



Reciclagem de Pavimentos: Pesquisas e Avanços do Grupo da UFSM



Universidade Federal de Santa Maria (2022)

Professors – 2016

Technicians – 2590

Students – 26.667

Graduação – 124 cursos

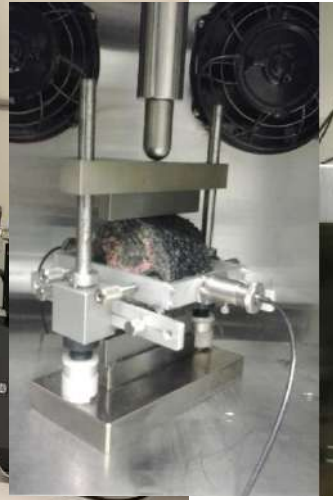
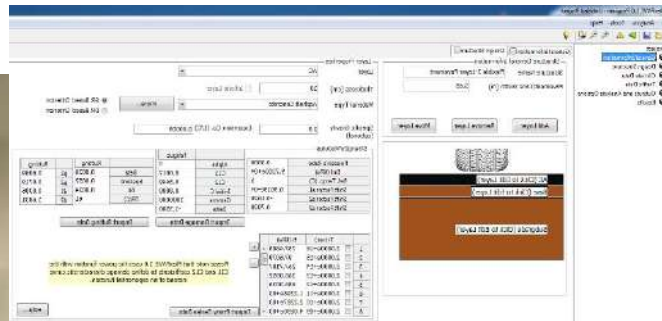
Pós-Graduação – 50 M e 30 D





Grupo de Pesquisa em Pavimentação e Segurança Viária

- 5 Professores/Pesquisadores
- 35 estudantes – Graduação, Mestrado e Doutorado



Introdução

CENÁRIO DAS RODOVIAS BRASILEIRAS

INFRAESTRUTURA RODOVIÁRIA
CNT-2019: **59%** dos trechos com problemas

Pesquisa **CNT** de **RODOVIAS** 2019

PREOCUPAÇÕES E METAS MUNDIAIS

DESENVOLVIMENTO SUSTENTÁVEL
17 ODS- ONU
Agenda 2030
Aquecimento Global



NECESSIDADE DE PRESERVAÇÃO DE RECURSOS

Reciclagem de pavimentos
Preservação de recursos financeiros e naturais

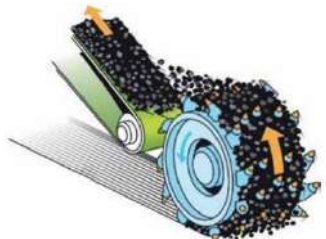
RECICLAGEM DE PAVIMENTOS

Construir pavimentos empregando materiais fresados já utilizados em obras

FORMAS DE RECICLAGEM DE PAVIMENTOS

OBRAS DE RESTAURAÇÃO

Fresagem
Geração de material fresado (RAP)



RECICLAGEM A QUENTE

- Possibilidade de **redução dos teores de ligantes**
- Amplamente difundida nos Estados Unidos
- Necessidade de usinas adequadas
- **Emissão de poluentes e gasto energético**

RECICLAGEM A FRIO

- **versatilidade**
- **Brasil** emprega mais a reciclagem a frio do que a quente
- Uso de aditivos/estabilizantes químicos (emulsão asfáltica, espuma asfáltica, cimento Portland...)
- **Comportamentos distintos de difícil previsão**



Escopo:



Reciclagem de Pavimento - RAP

1- Base Granular

2 - Base Negra

3 - Mistura à quente

- Mornas

- Aplicações

- 100%RAP com AR

1 - Base Granular

RECICLAGEM DE MATERIAIS FRESADOS DE DIFERENTES FONTES EM MISTURAS ESTABILIZADAS PARA USO EM CAMADAS GRANULARES DE PAVIMENTOS

Dissertação de Eduarda Fração Santos

Objetivo: Avaliar a influência do tipo e teor de RAP no comportamento mecânico das misturas;

1 Mistura sem fresado:

M0-100% AV

4 Misturas com **RAP-RS400**:

M1-100% RAP-RS; M2-70% RAP-RS;
M3-30% RAP-RS e M4-22% RAP-RS

4 Misturas com **RAP-BR290**:

M5-100% RAP-BR; M6-70% RAP-BR;
M7-20% RAP-BR e M8-21% RAP-BR

ENSAIOS TRIAXIAIS

ENSAIOS DE MR DNIT 134/2018-ME

M0-100%AV
M1-100%RAP-RS
M2-70%RAP-RS
M3-30%RAP-RS
M4-22%RAP-RS
M5-100%RAP-BR
M6-70%RAP-BR
M7-20%RAP-BR
M8-21%RAP-BR

9 x 3 = 27 Ensaios

ENSAIOS DE DP DNIT 179/2018 - IE

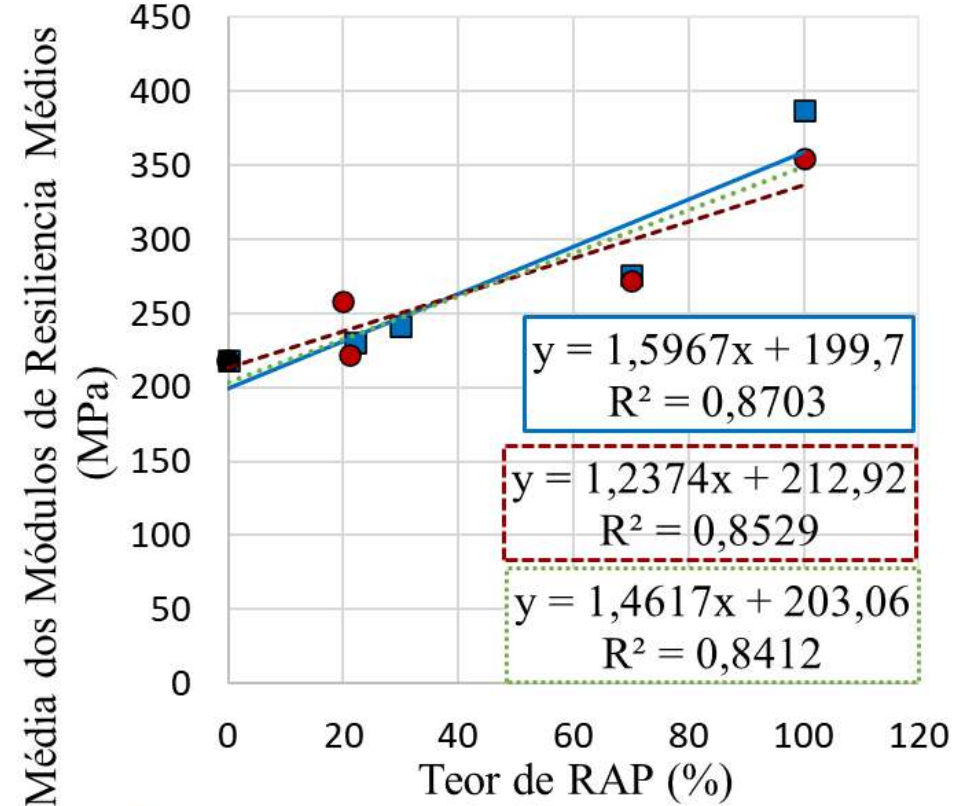
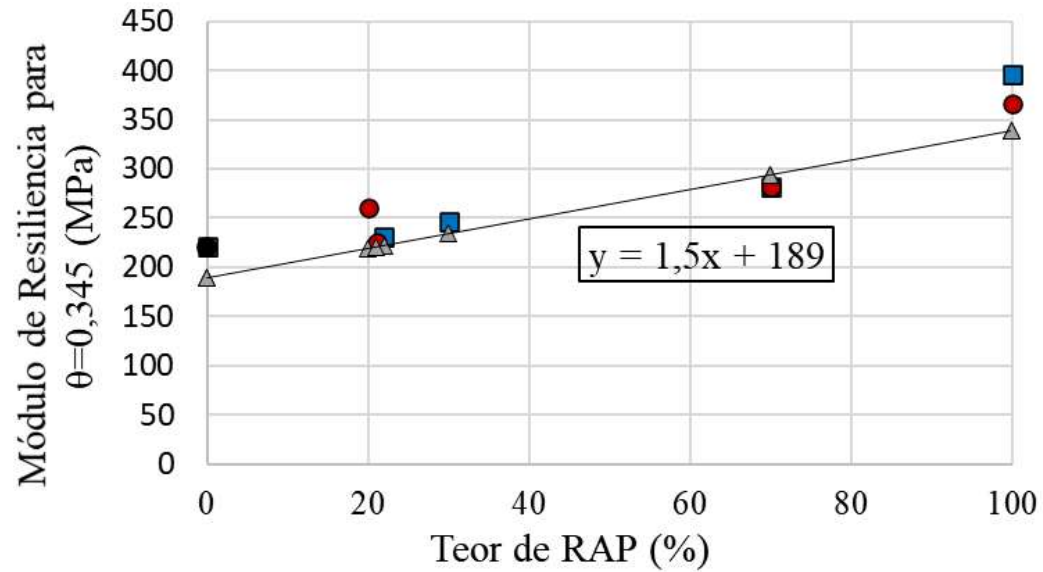
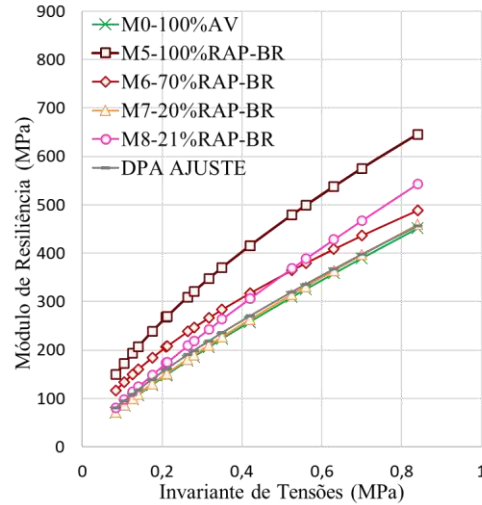
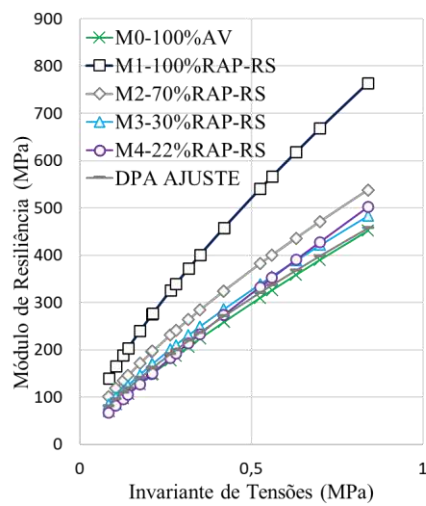
M0-100%AV
M1-100%RAP-RS
M3-30%RAP-RS

3 x 6 = 18 Ensaios

MODELOS DE
PREVISÃO PARA MR
E DP



Módulo ode Resiliência (MR)



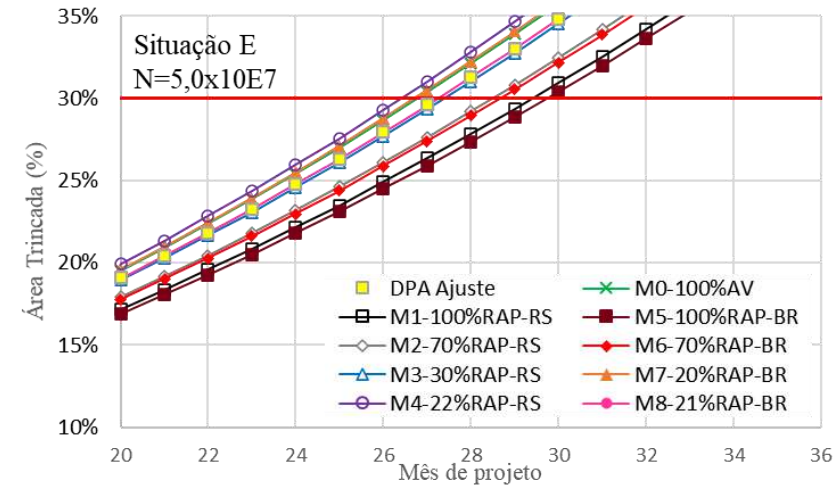
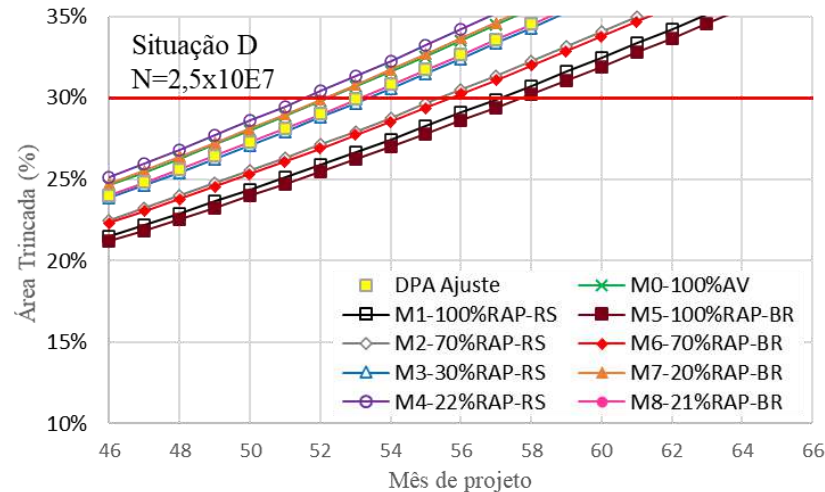
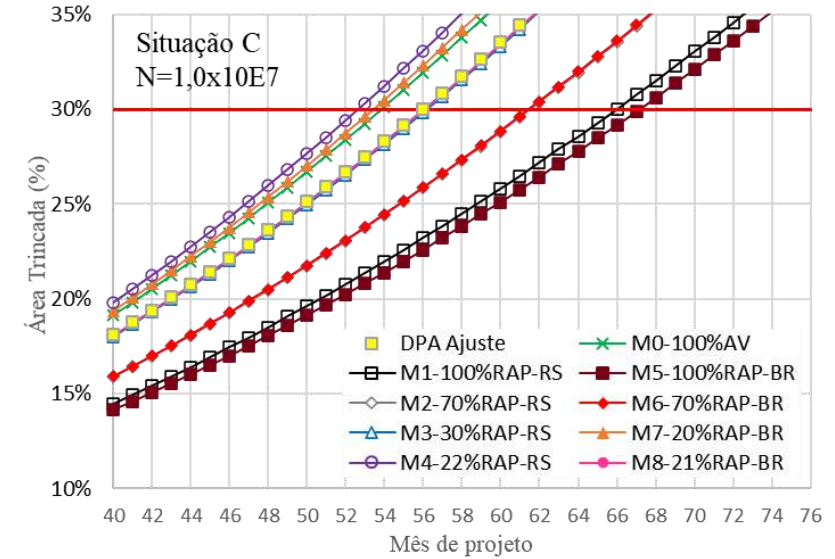
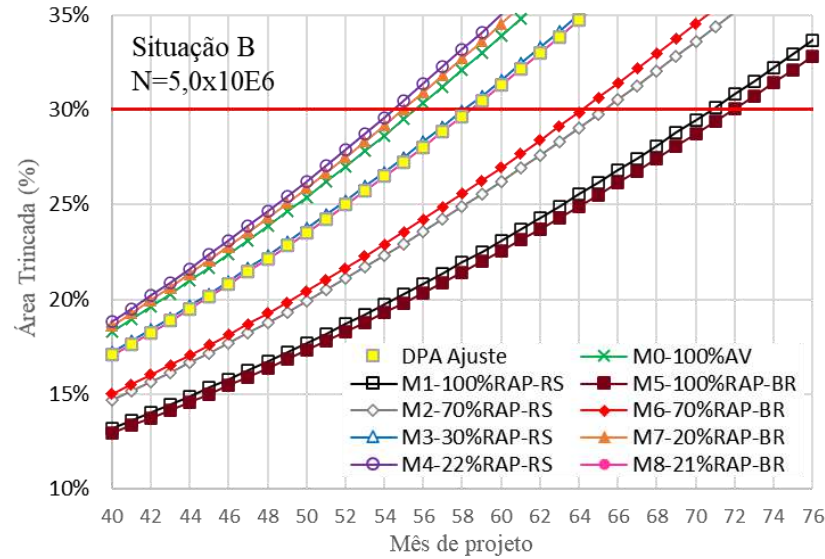
- RAP-RS400
- RAP-BR290
- Linear (RAP-RS400)
- - - Linear (RAP-BR290)
- ... Linear (TODOS)

ANÁLISE MECANICISTA

ÁREA TRINCADA



Aérea Trincada V.S. Tempo de projeto (Subleito = Solo JC) para as quatro situações



1: M4-22%RAP-RS
M7-20%RAP-BR
M0-100%AV

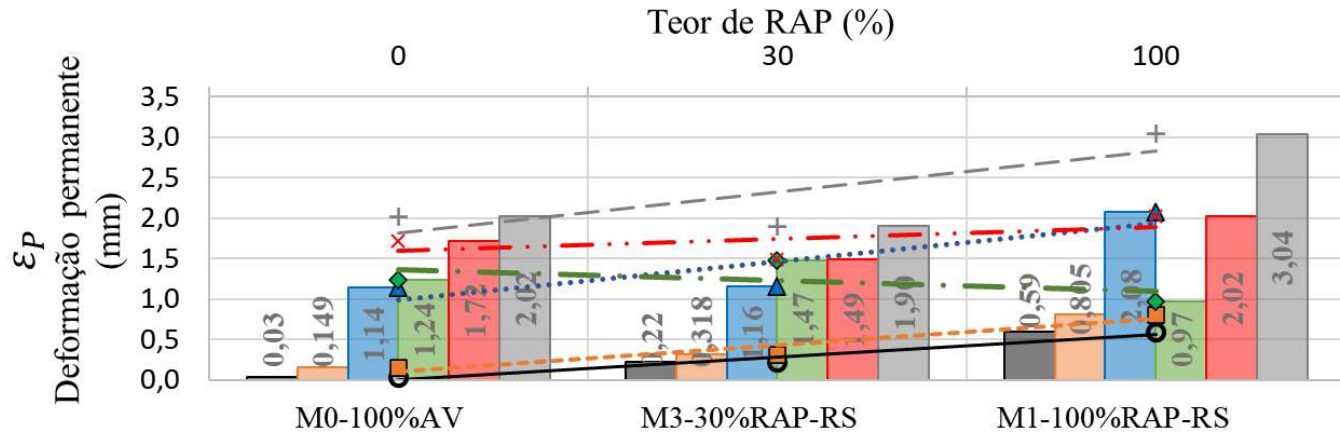
3: M2-70%RAP-RS
M6-70%RAP-BR

2: DPA-Ajuste
M3-30%RAP-RS
M8-21%RAP-BR

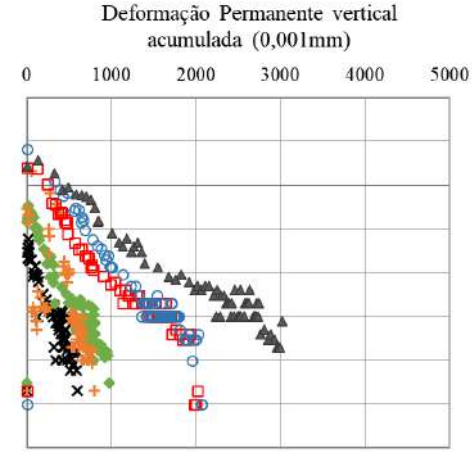
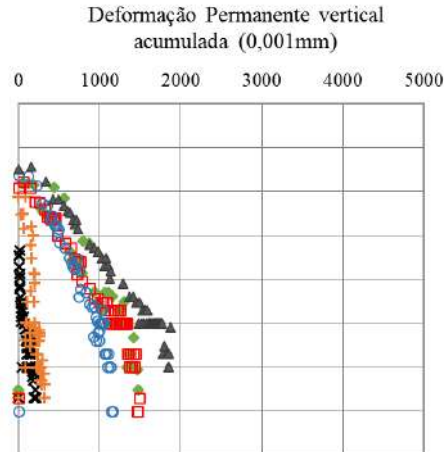
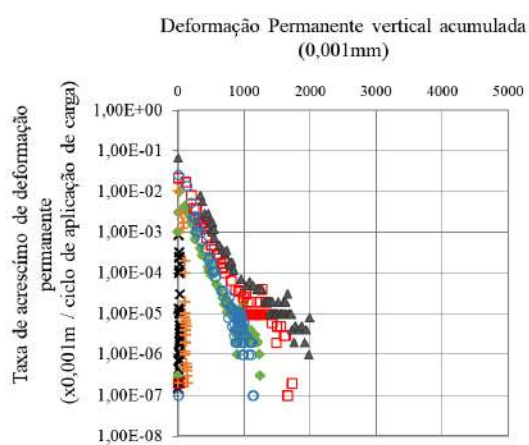
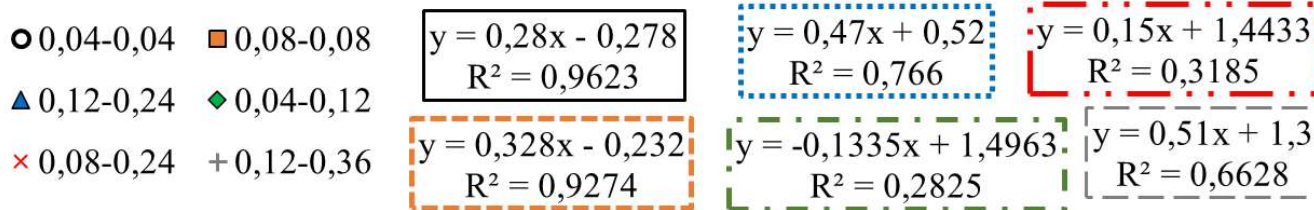
4: M1-100%RAP-RS
M5-100%RAP-BR



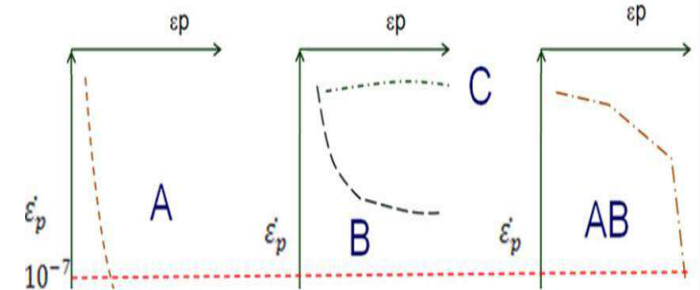
DEFORMAÇÃO PERMANENTE (DP)



A deformação permanente da superfície (ATR) para os pavimentos **não ultrapassaram 10 mm** em todos os níveis de tráfego analisados, quando a mistura **M1-100%RAP-RS** foi empregada como base granular;



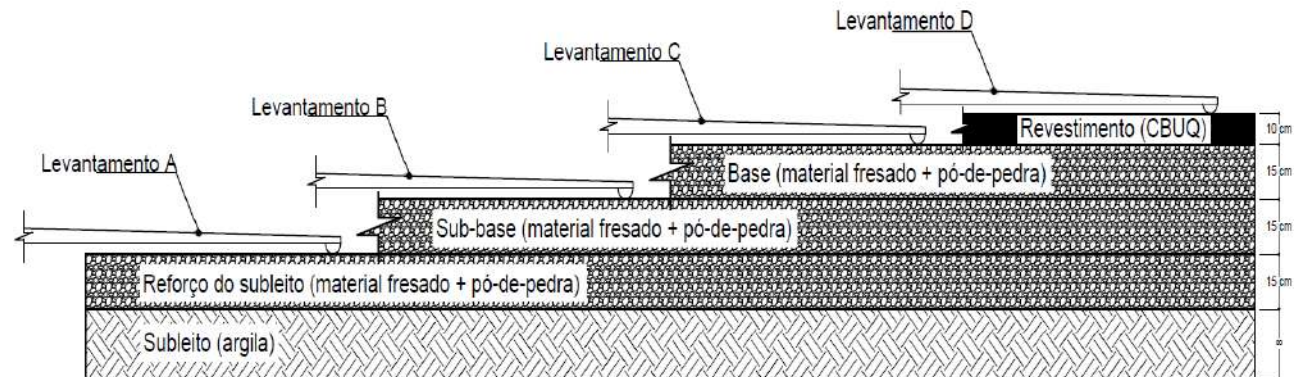
Shakedown

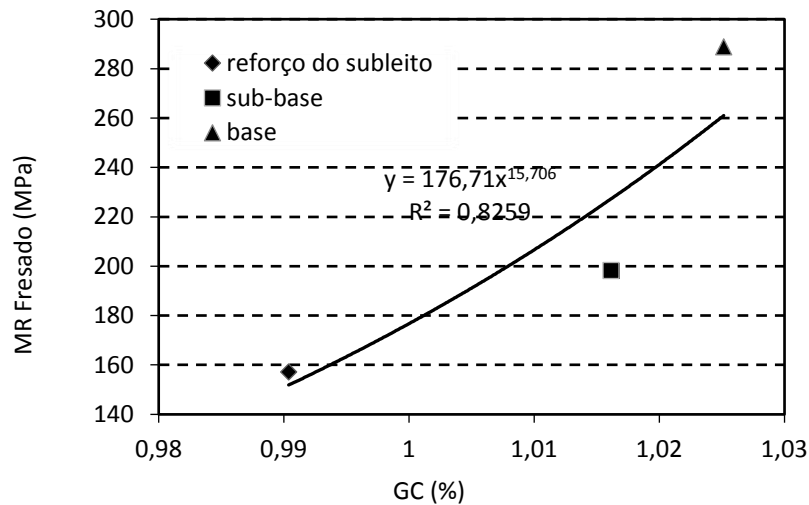


1 - Base Granular

Utilização de material fresado como camada de pavimentos em construção de faixa adicional. Revista Pavimentação, v. 41, p. 49, 2016.

HERMES, T. B. ; ECHEVERRIA, J. A. ; SPECHT, L. P.





Localização	do (0,01mm)	Localização	do (0,01mm)	Localização	do (0,01mm)
208+040	36	208+420	42	208+800	44
208+060	45	208+440	55	208+820	36
208+080	47	208+460	38	208+840	38
208+100	50	208+480	47	208+860	47
208+120	39	208+500	44	208+880	44
208+140	47	208+520	49	208+900	49
208+160	50	208+540	47	208+920	47
208+180	42	208+560	42	208+940	42
208+200	42	208+580	54	208+960	43
208+220	44	208+600	47	208+980	43
208+240	44	208+620	49	209+000	32
208+260	43	208+640	49	209+020	38
208+280	42	208+660	40	209+040	39
208+300	42	208+680	36	209+060	39
208+320	38	208+700	47	209+080	45
208+340	40	208+720	28	209+100	48
208+360	47	208+740	44	209+110	41
208+380	43	208+760	48		
208+400	47	208+780	43		

70% Fresado -30% Pó de Pedra

Valore típicos de MR

Bom Desempenho Campo

Custo

Nível Tecnológico

MÓDULO DE RESILIÊNCIA POR CAMADA (MPa)	CAMADA ONDE O LEVANTAMENTO FOI EXECUTADO					
	Reforço Subleito (A)	Sub-base (B)	Base (C)	Revestimento (D)	Média	Coeficiente de Variação
Revestimento				4099,86	4099,86	-
Base			288,89	306,29	297,59	4,1%
Sub-base		198,33	183,67	182,71	188,24	4,7%
Reforço do subleito	157,20	174,38	205,56	200,00	184,28	12,3%
Subleito	53,00	55,44	75,00	30,00	53,36	34,5%

2 - Base Negra

COMPORTAMENTO MECÂNICO DE MATERIAL RECICLADO A FRIO COM EMULSÃO E CIMENTO

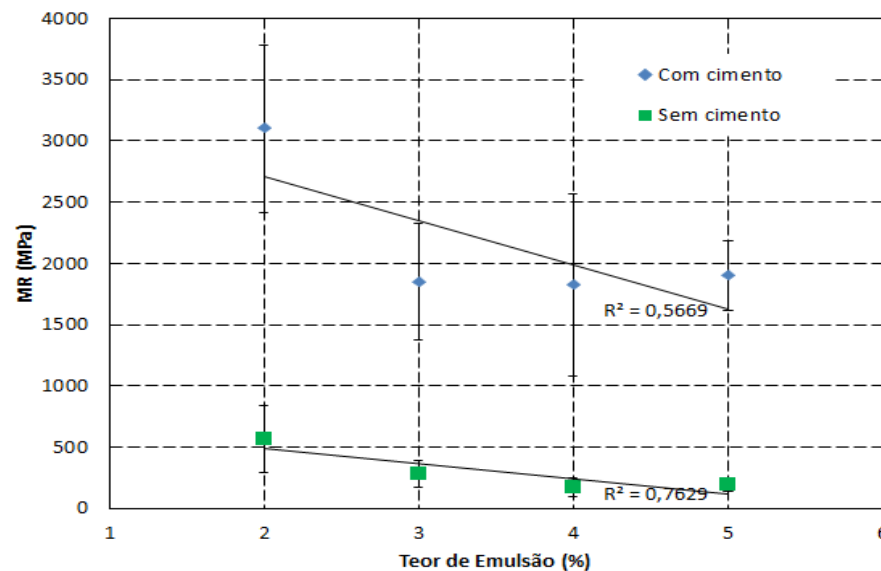
Mestrando: Eng. Civil Mateus Camargo Tanski

Objetivo: Avaliar Misturas Recicladas a Frio com adição de emulsão e cimento, com intuito de verificar o comportamento dos materiais para emprego em camadas de base e sub-base de pavimentos.

