°C)	62–74	52–62	65–95	82–105	88–110
AGPT/T125	Stress ratio at 10 °C min.	TBR[2]	TBR	TBR	TBR	TBR
AGPT/T121	Consistency 6% at 60 °C (Pa.s) min.[3]	1000	400	500	900	1000
AGPT/T121	Stiffness at 25 °C (kPa) max.	120	45	35	30	30
AGPT/T108	Segregation (%) max.	8	8	8	8	8
AGPT/T112	Flash point (°C) min.	250	250	250	250	250
AGPT/T103	Loss on heating (% mass) max.	0.6	0.6	0.6	0.6	0.6

Dutilidade Pocker chip – parâmetro de resistência a fadiga - TEXAS









DOT Texas - e DSR ao invés de BBR com placa 8mm

LOW TEMPERATURE DYNAMIC SHEAR RHEOMETER TESTING OF ASPHALT BINDER **TXDOT DESIGNATION: TEX-554-C**

Test Procedure for

LOW TEMPERATURE DYNAMIC SHEAR RHEOMETER TESTING OF ASPHALT BINDER

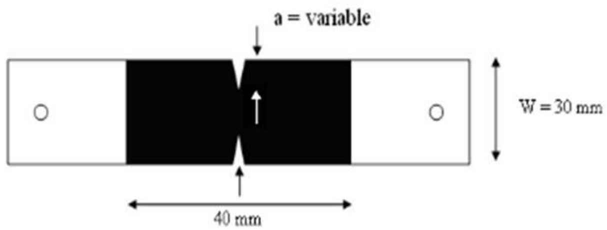
Texas Department of Transportation

TxDOT Designation: Tex-554-C

Effective Date: October 2024

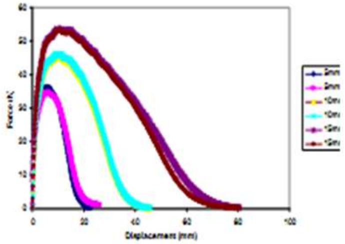
- Condicionar amostra a PG +10°C) for 2100 s;
- Testar amostra em placa 8mm com taxa de deformação de 1% na frequência angular de 10 c/s;
- Reportar a média G* e δ nos últimos 5 ciclos.

DENT – AASHTO 425-23 – parâmetro de fadiga



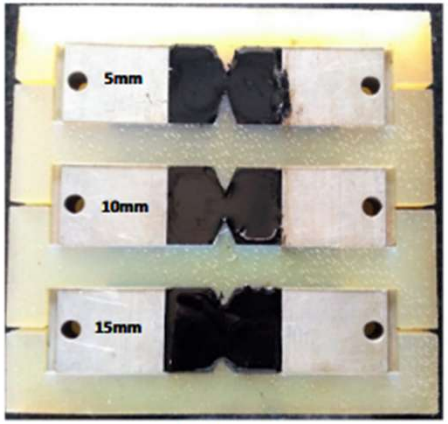
(a) Ligament definition

(b) Test samples and ductility instrument

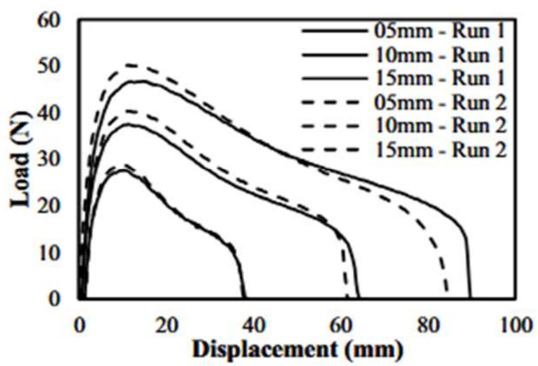


(c) Typical DENT test resu

Figure 10. FHWA DENT Test (*28*).



(a)



(b)

Fig. 2. (a) Silicon mold having 5 mm, 10 mm & 15 mm notch length (b) typical load displacement curve.

