

Resposta tribológica de óleos novos e usados: Efeito da textura, rugosidade e tipo de combustível

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Departamento de Engenharia Mecânica

11 de setembro de 2015

3^a. MOQUECA TRIBOLÓGICA

VITÓRIA - Setembro 2015

Continuando a conversa com a Henara, especialmente. Mas também com o Nathan, Cherlio, Leandro e Tanaka

Amilton Sinatora

Tiago Cusseau, Juan Sebastián Ruiz Acero, Rafael Obara, Gustavo Siebert, Marcos Ara André Zuin, Eduardo Trindade, Ane Cheila Rovani, Lucas Daher, Edmar Cervantes Linares, Francisco Profito, Luiz Alberto Pereira das Neves Franco



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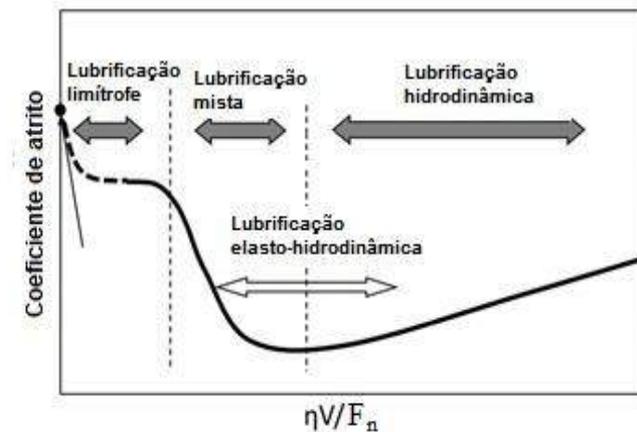
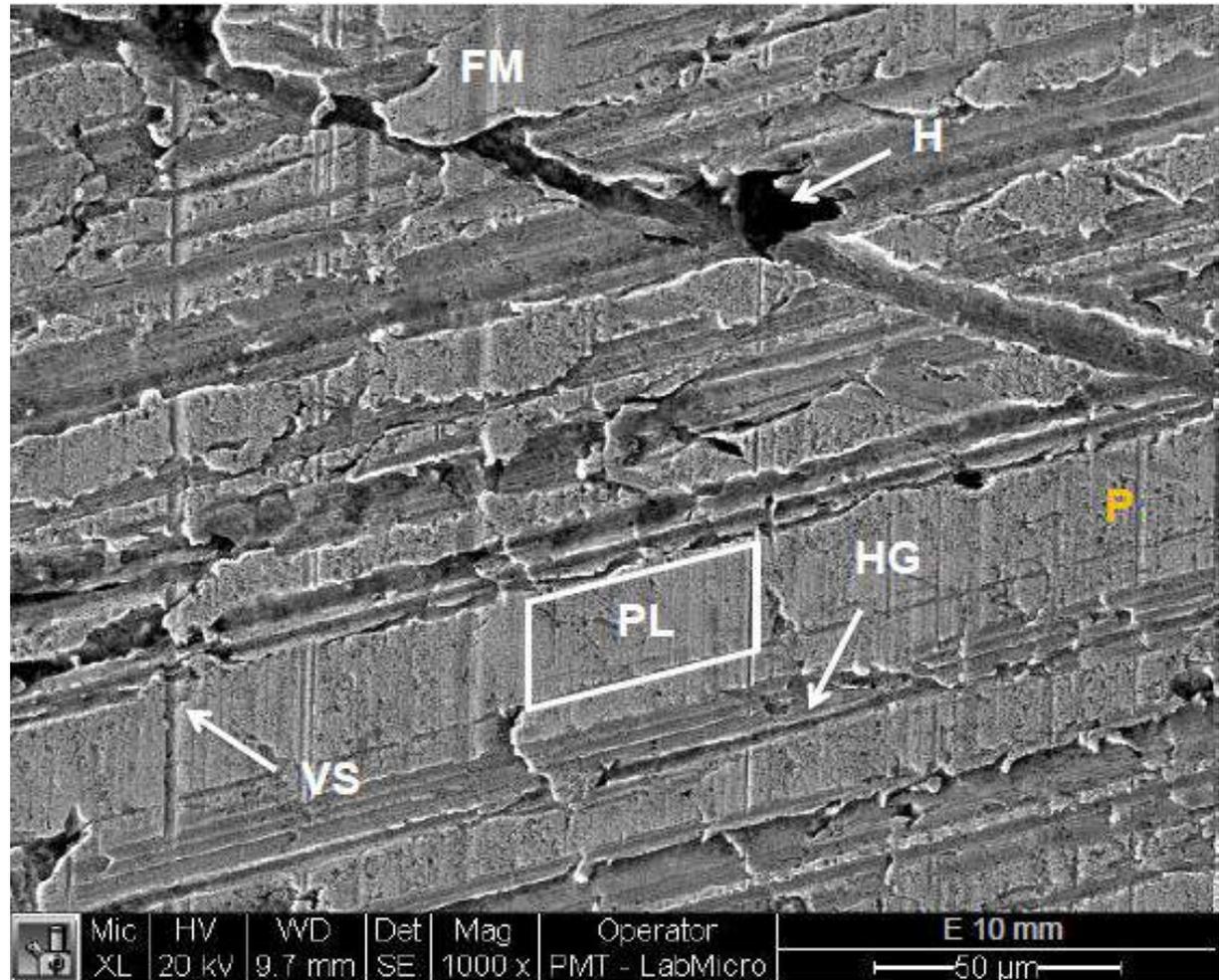
11 de setembro de 2015



Tribological challenges in flex-fuel engines

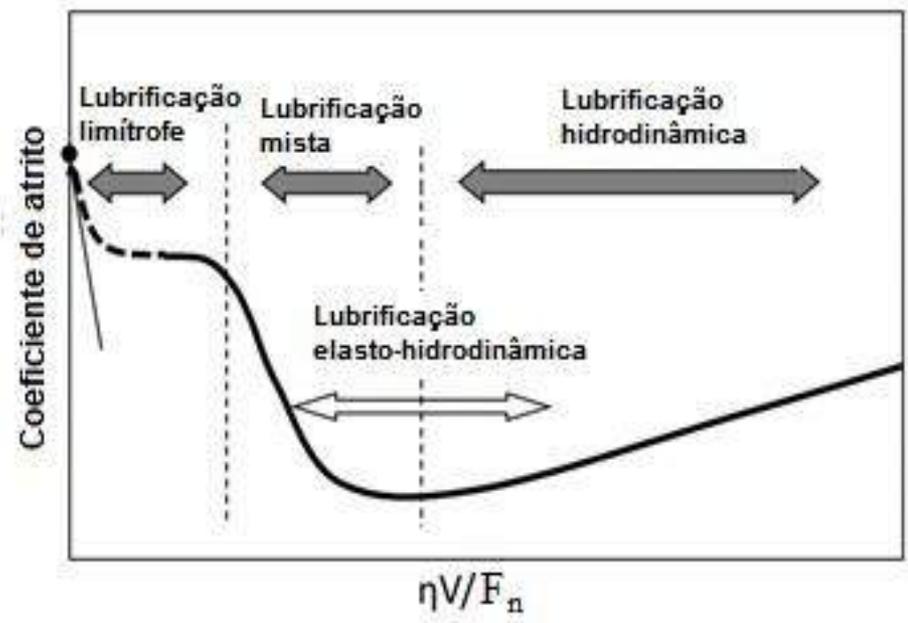
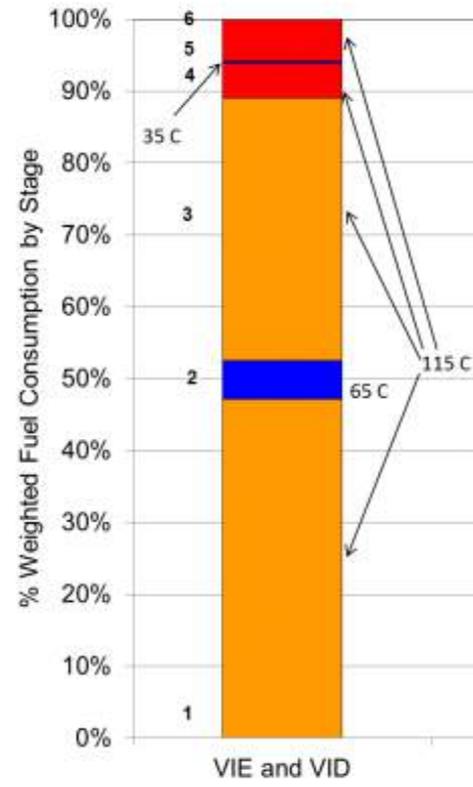
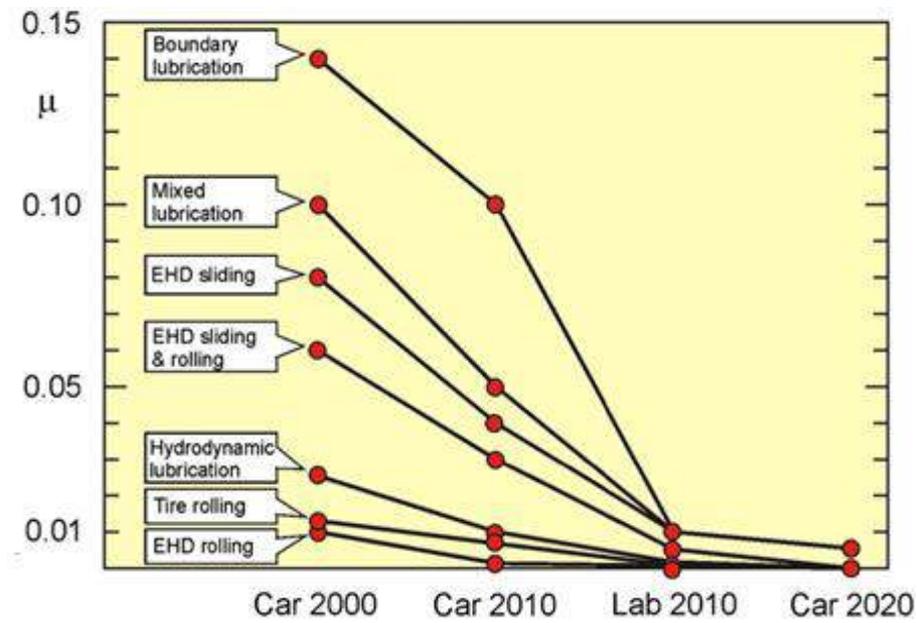