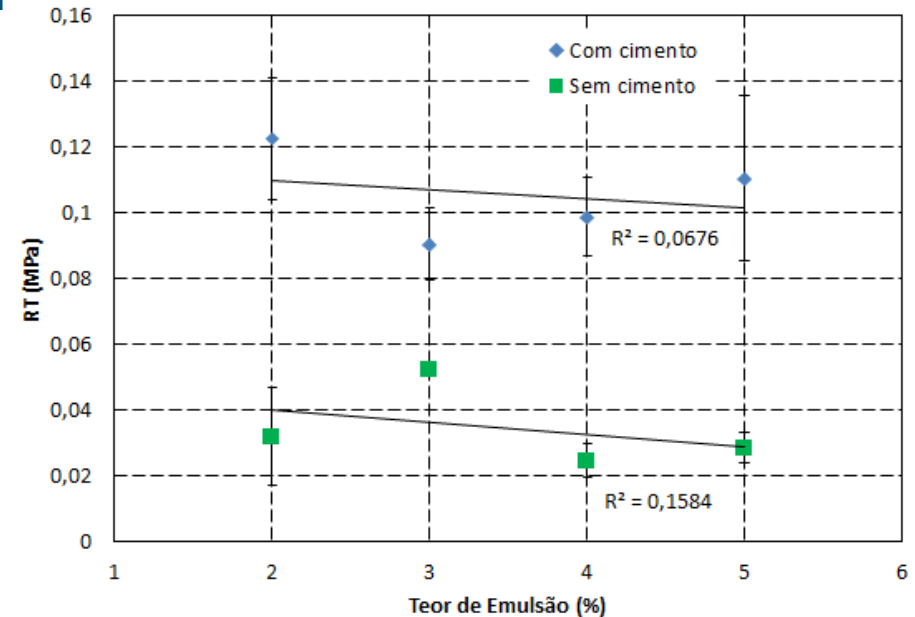
Analisar as misturas contendo diferentes teores de ligante emulsão asfáltica (2, 3, 4 e 5%) e cimento (0% e 1%);



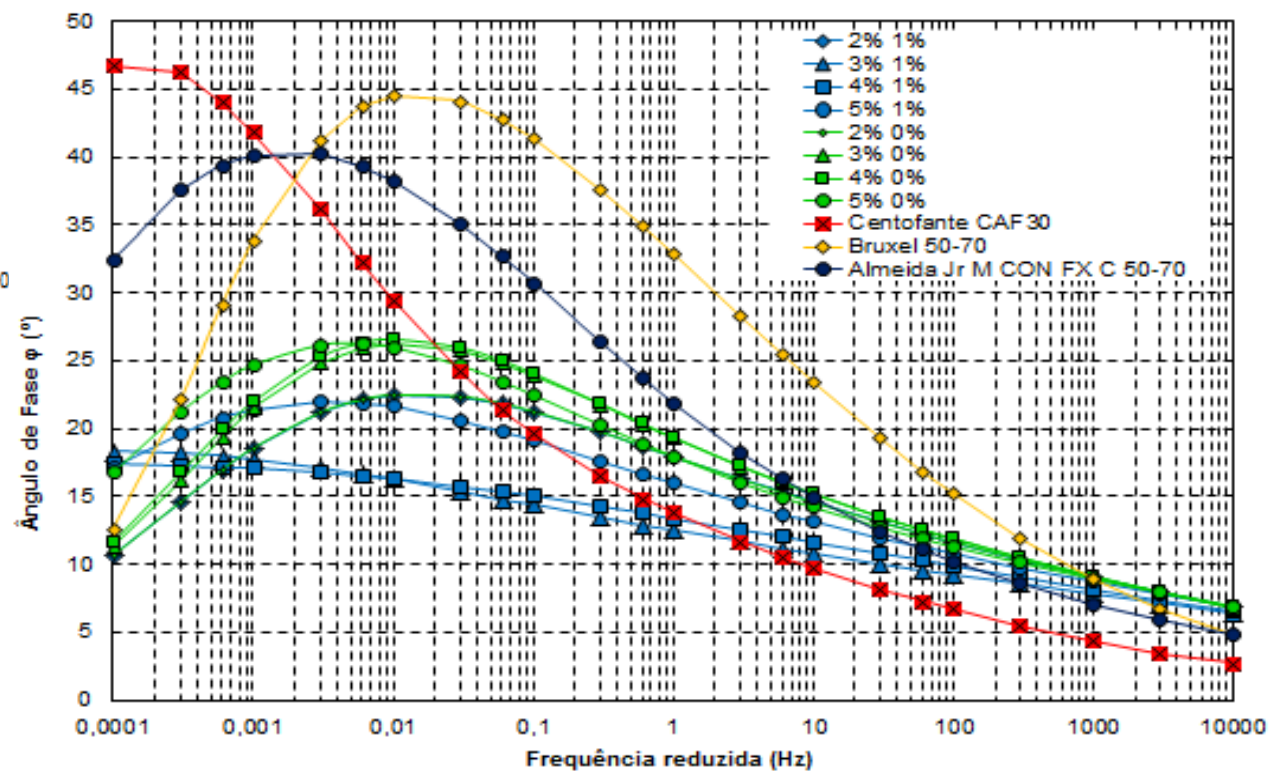
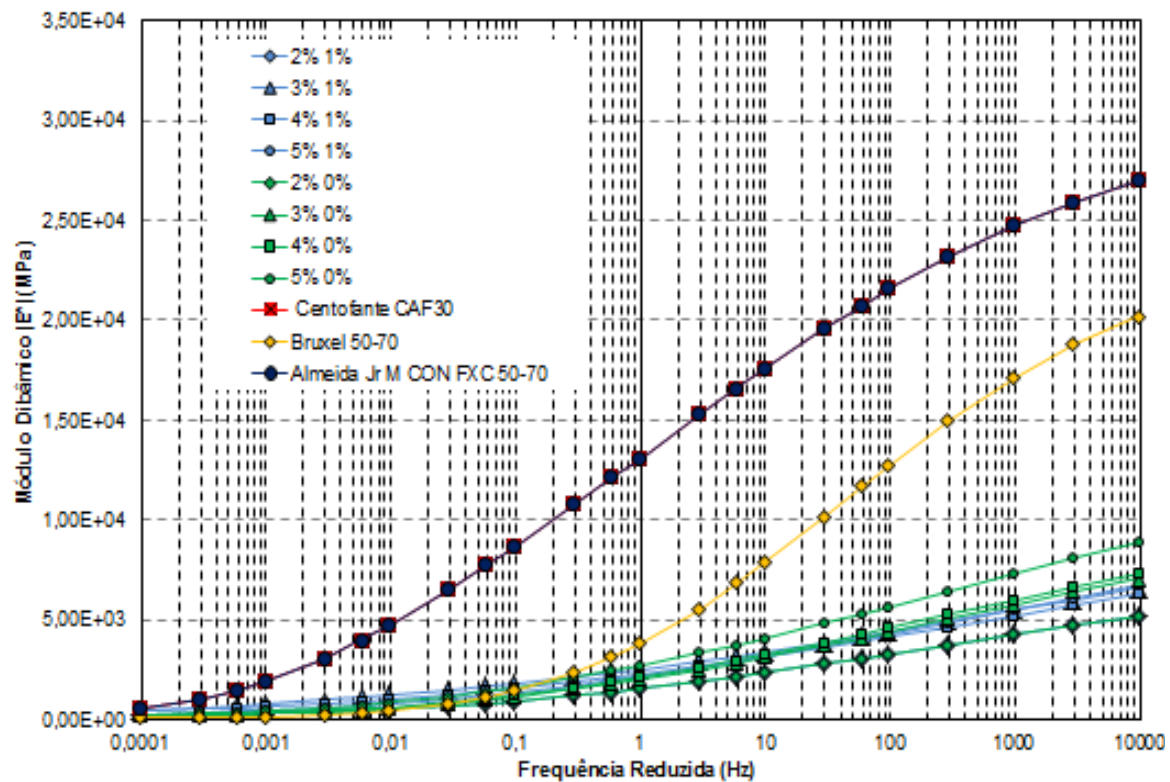
MR

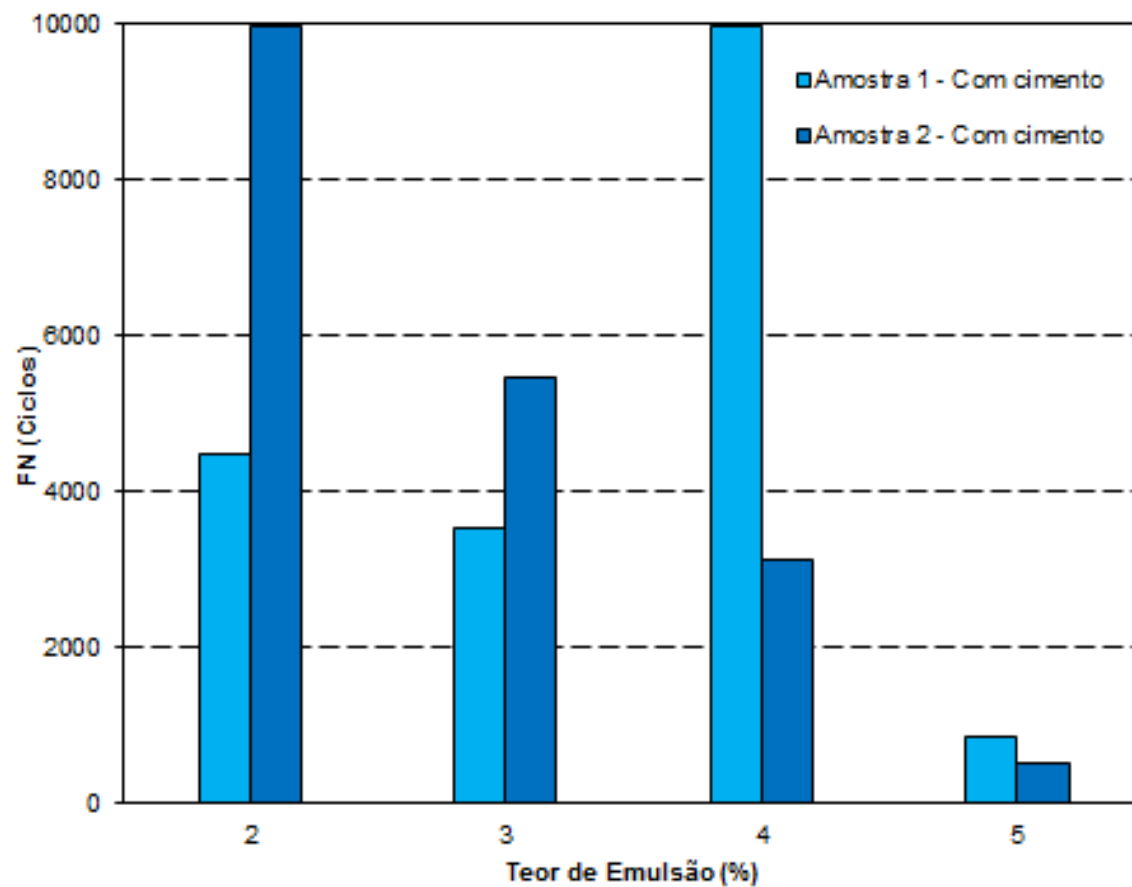
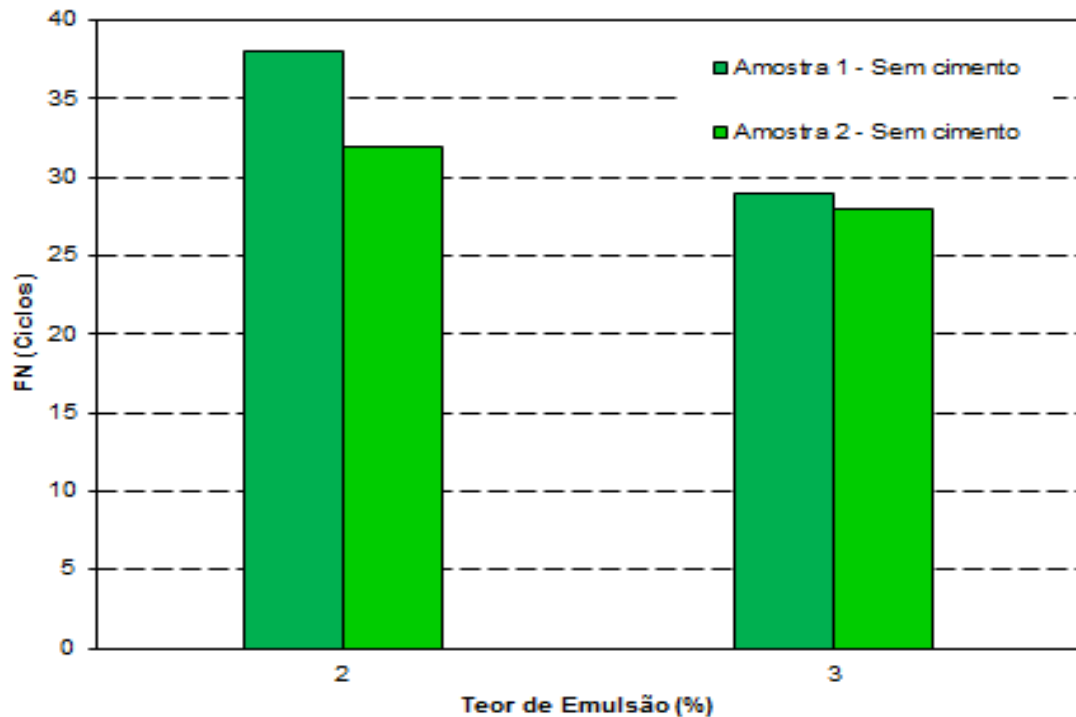


RT



Curvas Mestras





Misturas	FN	MD (Ciclo)	DP (Ciclo)	CV (%)	Parâmetros modelo Francken			
					A	B	C	D
2% 0%	38	35	3	8,57	2050,45	0,63	9,77	0,0952
	32				1692,72	0,71	1,23	0,1550
3% 0%	29	28,5	0,5	1,75	2155,45	0,73	0,07	0,2485
	28				1784,58	0,91	2011,76	0,0001
2% 1%	4502	7246	2744	37,87	710,34	0,34	20960,39	0,0000
	9990				3155,06	0,12	60,93	0,0000
3% 1%	3541	4503	962	21,36	936,47	0,29	1266,37	0,0002
	5465				755,52	0,28	462,37	0,0002
4% 1%	9985	6564,5	3420,5	52,11	1577,43	0,20	10839,35	0,0000
	3144				356,49	0,45	0,20	0,0019
5% 1%	858	691	167	24,17	675,85	0,46	0,53	0,0064
	524				1666,29	0,36	1,68	0,0088

Para onde vamos (tese da Chaveli):

- mecanismos de danificação - fadiga ou DP - efeito da água
- uso de emulsões especiais com agente reciclagem à frio (Sripath Technologies e CCB Asfaltos);
- escala de estudo - ligan



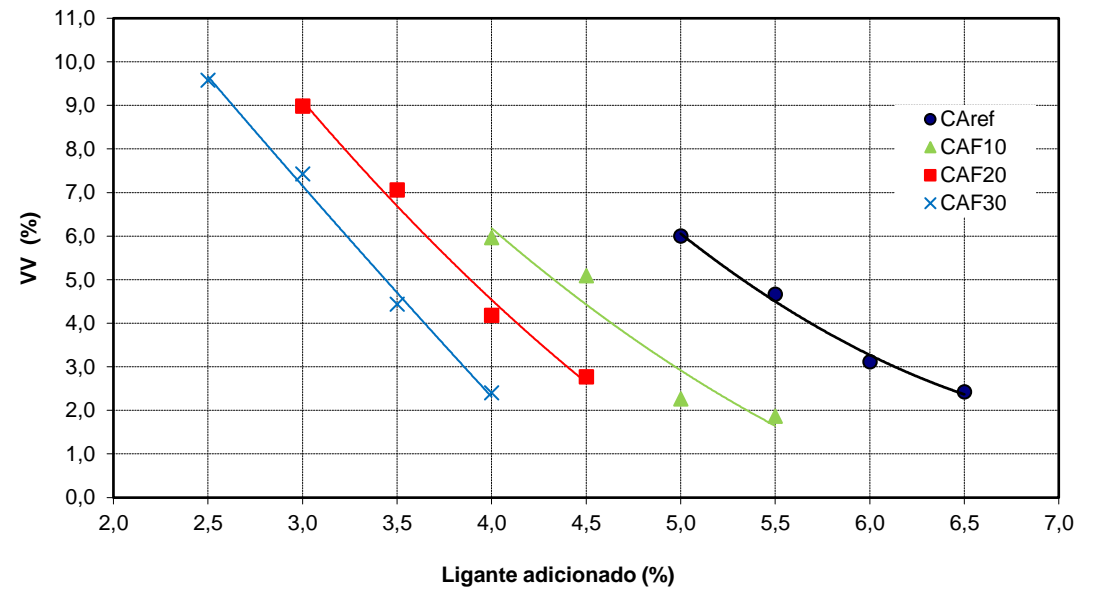
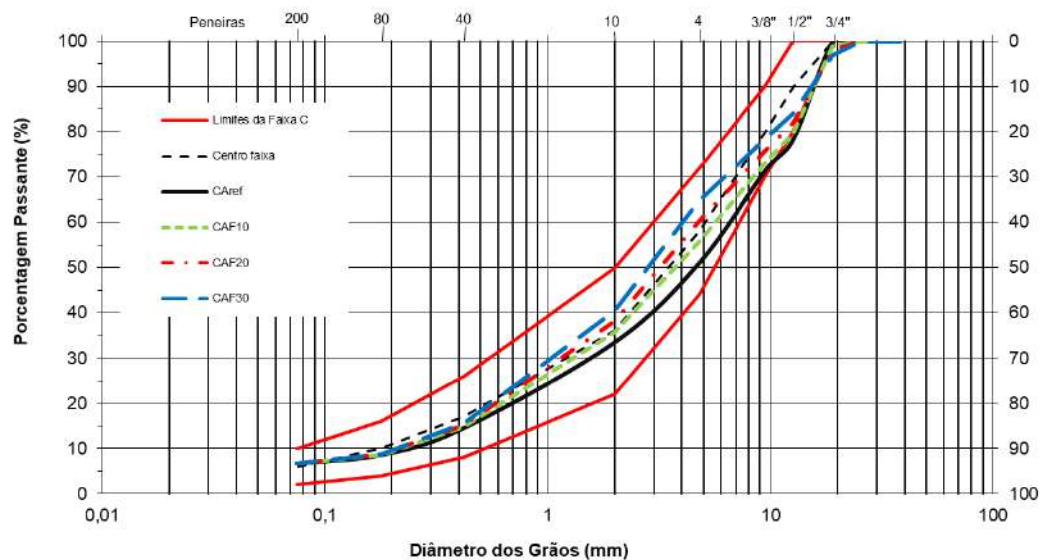
3 - Mistura à quente

ESTUDO LABORATORIAL DA UTILIZAÇÃO DE MATERIAL FRESADO EM MISTURAS DE RECICLAGEM A QUENTE

Dissertação - Roberta Centofante (2016)

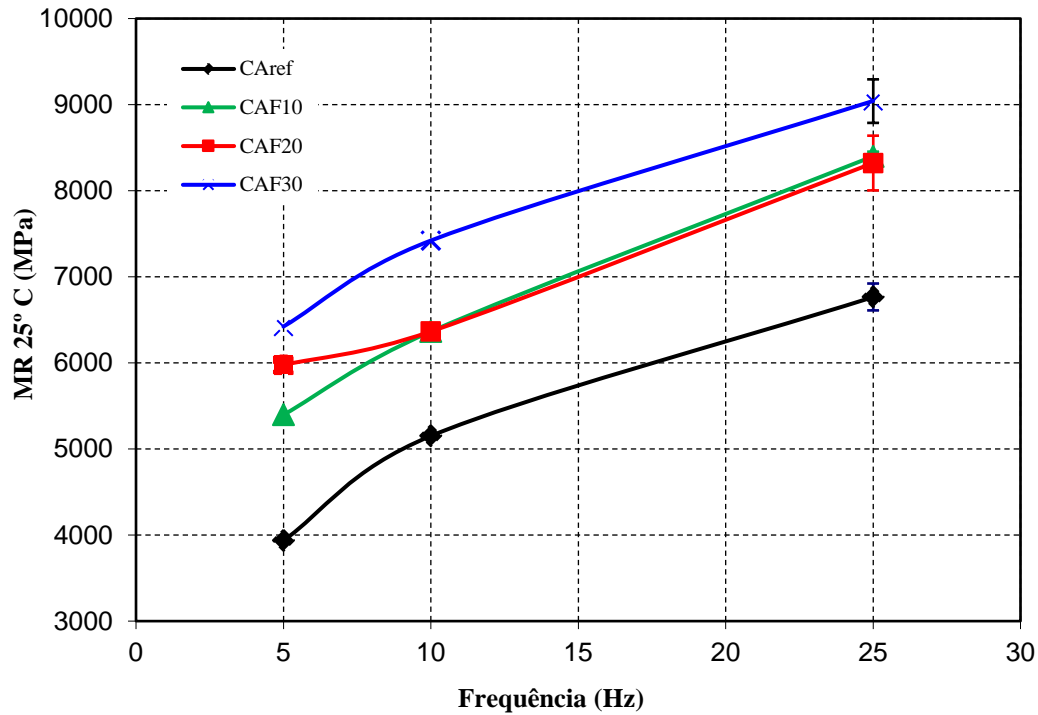
Foco no teor de fresado – 0 a 30% - ligante 50-70 e RAP 50-70

Dosagem



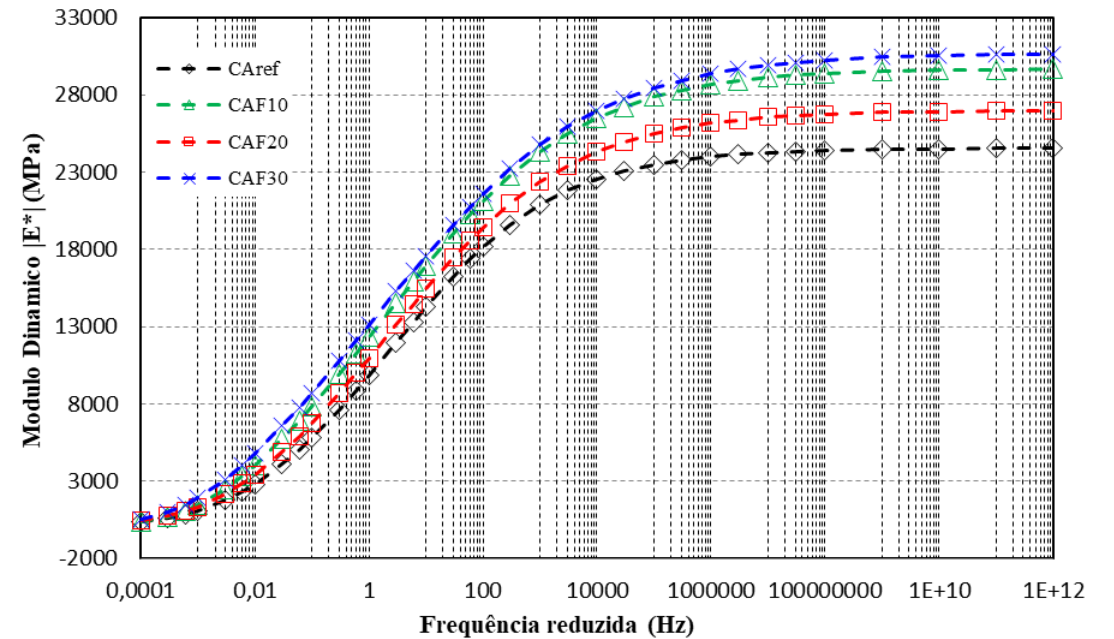
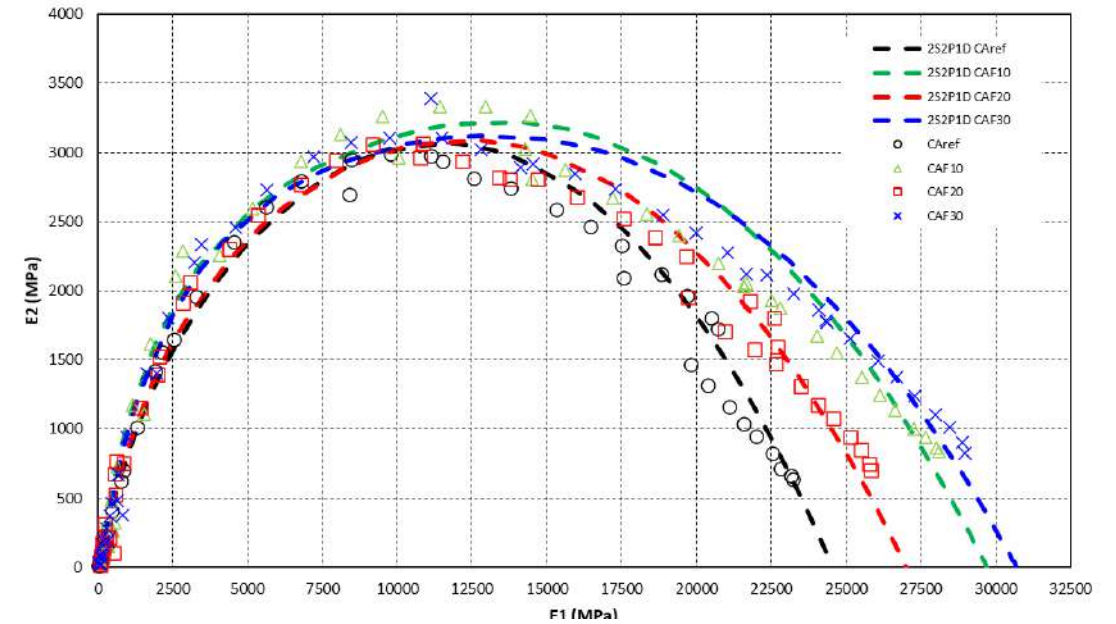
Rigidez

Elasticidade

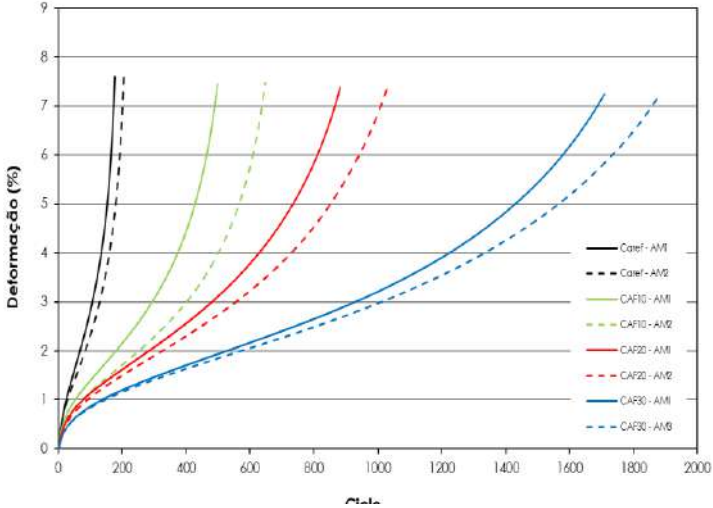


Elevação da Rigidez - interação ligante antigo - eficiência da mistura

Viscoelasticidade



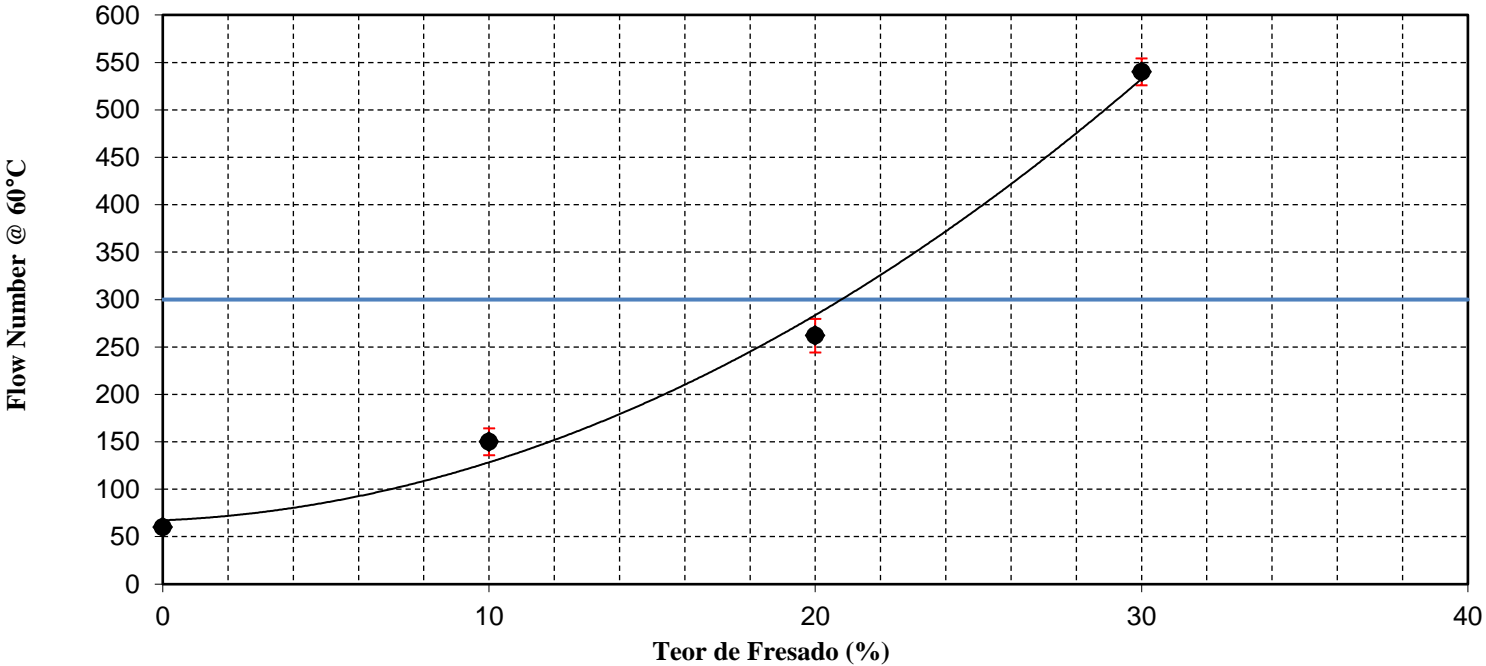
Resistência a Deformação Permanente - Flow Number - AASHTO TP 79-12



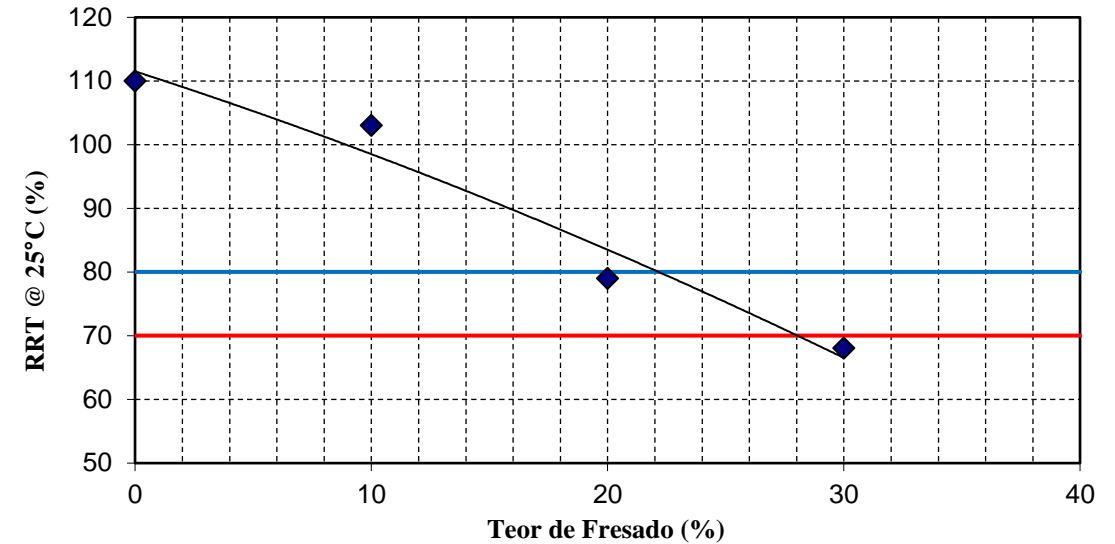
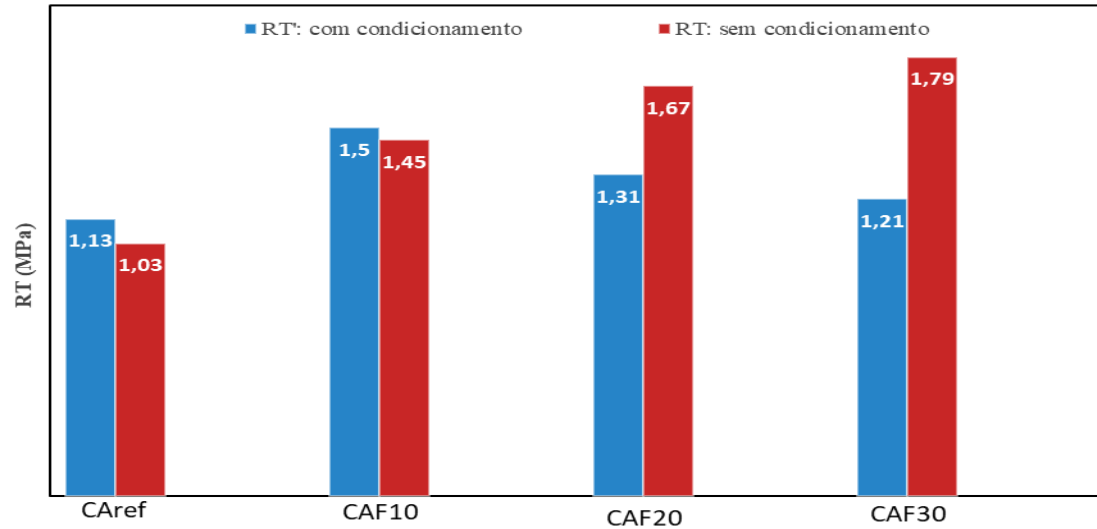
Mistura	FN	Média
Cref	60	60
	59	
CAF10	140	150
	160	
CAF20	250	262
	275	
CAF30	530	540
	550	