Parâmetros de desempenho para mistura a frio

Emulsões – PG (NCHRP) Inicialmente NCU

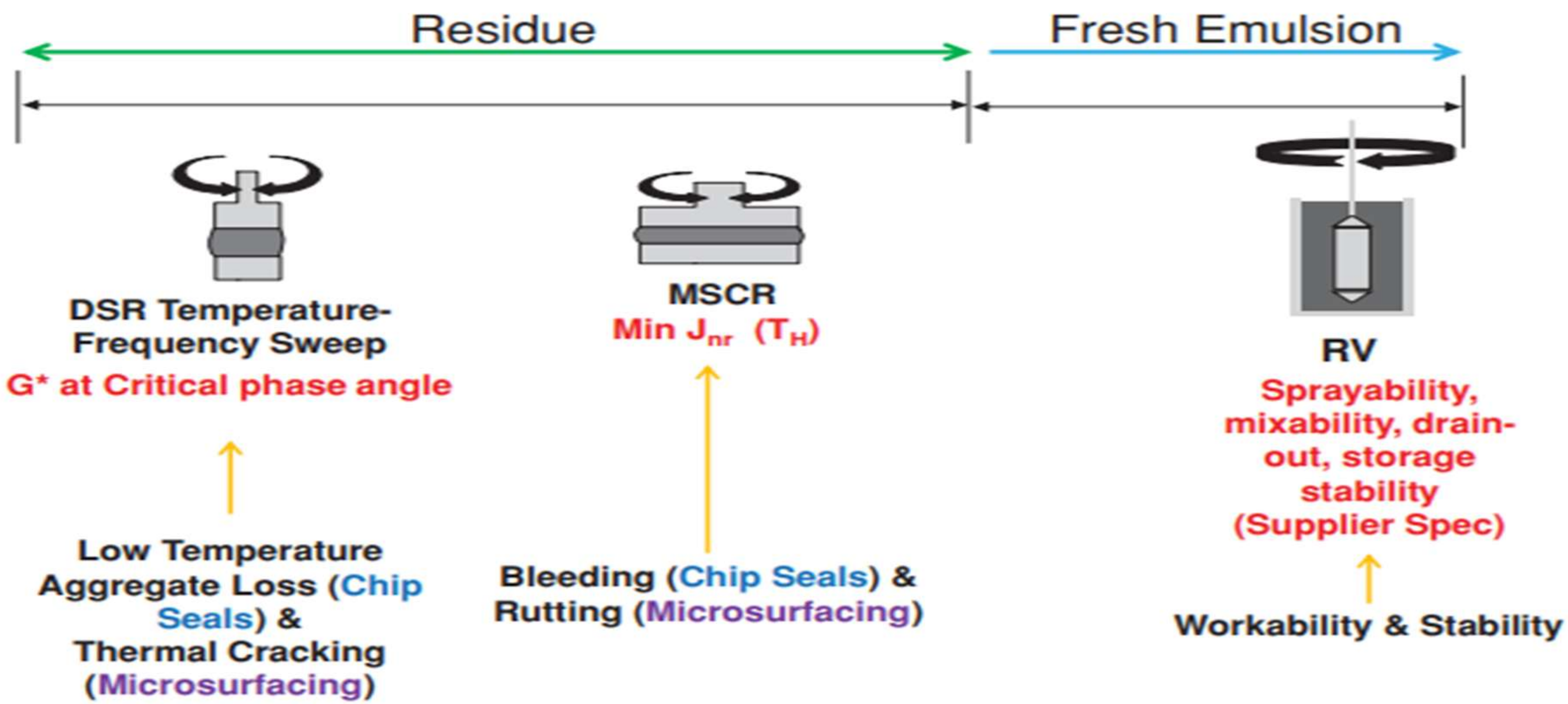
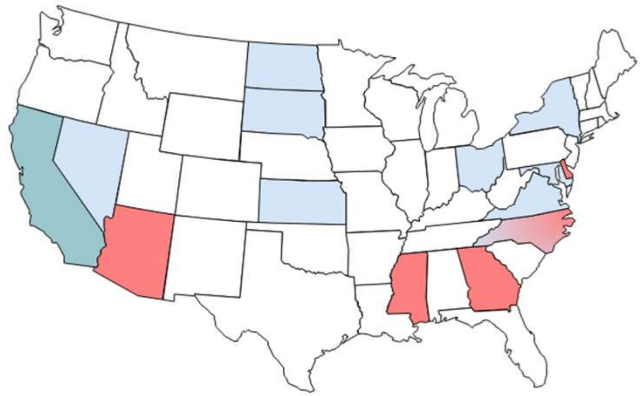