Contexto II



Entretanto além das dissipações devidas aos regimes de lubrificação existem riscos verticais (VS). Eles devem dissipar energia e não estão na curva de Stribeck. (Franco)

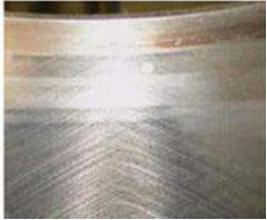
Contexto II



- Hydrodynamic - BLUE
- Mixed - ORANGE
- Boundary - RED

5W30-SM oils must fulfil the Fuel Economy Improvement according ASTM

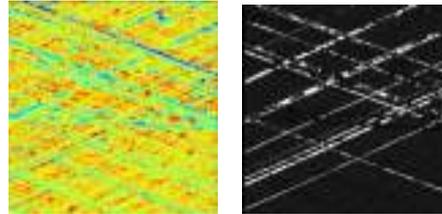
1- Cylinder Bore



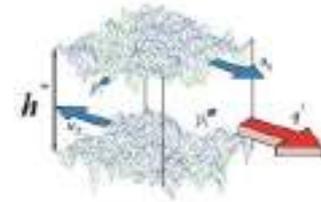
2- Topography measurement



3- Topography analysis



4- Mixed regime model (deterministic)



5- Engine Model



Modelo lubrificação limítrofe

Aditivos – adsorção

Aditivos – formação de filmes

Abrasão (Franco)

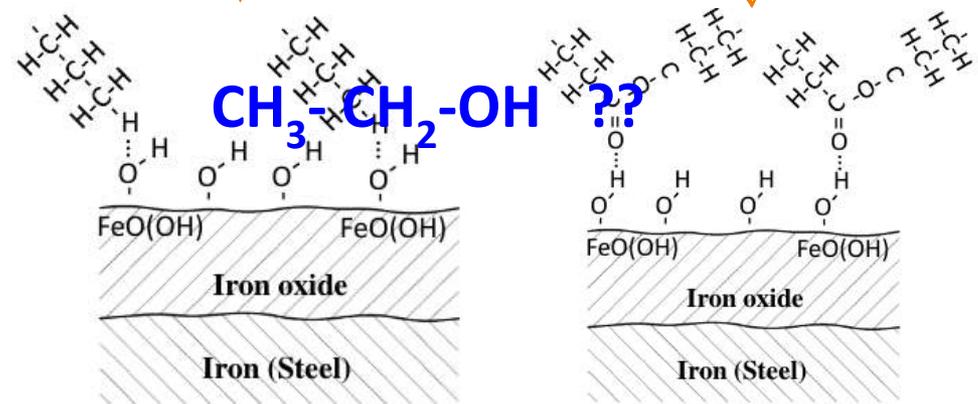
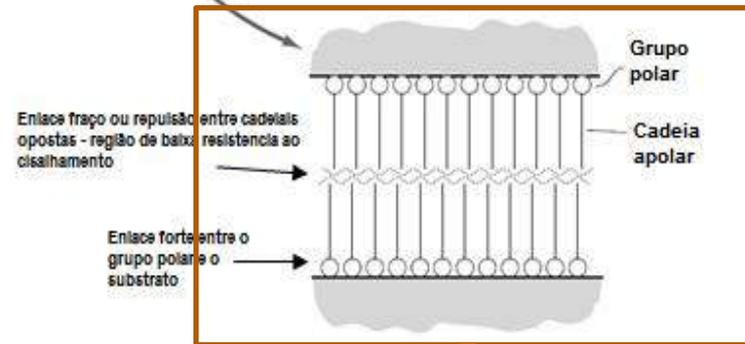
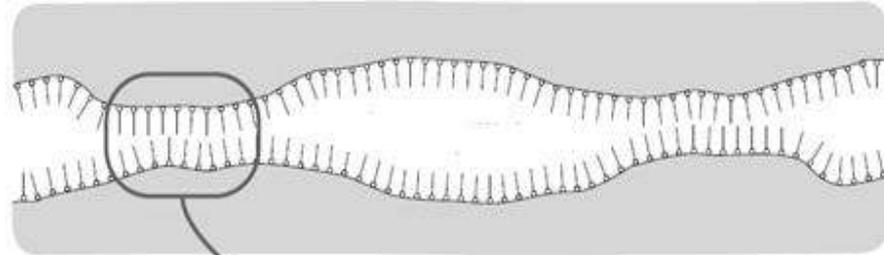
Aditivos que agem por adsorção

A Henara mostrou quarta feira que:

Adição de etanol aumenta espessura

Não causa elevação coeficiente de atrito

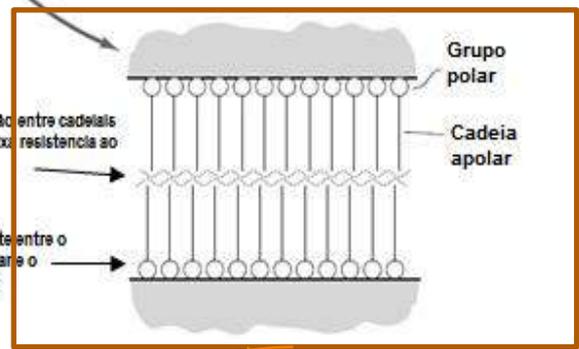
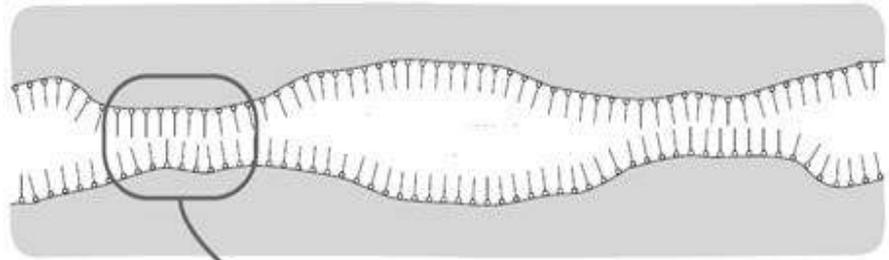
Como explicar uma vez que etanol e aditivo por adsorção são polares e deveriam disputar espaço na área real de contato?



Relação com óleo base

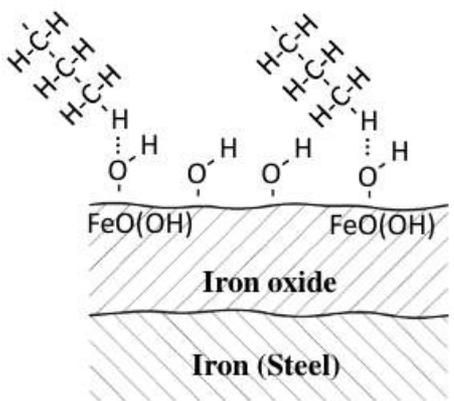
Relação com aditivo

Aditivos que agem por adsorção

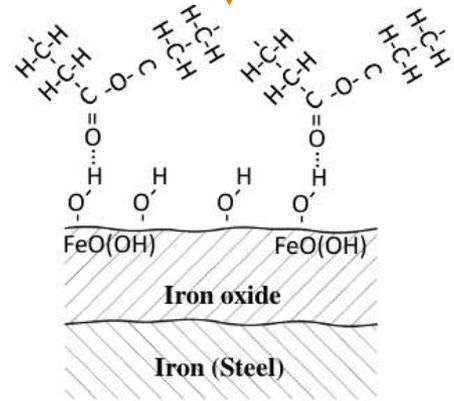


Enlace fraco ou repulsão entre cadeias opostas - região de baixa resistência ao cisalhamento

Enlace forte entre o grupo polar e o substrato



Relação com óleo base



Relação com aditivo

Monocamada sem interação lateral Langmuir

$$\frac{\theta}{1 - \theta} = K_{ads} \cdot C$$

$$\theta = \frac{\mu - \mu_b}{\mu_a - \mu_b}$$

Monocamada com interação lateral Frumkin-Fowler-Guggenheim

$$\ln \left[\frac{\theta}{(1 - \theta) \cdot C} \right] = \ln K_{ads} + g_a \cdot \theta$$