Temperatura:
60°C

CP 10 x 15 cm
V_v = 7% (±0,5%)



Efeito Deletério da Água - AASTO T283



Desgaste Cantabro

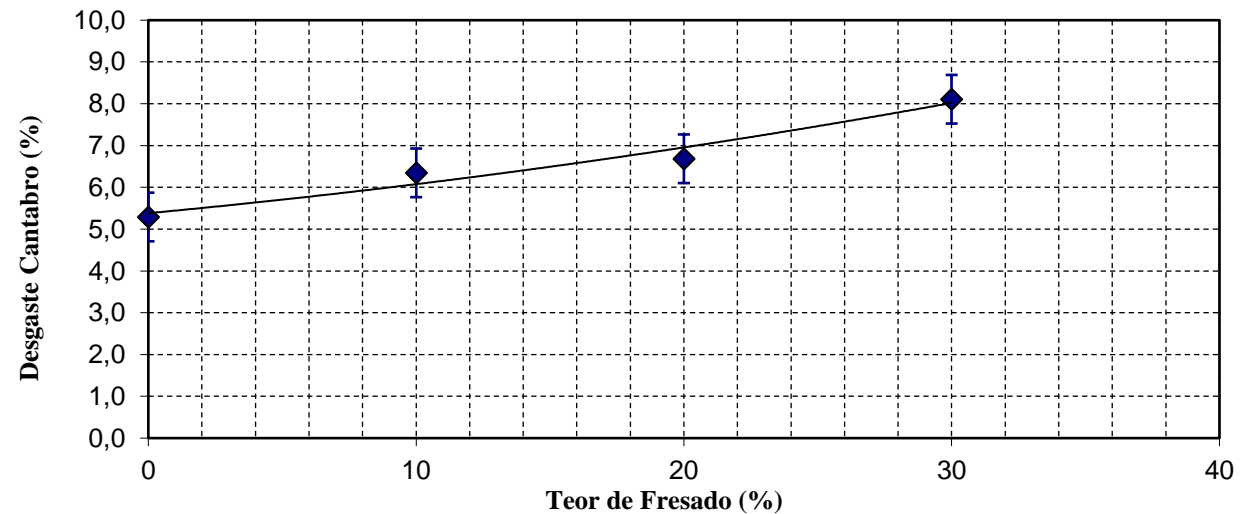
Tamanho máximo nominal

Fonte do fresado

Reproduzir usina

X

Otimizar material



AVALIAÇÃO DE MISTURAS ASFÁLTICAS RECICLADAS MORNAS COM USO DE LIGANTES CONVENCIONAL E MODIFICADO POR POLÍMERO

Dissertação KÁTIA ALINE BOHN (2017)

Mistura Convencional
CAP 50/70

Mistura Convencional
CAP 60/85

Mistura Morna
CAP 50/70

Mistura Morna
CAP 60/85

Mistura Morna 25% Fresado
CAP 50/70

Mistura Morna 25% Fresado
CAP 60/85

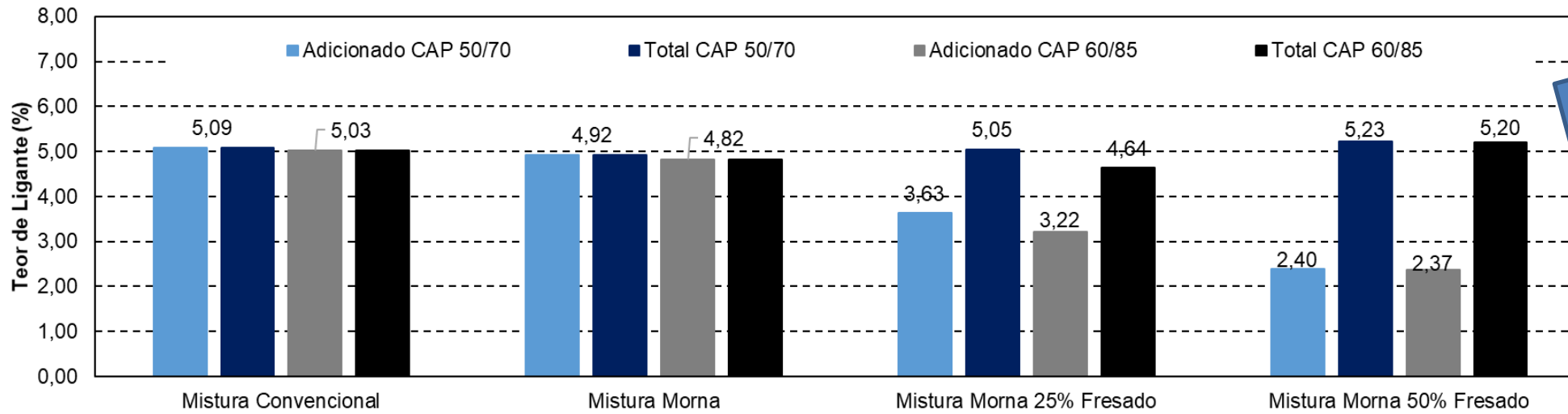
Mistura 50% Fresado
CAP 50/70

Mistura 50% Fresado
CAP 60/85

**MISTURAS
ASFÁLTICAS
RECICLADAS
MORNAS**

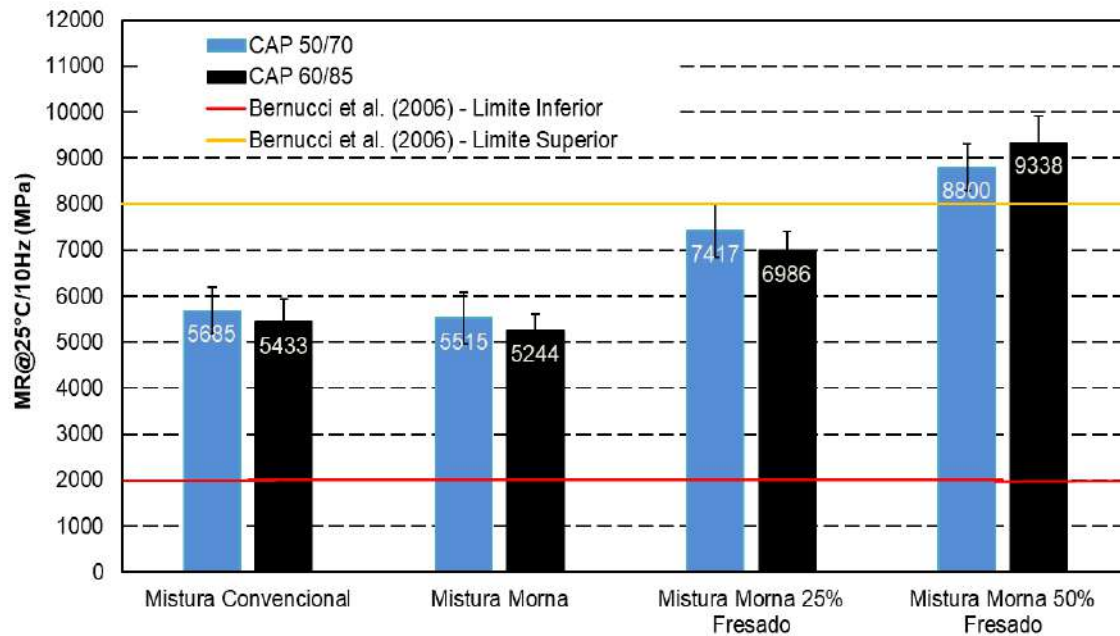
O material fresado nas moldagens era aquecido a **110°C** (por 2 a 3 horas)

Teor de ligante

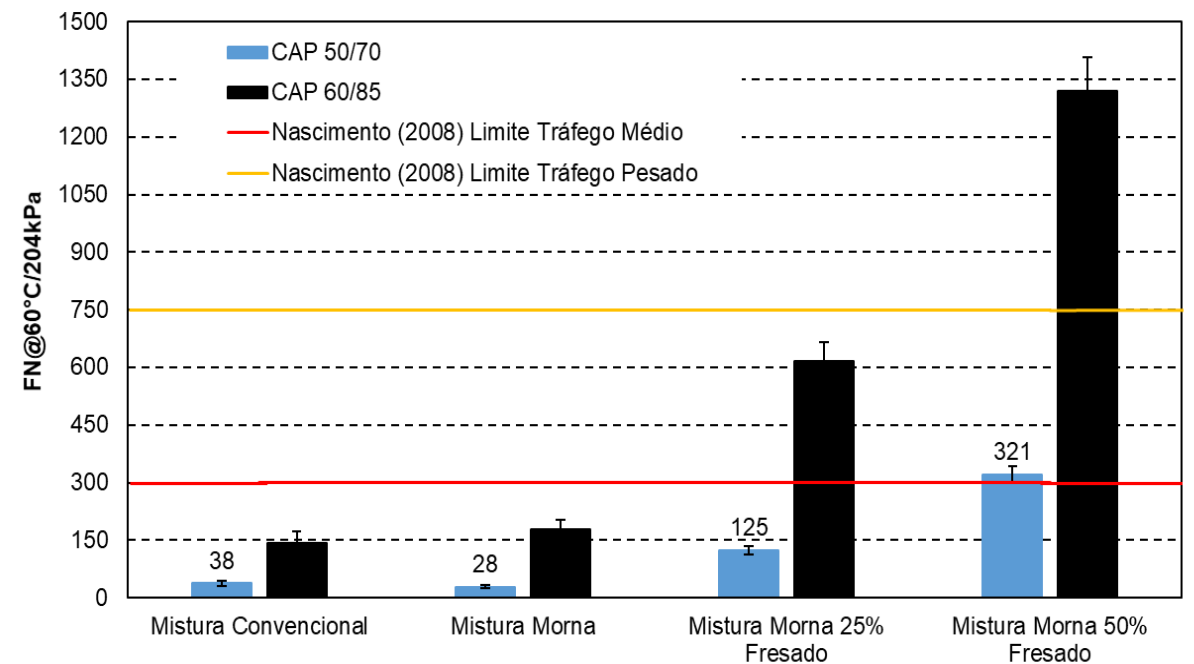


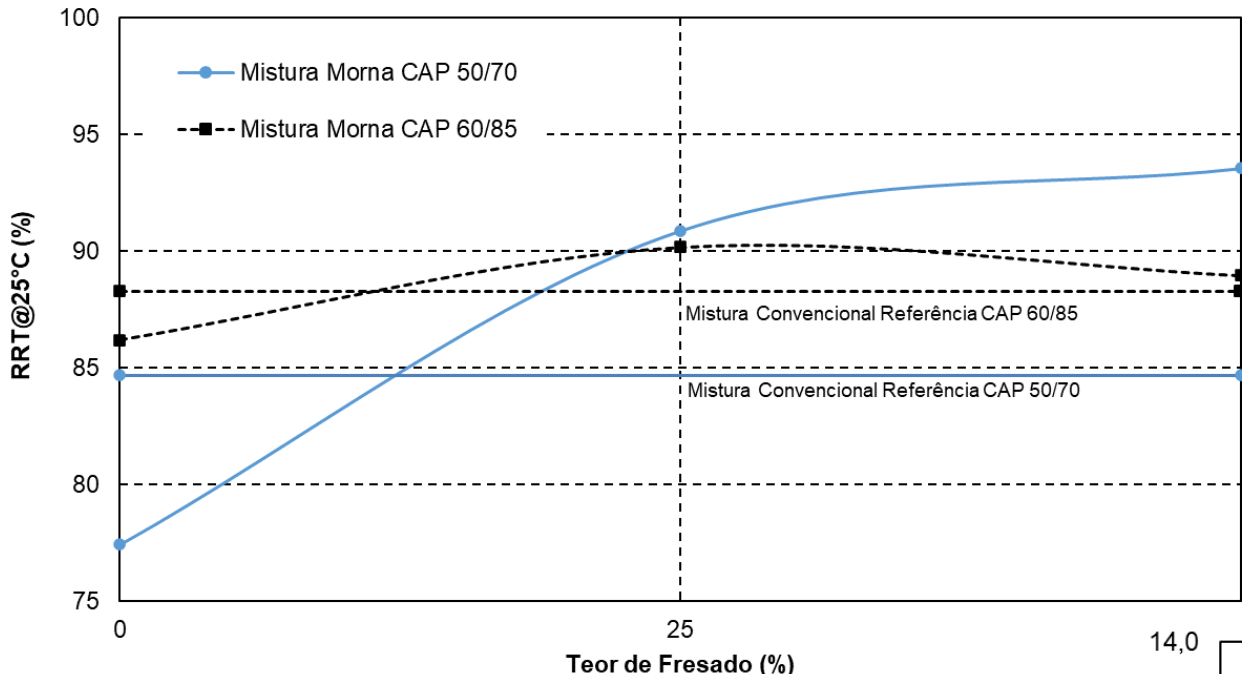
**FRESADO
NÃO "BLACK
ROCK"**

Rigidez - Módulo de Resiliência



Flow Number



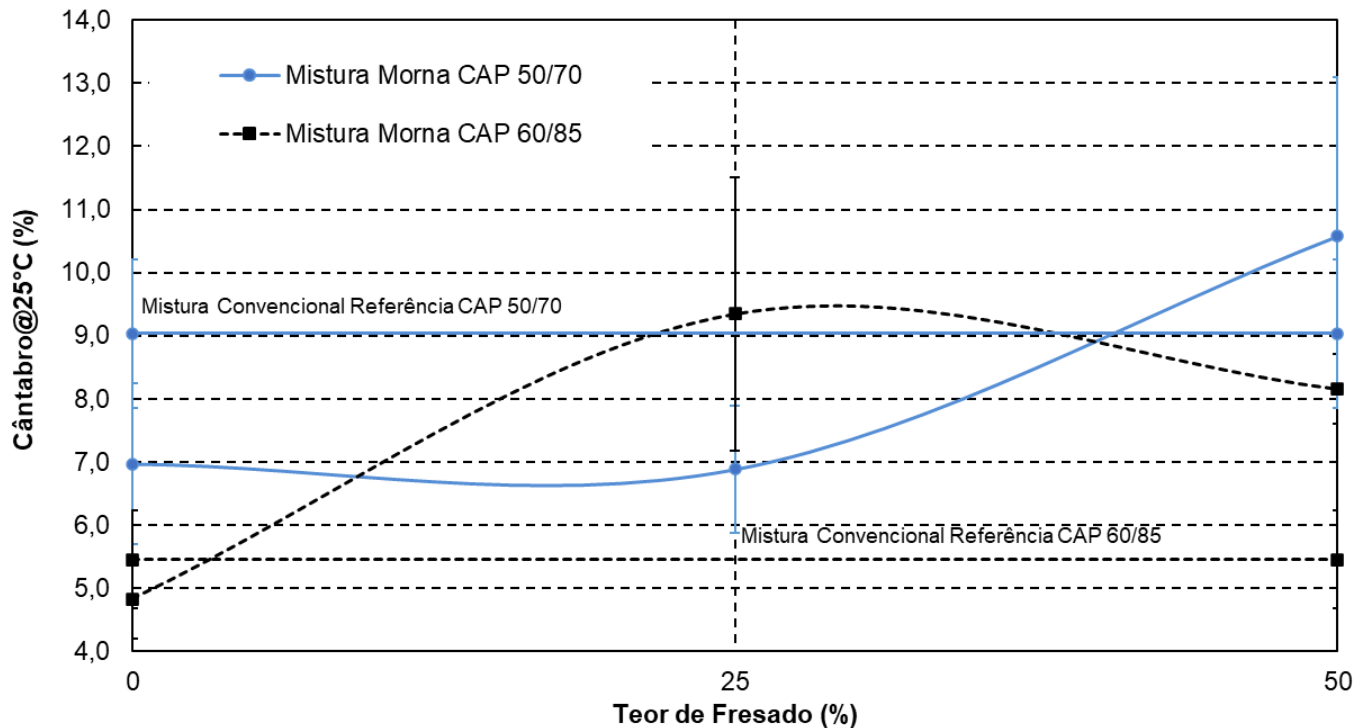


Lottman Test

Efeito Positivo do Aditivo e do ligante 80/85E

Desgaste Cantabro

Para onde ir....
Fadiga
Grau de mistura
Usinagem

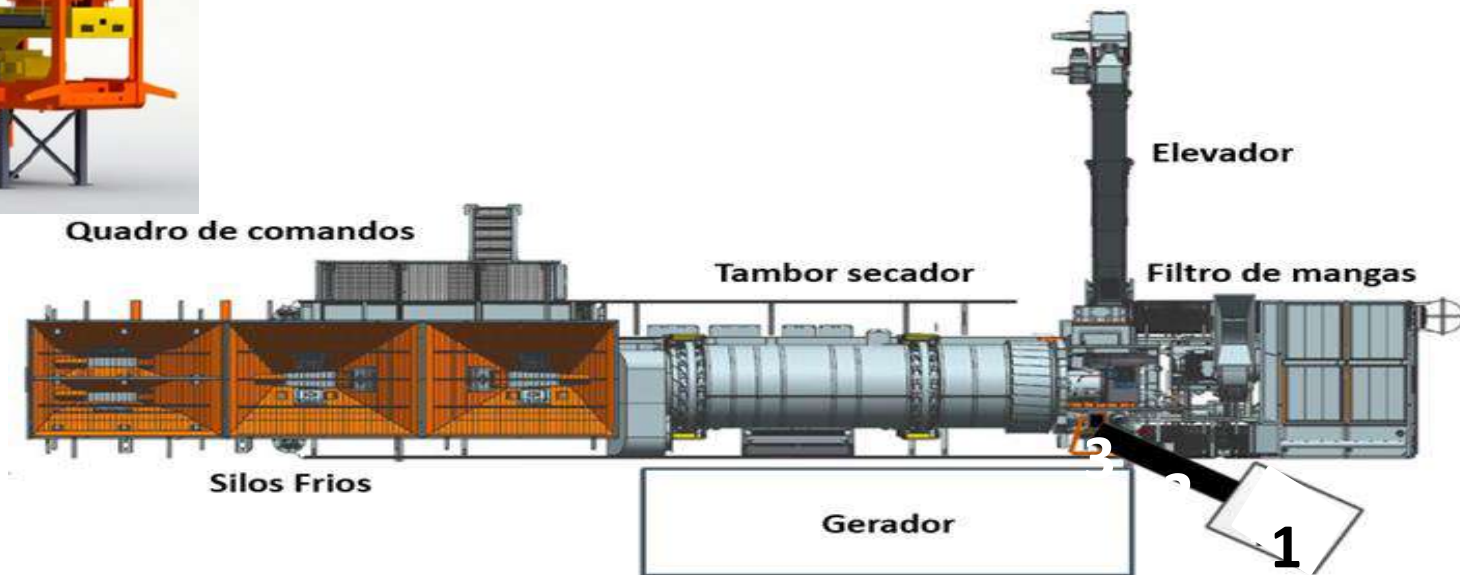


ADAPTAÇÃO DE USINA PARA RECICLAGEM À QUENTE E AVALIAÇÃO LABORATORIAL DAS MISTURAS ASFÁLTICAS PRODUZIDAS

Dissertação Felipe Cipriani Luzzi (2019)



Adaptar usina volumétrica e produzir misturas asfálticas recicladas à quente = 10, 20 e 30%



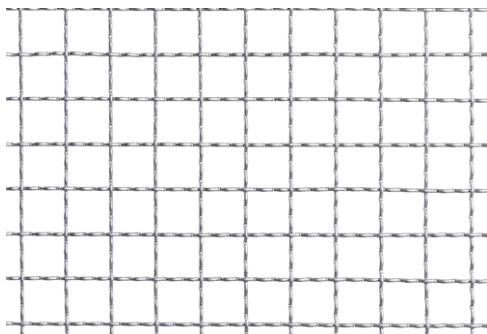
Triunfo
CONCEPA

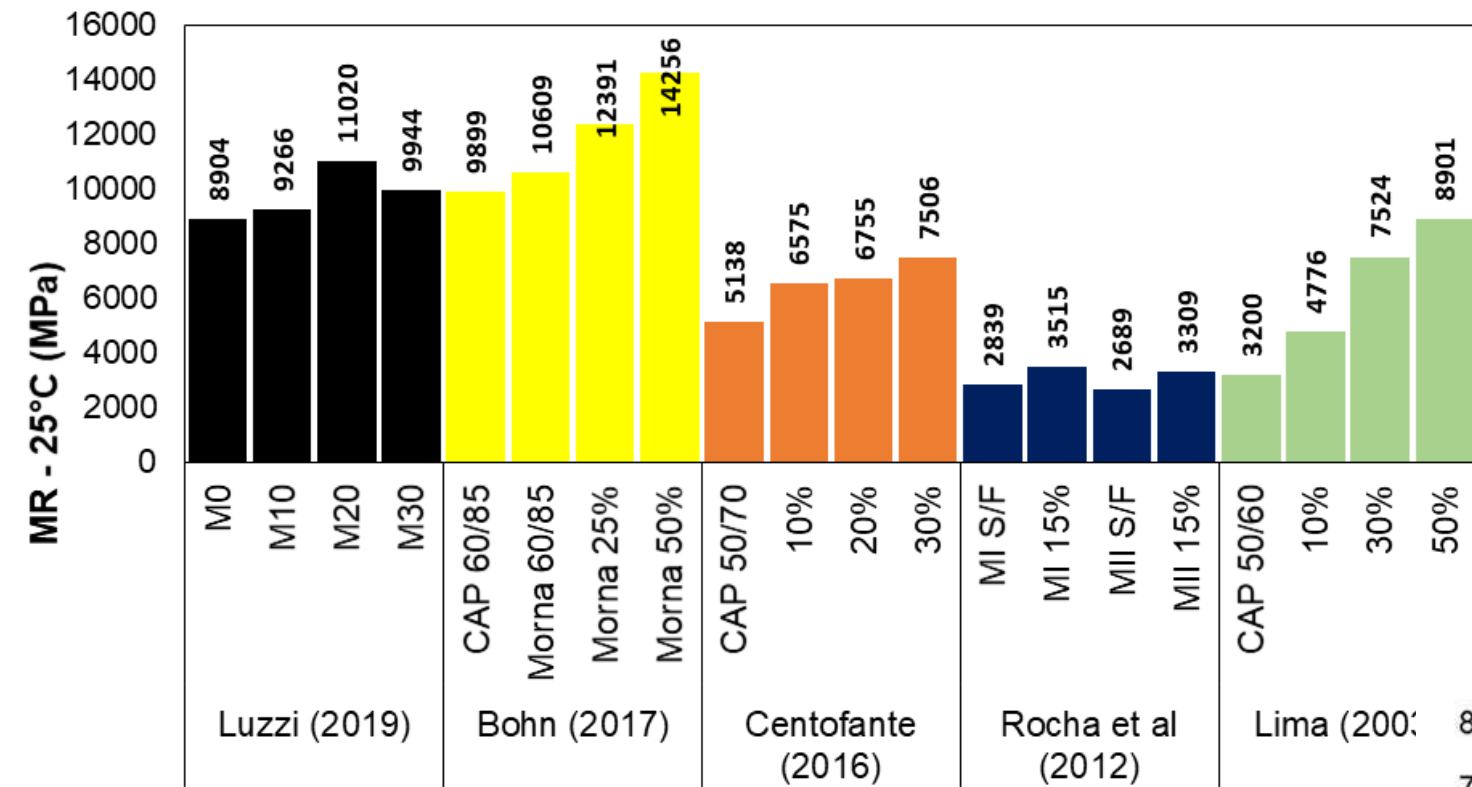


PROCESSO DE BENEFICIAMENTO/PENEIRAMENTO RAP com AMP 60-85E



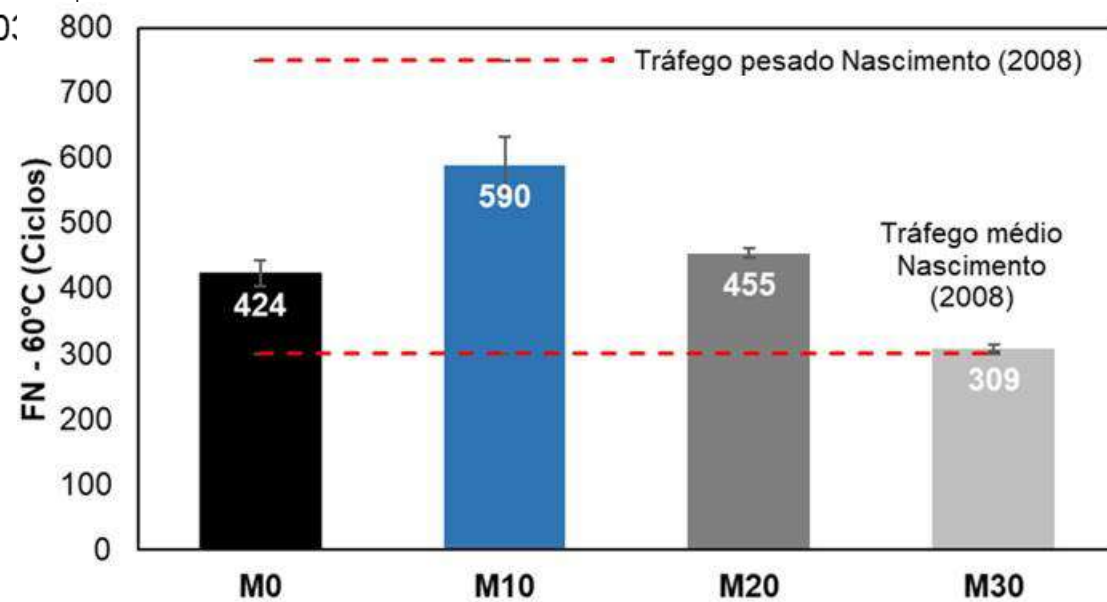
Peneira 19mm



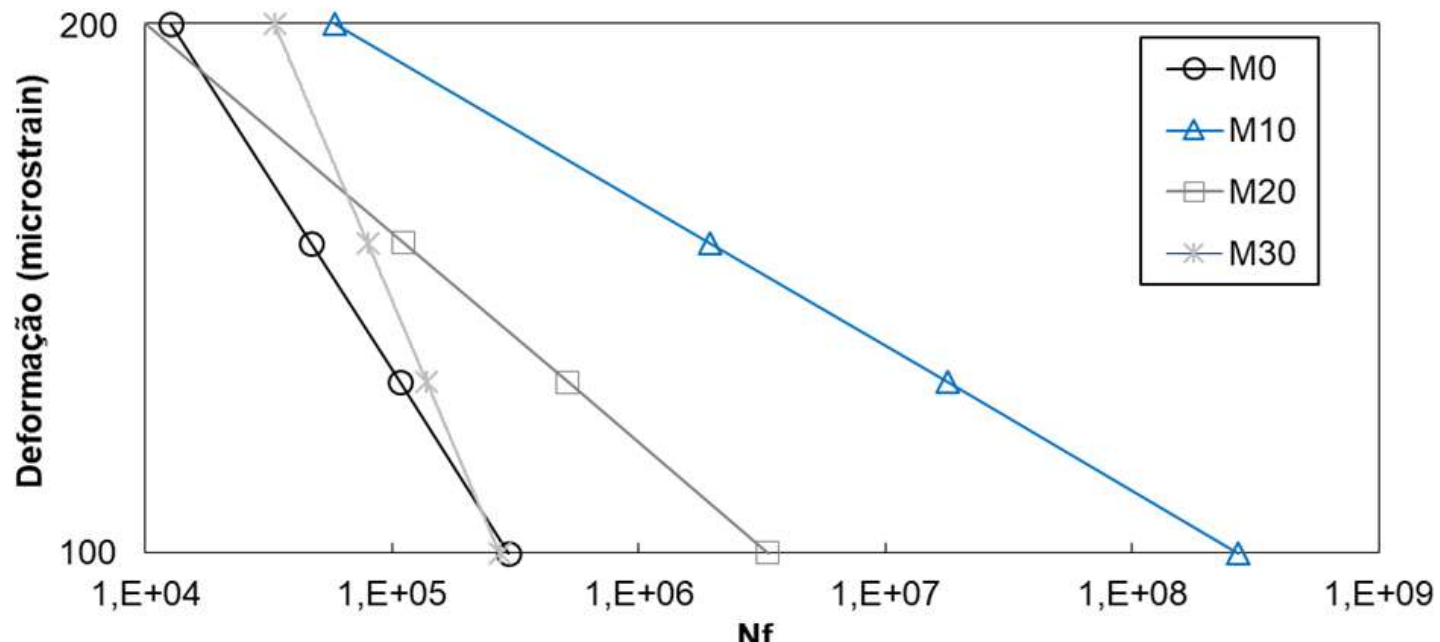
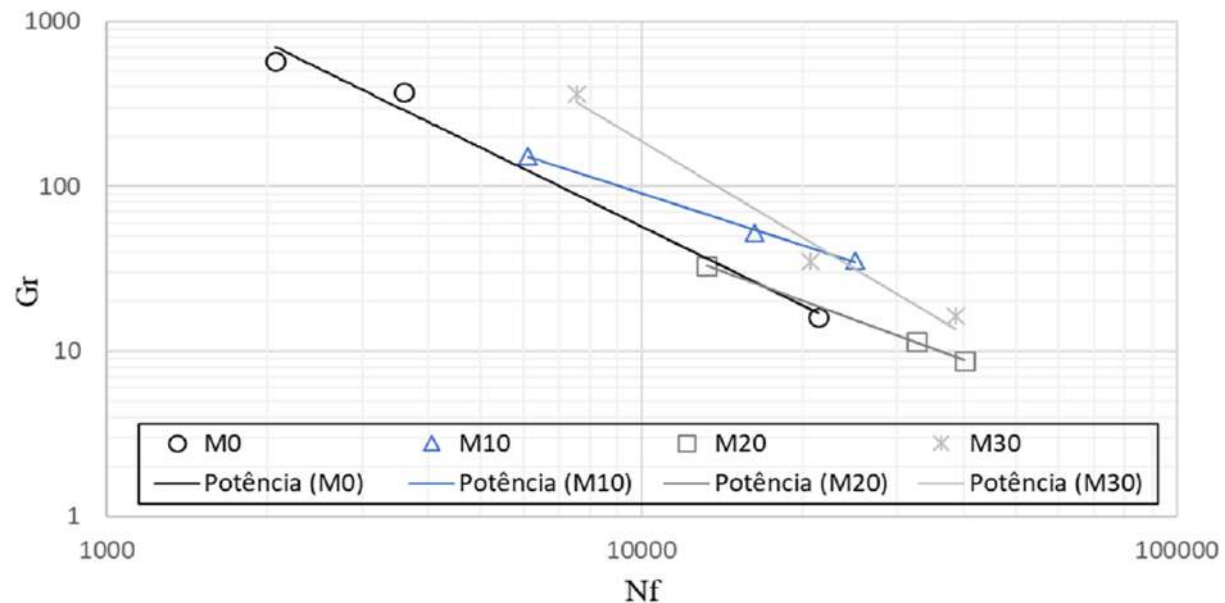
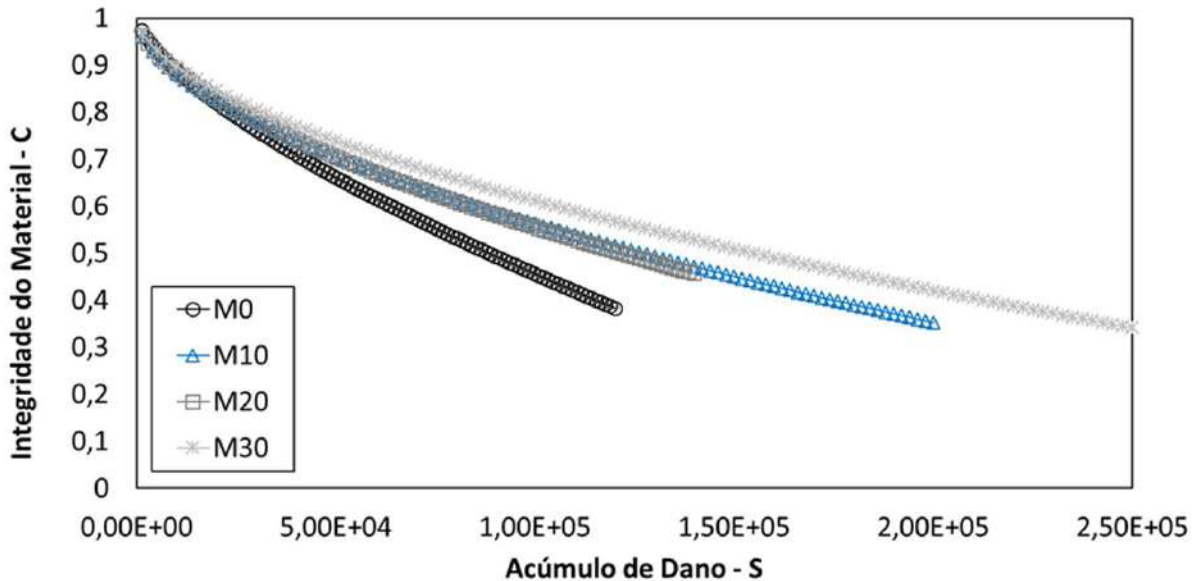