Figure 2.1. Recommended EPG specification tests for emulsions.

NCHRP 09-63: A Calibrated and Validated National Performance Related Specification for Emulsified Asphalt Binder

Field Projects 2020-22



Projetos de campo: 2019-2020

FIGURE 1. Location of NCHRP 09-63 Field Projects (shaded)

TABLE 12. Field Experiment Projects

PROJECT INFO						
Project #	Route/Street	City/Town	State	Agency	Type	Actual Construction Date
1	Rt. 80	Sherburne	NY	NYSDOT	Chip Seal w/Fog and Sand	9/6/2019
2	RT. 11	Homer	NY	NYSDOT	Chip Seal w/Fog and Sand	7/17/2020
3	Padgett Rd.	Union Mills	NC	Rutherford Co.	Double Chip Seal	7/22/2020
4	Rt. 9B	Rouses Point	NY	NYSDOT	Double Microsurfacing	8/10/2020
5	SR 117	Belle Center	OH	OHDOT	Microsurfacing	8/20/2020
6	CR 2	Colgan	ND	Divide Co.	Microsurfacing	8/27/2020
7	US 85	Fortuna	ND	NDDOT	Chip Seal w/Fog	8/28/2020
8	Norris Peak Rd	Rapid City	SD	Pennington Co.	Chip Seal w/Fog	9/1/2020
9	US 6	Dyer	NV	NVDOT	Chip Seal w/Fog and Sand	9/10/2020
10	SW Gage Blvd	Topeka	KS	Mission Township	Chip Seal	9/17/2020
11	CR 660	Farmville	VA	Cumberland Co.	Double Chip Seal	9/21/2020
12	Beulah Road	Vienna	VA	VDOT	Microsurfacing	9/22/2020
13	Arrants Road	North East	MD	Cecil Co.	Slurry Seal	9/25/2020

Task Force

Classificação da emulsão - EPG

■ Examples of chip seals EPG

Classification of emulsified asphalt performance

Workability index of emulsified asphalt

Residue high and low temperature index

Existing Emulsion Name	Proposed EPG Grade			Fresh Emulsion Tests				Residual Binder Tests		Pass & Grade or Fail at Test Temp/ Traffic Level
CRS-2 (NC)										CRS-EPG67-19L
										Fail
										Fail
CRS-2L (F)	CRS	67-19	Low	1.1 Pass	1.0 Pass	180 Pass	350 Pass	6.75 Pass at Low	14 Pass at Low	CRS-EPG67-19L
			Med					6.75 Fail at Med	14 Pass at Med	Fail
			High					6.75 Fail at High	14 Fail at High	Fail
CRS-2P (A)			Low	0.3 Pass	1.0 Pass	80 Pass	450 Pass	2.5 Pass at Low	4 Pass at Low	CRS-EPG67-19L
			Med					2.5 Pass at Med	4 Pass at Med	CRS-EPG67-19M
			High					2.5 Pass at High	4 Pass at H	