Mais de uma camada - Temkin

Adsorção substitucional – Flory Huggins

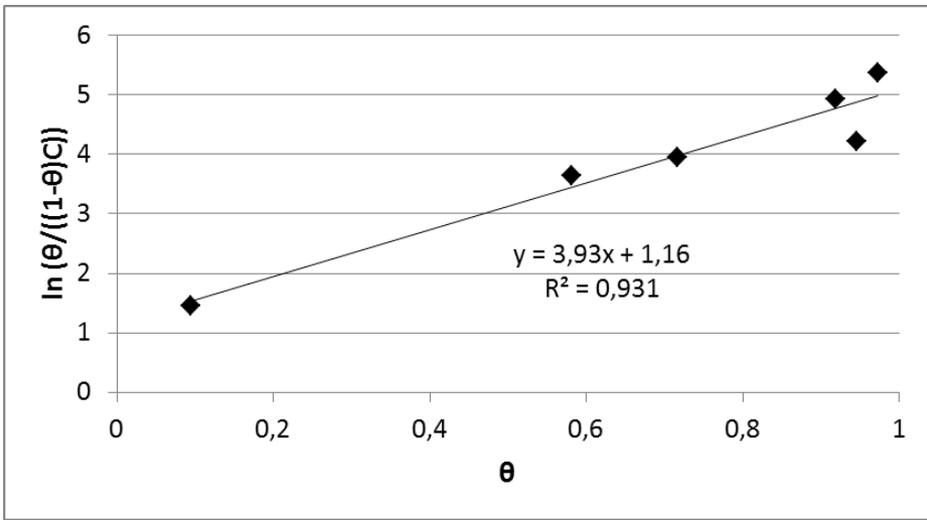
Guedes, I. C. 1996 Tese
Doutorado

Aditivos que agem por adsorção

Trindade
2014

Tabela 4.4 – Ajuste dos diferentes modelos de adsorção

Modelo	Variáveis relacionadas	80 °C e 50 N		80 °C e 150 N	
		R ²	Valor p	R ²	Valor p
Langmuir (1)	C vs. $\theta/(1-\theta)$	0,525	0,103	0,506	0,104
Langmuir (2)	C vs. C/ θ	0,289	0,272	0,572	0,082
Flory-Huggins	$\ln(\theta/C)$ vs. $\ln(1-\theta)$	0,045	0,688	0,051	0,666
Temkin	θ vs. $\ln(\theta/C)$	0,021	0,784	0,001	0,996
Frumkin	θ vs. $\ln(\theta/((1-\theta)C))$	0,931	0,002	0,894	0,004



	80 °C e 50 N	80 °C e 150 N
K_{ads}	$3,2 \pm 1,3$	$4,3 \pm 1,9$
g_a	$3,9 \pm 0,5$	$3,4 \pm 0,5$
ΔG_0 (kJ/mol)	$-3,4 \pm 1,2$	$-4,3 \pm 1,3$

$$\Delta G_0 = -R \cdot T \cdot \ln K_{ads}$$

$$\Delta G_{ads} = \Delta G_0 + R \cdot T \cdot g_a \cdot \theta$$

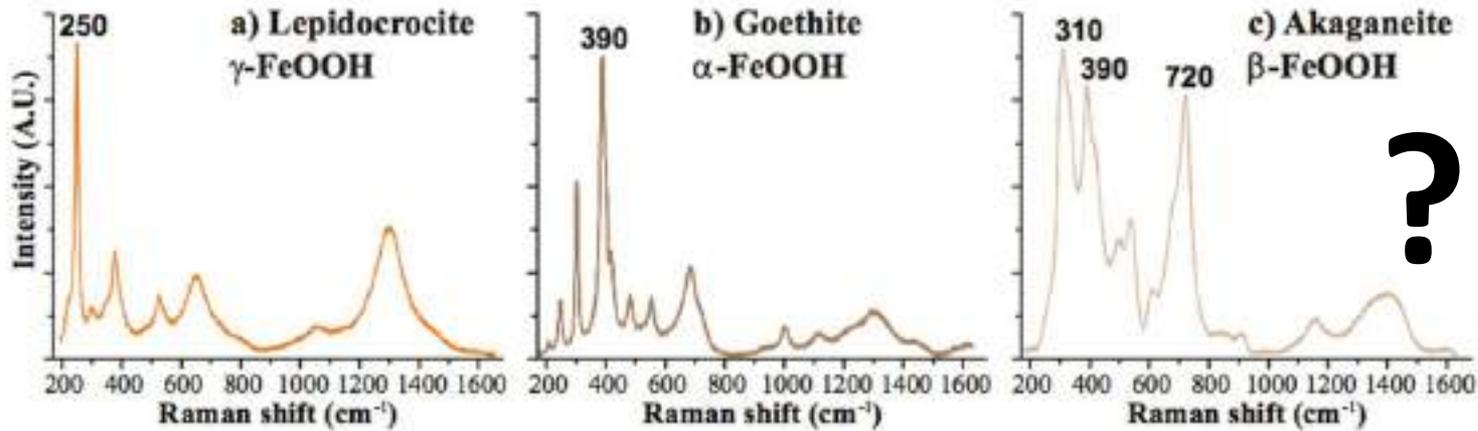
NERA COICIDÊNCIA !!!

Energia livre para adsorção (e para interação lateral) - !!

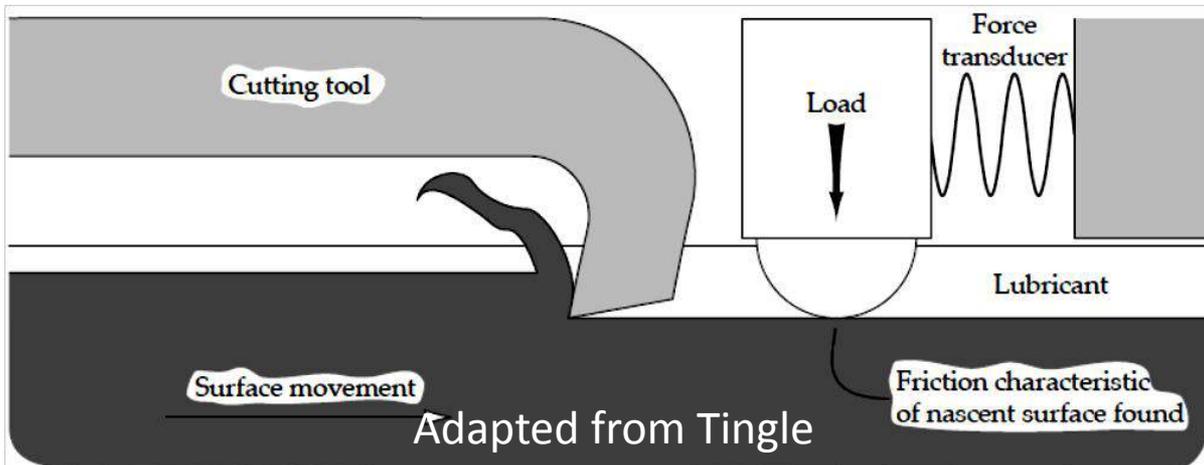
MERA COINCIDÊNCIA !!!

O que pode ser coincidência ou ter dado errado por coincidência?

1. Churrasco de Lepdocrocita



2. Nem Hardy nem Tingle tinham razão



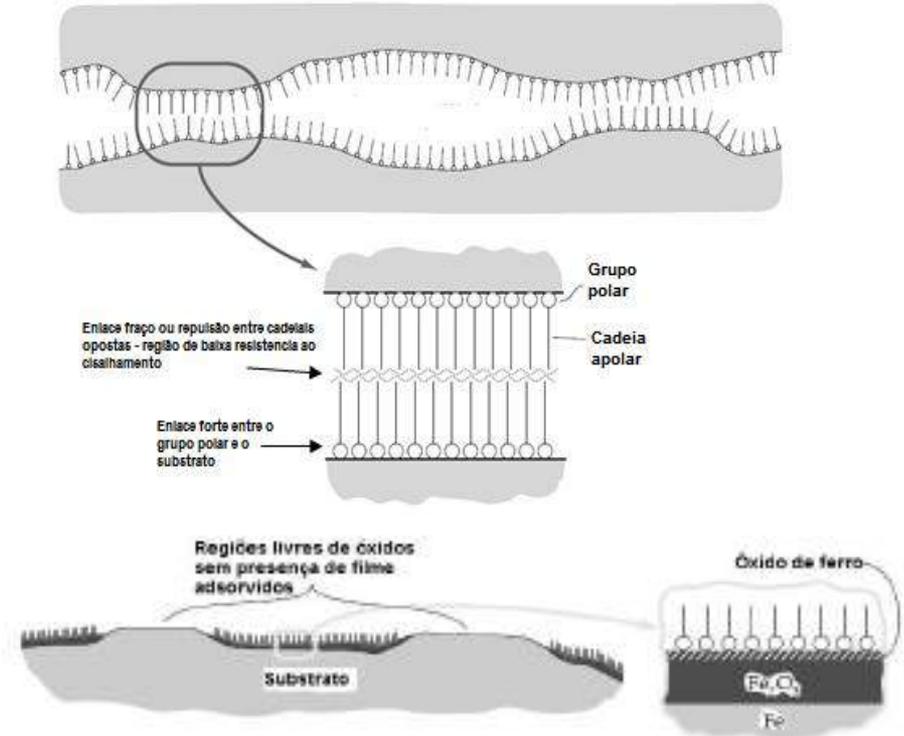
3. “Outros”
adsorveram e nós
imaginamos que
tivesse sido o éster

Aditivos (modificador de atrito) que agem por formação de filme

Henara mostrou quarta feira

- Depende da temperatura (maior melhor)
- Depende da concentração
- Prejudicado pelo etanol (água)
- Se confirma em sistema alternativo (metal – metal)?
- A topografia afeta?
- O efeito é duradouro?