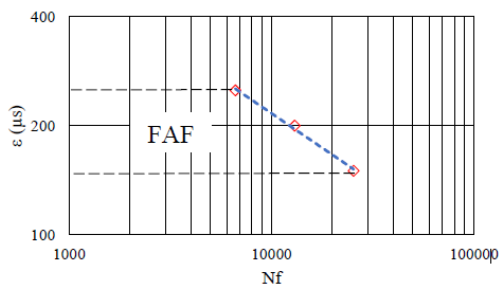
Rigidez - Módulo de Resiliência

Flow Number

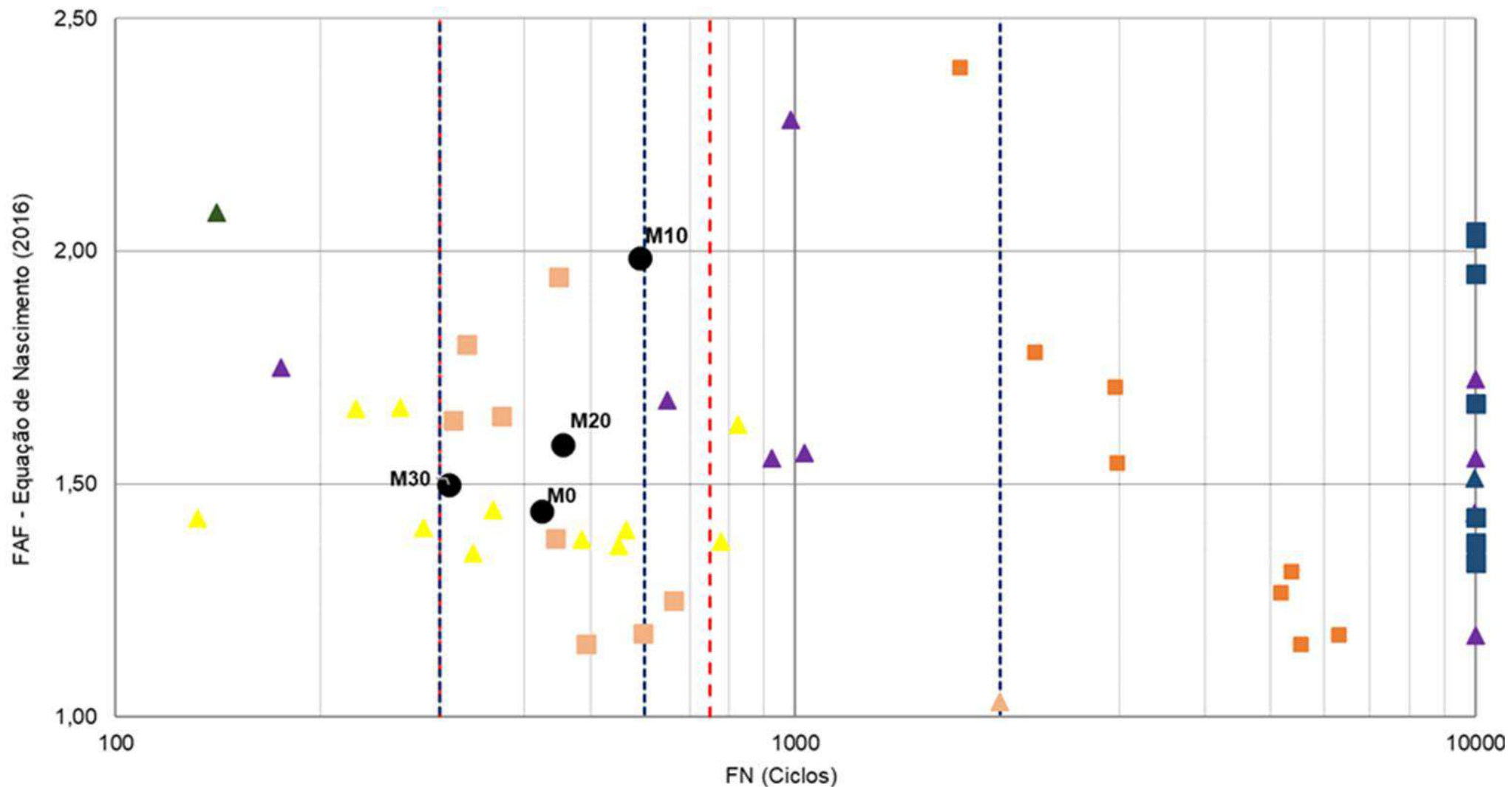


Fadiga à tração





Mistura	FAF	Posição	Mistura	FAF	Posição
Boeira (2018) AMP M	2,397	1°	Schuster (2018) ECO	1,542	27°
Schuster (2018) ECO	2,394	2°	Boeira (2018) HIMA S	1,512	28°
Schuster (2018) AMP	2,282	3°	M30	1,499	29°
Schuster (2018) ECO	2,082	4°	Schuster (2018) 50/70	1,445	30°
Boeira (2018) HIMA M	2,041	5°	M0	1,441	31°
Boeira (2018) HIMA S	2,028	6°	Schuster (2018) AMP	1,436	32°
M10	1,987	7°	Boeira (2018) HIMA S	1,429	33°
Boeira (2018) HIMA M	1,953	8°	Schuster (2018) 50/70	1,426	34°
Boeira (2018) 50/70 M	1,944	9°	Schuster (2018) 50/70	1,405	35°
Boeira (2018) 50/70 M	1,800	10°	Schuster (2018) 50/70	1,400	36°
Boeira (2018) AMP M	1,785	11°	Boeira (2018) 50/70 S	1,383	37°
Schuster (2018) AMP	1,750	12°	Schuster (2018) 50/70	1,382	38°
Schuster (2018) AMP	1,725	13°	Schuster (2018) 50/70	1,376	39°
Boeira (2018) AMP M	1,709	14°	Boeira (2018) HIMA M	1,374	40°
Schuster (2018) AMP	1,680	15°	Schuster (2018) 50/70	1,368	41°
Boeira (2018) HIMA M	1,674	16°	Schuster (2018) 50/70	1,351	42°
Schuster (2018) 50/70	1,665	17°	Boeira (2018) HIMA S	1,331	43°
Schuster (2018) 50/70	1,661	18°	Boeira (2018) AMP S	1,313	44°
Boeira (2018) 50/70 M	1,647	19°	Boeira (2018) AMP S	1,269	45°
Boeira (2018) 50/70 M	1,638	20°	Boeira (2018) 50/70 S	1,248	46°
Schuster (2018) 50/70	1,628	21°	Boeira (2018) 50/70 S	1,178	47°
M20	1,584	22°	Schuster (2018) AMP	1,175	48°
Schuster (2018) AMP	1,567	23°	Boeira (2018) AMP S	1,175	49°
Schuster (2018) AMP	1,555	24°	Boeira (2018) AMP S	1,157	50°
Schuster (2018) AMP	1,555	25°	Boeira (2018) 50/70 S	1,156	51°
Boeira (2018) AMP M	1,546	26°	Schuster (2018) TLAf	1,031	52°



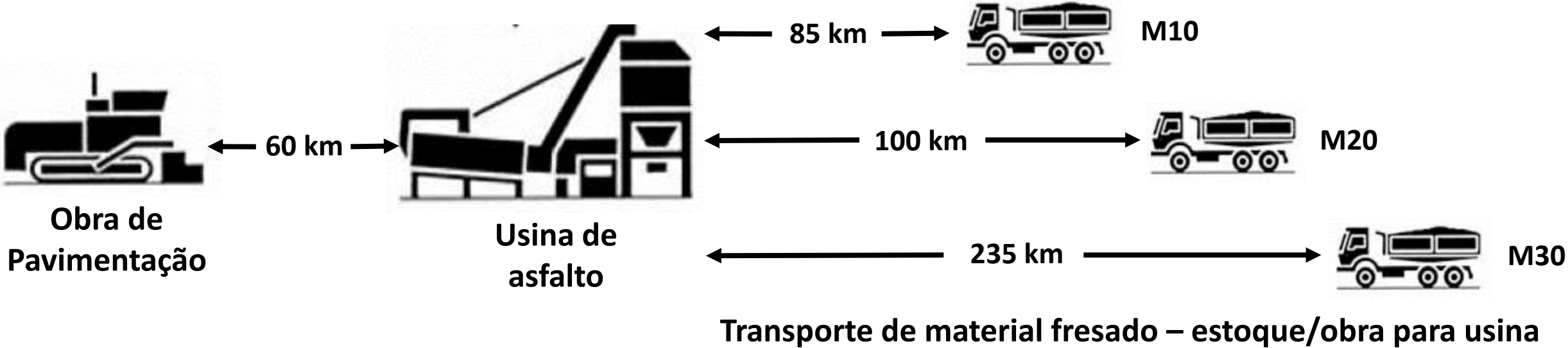
- LUZZI (2019)
- ▲ SCHUSTER (2018) TLAF
- ▲ SCHUSTER (2018) 50/70
- BOEIRA (2018) 50/70
- ▲ SCHUSTER (2018) AMP
- BOEIRA (2018) AMP
- ▲ SCHUSTER (2018) ECO
- BOEIRA (2018) HIMA
- - - Tráfego Médio Nascimento (2008)
- - - Tráfego Pesado Nascimento (2008)
- - - Tráfego Médio Faccin (2018)
- - - Tráfego Pesado Faccin (2018)
- - - Tráfego Ext. Pesado Faccin (2018)

ENSAIOS LABORATORIAIS – FADIGA A TRAÇÃO-COMPRESSÃO

Custos da usinagem e aplicação das misturas

Mistura	Total ligante R\$/m ³	Total serviço + transp. R\$/m ³	Total transp. Fresado R\$/m ³	Total R\$/m ³
M0	R\$ 347,21	R\$ 329,74	R\$ -	R\$ 676,94
M10	R\$ 325,27	R\$ 344,95	R\$ 4,69	R\$ 674,91
M20	R\$ 298,82	R\$ 362,00	R\$ 9,38	R\$ 670,20
M30	R\$ 240,61	R\$ 381,13	R\$ 14,08	R\$ 635,82

≈ 6,5% ↓ \$\$



Custos da usinagem e aplicação das misturas – após deterioração das estruturas

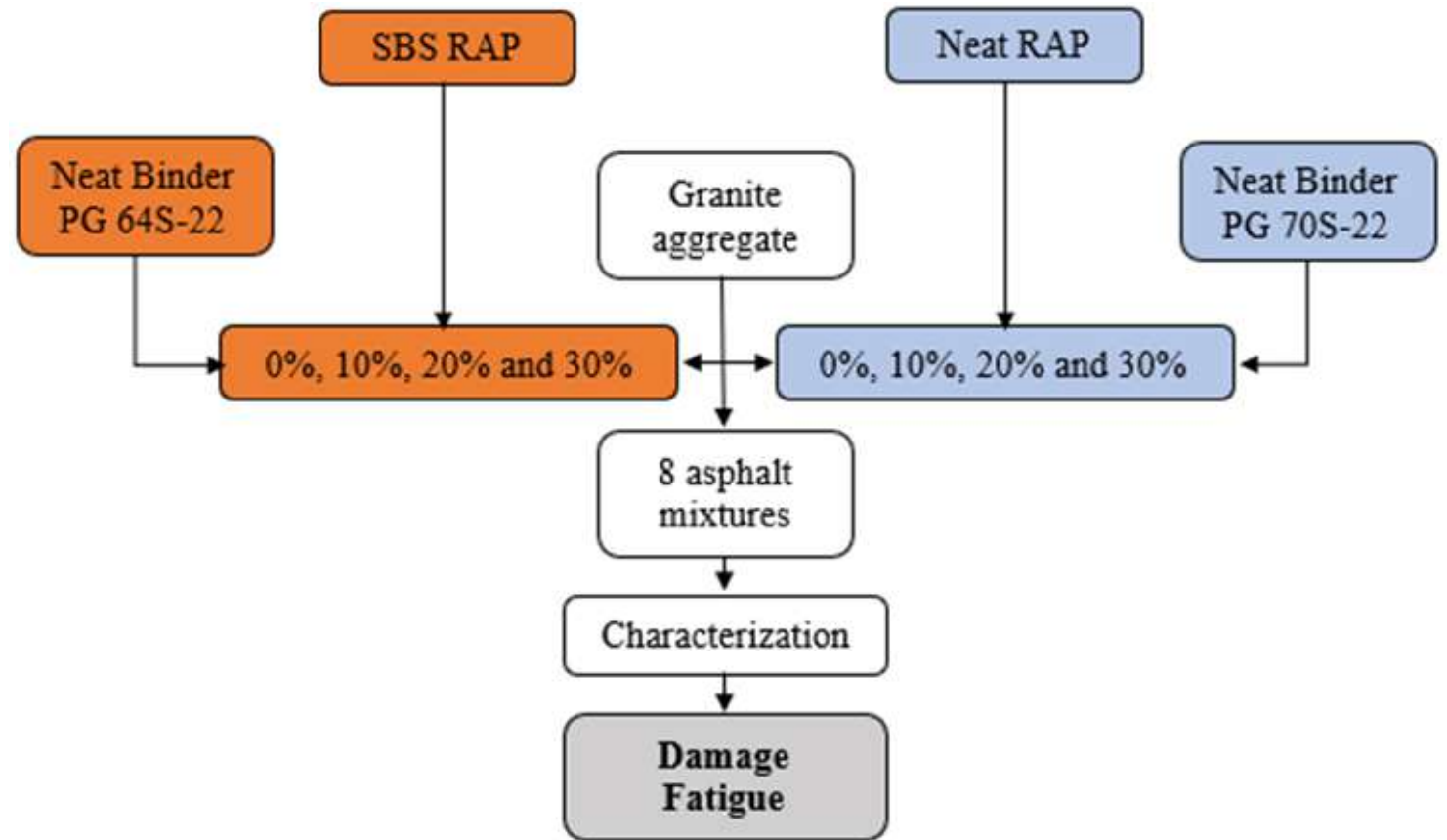
	Espessuras (cm)	Módulo (MPa)	ν
REVESTIMENTO	5, 10 e 15	E* (cada mistura)	0,35
BASE	15	202	0,3
SUBBASE	20	197	0,4
SUBLEITO	0	84	0,45

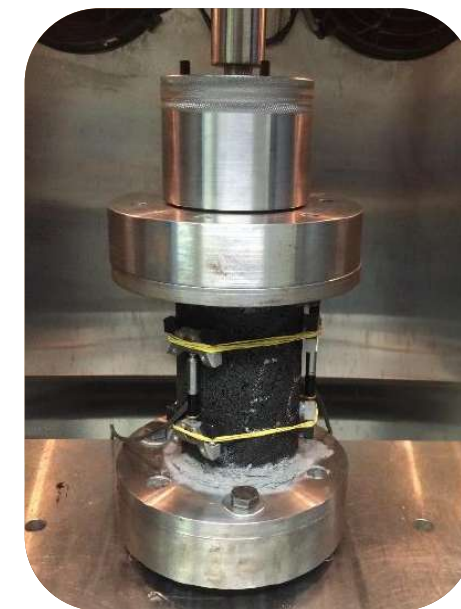
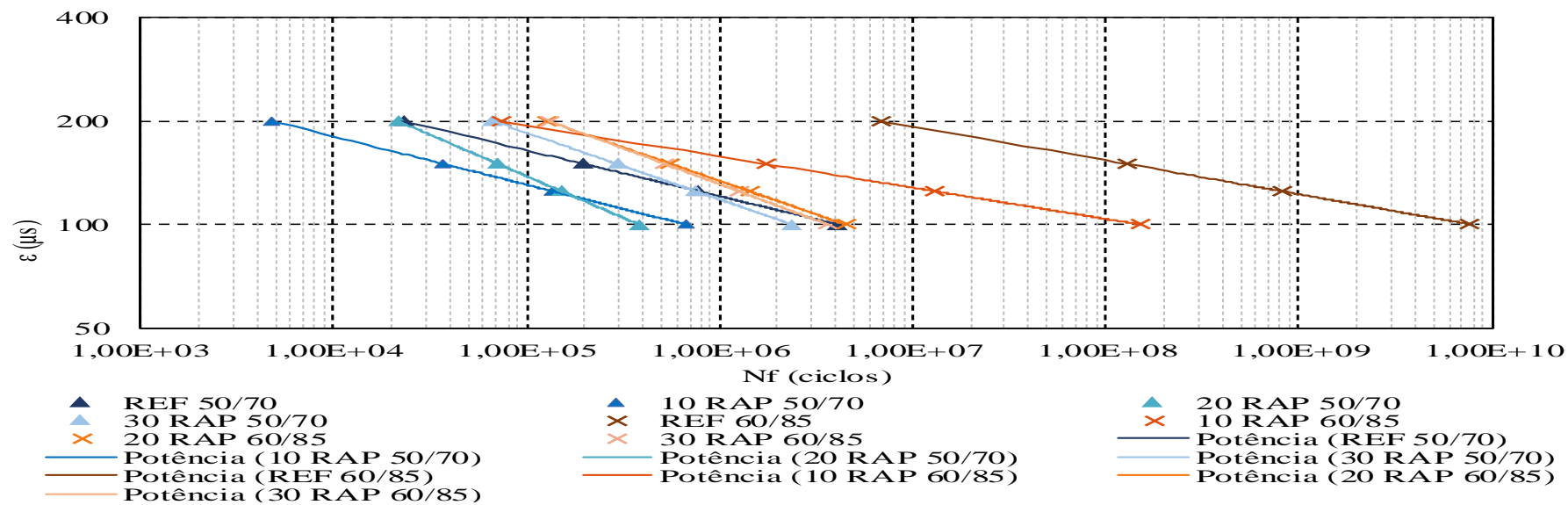
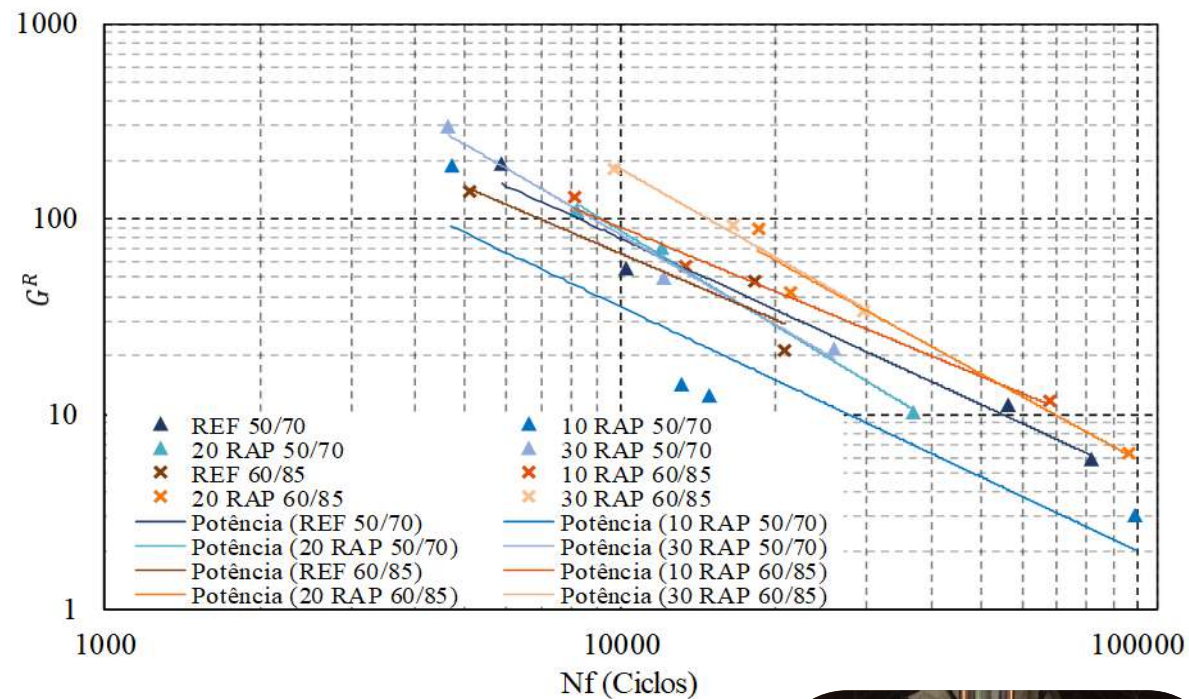
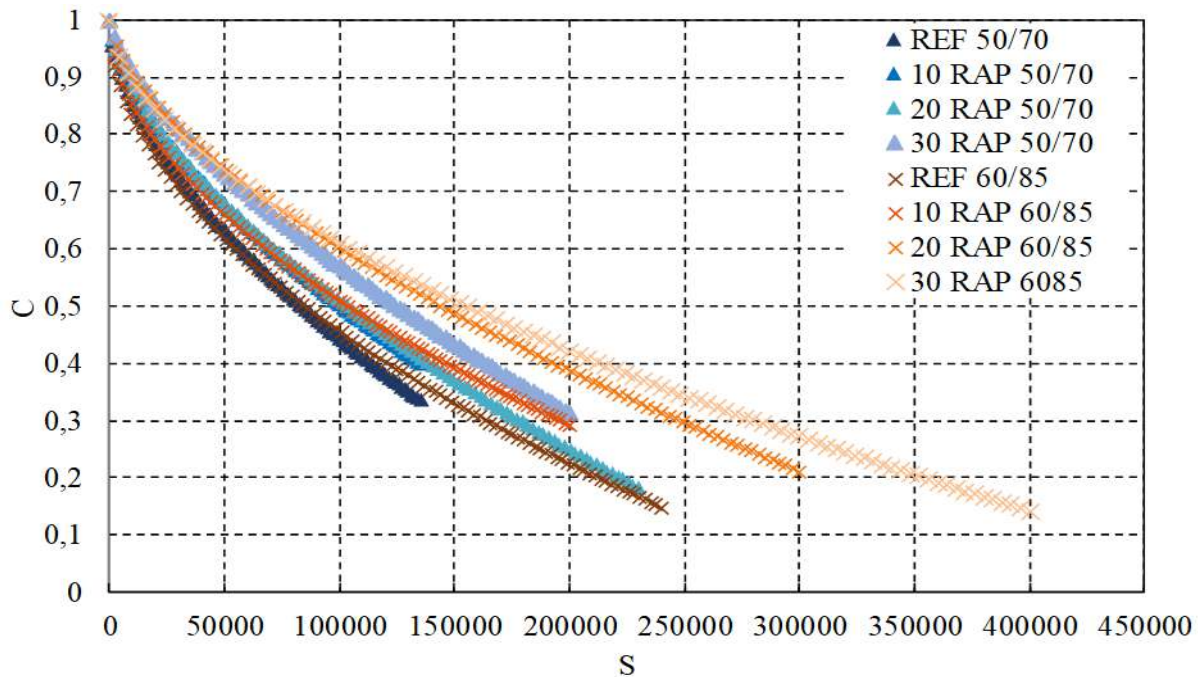
Mistura	R\$/ton	Nf	R\$/Nf
M0	R\$ 676,94	250000	R\$ 0,0027078
M10	R\$ 674,91	81123813	R\$ 0,0000083
M20	R\$ 670,20	71909000	R\$ 0,0000093
M30	R\$ 635,82	166667	R\$ 0,0038149

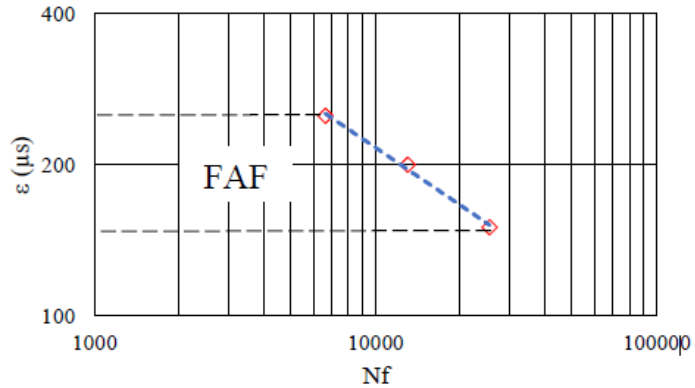
- ✓ Verifica-se que, avaliando unicamente o valor associado aos serviços, a escolha seria por utilizar a mistura com 30% de material fresado, o que pode se tornar equivocado.
- ✓ Quando se analisa o R\$/Nf, nota-se que, assim como nos resultados de ensaios que inferem a resistência a deformação permanente e de vida de fadiga, o ideal é a escolha da mistura com 10% de RAP – muito em função do processo de usinagem

ANÁLISE DE RIGIDEZ E DANIFICAÇÃO DE MISTURAS ASFÁLTICAS RECICLADAS A QUENTE COM DIFERENTES TIPOS E TEORES DE RAP

Dissertação: Bethania Machado Correa (2020)



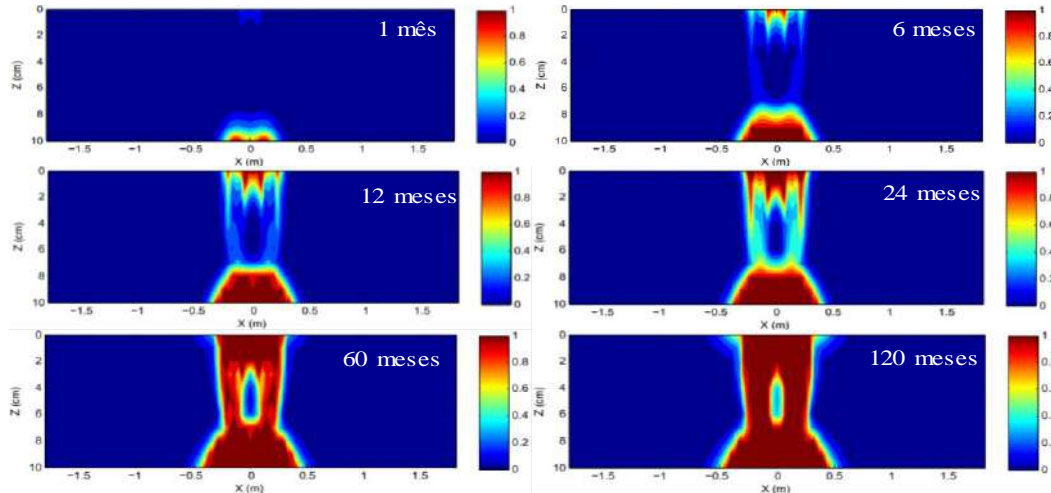
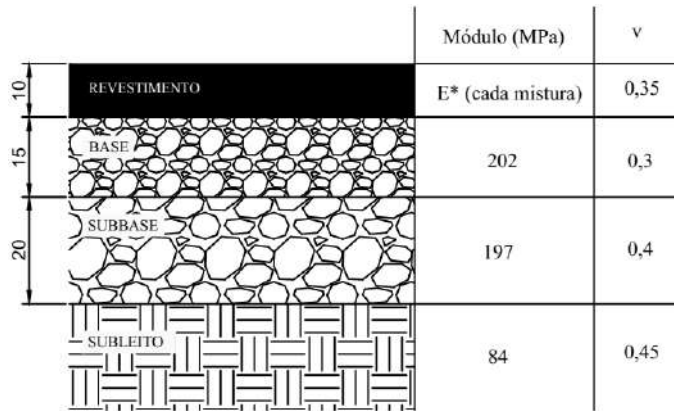