CRS-EPG67-19L

from NCHRP837

Emulsão catiônica ruptura rápida
Temperatura pavimento 67-19
Baixo tráfego

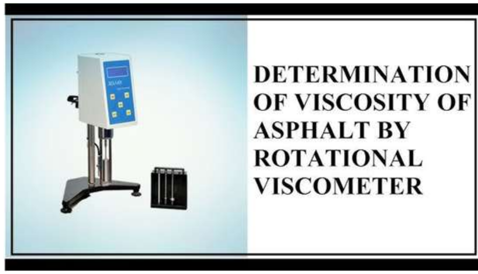
EUA e Africa do Sul - requisitos de desempenho preliminares

África do Sul

Engineering Property	Test Method	Parameter(s) Measured
Tests on Fresh Emulsion Properties (Constructability)		
Storage Stability	Modified ASTM D6930 – Settlement and Sedimentation	• Rotational Viscosity, η. • B-24-hour Separation Ratio (R_s) • C-24-hour Stability Ratio (R_d)
Sprayability	Modified AASHTO TP48 - Rotational Viscometer	• Rotational Viscosity, η. • @ high shear at (XX 1/sec)
Drain-Out	Modified AASHTO TP48-Rotational Viscometer	• Rotational Viscosity, η. • @ low shear rate (XX 1/sec)
Resistance to Early Raveling /Curing	AASHTO TP 91-11 Bitumen Bond Strength (BBS)	• A-Minimum Pull-Out Tensile Strength (POS) @ XX hrs. of Curing Time
Residue Recovery Method: ASTM D7497 Method B		
Resistance to Bleeding and Flushing	Multiple Stress Creep and Recovery Test (AASHTO TP 70)	• J_{nr} • Stress Sensitivity
Resistance Raveling	Bitumen Bond Strength Test (AASHTO TP-91)	• Wet and Dry Pull-off Bond Strength • Moisture Damage ratio
	DSR-Linear Amplitude Test	• Strain at maximum Stress
Early Fatigue	Linear Amplitude Sweep Test (LAS)	• Number of Cycles to failure (N_f) at specified % Strain
Polymer Identifier	Elastic Recovery DSR	• % recovery
Tests on PAV Aged (AASHTO R28) Materials		
Late Fatigue	Linear Amplitude Sweep Test (LAS)	• Cycles to failure (N_f) at specified % Strain • Aging Susceptibility
Resistance to Thermal Cracking	DSR Frequency Sweep to estimate BBR properties.	• Estimated S(60), m(60)

EUA

Property	Test Method	Parameter(s) Measured
Storage Stability[a]	Modified ASTM D6930 – Settlement and Sedimentation	A Rotational viscosity, η B 24-hour separation ratio (*Rs*) C 24-hour stability ratio (*Rd*)
Sprayability[b]	Modified AASHTO TP 48 – Rotational Viscometer	Rotational viscosity, η, @ high shear rate
Drainout[b]	Modified AASHTO TP 48 – Rotational Viscometer	Rotational viscosity, η, @ low shear rate
Mixability[c]	Modified AASHTO TP 48 – Rotational Viscometer	Rotational viscosity, η, @ 5 rpm
Curing Time[d]	Modified ASTM D3121 – Rolling Ball Test	Rolling distance, time to 25 cm rolling distance