Adsorção

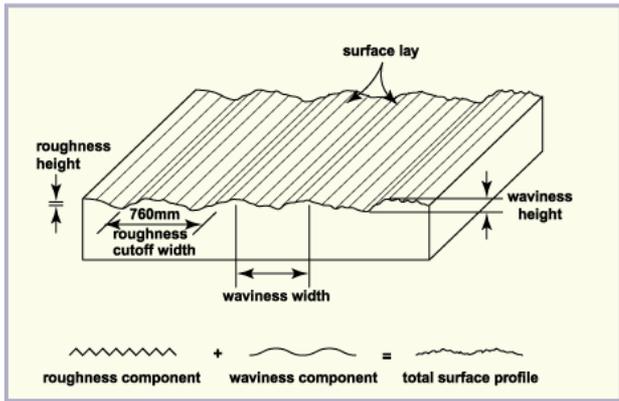


Formação de camada amorfa (?) por reação



Modificadores de atrito - MoDTC

Efeito da rugosidade e textura

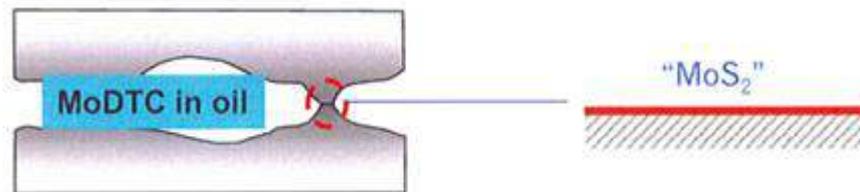


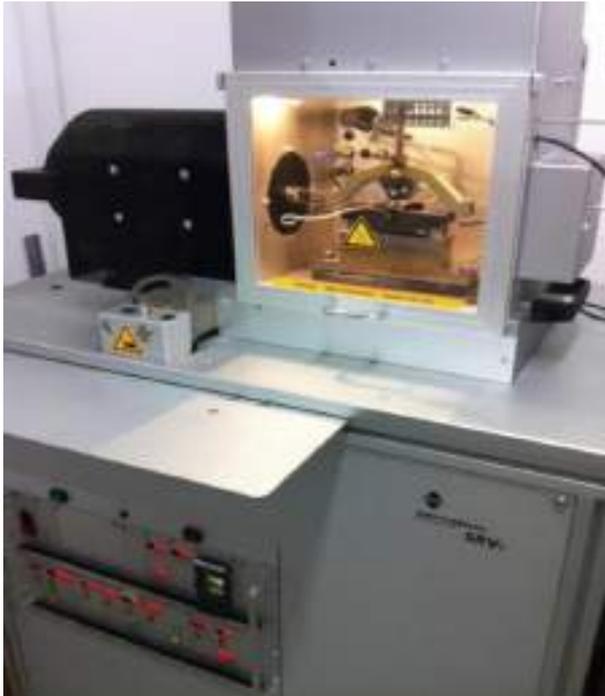
Estudar

Degradação de lubrificantes



Ativação do MoDTC





	C(%)	Si(%)	Mn(%)	Cr(%)	Mo(%)	V(%)
AISI H13	0,4	1,0	0,4	5,2	1,5	0,9
AISI 52100	1,0	0,3	0,4	1,5	-	-

Parâmetros de ensaio

Força [N]: 35

Pressão média[GPa]: 1,1

Semi-largura de Hertz [mm]: 0,1

Temperatura da interface [C]: 40

Stroke [mm]: 5

Frequência [Hz]: 10

Velocidade média [mm/s]: 100

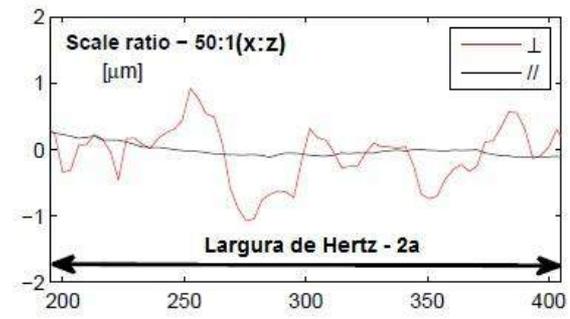
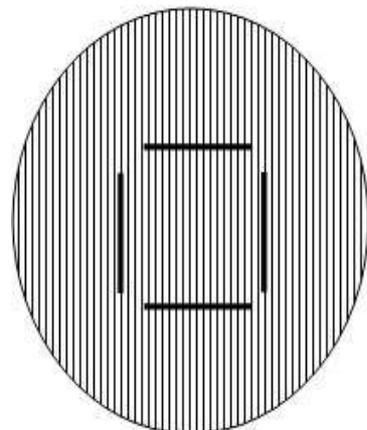
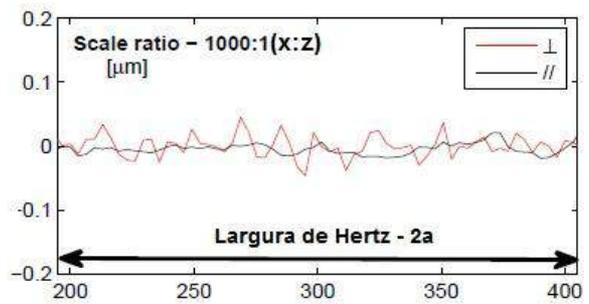
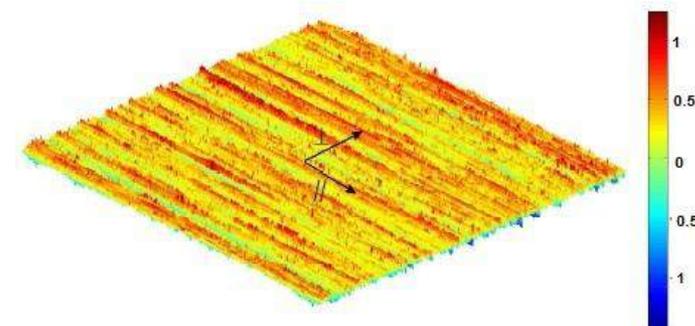
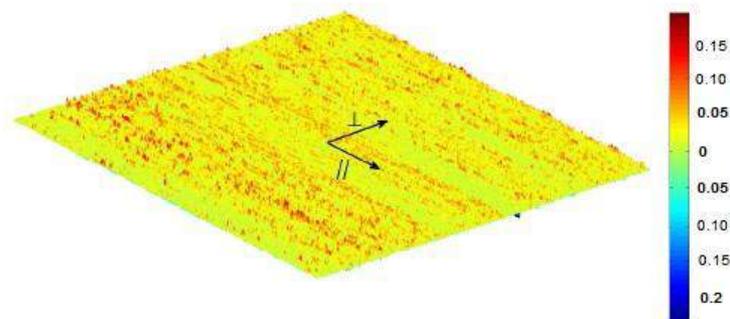
Velocidade máxima [mm/s]: 150

Tempo [min]: 20



Topografia

Tipo de superfície	Sq (μm)
Disco liso	$0,051 \pm 0,003$
Disco rugoso	$0,401 \pm 0,026$