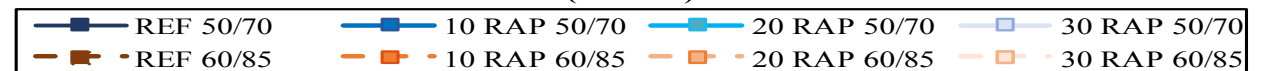
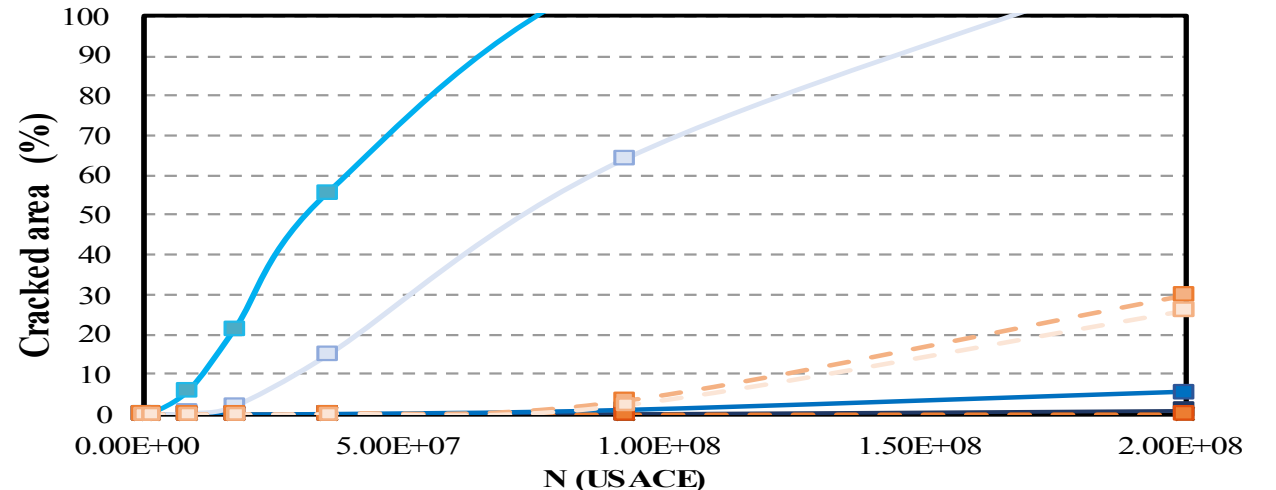
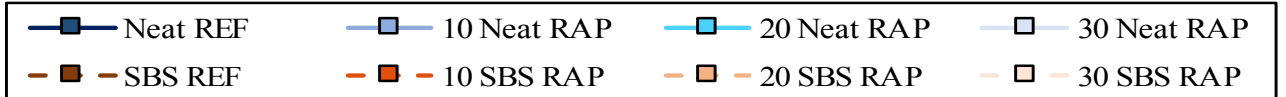
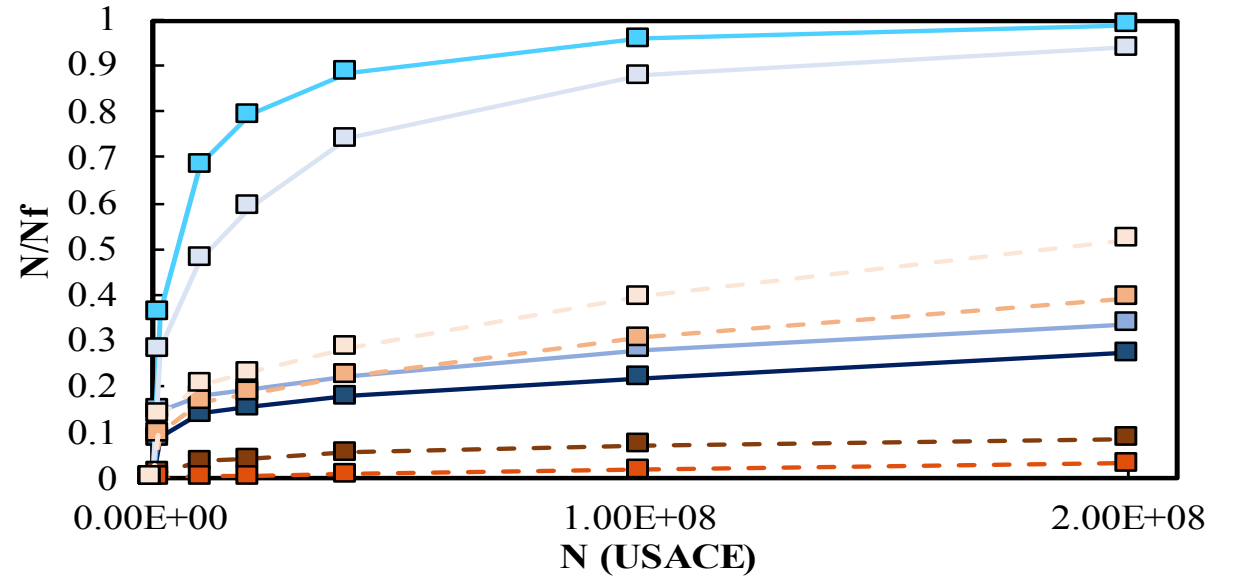
Mistura	FFM	Posição
REF 60/85	2,517	1°
Boeira (2018) AMP M	2,397	2°
Schuster (2018) ECO	2,394	3°
Schuster (2018) AMP	2,282	4°
Schuster (2018) ECO	2,082	5°
Boeira (2018) HIMA M	2,041	6°
Boeira (2018) HIMA S	2,028	7°
<i>Luzzi (2019) M10</i>	<i>1,987</i>	<i>8°</i>
10 RAP 60/85	1,962	9°
Boeira (2018) HIMA M	1,953	10°
Boeira (2018) 50/70 M	1,944	11°
Boeira (2018) 50/70 M	1,800	12°
Boeira (2018) AMP M	1,785	13°
20 RAP 60/85	1,769	14°
30 RAP 60/85	1,758	15°
Schuster (2018) AMP	1,750	16°
Schuster (2018) AMP	1,725	17°
Boeira (2018) AMP M	1,709	18°
Schuster (2018) AMP	1,680	19°
Boeira (2018) HIMA M	1,674	20°
Schuster (2018) 50/70	1,665	21°
Schuster (2018) 50/70	1,661	22°
REF 50/70	1,651	23°
Boeira (2018) 50/70 M	1,647	24°
Boeira (2018) 50/70 M	1,638	25°
Schuster (2018) 50/70	1,628	26°
30 RAP 50/70	1,611	27°
<i>Luzzi (2019) M20</i>	<i>1,584</i>	<i>28°</i>
Schuster (2018) AMP	1,567	29°
Schuster (2018) AMP	1,555	30°

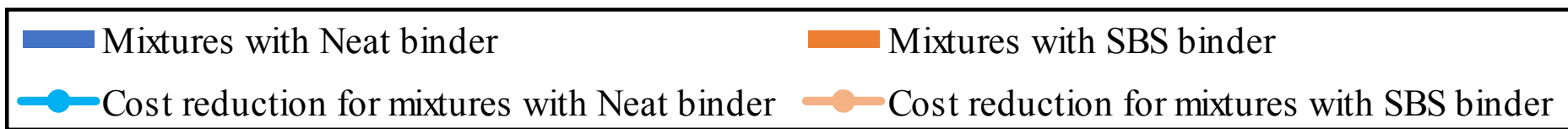
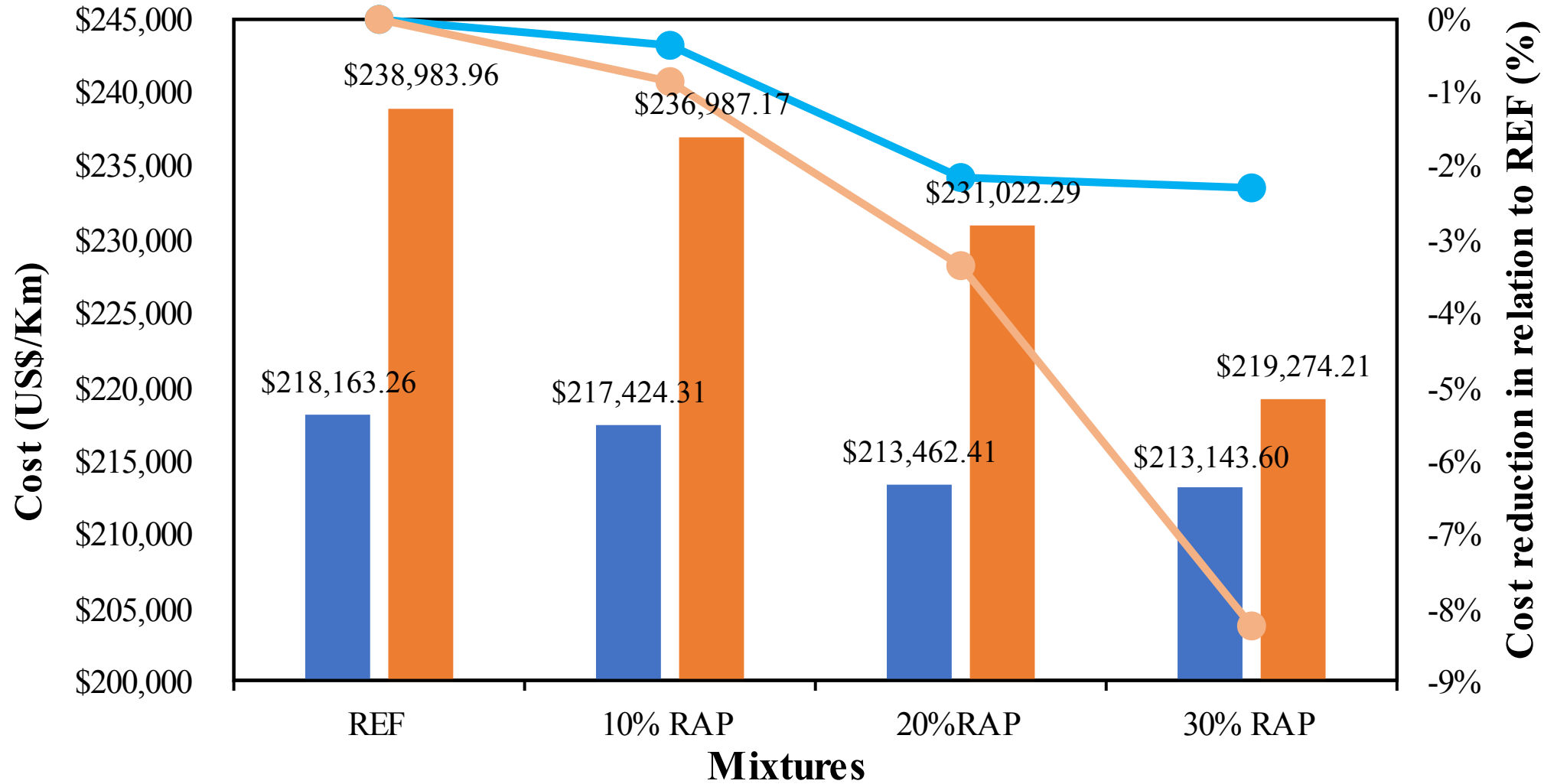
Mistura	FFM	Posição
Schuster (2018) AMP	1,555	31°
Boeira (2018) AMP M	1,546	32°
Schuster (2018) ECO	1,542	33°
Boeira (2018) HIMA S	1,512	34°
<i>Luzzi (2019) M30</i>	<i>1,499</i>	<i>35°</i>
20 RAP 50/70	1,492	36°
Schuster (2018) 50/70	1,445	37°
<i>Luzzi (2019) M0</i>	<i>1,441</i>	<i>38°</i>
Schuster (2018) AMP	1,436	39°
10 RAP 50/70	1,430	40°
Boeira (2018) HIMA S	1,429	41°
Schuster (2018) 50/70	1,426	42°
Schuster (2018) 50/70	1,405	43°
Schuster (2018) 50/70	1,400	44°
Boeira (2018) 50/70 S	1,383	45°
Schuster (2018) 50/70	1,382	46°
Schuster (2018) 50/70	1,376	47°
Boeira (2018) HIMA M	1,374	48°
Schuster (2018) 50/70	1,368	49°
Schuster (2018) 50/70	1,351	50°
Boeira (2018) HIMA S	1,331	51°
Boeira (2018) AMP S	1,313	52°
Boeira (2018) AMP S	1,269	53°
Boeira (2018) 50/70 S	1,248	54°
Boeira (2018) 50/70 S	1,178	55°
Schuster (2018) AMP	1,175	56°
Boeira (2018) AMP S	1,175	57°
Boeira (2018) AMP S	1,157	58°
Boeira (2018) 50/70 S	1,156	59°
Schuster (2018) TLAF	1,031	60°

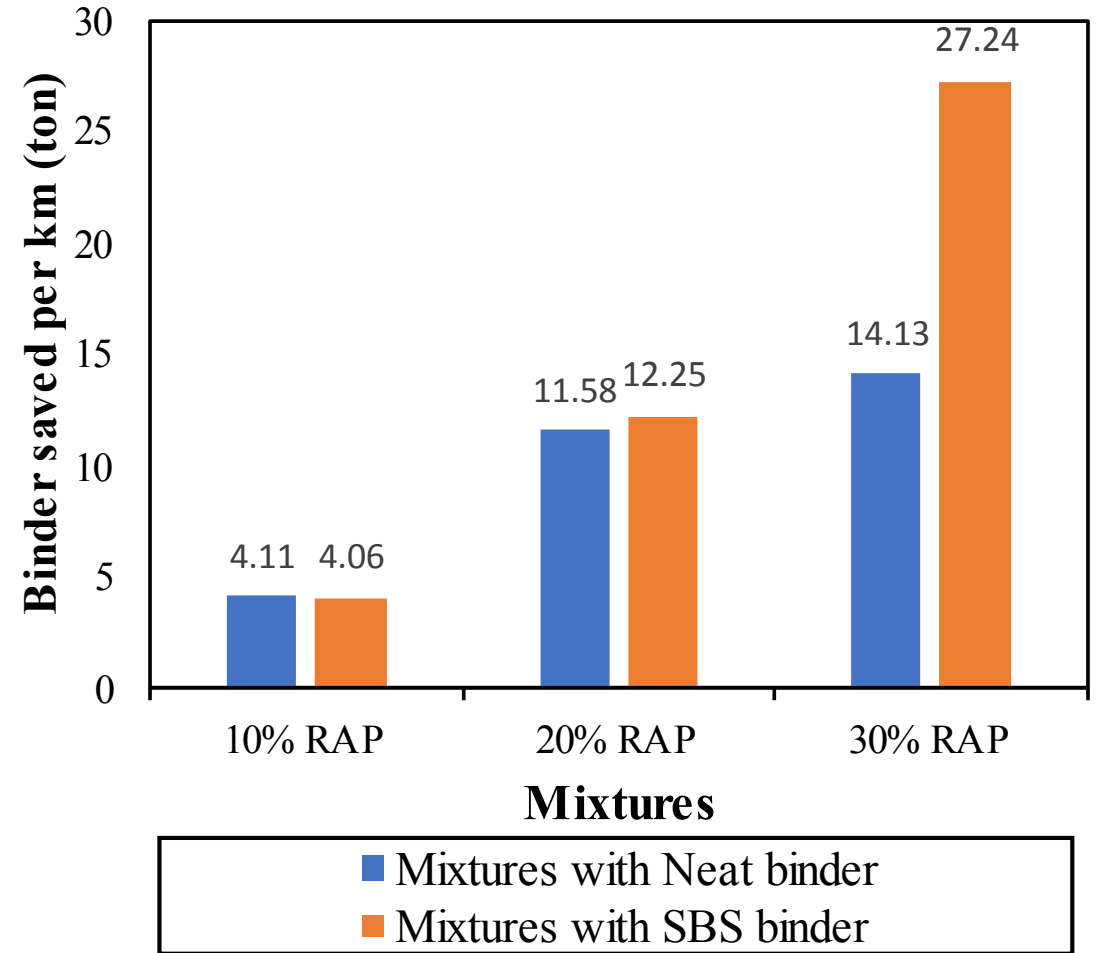
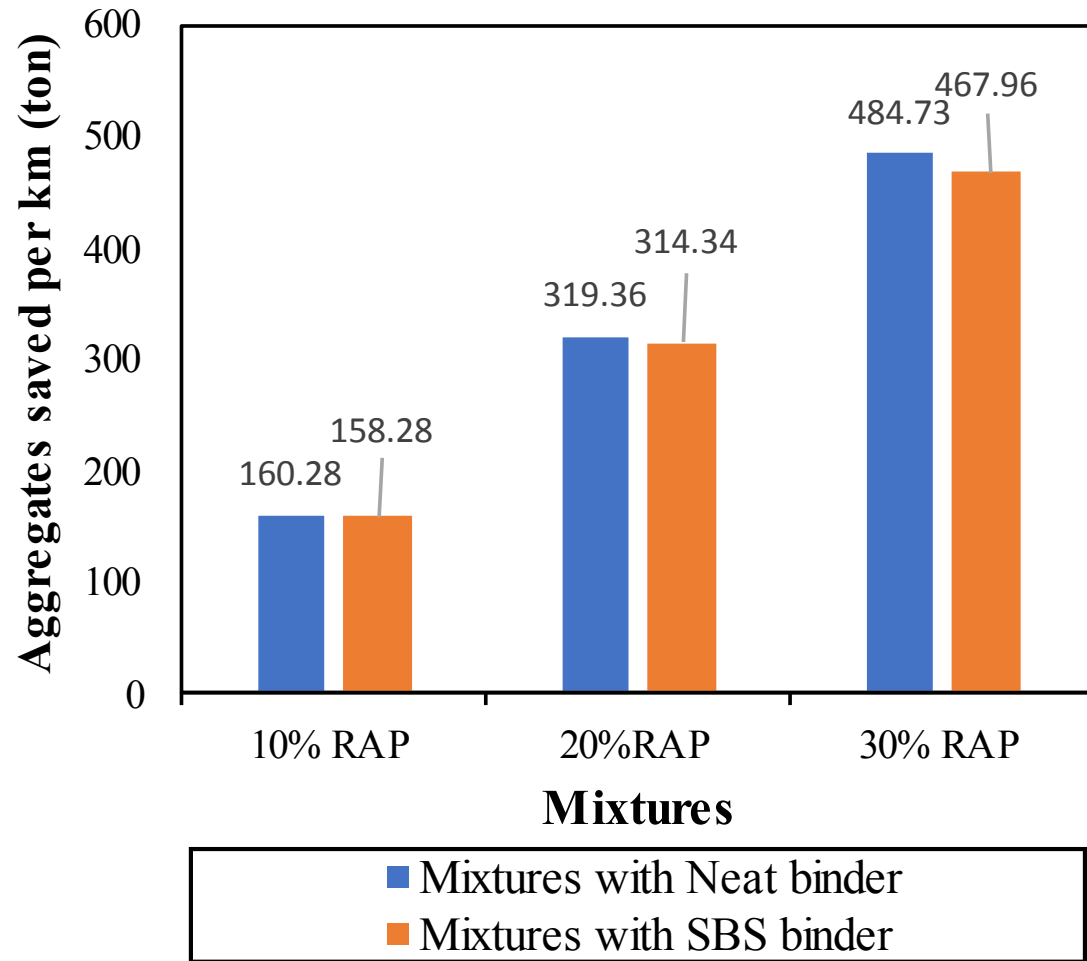


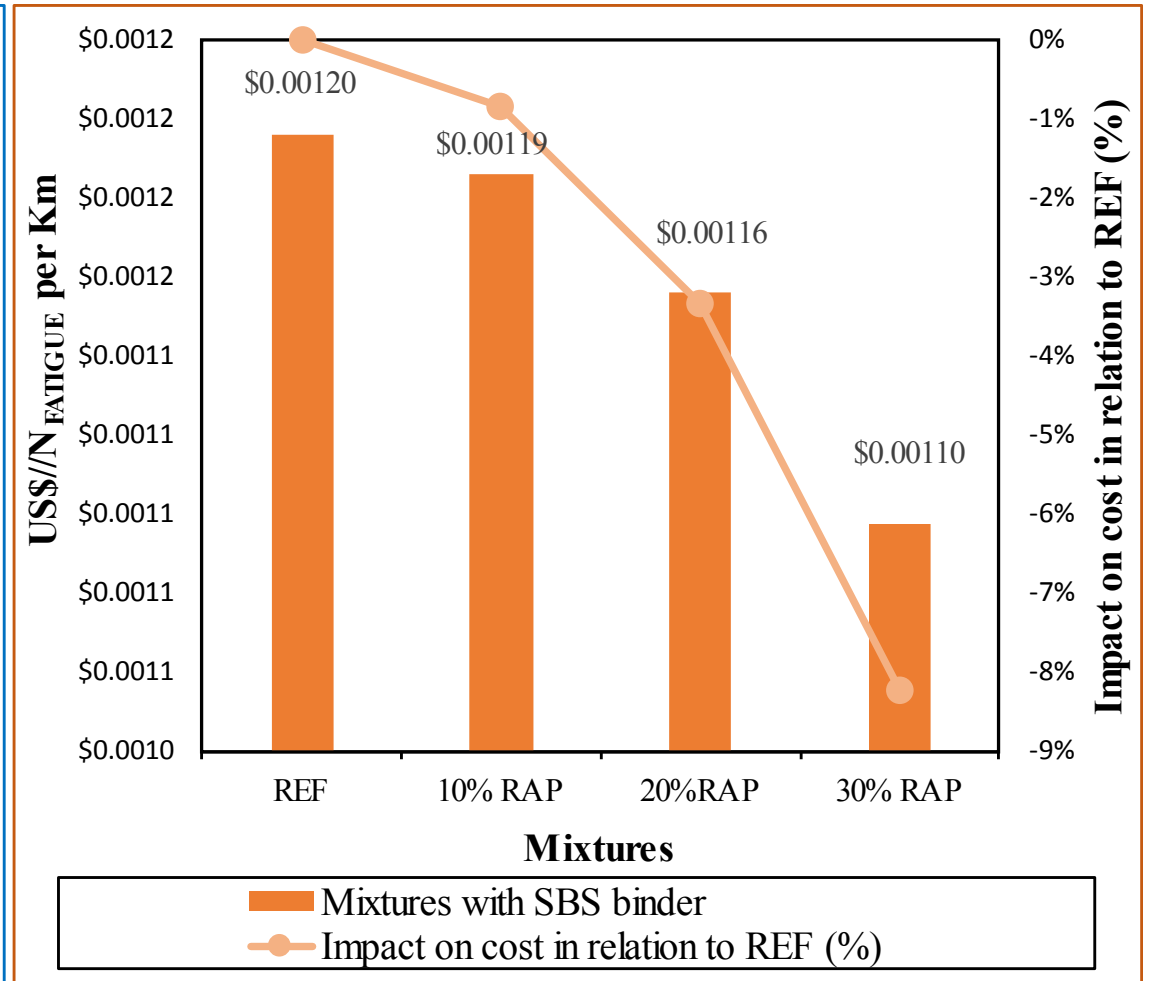
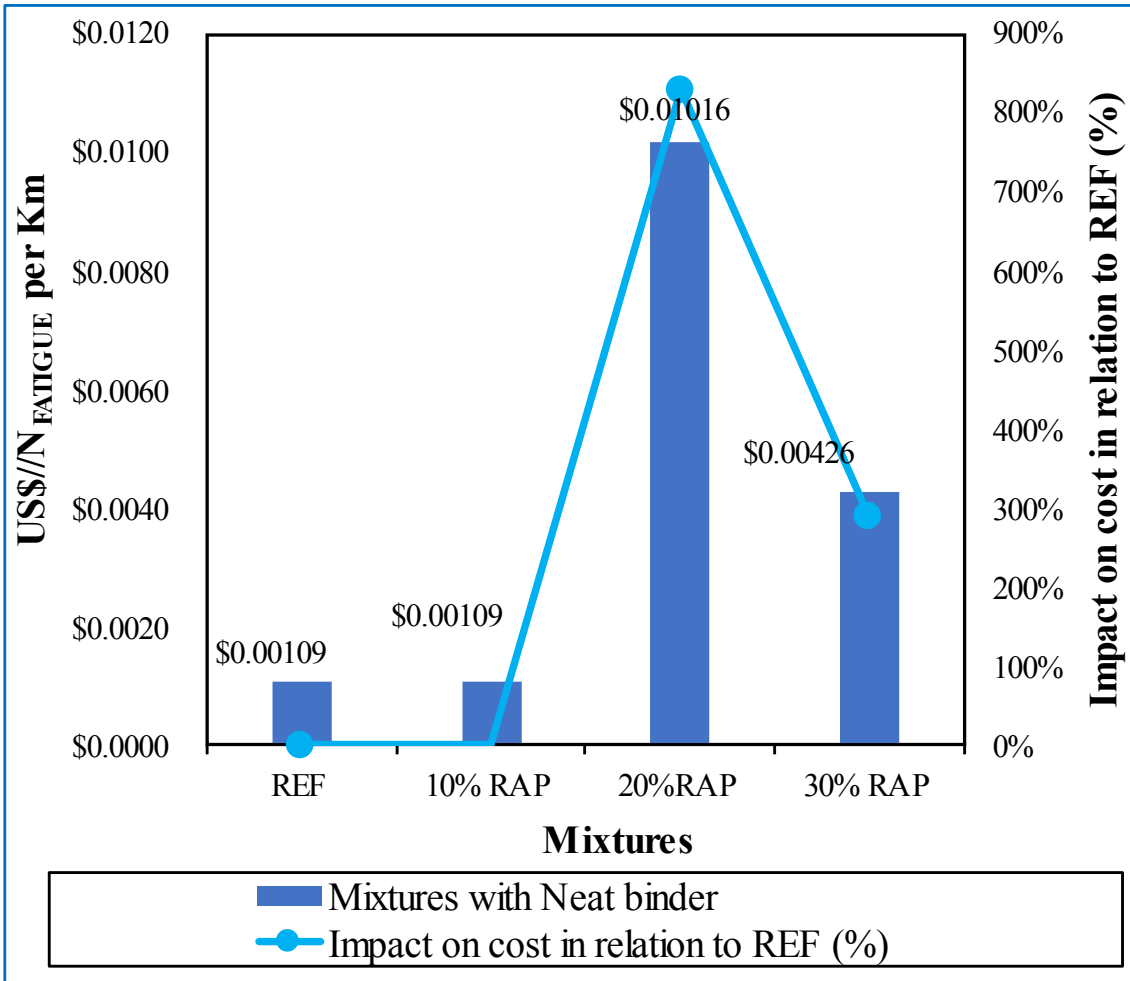


**Fadiga - importância do ligante e do fresado
+ fresado - piora a fadiga**



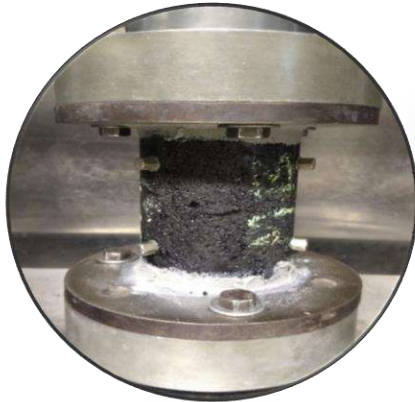
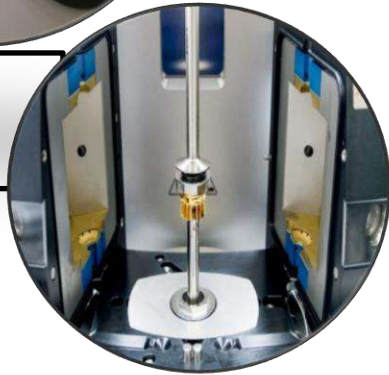
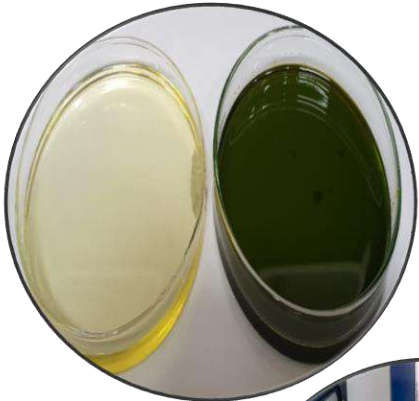
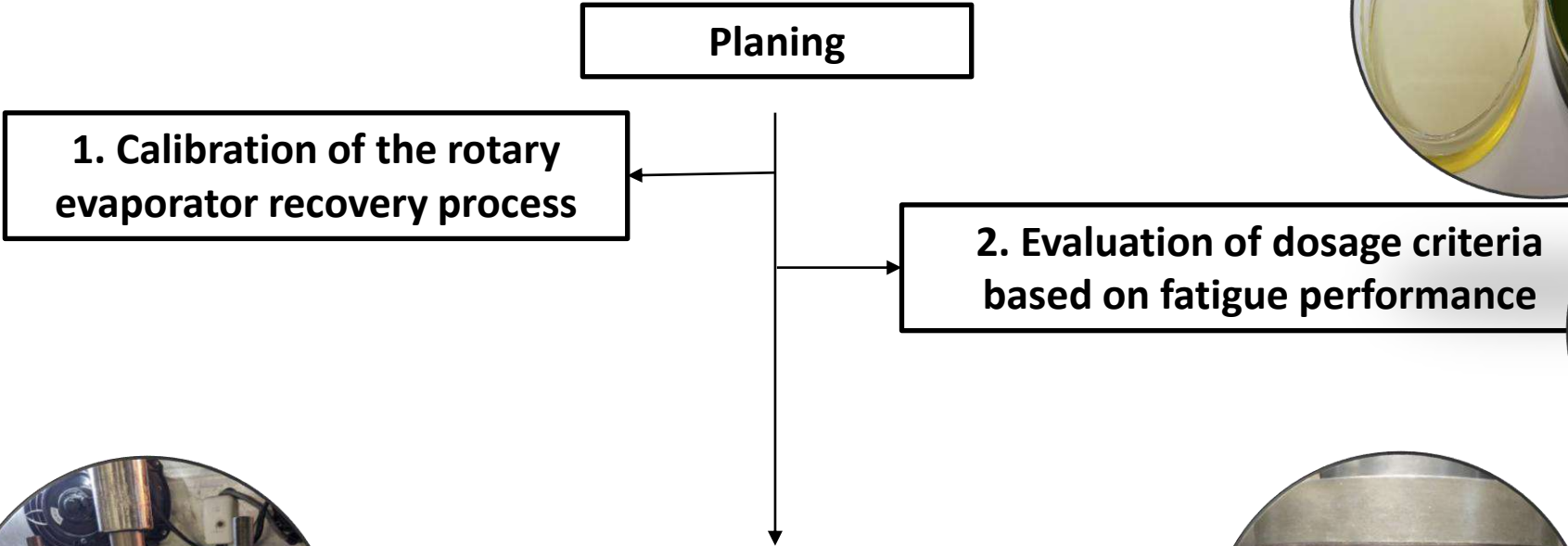






100% Reclaimed Asphalt Mixtures: recovery binder and recycling agent dosage selection methods based on the fatigue performance

Tese do Pedro Orlando



CALIBRATION OF THE ROTARY EVAPORATOR RECOVERY PROCESS

(2) Recovery process



Temperature Performance Grade, Frequency and Temperature Sweep, Multiple Stress Creep and Recovery, and Linear Amplitude Sweep



Duration - SBS I



- ASTM: following the standard normative procedures, the process took approximately 45 minutes for both RAPs. ASTM D 5404 (2017)