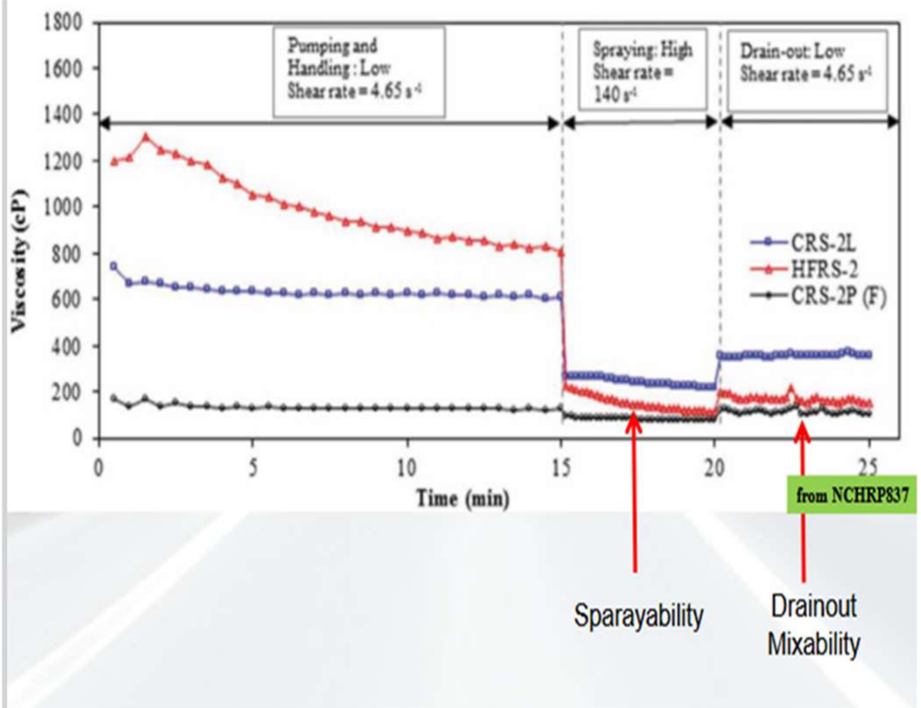


Performance Characteristic	Test Method	Parameter(s) Measured
Rutting at High-temperature EPG	Multiple Stress Creep and Recovery Test	▪ Non-recoverable Creep Compliance, J_{nr}
Thermal Cracking at Low-temperature EPG	Dynamic Shear Rheometer Frequency Sweep Test	▪ Dynamic Shear Modulus (G^*) at $\delta_{critical}$

Trabalhabilidade

Simulação do processo de aplicação

Testes na emulsão virgem - propriedades de trabalhabilidade		
Propriedade	**Método**	**Parâmetro medido**
Pulverizabilidade	AASHTO TP 48 modificado	viscosidade rotacional 150 rpm
Drenagem TS		viscosidade rotacional 5 rpm
Mixabilidade Micro		viscosidade rotacional 5rpm



Etapa 1 – Emulsão no tanque – manuseio e bombeamento - 5 rpm

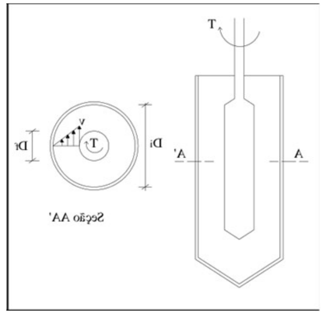
Etapa 2 – Pulverização da emulsão (TS) – 150 rpm

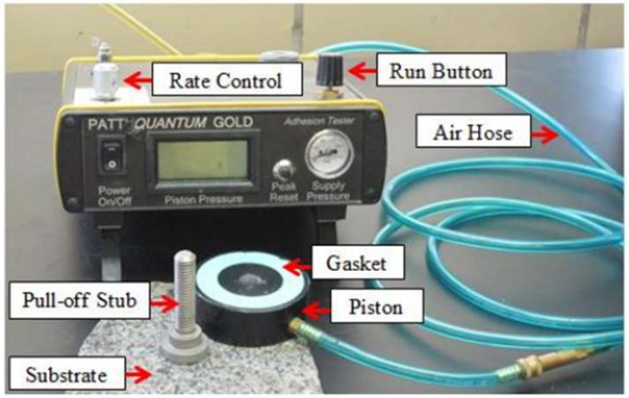
Etapa 3 – Drenagem (TS) e Mixabilidade (Micro)na superfície do pavimento- 5rpm