Lubrificantes

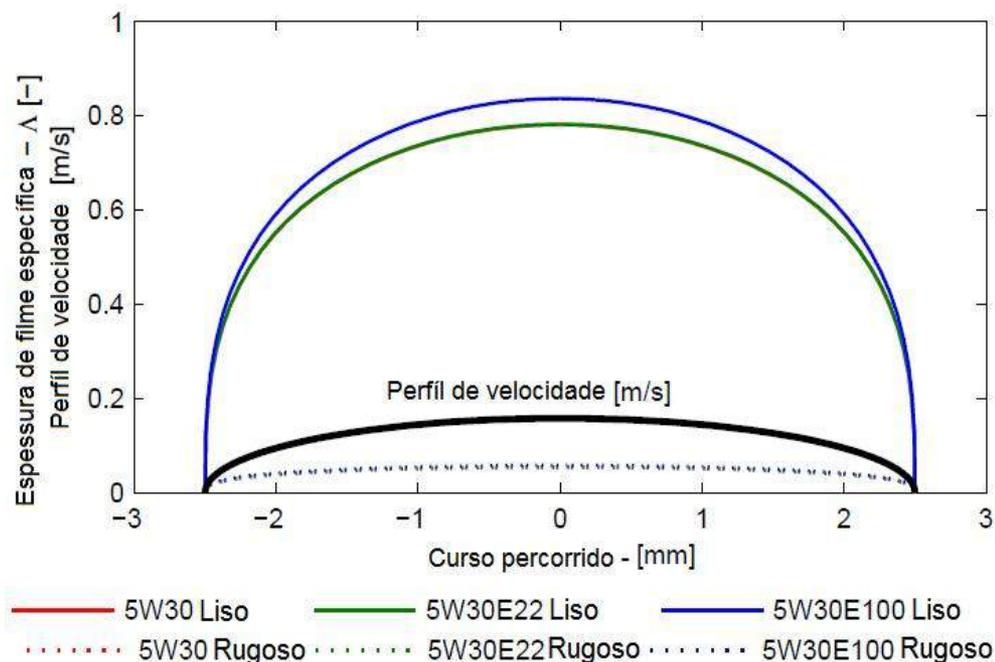
Óleo base

5W30

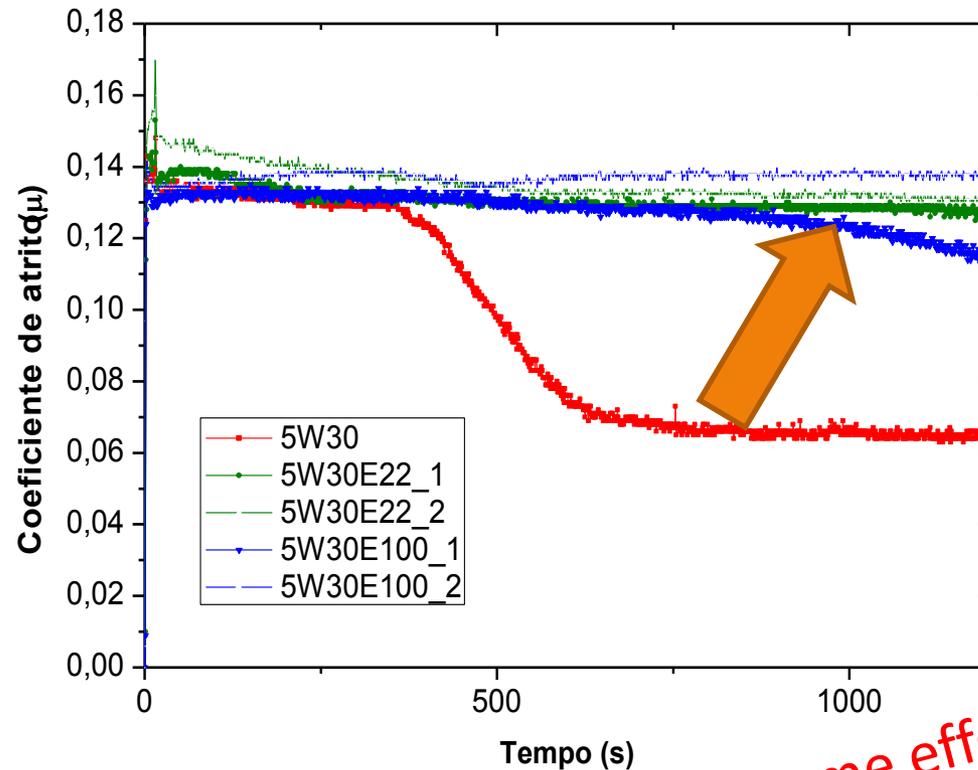
5W30 E22

5W30 E100

- 5W30 = Óleo de motor 5w30 SM
- 5W30 E22 = 5w30 usado em automóvel abastecido com gasolina
- 5W30 E100 = 5w30 usado em automóvel abastecido com etanol



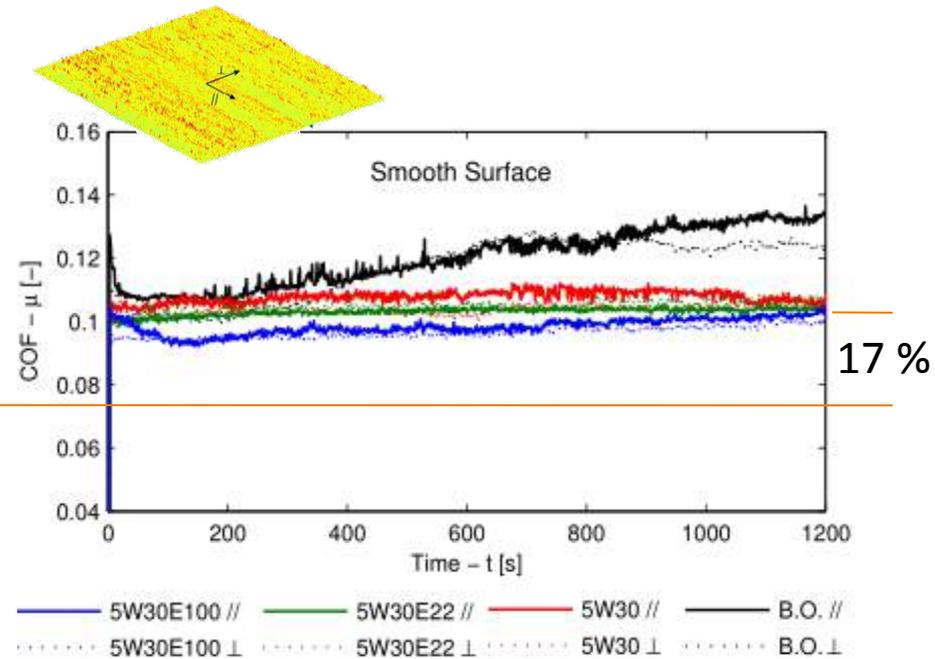
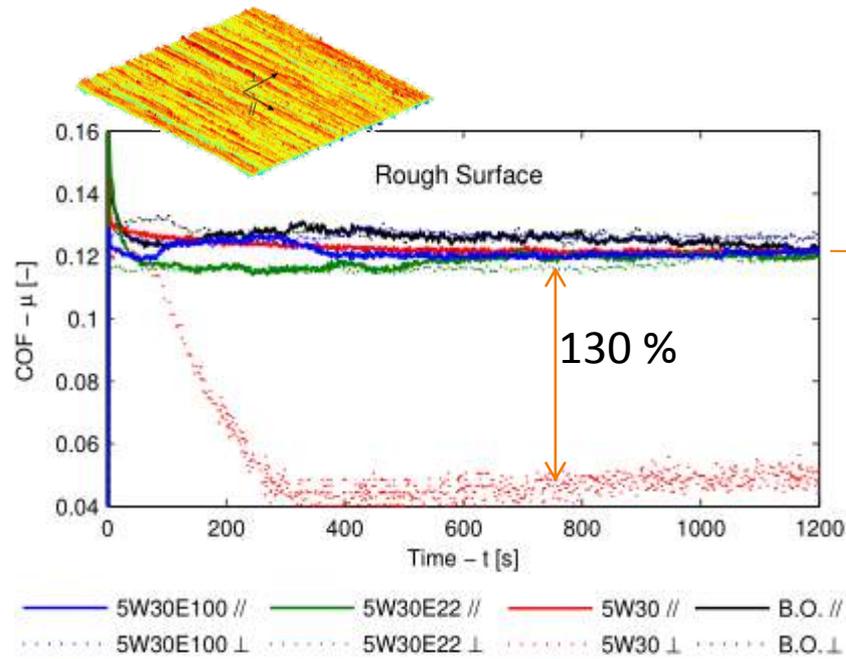
- 8 and 20 % w/w of ethanol were added to fresh 5W30-SM just before the test
- 8 and 20 % w/w of gas were added to fresh 5W30-SM just before the test



Explica (!?) por que atrito com etanol é maior

The same effect of oil aging in dynamometers, engines and thermal degradation !!!!!