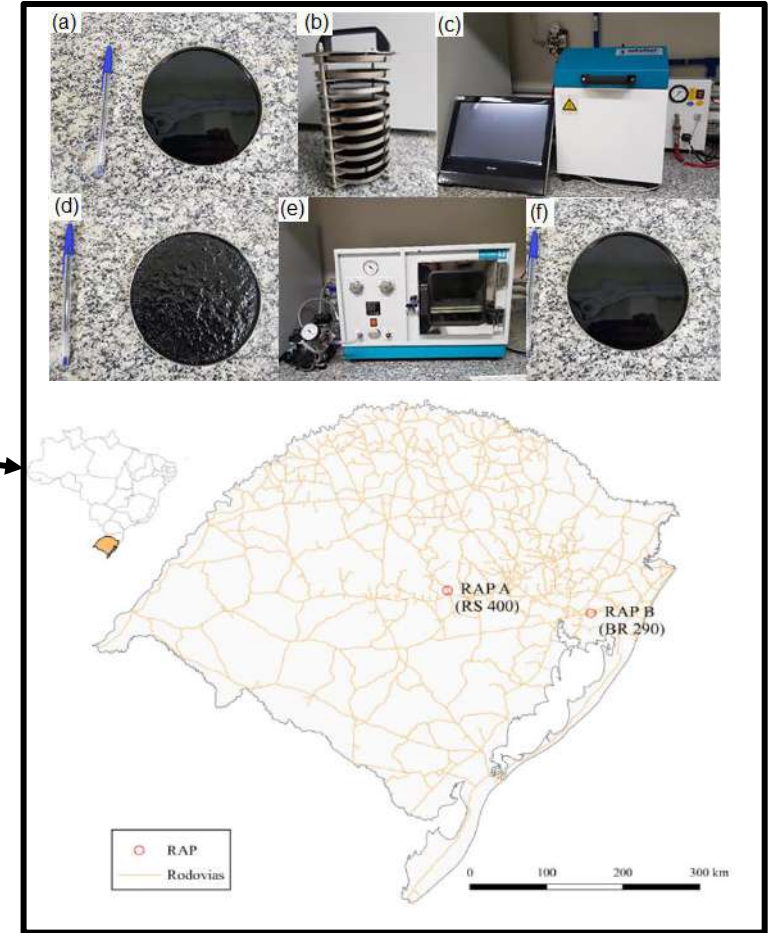
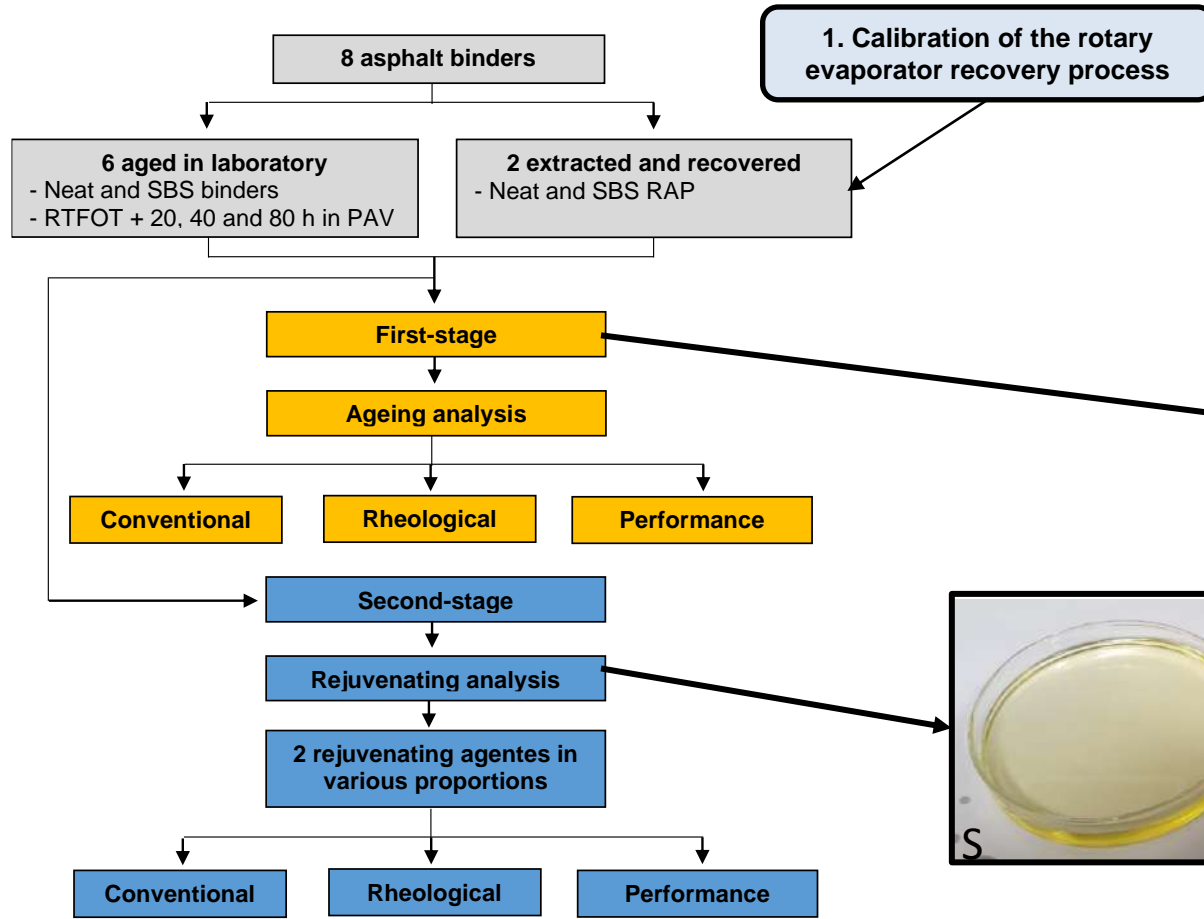
Type, modification and level of aging influence the distillation time. Higher aging and modification require longer processing times.

The ASTM D5404 (2017) was not efficient in promoting the complete evaporation of the TCE from the binders extracted from the RAP.

FTIR did not identify the presence of low concentrations of residual solvent. However, the low solvent concentrations promoted changes in the properties of the binders, identified in the rheological and performance tests.

Continuous PGH, MSCR and LAS proved to be assertive in the process calibration.

2. Evaluation of dosage criteria based on fatigue performance



Tests:

Penetration, frequency and temperature sweep, PGH, MSCR and LAS tests

Tabela 1 – The rejuvenating agent content added in the aged asphalt binders

Asphalt binders	RA contentes (AR1 and AR2)	Designations
Neat 40PAV	2, 4 and 6%	Neat 40PAV (2, 4, 6%) (S, R)
Neat 80PAV	2, 4 and 6%	Neat 80PAV (2, 4, 6%) (S, R)
SBS 40PAV	2, 4 and 6%	SBS 40PAV (2, 4, 8%) (S, R)
SBS 80PAV	2, 4 and 8%	SBS 80PAV (2, 4, 8%) (S, R)
Neat RAP	4, 8, 12 and 16%	Neat RAP (4, 8, 12, 16%) (S, R)
SBS RAP	4, 8, 12 and 16%	SBS RAP (4, 8, 12, 16%) (S, R)

Failure definitions

- 50% drop in stiffness;
- 35% reduction in material integrity (as represented by $|G^*|. \sin \delta$);
- Peak of $C.N$, where N denotes cycle number and C is the normalized modulus;
- Peak of $\tau.N$, where τ is the shear stress;
- Peak of shear stress;
- Peak of phase angle;
- Peak of stored pseudo-strain-energy (PSE), or W_S^R ;
- Peak of $C^2.N.(1-C)$;

Failure criteria

- G^R ;
- D^R ;
- $Cum(1-C)$
- $W_r [R+S]$;
- $W_r [R]$;

Fatigue law

- Wang (2015);
- Wang (2018);
- Safaei (2017);

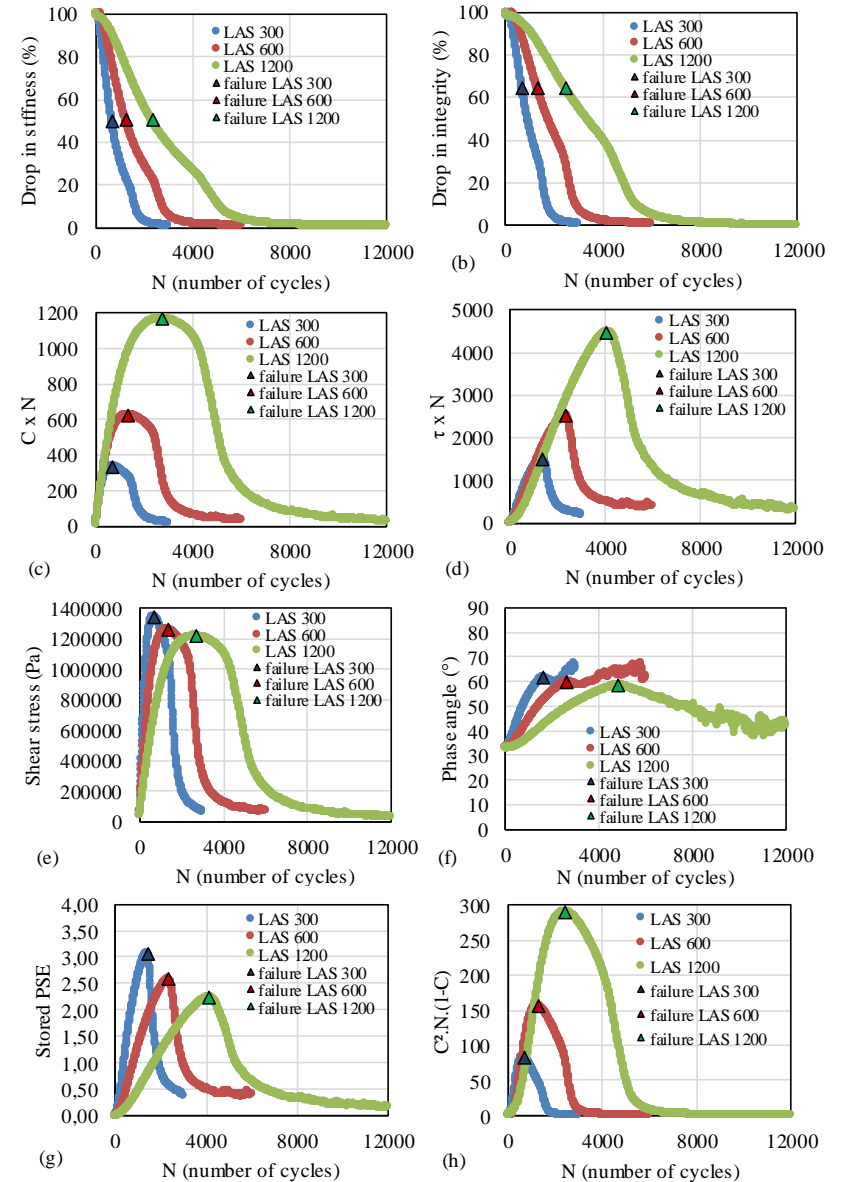
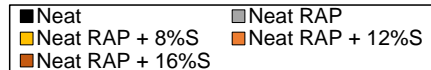
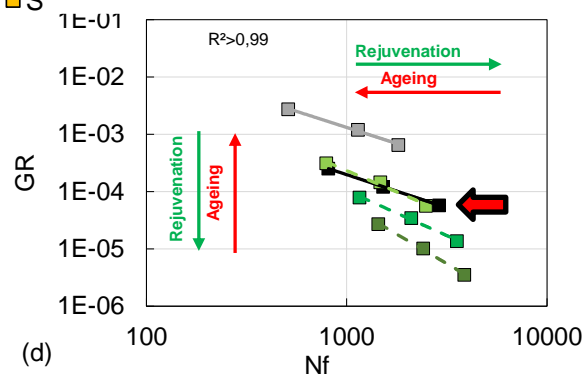
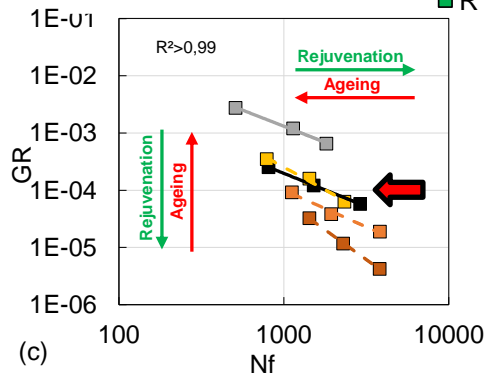
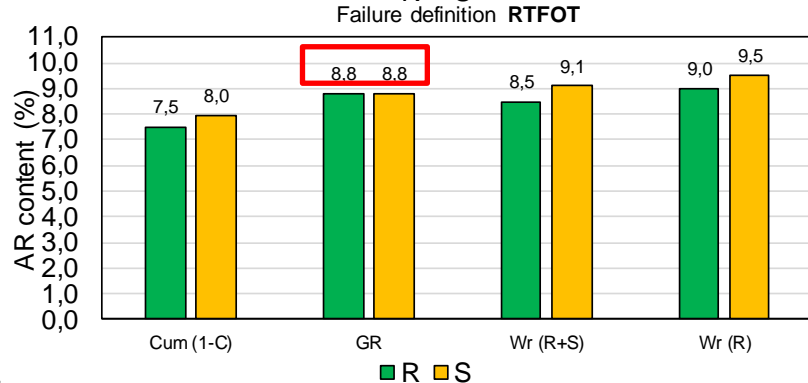
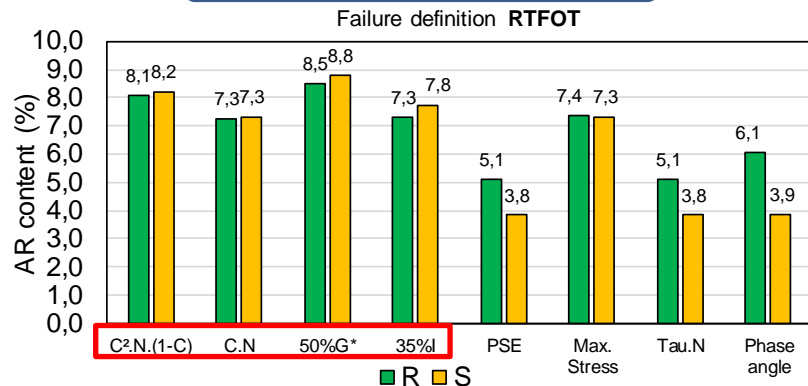
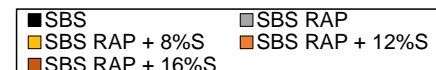
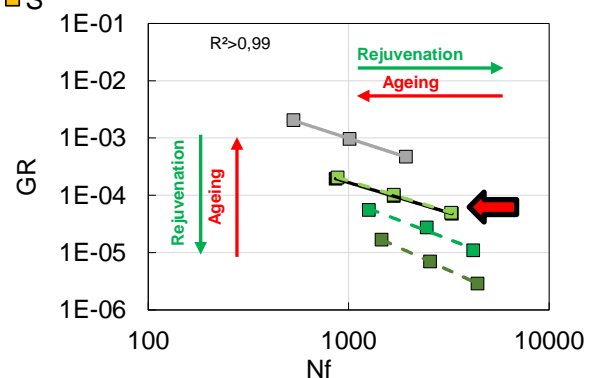
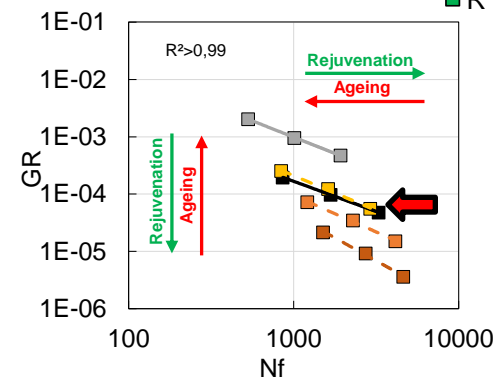
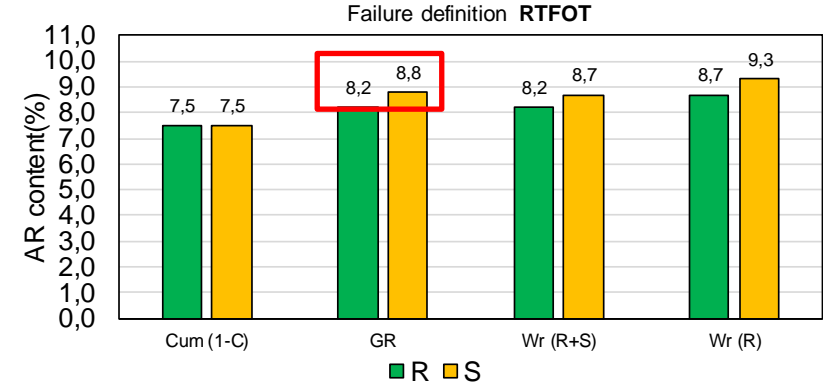
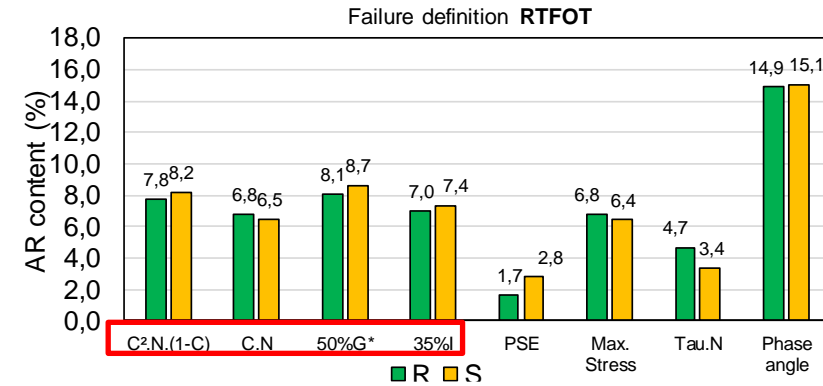


Figura 1. Definições de falhas avaliadas

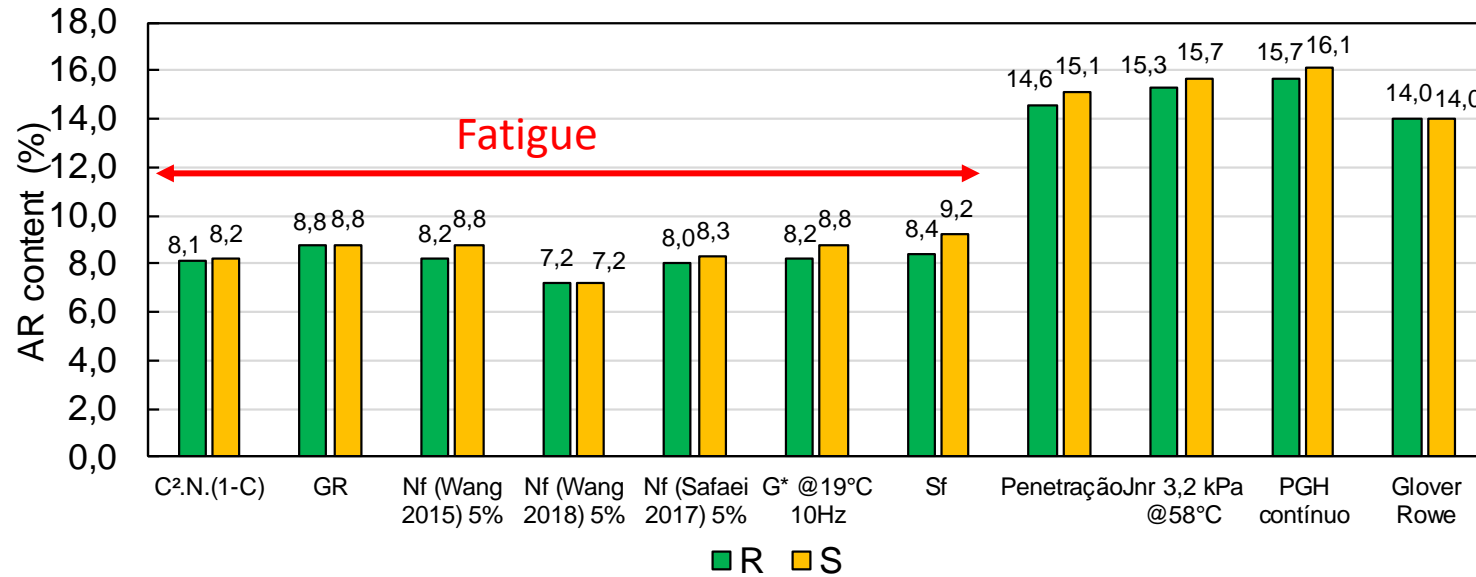
Neat RAP



SBS RAP



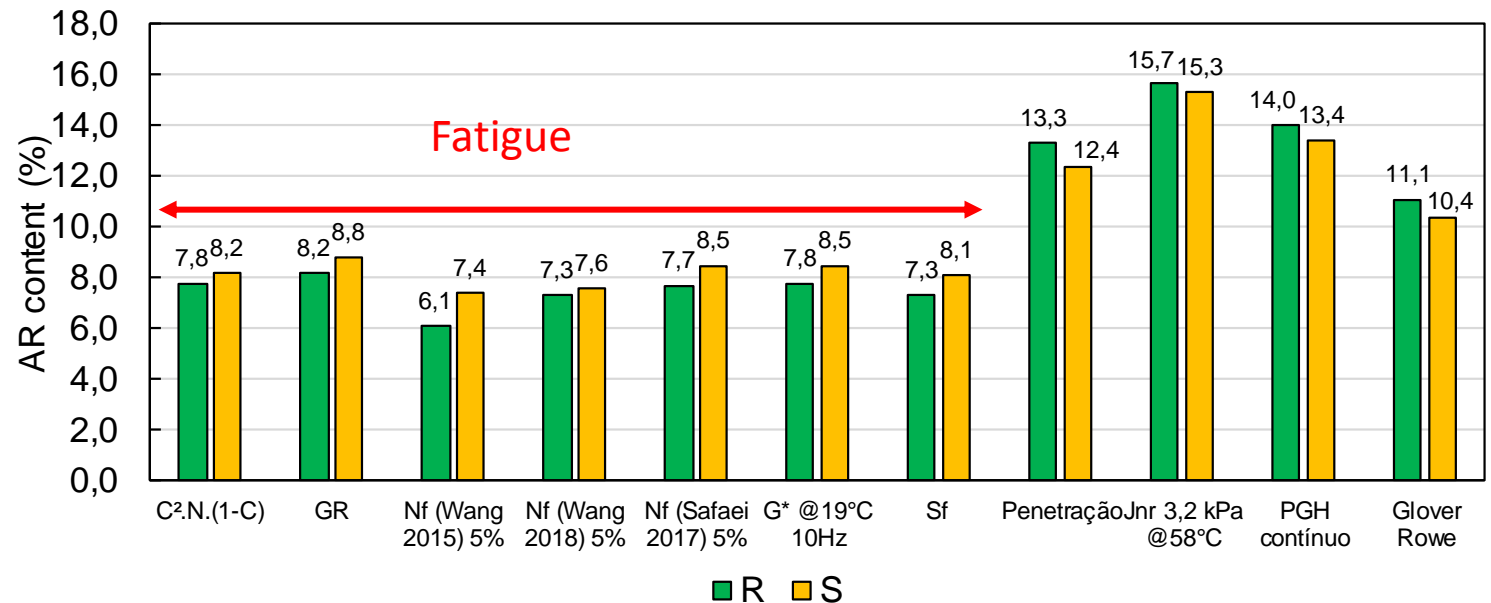
Neat RAP - RTFOT condition



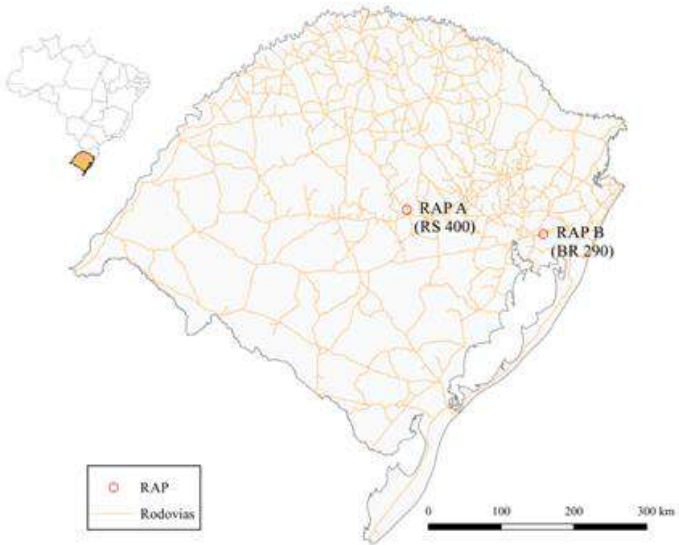
The parameters related to fatigue (failure definitions, failure criteria and fatigue law) converge to the same content of rejuvenating agent;

The dosage of the rejuvenating agent content by fatigue criteria is lower than the other criteria such as penetration, PGH, Glover Rowe and Jnr;

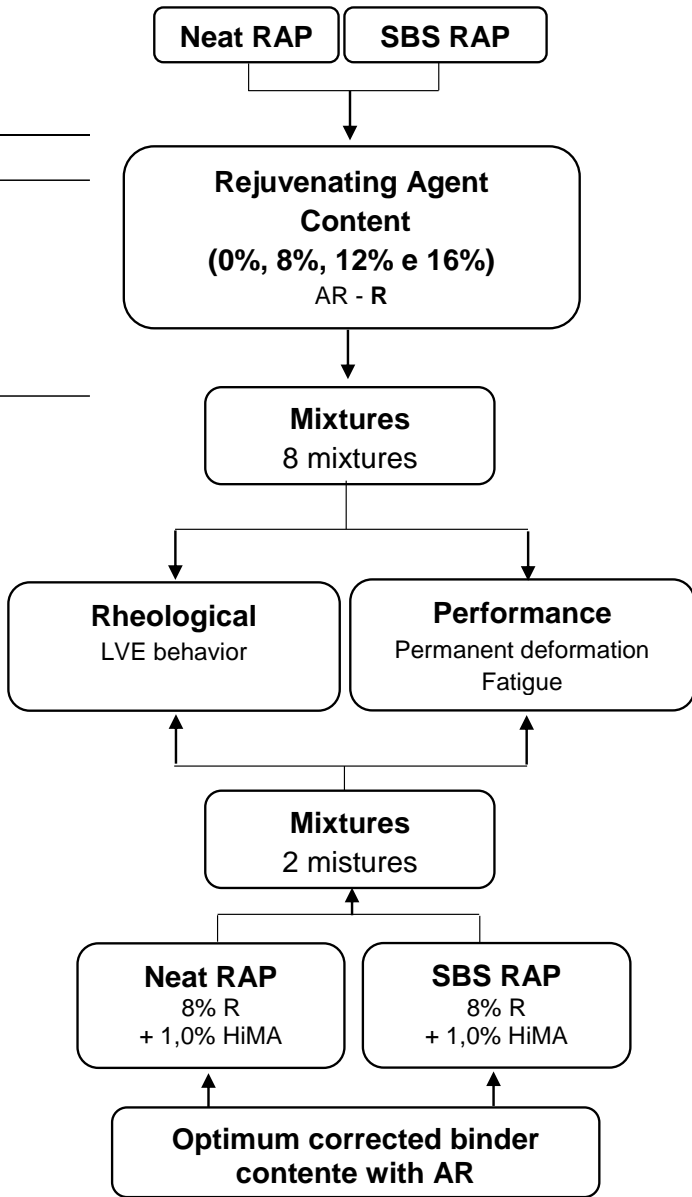
SBS RAP - RTFOT condition



Performance of 100% Reclaimed Asphalt Mixtures with Rejuvenating Agent



Characterization	Neat RAP	SBS RAP
Penetration	8 dmm	10 dmm
Softening Point	75 °C	75 °C
Continuous PHG	93,9 °C	92,8 °C
Binder Content	5,38%	5,76%
Gmm	2,674 g/cm ³	2,542 g/cm ³



Neat RAP



SBS RAP



Degree of Binder Activity (DoA)

Neat RAP

SBS RAP

100% RAP

Processing temperatures

70°C
100°C
140°C
170°C
190°C

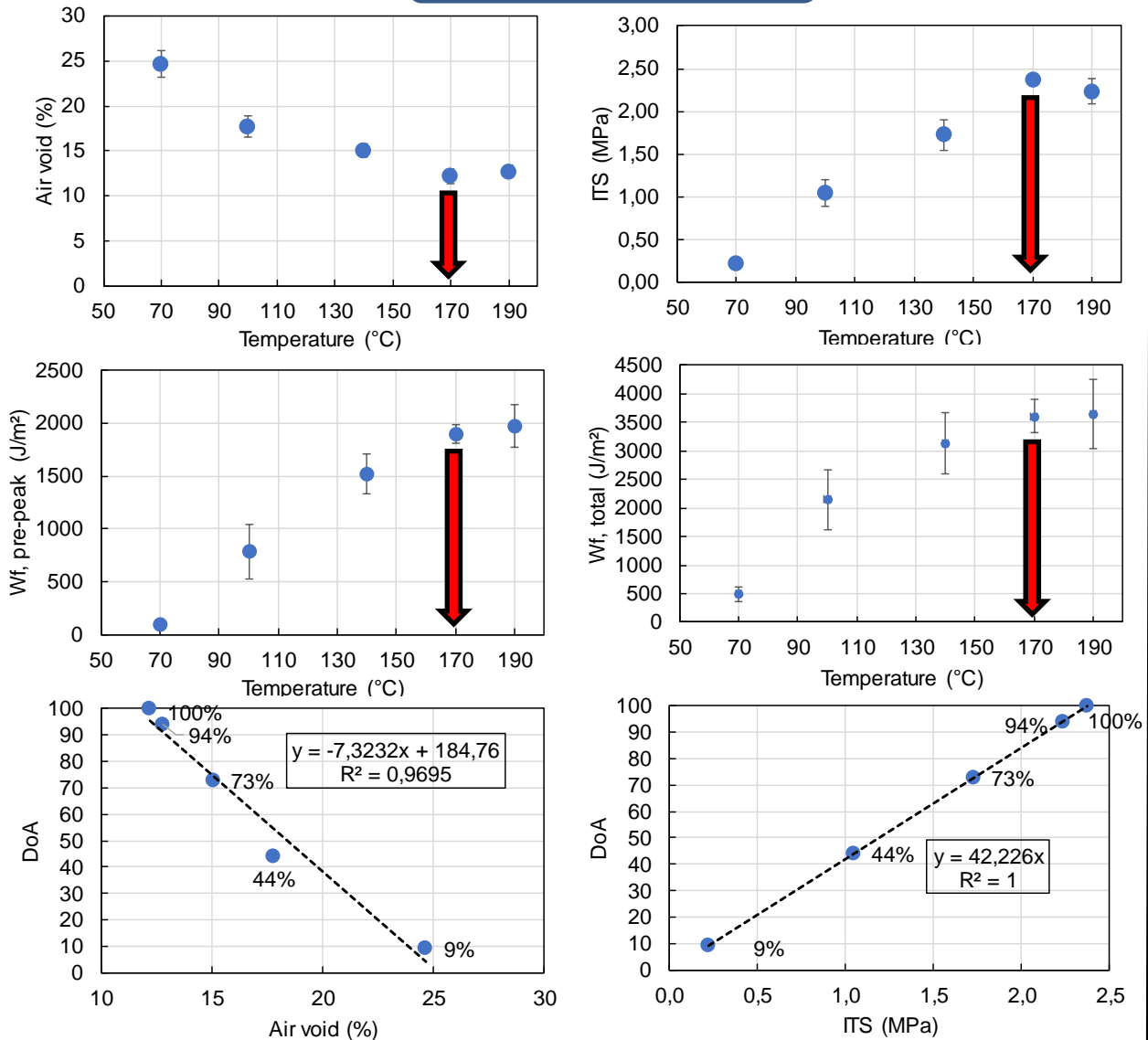
Indirect tensile test
Test Energy (total, pre and post-peak)
Void volume