Trabalhabilidade

Testes na emulsão virgem - propriedades de trabalhabilidade

Propriedades	Método	Parâmetro medido
Estabilidade à estocagem	ASTM D 6930/19 modificado Amostra estocada sedimentação	viscosidade rotacional
		B - 24 horas razão de separação (Rs) (η topo / η fundo)
		C - 24 horas razão de estabilidade η Antes / η Depois condicionamento (Rd)
Resistência a cura precoce	AASHTO TP 91-11 BBS	A - mínimo resistência à tração POS
	Resistencia a adesão do ligante	XX h de tempo de cura





NCHRP 09-63 Draft EAPG Specification (V1): Chip Seals

Emulsion Performance Grade	EPG 55					EPG 61					EPG 67			
	-19	-25	-31	-37	-43	-13	-19	-25	-31	-37	-13	-19	-25	-31
Surface design high temperature[1], °C	< 55					< 61					< 67			
Surface design low temperature[1], °C	> -19	> -25	> -31	> -37	> -43	> -13	> -19	> -25	> -31	> -37	> -13	> -19	> -25	> -31
Tests on Recovered Residue (AASHTO R78, Procedure B)														
High Temperature Parameter														
G*/sin δ ≥ 0.65 kPa, 10 rad/s @ Test Temperature, °C[2]	55					61					67			
Low Temperature Parameter														
G^* at δ_c, MPa[3] Low Traffic[4] $G^* \le 30$ MPa @ δ_c, degrees High Traffic[5] $G^* \le 15$ MPa @ δ_c, degrees	48	45	42	39	36	51	48	45	42	39	51	48	45	42
OPTIONAL Polymer Presence Indicator														
Max. δ at $T_{c,high}$, degrees[6]	n/a	n/a	n/a	84	80	n/a	n/a	n/a	84	80	n/a	n/a	84	80

NOTES:

1. Determined at the pavement surface to represent the high and low design temperature for the EPG. Temperatures may be determined from experience or may be estimated using equations LTPPBind Online, modified to represent the expected surface temperature. High surface temperatures are generally 3°C to 4°C greater than those determined for PG asphalt binders used for paving.
2. AASHTO T315 is used to determine the G*/sin δ value of the EPG asphalt binder.
3. G^* at δ_c is determined using temperature-frequency sweep testing at 5 and 15°C following the research test procedure described in NCHRP Report 837.
4. Low traffic is defined as having an AADT of 1,000 vehicles or less.
5. High traffic is defined as having an AADT greater than 1,000 but less than 20,000 vehicles.
6. Phase angle (δ) is determined at the continuous high temperature grade – $T_{c,high}$ – where G*/sin δ = 0.65 kPa. Two temperatures are needed – one where G*/sin δ < 0.65 kPa and one where G*/sin δ > 0.65 kPa – so that the phase angle can be interpolated at the temperature where G*/sin δ = 0.65 kPa.