4b. Friction Coefficient Analysis



➤ 5W30 \perp showed friction reduction

➤ $\text{COF}_{\perp} \approx \text{COF}_{//}$

➤ Used oils \approx Base oil

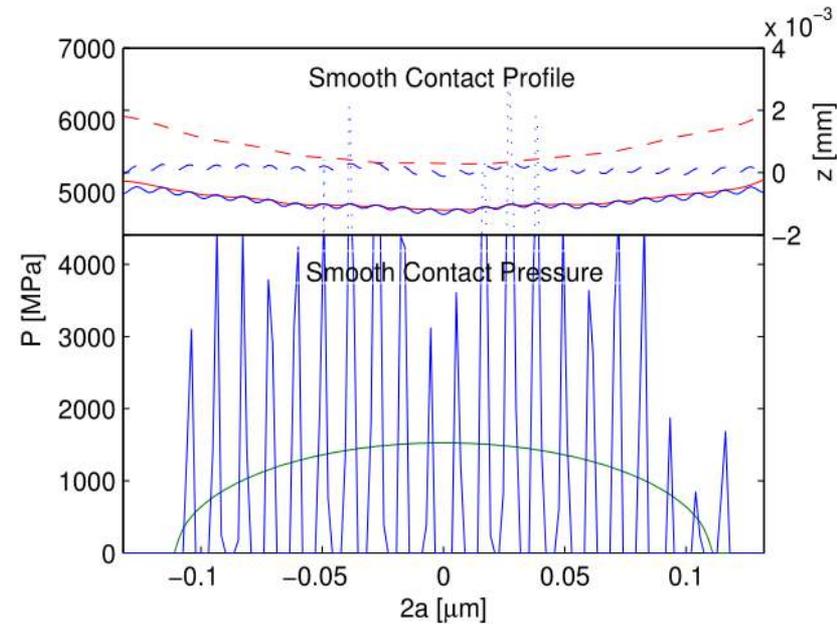
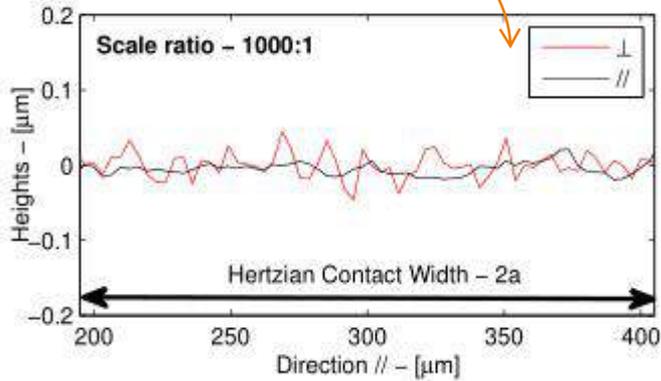
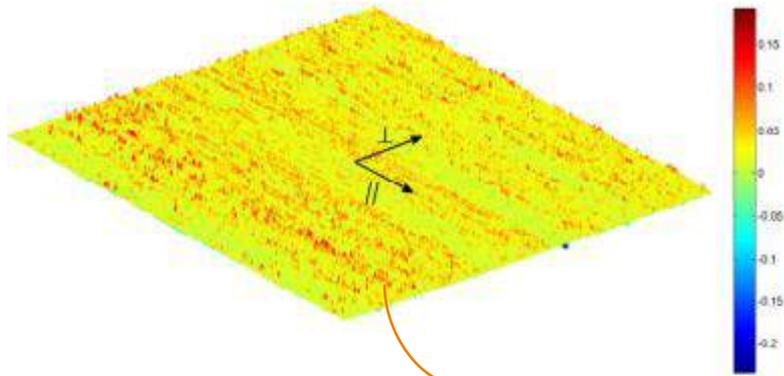
➤ Friction reduction was not observed

➤ $\text{COF}_{\perp} \approx \text{COF}_{//}$

➤ Base oil friction increases with time

➤ $\text{COF}_{\text{Rough}} > \text{COF}_{\text{Smooth}} (\approx 17 \%)$

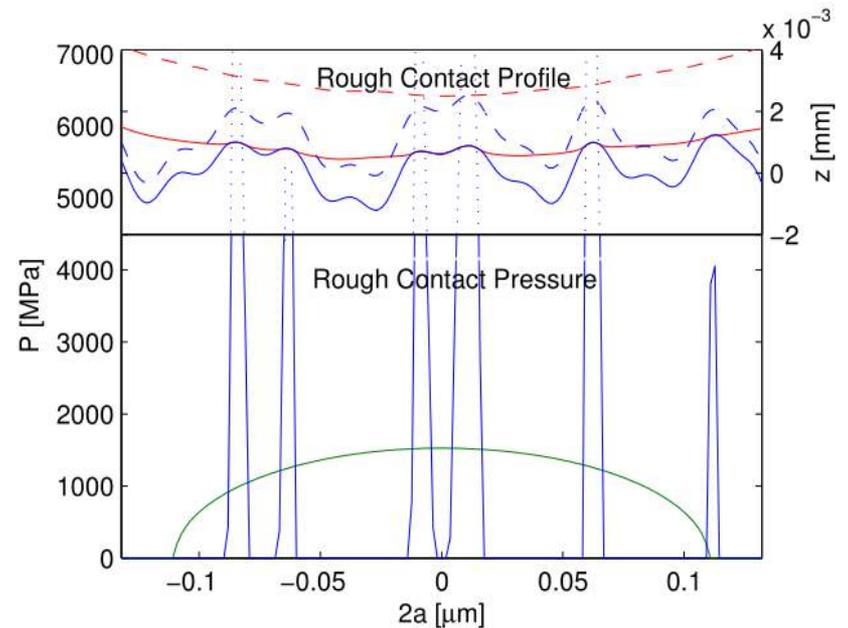
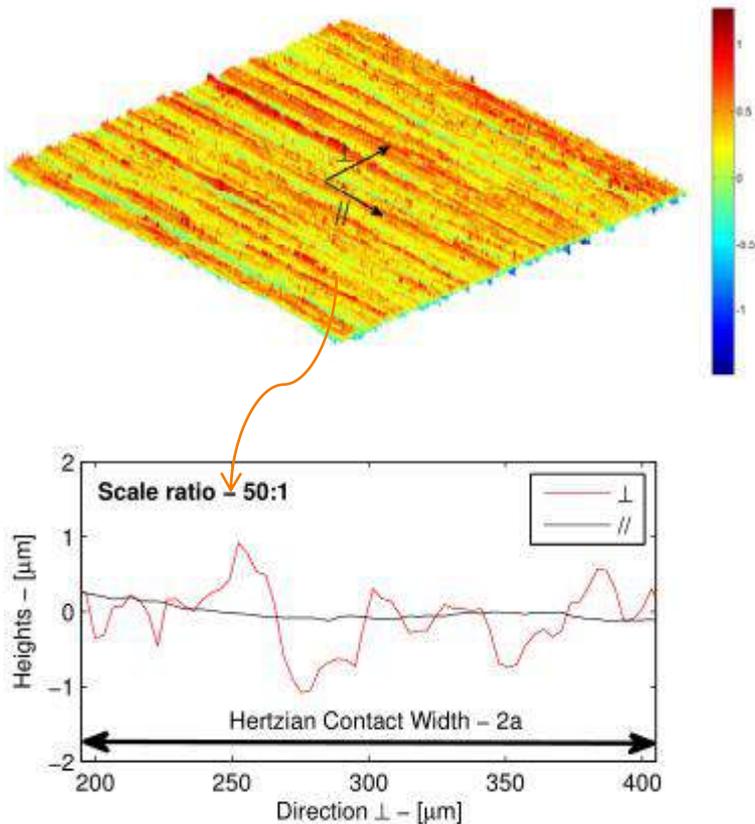
Smooth Surface – $Sq=0.02 \mu\text{m}$



$P_0 < H$
Elastic Field

Na superfície lisa em ambas as direções a tensão de contato é menor que a dureza (do mais mole). **A casca do ovo não quebra!**

Rough Surface – $Sa=0.40 \mu\text{m}$



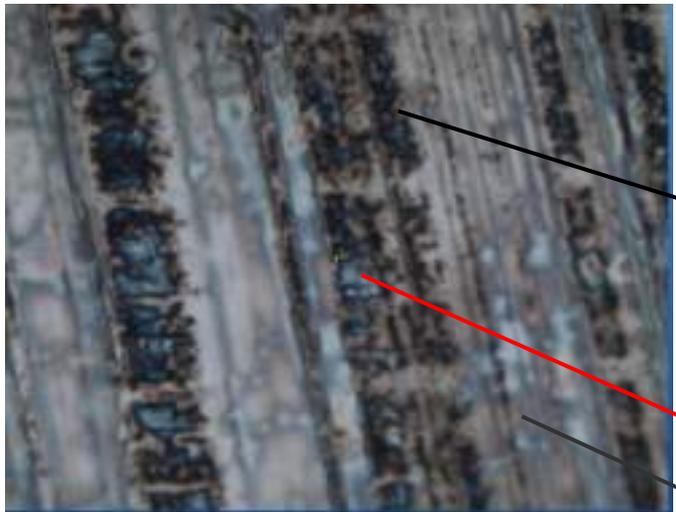
$P_0 > H$
Elastic field (macro)
Plastic field (micro)

Na superfície mais rugosa, na direção perpendicular a tensão de contato é maior que a dureza (do mais mole). **A casca do ovo pode quebrar!**

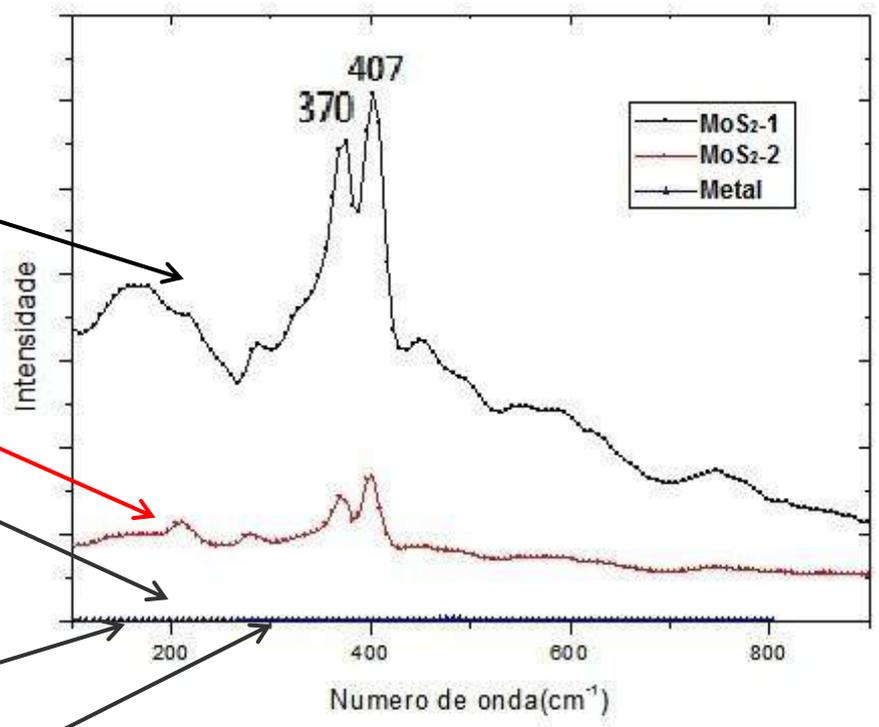
Vale para cerâmicas, filmes tribológicos, pode ser combinado com K_{IC} , K_{ISCC} . Temperaturas elevadas.