Degree of binder activity

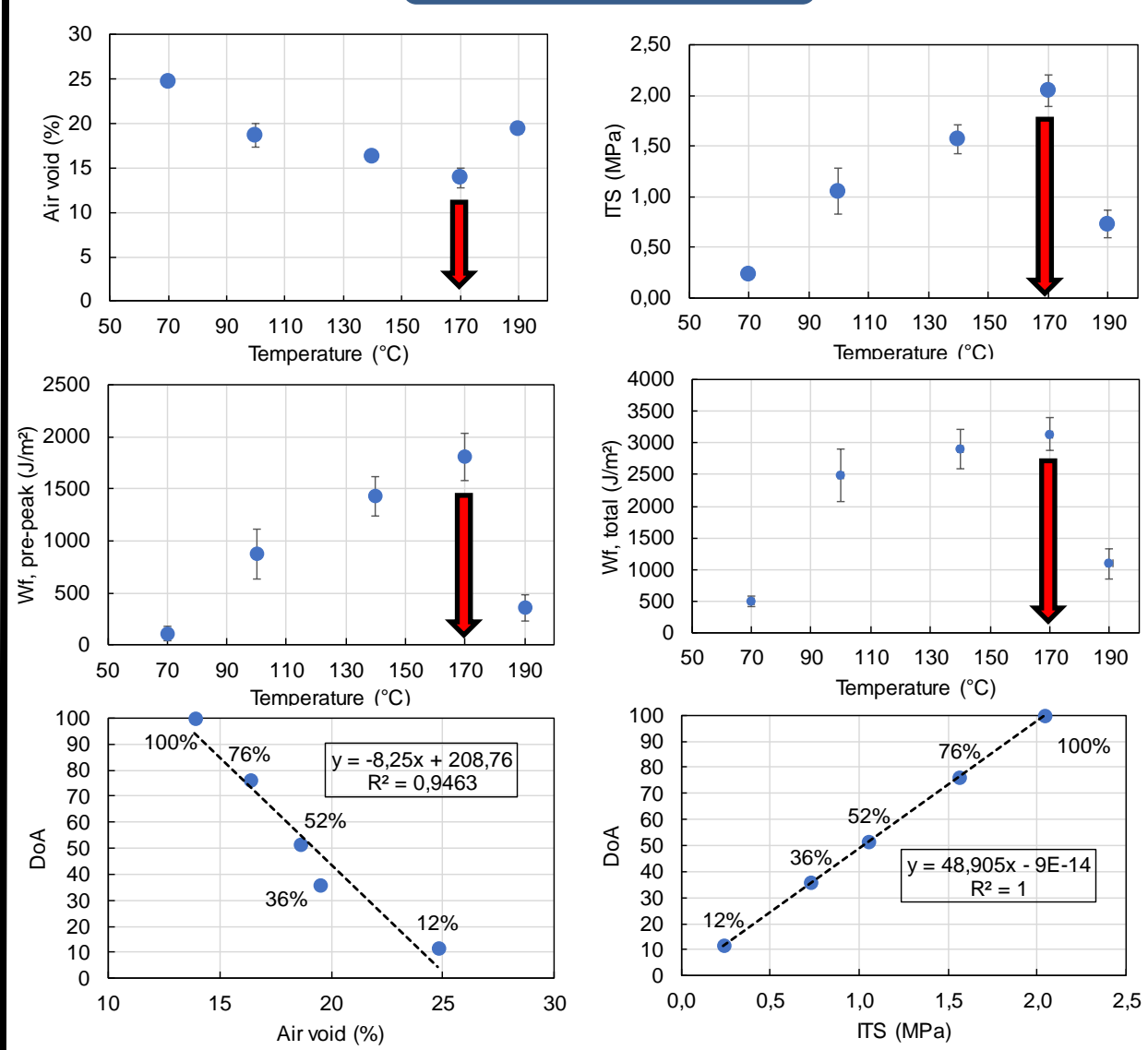
Input to production of asphalt mixtures



Neat RAP



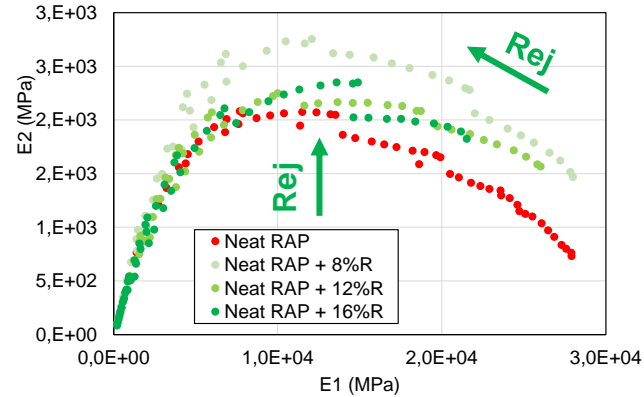
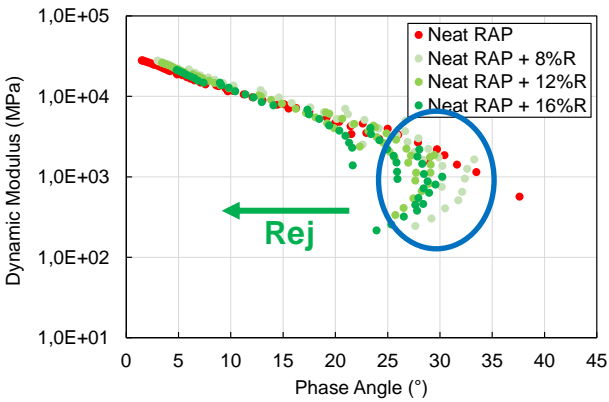
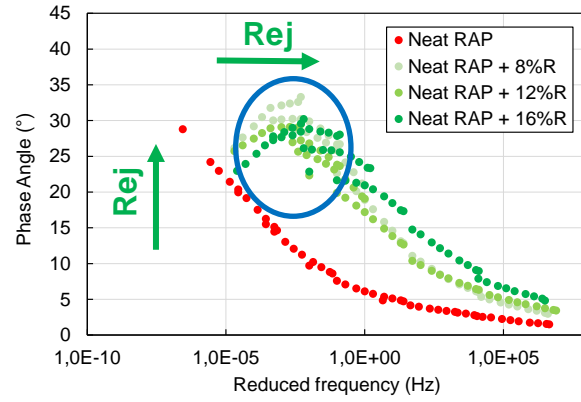
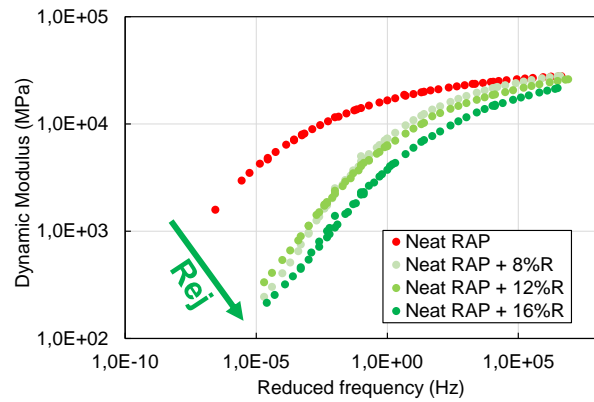
SBS RAP



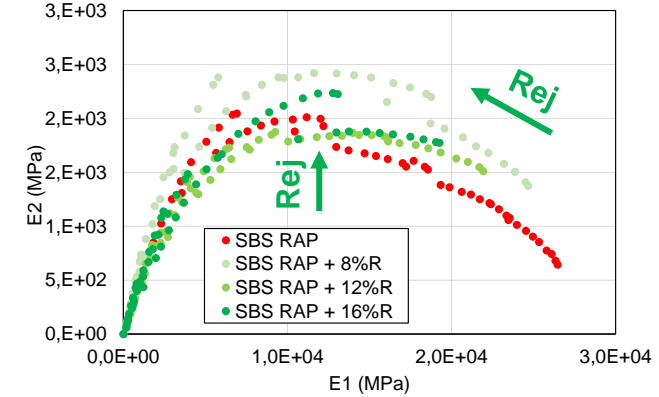
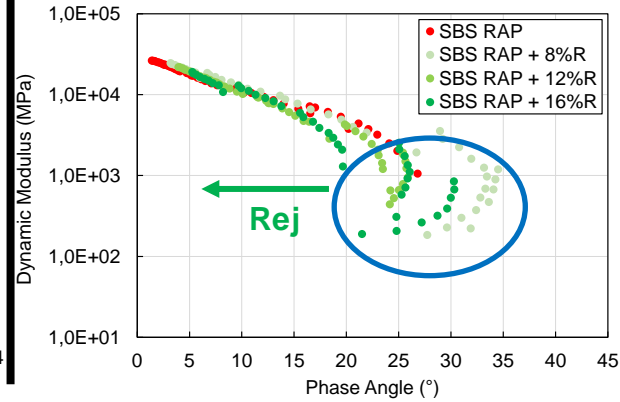
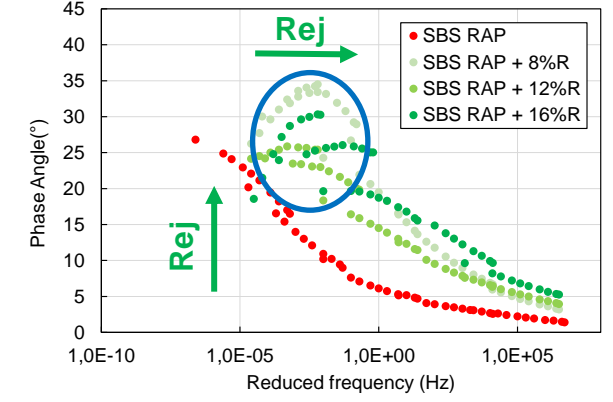
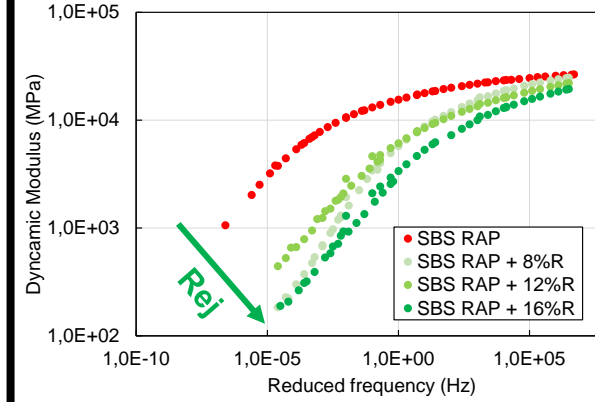
(a)



Neat RAP



SBS RAP



Frequencies:

25 Hz, 20 Hz, 10 Hz, 5 Hz, 2 Hz, 1 Hz, 0,5 Hz, 0,2 Hz, 0,1 Hz;

Temperatures:

-10°C, 4°C, 21°C, 37°C e 54°C

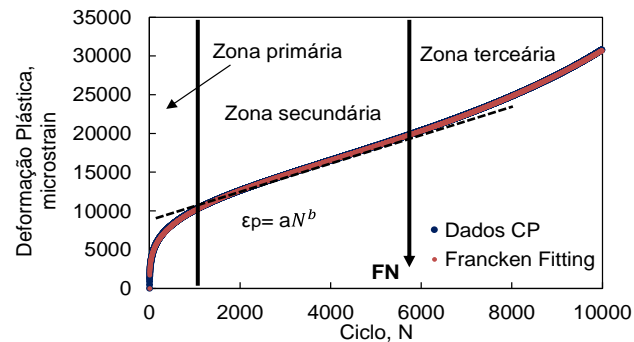
Deformation

50 a 75 $\mu\text{m}/\text{m}$

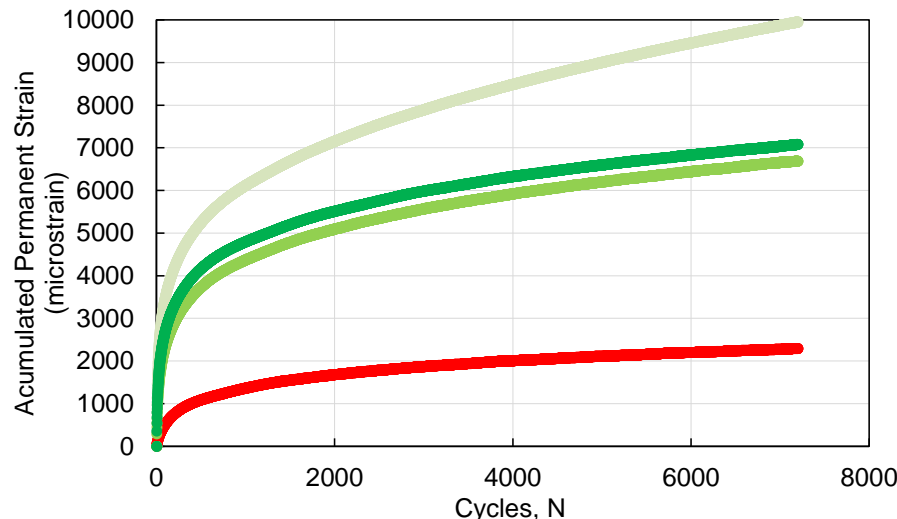
Samples:

10x15 e Vv= 5,5 \pm 0,5%

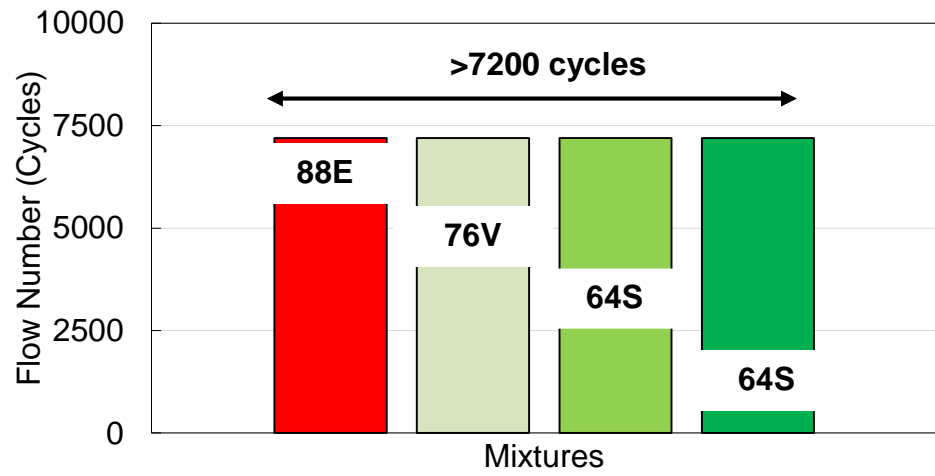
Temperature:
60°C
Load:
204 kPa
Samples:
10x15 e Vv= 7,0 ± 1,0%



Neat RAP

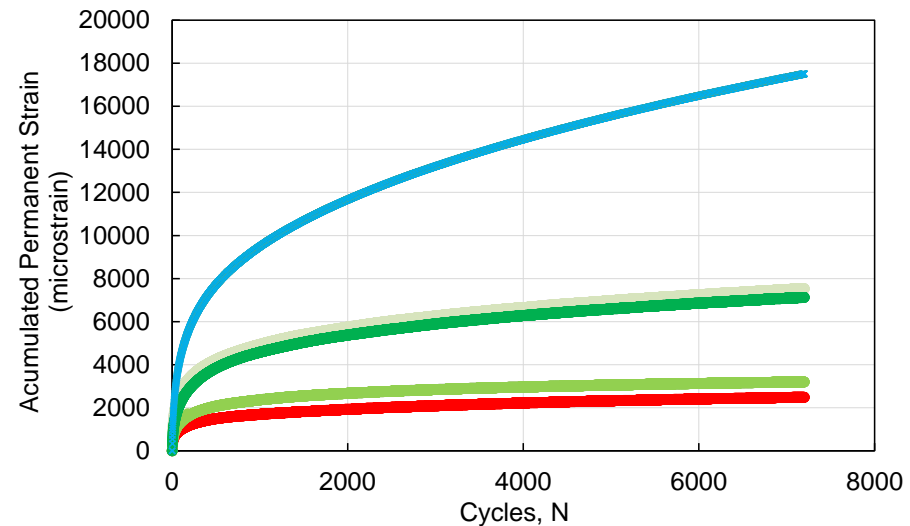


- Neat RAP
- Neat RAP + 8%R
- Neat RAP + 12%R
- Neat RAP + 16%R

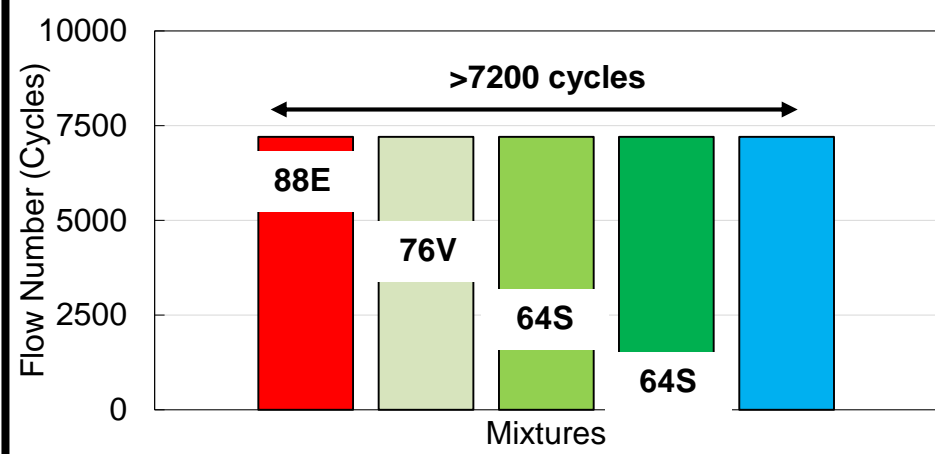


- SBS RAP
- SBS RAP + 8%R
- SBS RAP + 12%R
- SBS RAP + 16%R

SBS RAP



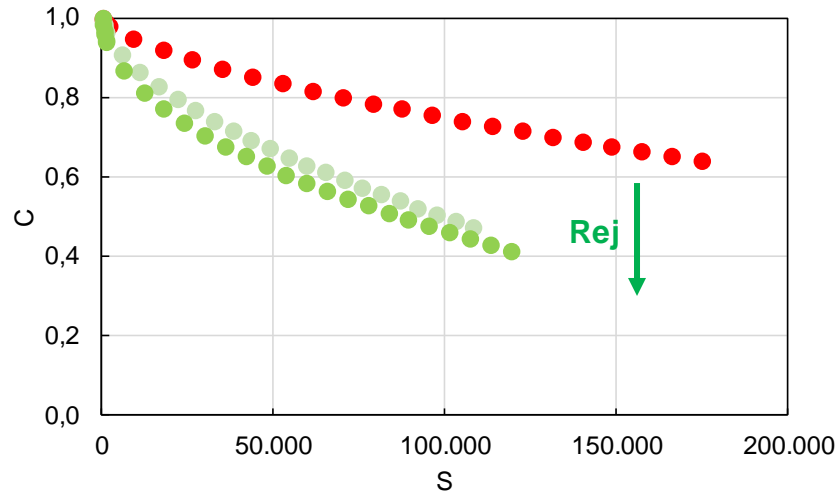
- SBS RAP
- SBS RAP + 8%R
- SBS RAP + 12%R
- SBS RAP + 16%R
- × SBS RAP + 8%R + 1%HiMA



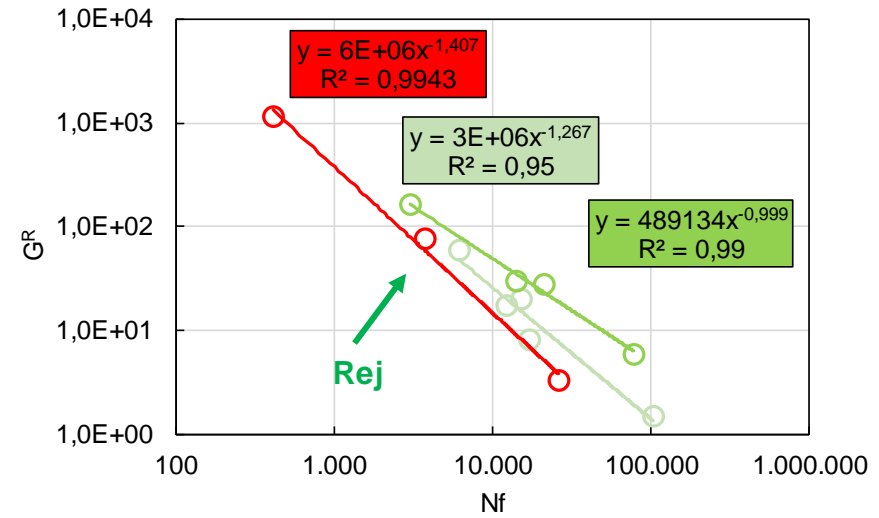
- SBS RAP
- SBS RAP + 8%R
- SBS RAP + 12%R
- SBS RAP + 16%R
- SBS RAP + 8%R + 1%HiMA



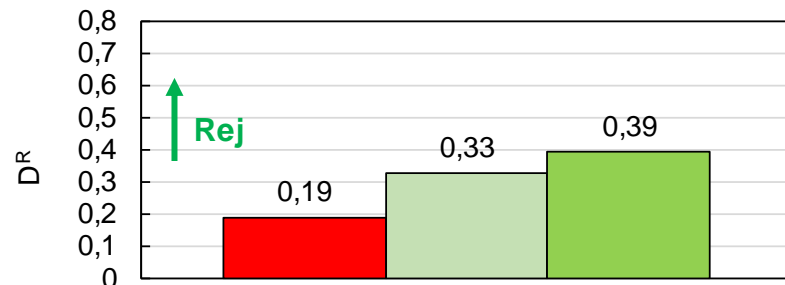
Neat RAP



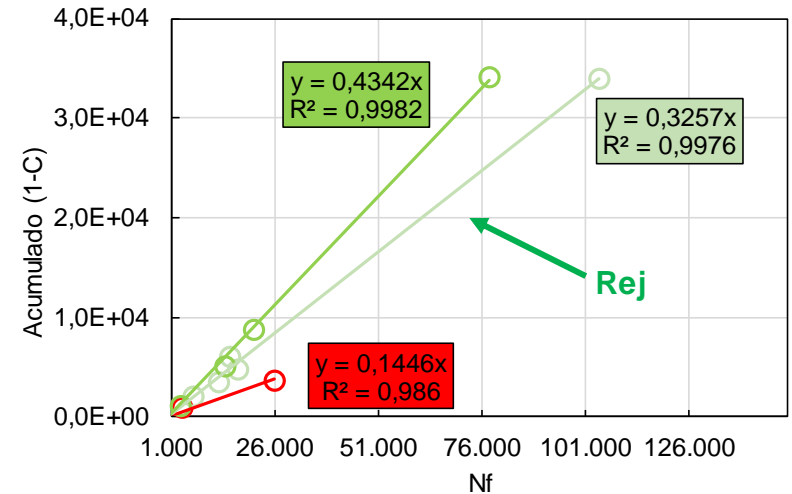
● Neat RAP ● Neat RAP + 8%R ● Neat RAP + 12%R



○ Neat RAP ○ Neat RAP + 8%R ○ Neat RAP + 12%R



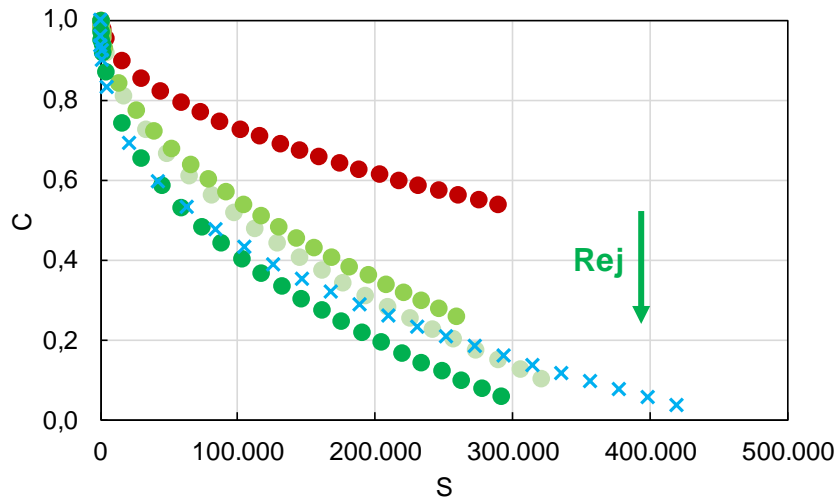
■ Neat RAP ■ Neat RAP + 8%R ■ Neat RAP + 12%R



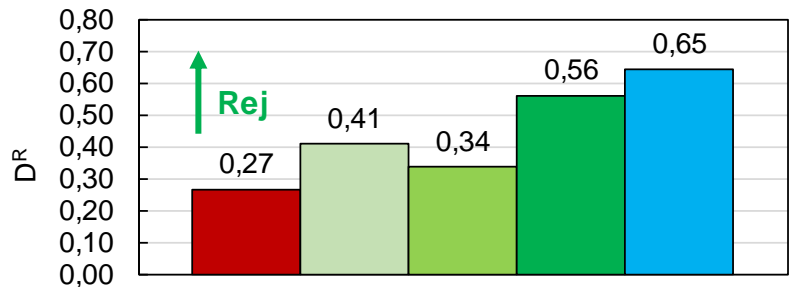
○ Neat RAP ○ SBS RAP + 8%R ○ SBS RAP + 12%R

S-VECD
GR (Sabouri and Kim, 2014)
DR (Wang and Kim, 2017)

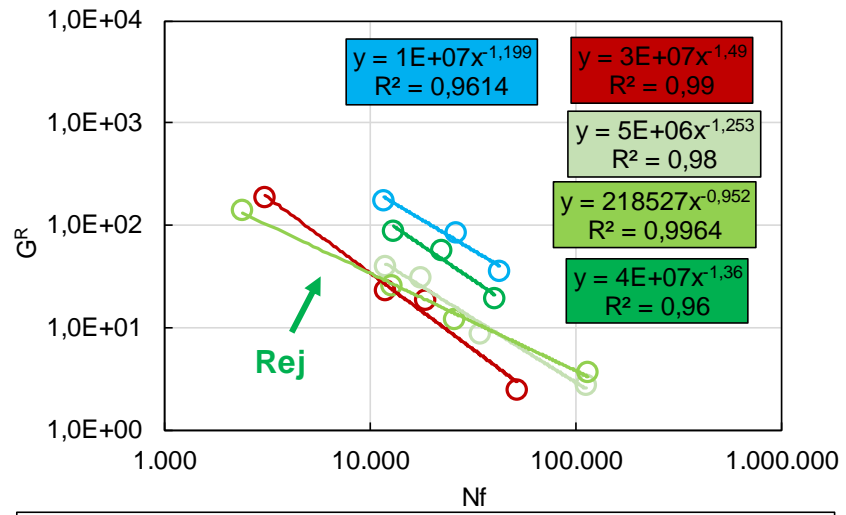
SBS RAP



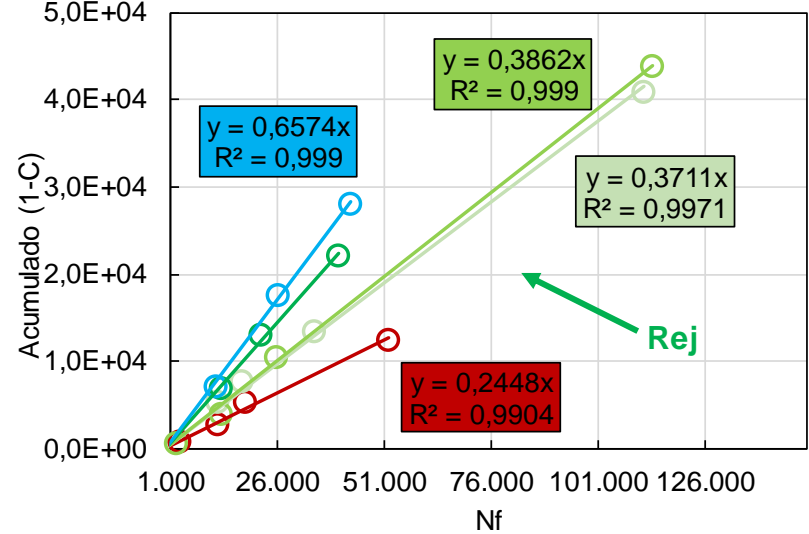
- SBS RAP
- SBS RAP + 8%R
- SBS RAP + 12%R
- SBS RAP + 16%R
- × SBS RAP + 8%R + 1%HiMA



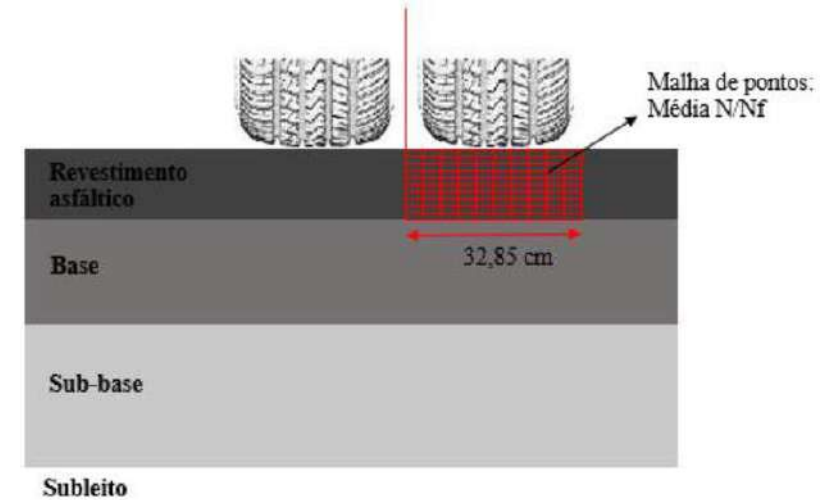
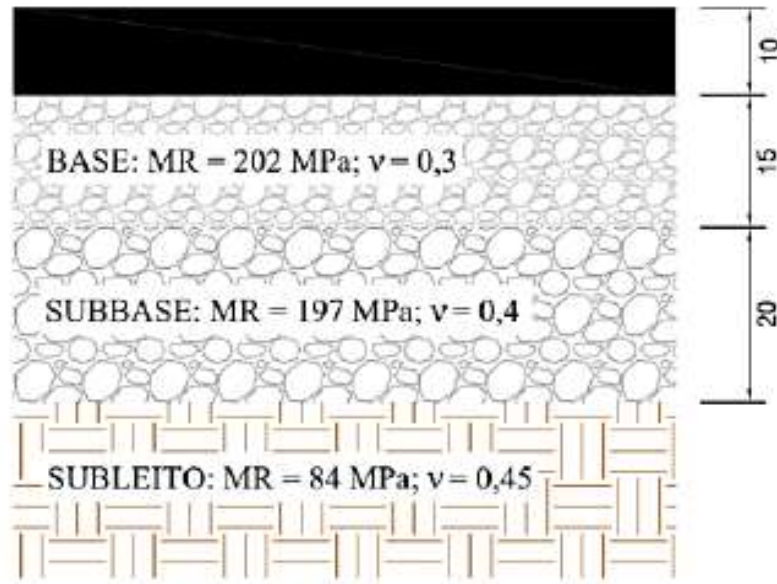
- SBS RAP
- SBS RAP + 8%R
- SBS RAP + 12%R
- SBS RAP + 16%R
- SBS RAP + 8%R + 1%HiMA



- SBS RAP
- SBS RAP + 8%R
- SBS RAP + 12%R
- SBS RAP + 8%R + 1%HiMA



- SBS RAP
- SBS RAP + 8%R
- SBS RAP + 12%R
- SBS RAP + 8%R + 1%HiMA

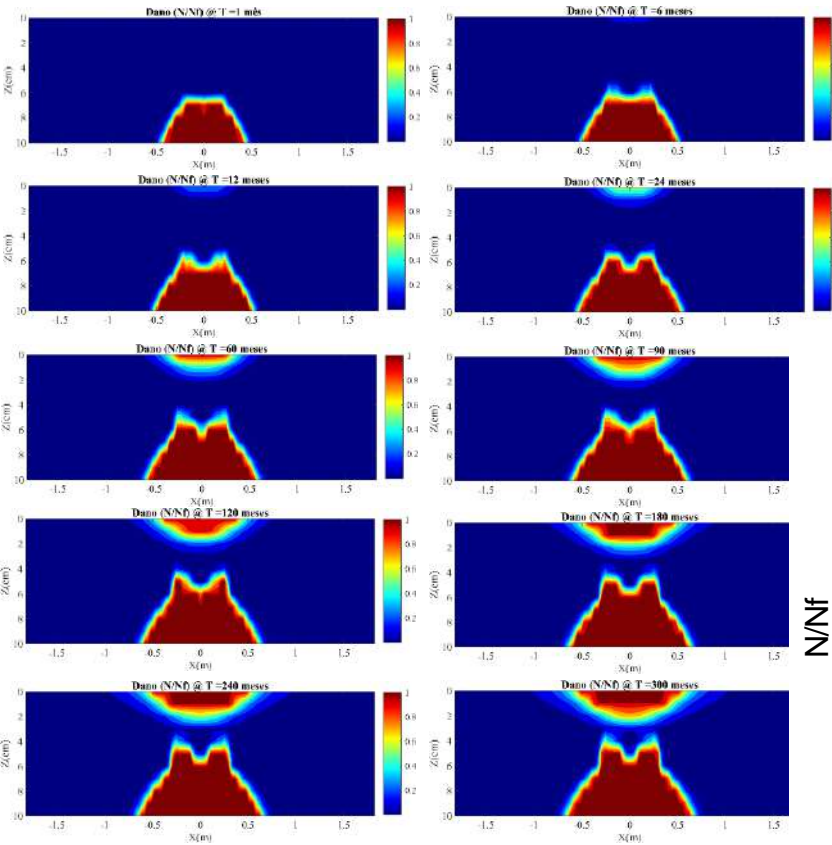


Climate: Ijuí-RS/Santa Maria-RS (San Diego's temperature typically varies from 9°C to 25°C);

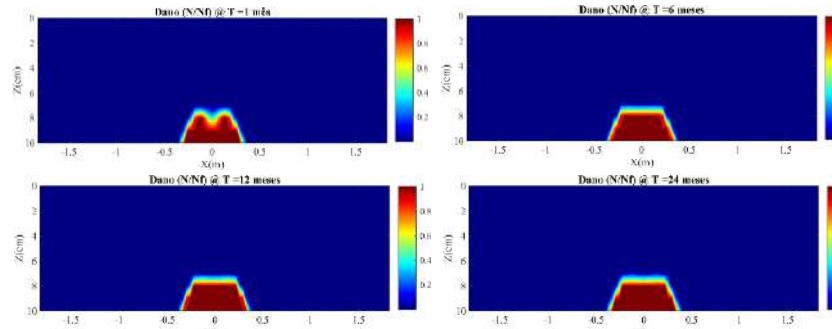
Nf = 5 x 10⁷;

Traffic was the local average daily truck traffic imposed by **80 kN twin-wheel single axles** with **0.80 MPa inflated tires** on a rectangular contact area with a **1.5714 length/width** ratio and **80 km/h traffic speed**. The analysis points that were adopted to calculate the accumulated average damage values were determined according to **110-point** mesh distributed over the asphalt concrete layer that is subjected to cracking.