Obtenção do resíduo da emulsão

J. Mater. Civ. Eng., 2024, 36(10): 04024315

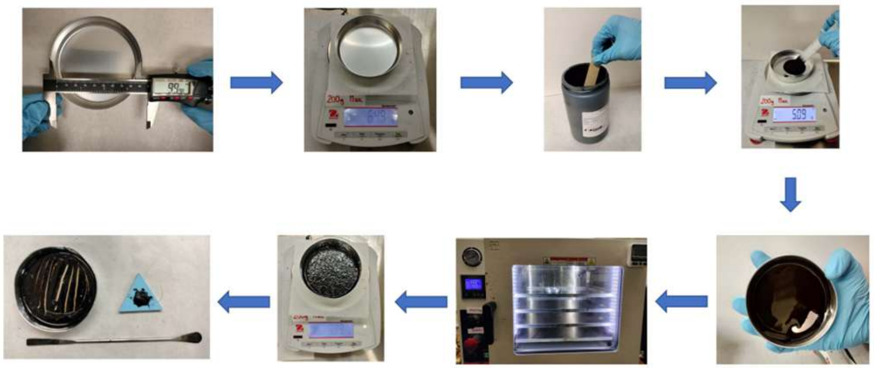
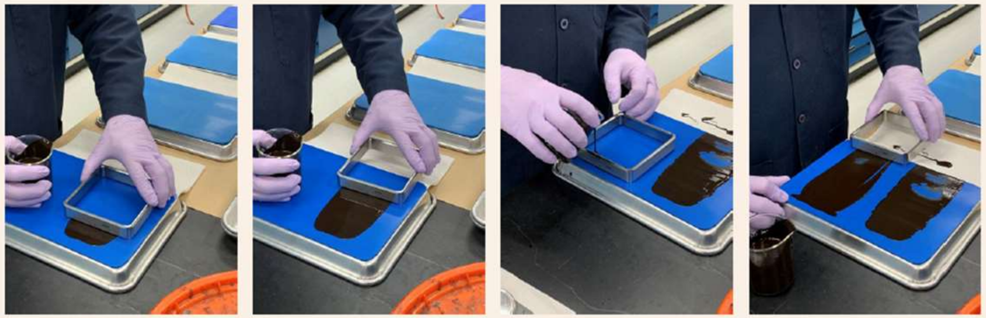


Fig. 2. Step-by-step guide for emulsion residue recovery.

ASTM D7944-15 Standard Practice for Recovery of Emulsified Asphalt Residue Using a Vacuum Oven

Estufa a 70ºC e vácuo de 90mBar por 2 horas

AASHTO R 78 Procedure B and ASTM D7944



24 horas a temperatura ambiente seguido por 24 horas em estufa de ar forçada a 60°C

Resistencia a deformação permanente

	EPG 55					EPG 61					EPG 67			
Grau de desempenho da emulsão	-19	-25	-31	-37	-43	-13	-19	-25	-31	-43	-13	-19	-25	-31
Temperatura baixa do pavimento, °C	55					61					67			
Temperatura alta do pavimento, °C	-19	-25	-31	-37	-43	-19	-25	-31	-37	-43	-13	-19	-25	-31
Testes no resíduo da emulsão														
Ensaio														
G*/senδ> 0,65kPa, 10 rad/s na temperatura teste	55					61					67			

Resistencia a trincamento

Grau de desempenho da emulsão	EPG 55					EPG 61					EPG 67			
	-19	-25	-31	-37	-43	-13	-19	-25	-31	-43	-13	-19	-25	-31
Temperatura baixa do pavimento, °C	55					61					67			
Temperatura alta do pavimento, °C	-19	-25	-31	-37	-43	-19	-25	-31	-37	-43	-13	-19	-25	-31
Testes no resíduo da emulsão														
G* a δc, MPa														
Baixo tráfego														
G < 30 Mpa a δc, °	48	45	42	39	36	51	48	45	42	39	51	48	45	42
Alto tráfego														
G < 15 Mpa a δc, °														

Especificação australiana – parâmetro de resistência a deformação permanente
Emulsão modificada 2020