Raman na condição Disco rugoso 5w30

Perpendicular



Paralela



MoS₂

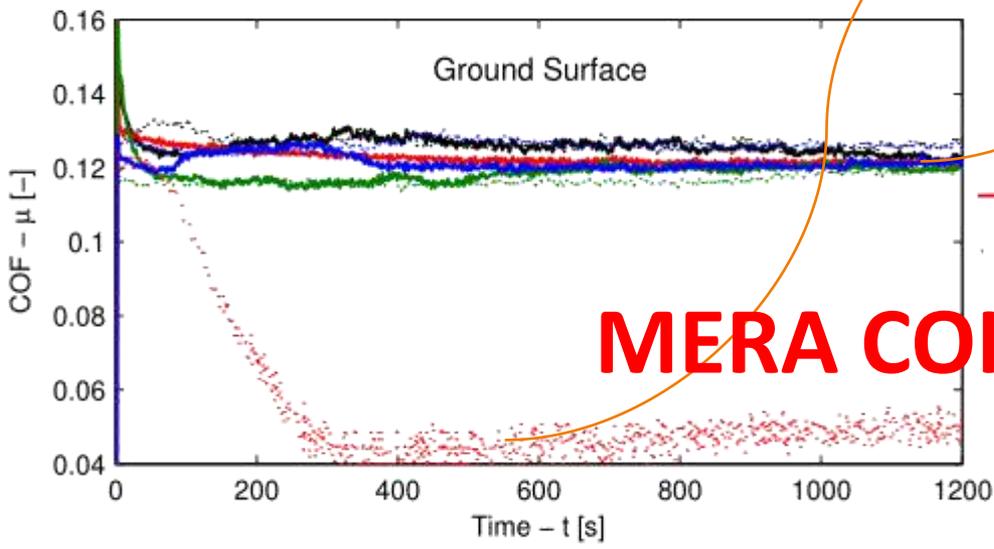
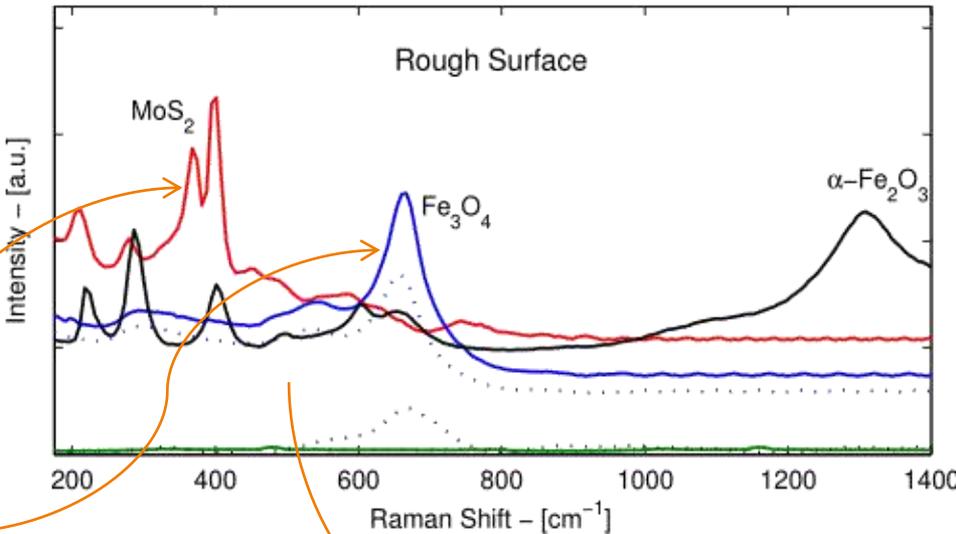
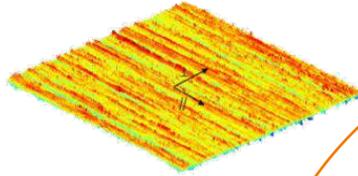
Li et al, 2012

Se pode quebrar (o filme de óxido) então, **segundo a crença vigente** pode formar MoS₂

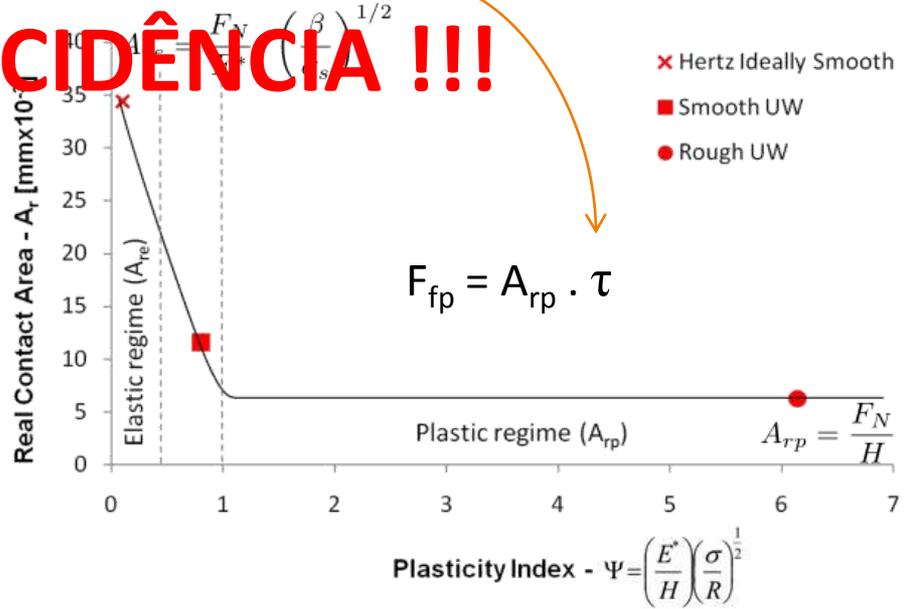
4b. Friction Coefficient Analysis

Recall that:

$\Lambda < 1$ & $\Psi \gg 1$



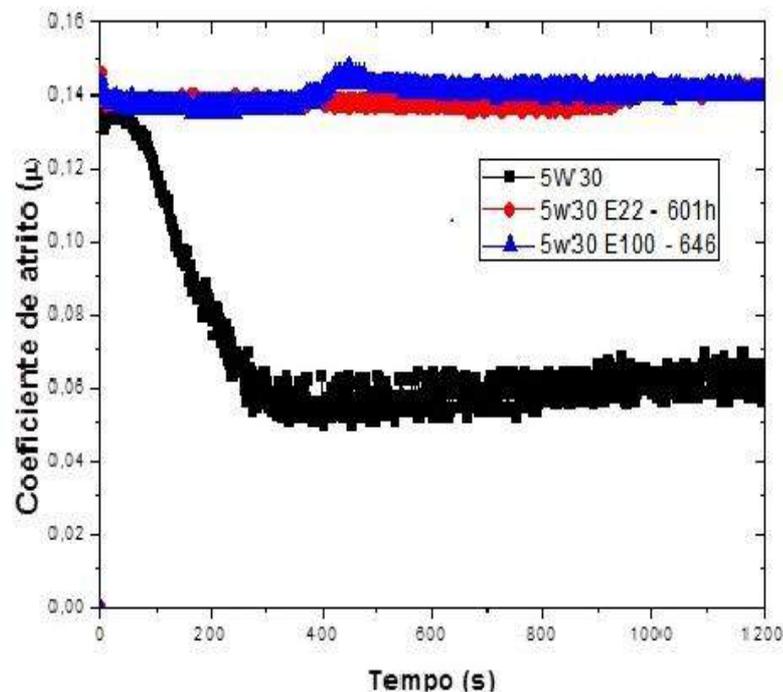
MERA COINCIDÊNCIA !!!