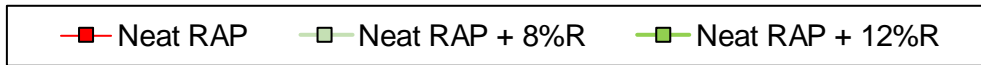
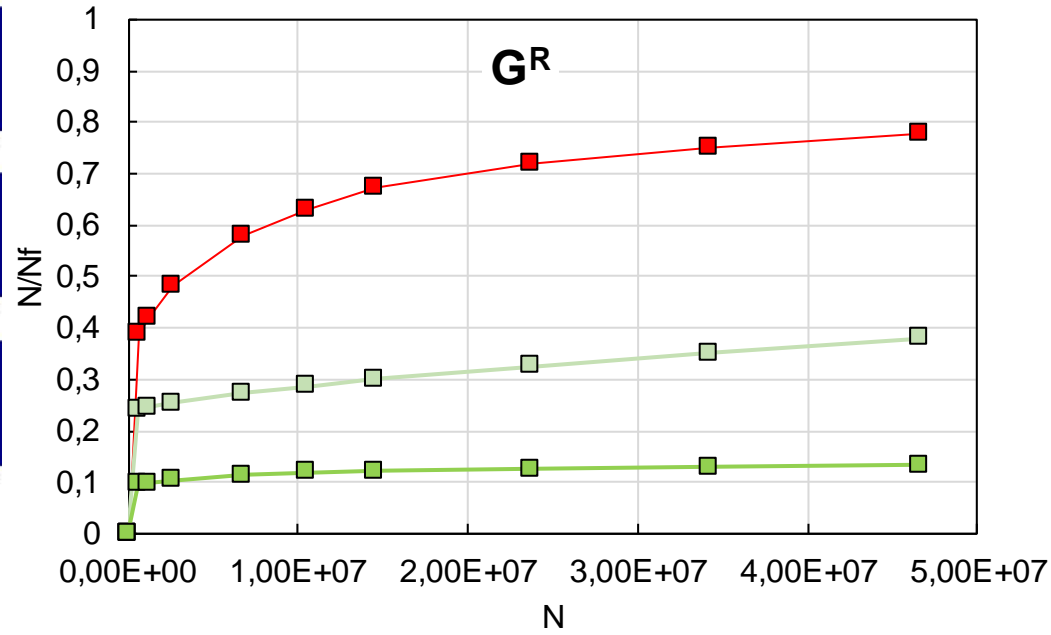
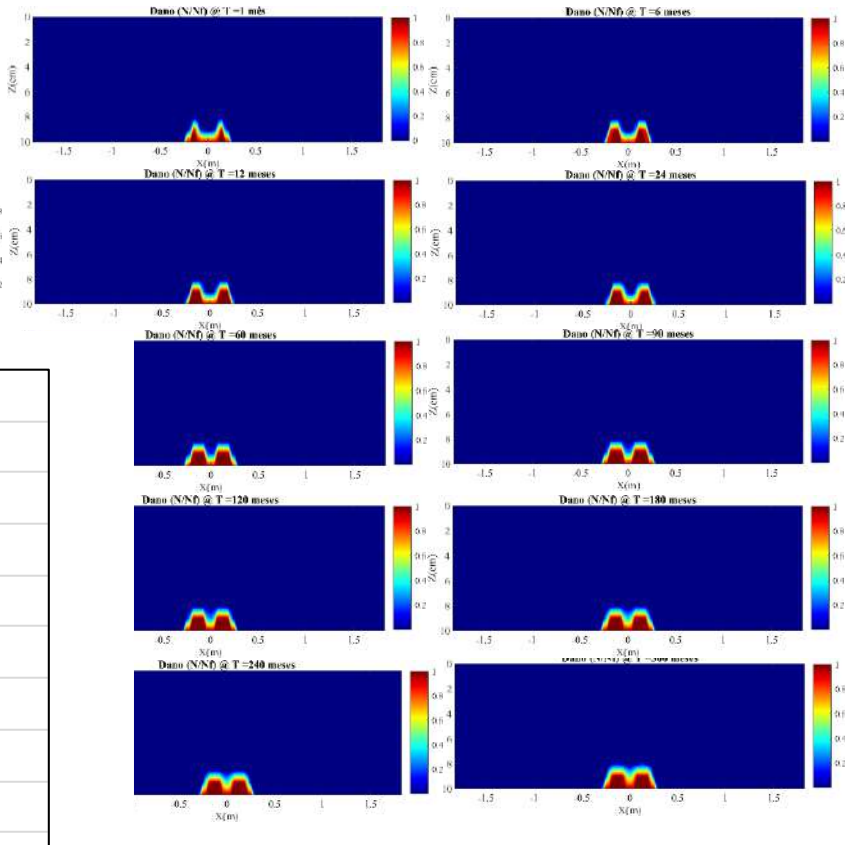
Neat RAP



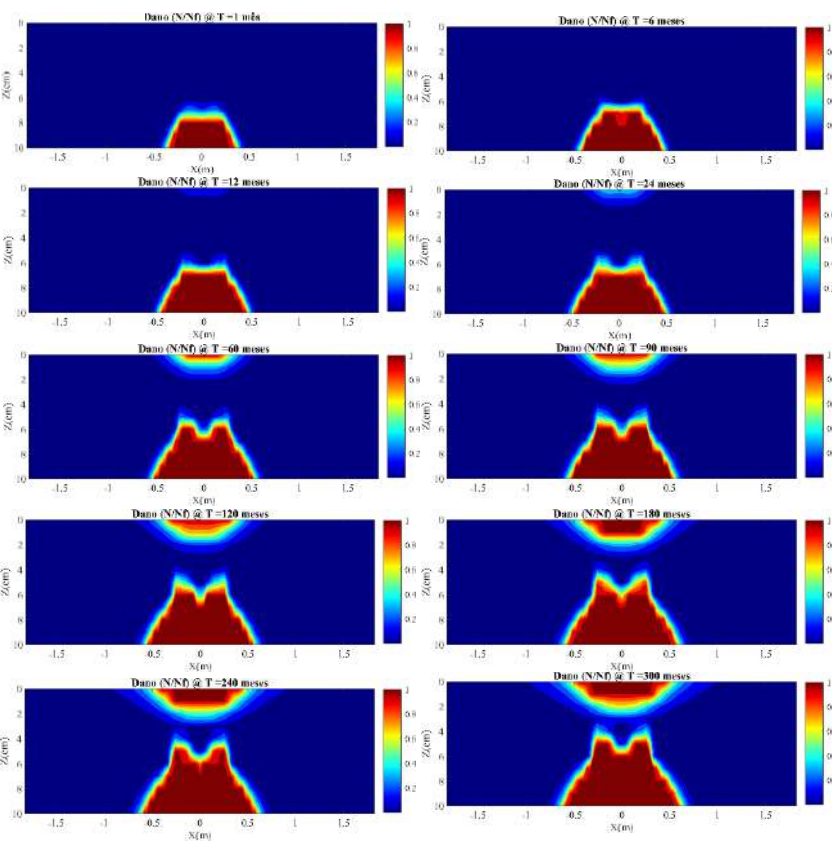
Neat RAP + 8%R



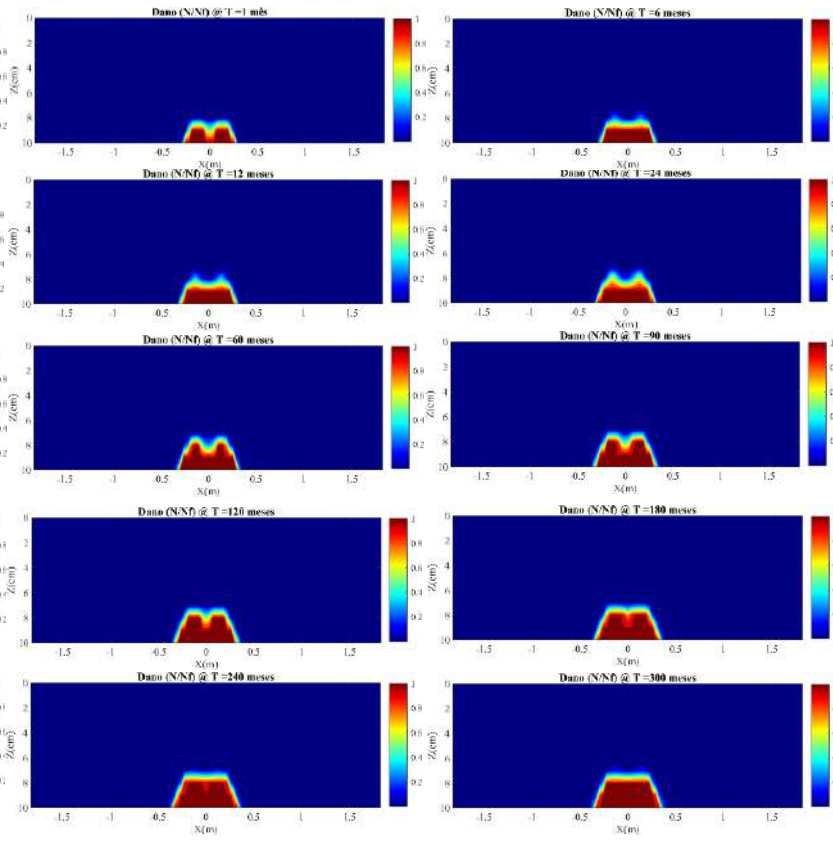
Neat RAP + 12%R



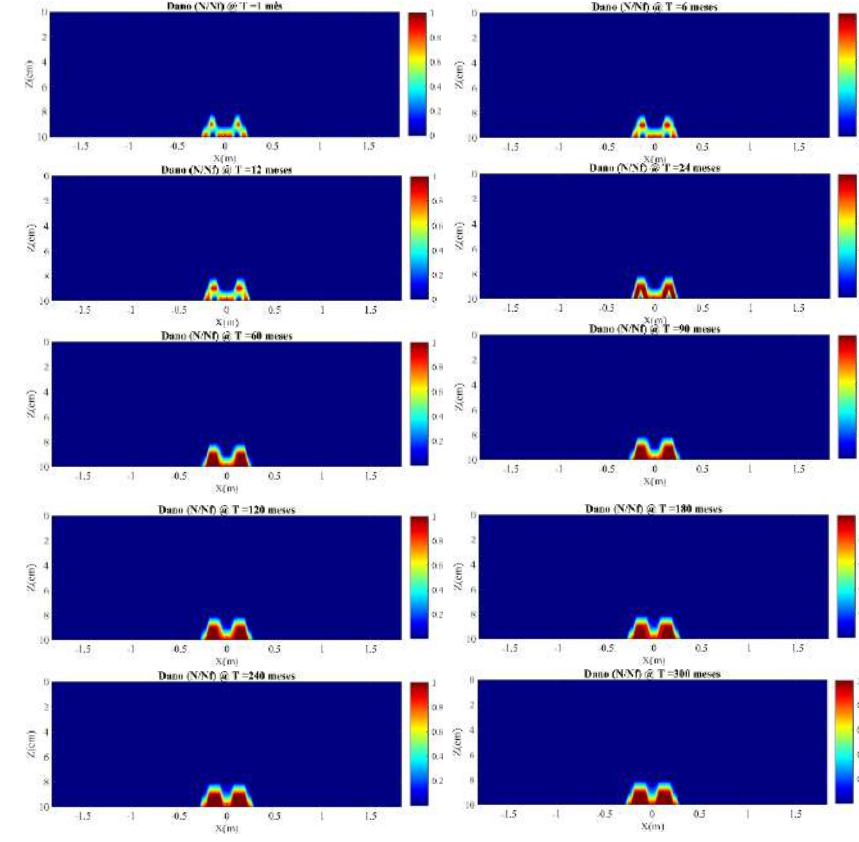
SBS RAP



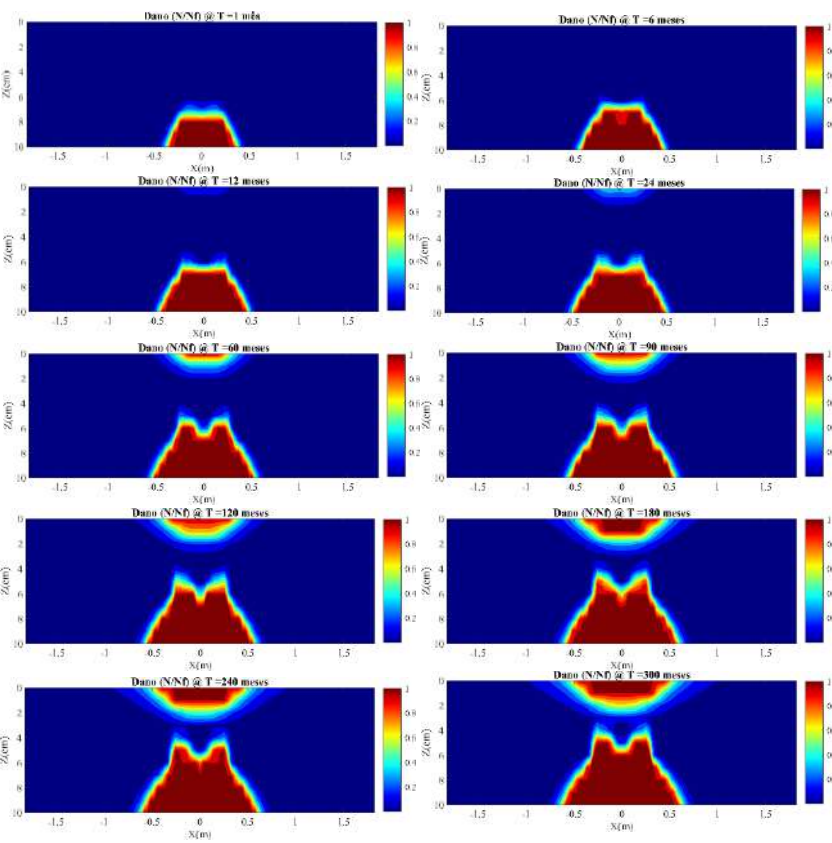
SBS RAP + 8%R



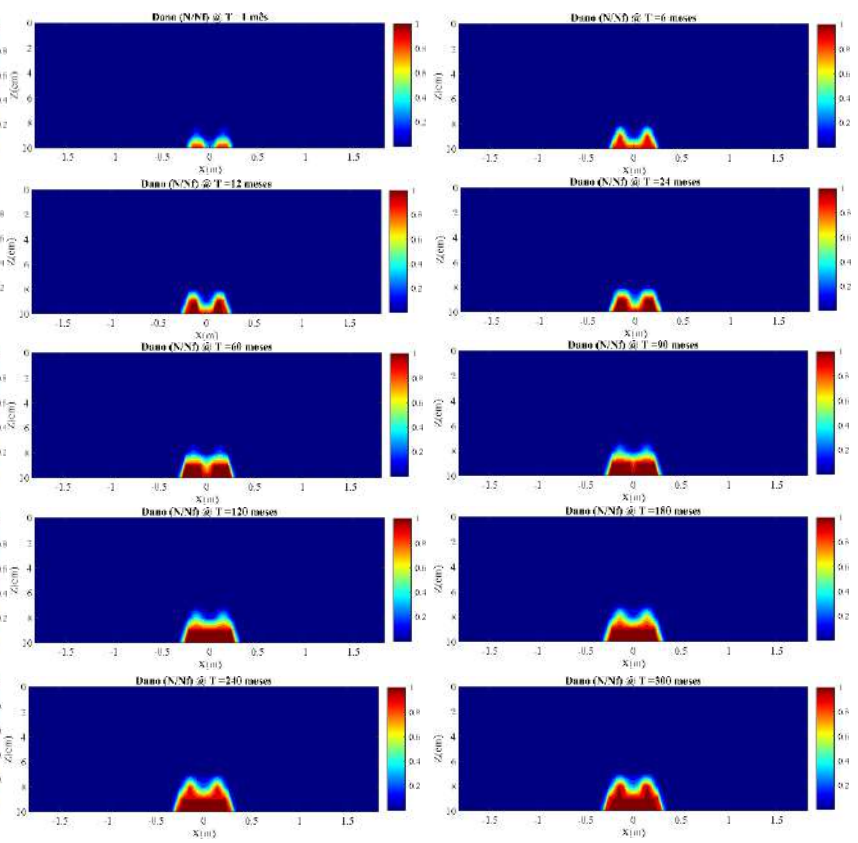
SBS RAP + 12%R



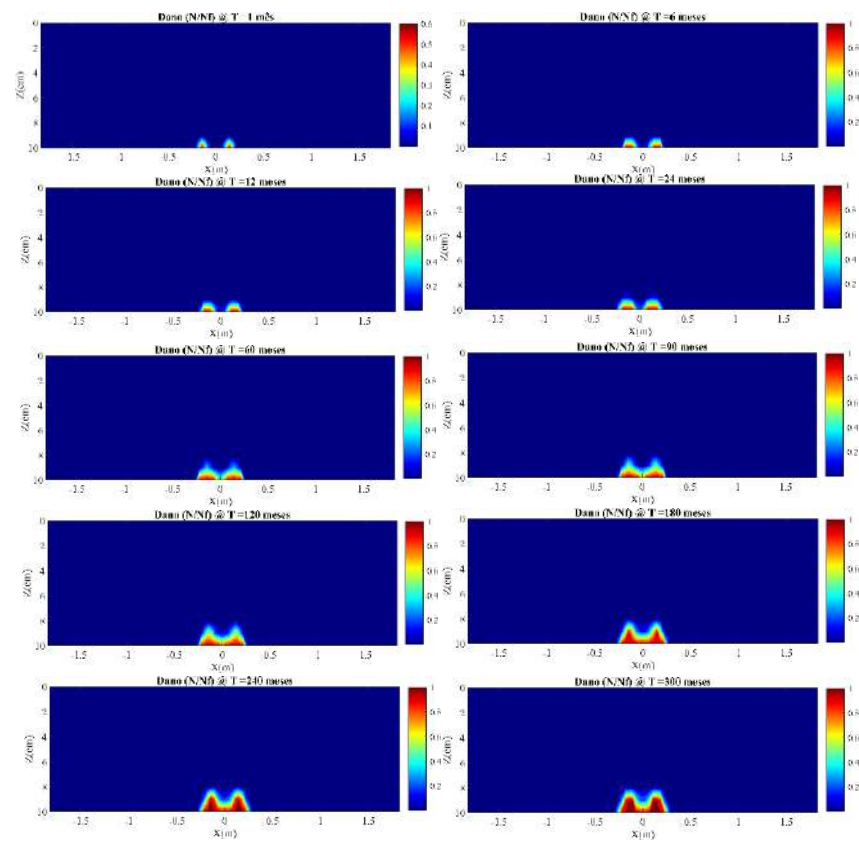
SBS RAP



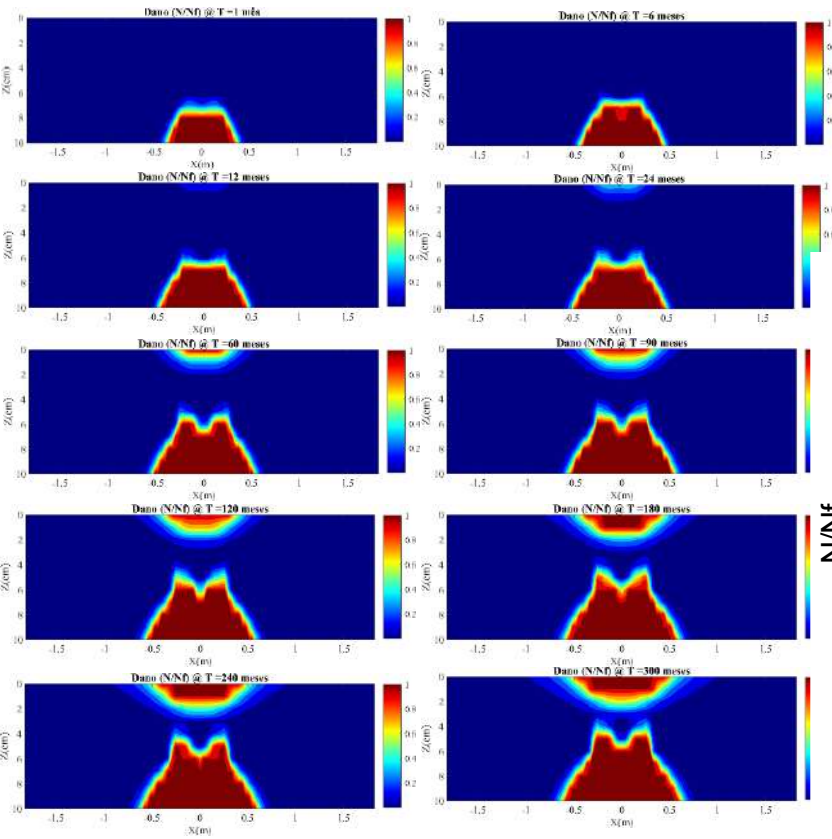
SBS RAP + 16%R



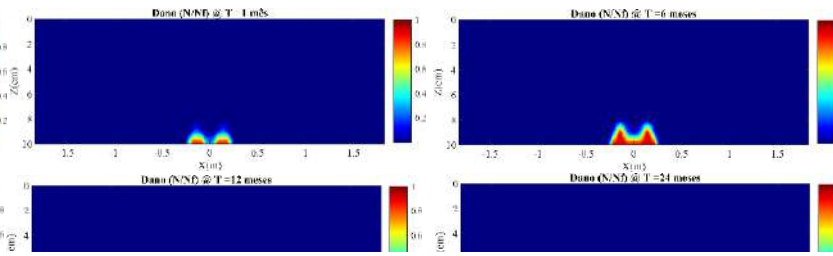
SBS RAP + 8%R + 1%HiMA



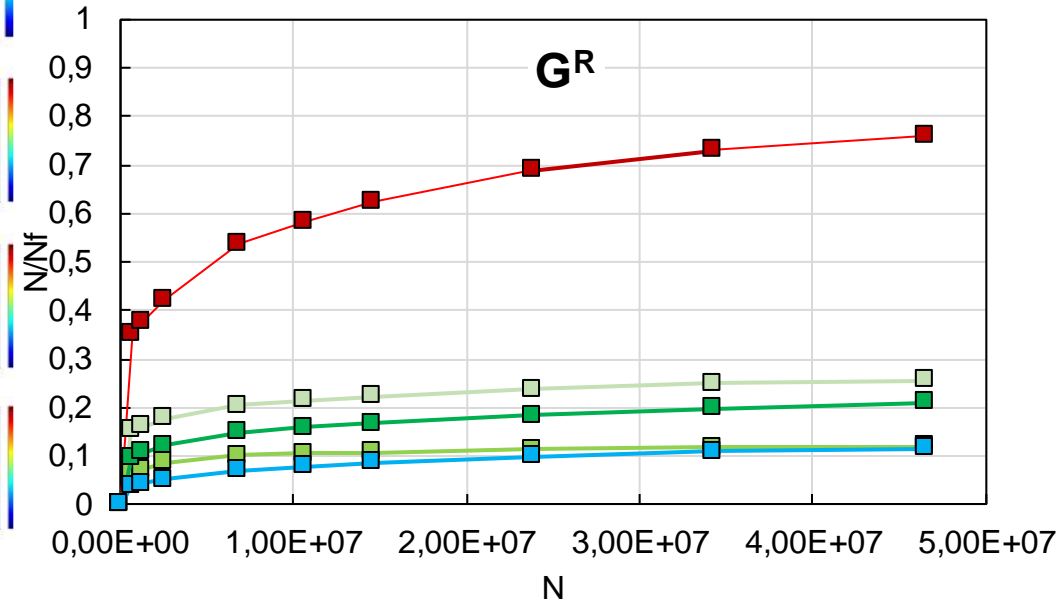
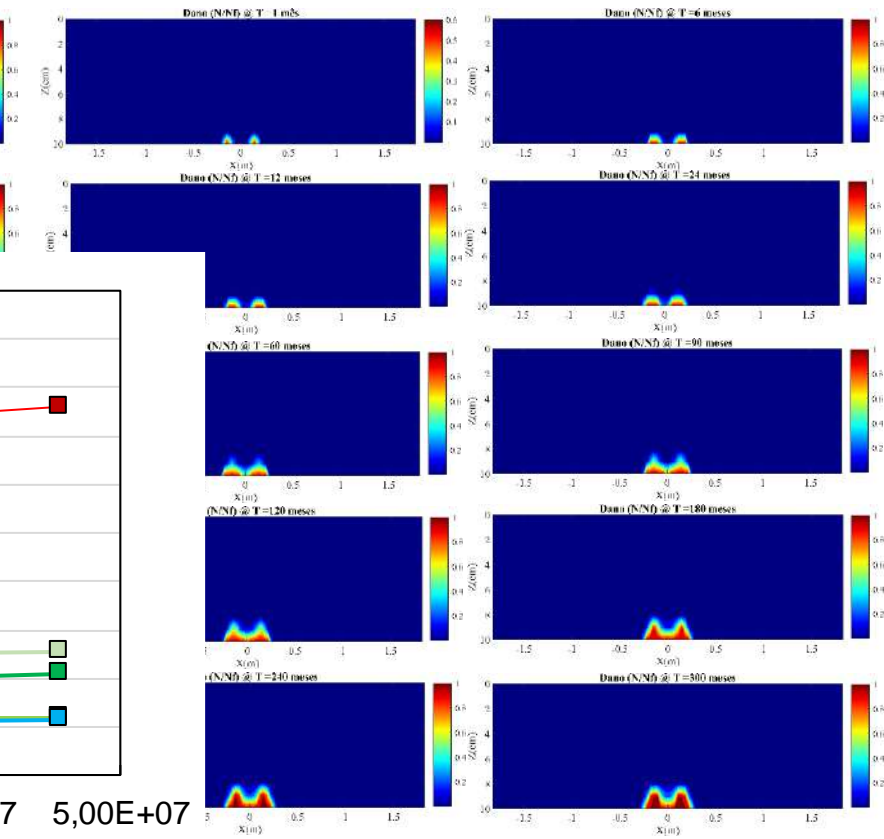
SBS RAP



SBS RAP + 16%R



SBS RAP + 8%R + 1%HiMA



Fatigue performance for both RAP materials were similar to those identified in the binder tests;

The 8% content of rejuvenating agent was enough to recover the fatigue life of both RAPs materials, maintaining a good performance at permanent deformation;

The COAC (Optimum Corrected Binder Content) methodology together with 8%R improved the fatigue life of the mixture with SBS RAP without promoting a susceptibility to permanent deformation.

E agora...

É possível

É viável economicamente

Mundo todo já usa

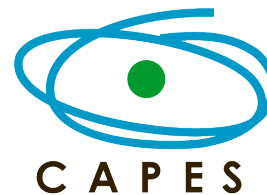
Mas precisa tecnologia e conhecimento...

Luciano Pivoto Specht

luspecht@ufsm.br



L'école de l'aménagement durable des territoires



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