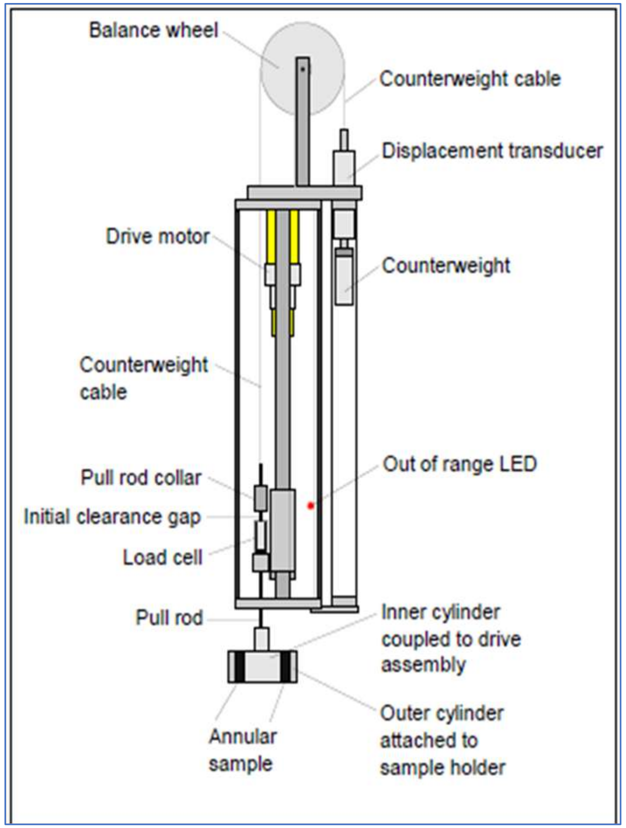


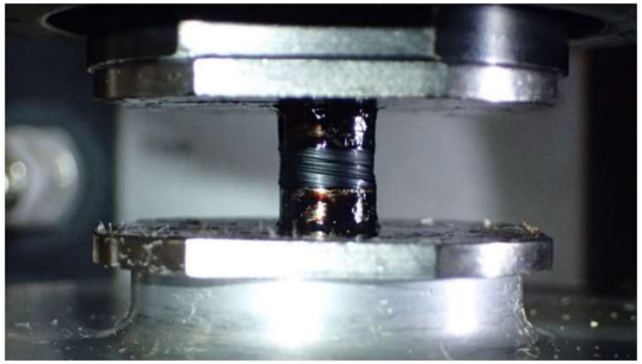
TABLE 511.4 PROPERTIES OF PMB FOR SPRAYED SEALING

Binder Property	Test Method	Binder Class				
		S10E	S20E	S25E	S35E	S45R (Note 2)
Stress ratio at 10 °C Minimum	AG:PT/T125	Report	Report	Report	Report	Report
Consistency 6% at 60°C (Pa.s) Minimum	AG:PT/T121 (Note 1)	300	500	900	250	800
Stiffness at 15°C (kPa) Maximum	AG:PT/T121	140	N/A	N/A	180	Report
Stiffness at 25°C (kPa) Maximum	AG:PT/T121	N/A	35	30	N/A	N/A
Compressive Limit at 70°C, 2kg mm (minimum)	AG:PT/T132	N/A	N/A	N/A	N/A	0.2
Viscosity at 165°C (Pa.s) Maximum (Note 3)	AG:PT/T111 or AS/NZS 2341.4	0.55	0.6	0.9	0.55	4.5
Flash Point (°C) Minimum	AG:PT/T112	250	250	250	250	250
Loss on Heating (% mass) Maximum	AG:PT/T103	0.6	0.6	0.6	0.6	0.6

Especificação australiana – parâmetro de resistência a fadiga - taxa de tensão a 10°C
Emulsão modificada 2020

Razão de tensão a 10°C

Figure 9.1: Distressed binder after testing



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Viscosity at 165°C (Pa.s) Maximum (Note 3)	AG:PT/T111 or AS/NZS 2341.4	0.55	0.6	0.9	0.55	4.5
Flash Point (°C) Minimum	AG:PT/T112	250	250	250	250	250
Loss on Heating (% mass) Maximum	AG:PT/T103	0.6	0.6	0.6	0.6	0.6

Conclusões – Ensaios reológicos EPG

- **Ensaios de trabalhabilidade devem ajudar na aplicação;**
- **Ensaios reológicos no resíduo da emulsão podem vir a garantir a seleção do ligante de acordo com clima e tráfego;**
- **Mais testes em campo nos estados americanos irão melhorar ainda mais a escolha dos ensaios e dos limites;**
- **A concepção da especificação australiana está relacionada apenas ao AMP usado na emulsão, ainda leva em conta alguns ensaios empíricos;**


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