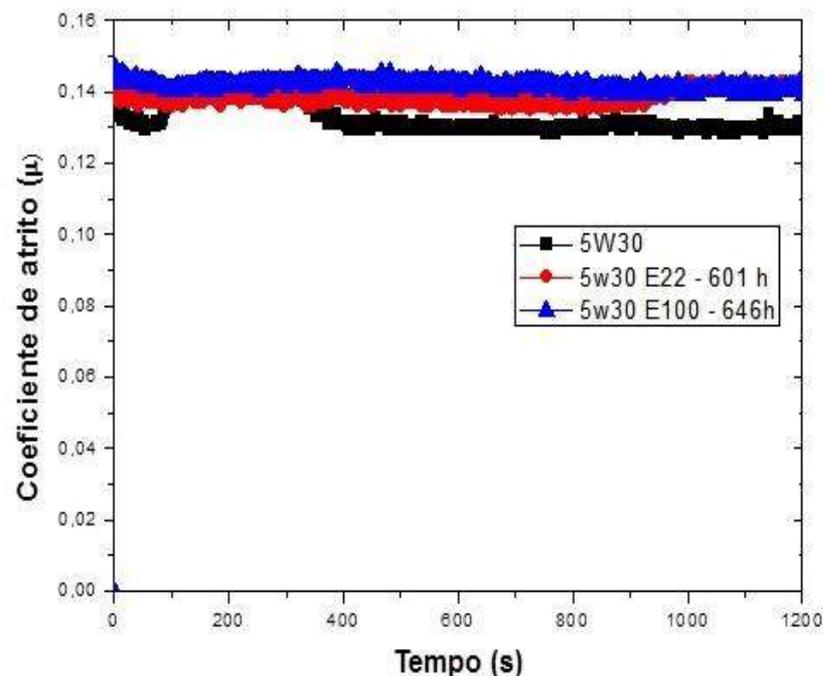
Os que não mostraram efeito do FM tem óxidos

Efeito da pressão

Pressão 1,1 GPa



Pressão 0,75 GPa



Diminuir pressão translada curva de tensões nas áreas reais de contato para região elástica. O filme de óxido sobrevive? Por isso MoDTC não se decompõem?

MERA COINCIDÊNCIA afinal “os óxidos são catalizadores inclusive a platina” e portanto.....

Obrigado!

Efeito da rugosidade – discos rugosos

Superfícies rugosas

 $\Lambda \ll l$
 $\psi > 1$

Dissipação viscosa



- Pequena devido a filmes de óleo de pouca espessura

Adesão



- Pequena devido à presença de filme lubrificante
- Grandes diferenças quando os efeitos devidos ao crescimento de junção são significativos

Deformação plástica



- Dependência da topografia do corpo mais duro

$$\mu_d = \tan(\theta)$$

Efeito da rugosidade – discos lisos

Superfícies lisas

$$\Lambda \approx 1$$

$$\Psi < 1$$

Dissipação viscosa



- Até 15 vezes maior comparado com a condição de disco rugoso

Adesão



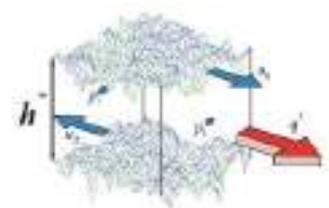
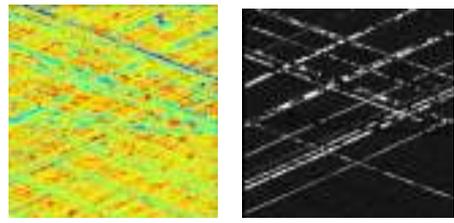
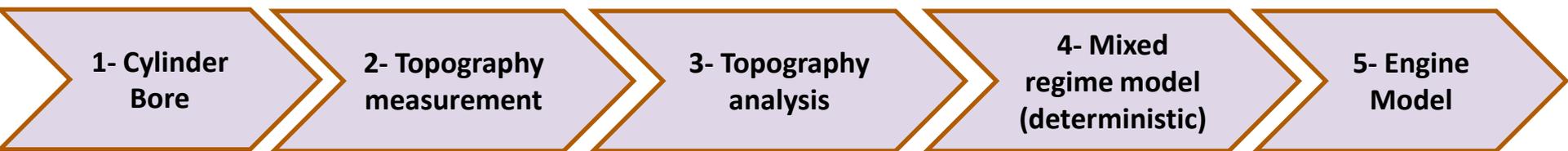
- Pequena devido à presença de filme lubrificante
- Grandes diferenças quando os efeitos devidos ao crescimento de junção são significativos

Deformação plástica



- Dependência da topografia do corpo mais duro
- Menor comparado com a condição de disco rugoso

The LFS approach for engine cylinder tribological optimization



Literature / Industry

<p>Plateau etc. Coated bores</p> <p>J.M.BORDES (PSA) 2014</p>	<p>ASSESSMENT OF 3D PARAMETERS FOR THE CHARACTERISATION OF CYLINDER TREADS</p> <p>Pehnelt (Audi AG) et al. MTZ 04/2013</p>	<p>WEAR DETECTION ON CYLINDER LINERS WITH OPTICAL 3D MEASURING TECHNOLOGY</p> <p>Rubach (VW AG) et al. MTZ 03/2014</p>	<p>P_Hyd P_Asp</p> <p>Chen et al. (MIT) 2012</p>	<p>Delta Friction Losses (%)</p> <p>Schutz, M. (Daimler) et al. MTZ 06/2013</p>
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Recent TriboFlex publications

Lyon 2015 – Effect of cylinder liner wear on the mixed lubrication regime of TLOCs

Trib. International 2014 - Partitioned fluid-structure methods applied to the solution of elastohydrodynamic conformal contacts.

Leeds/Lyon 2014-Effect of Cylinder Liner Wear on the Mixed Lubrication Regime of TLOCs

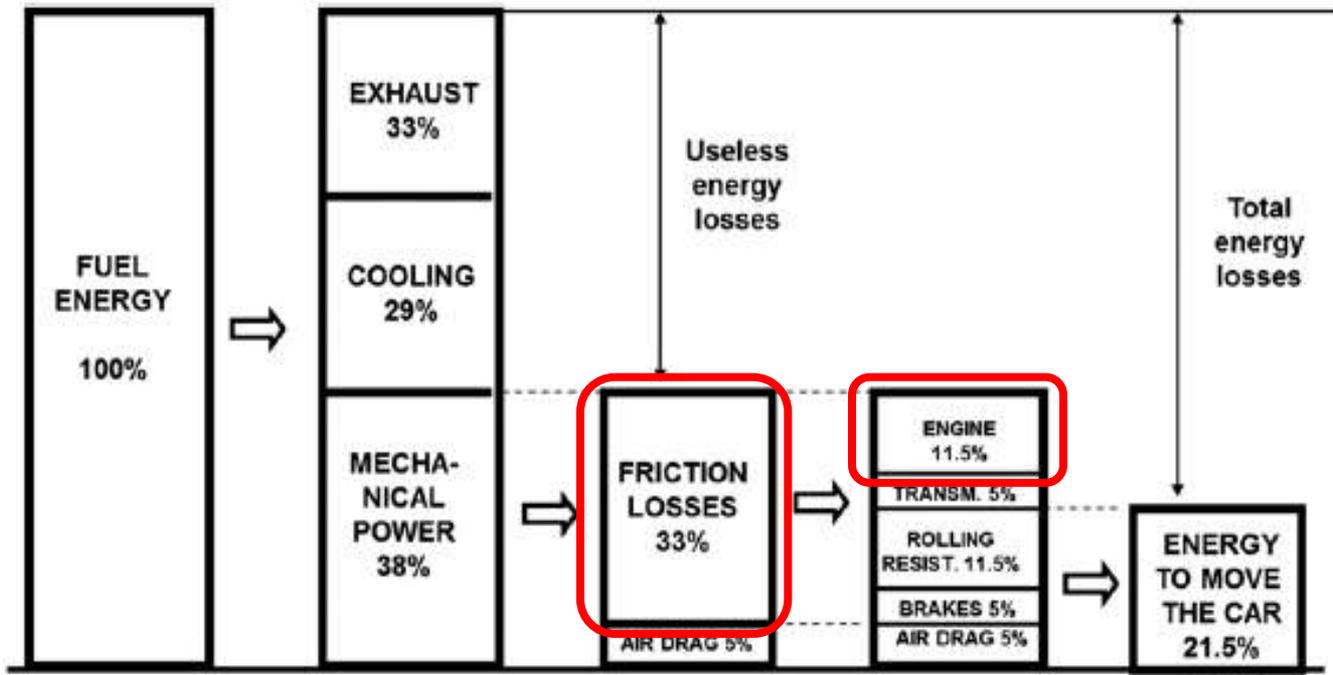
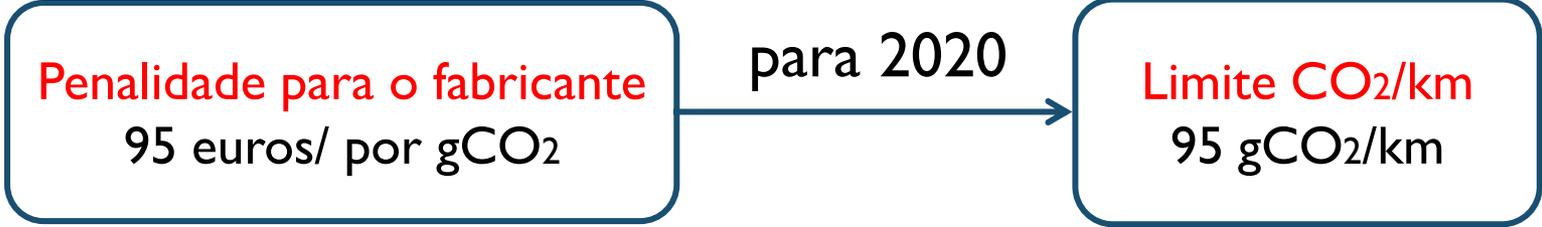
SAE 2014-36-0323 - Folded metal and other surface parameters on combustion engine cylinders

Lub. Science 2014 - Friction and wear performance of MoDTC-containing and ester-containing lubricants over steel surfaces under reciprocating conditions

SAE 2014-06-0302 Folded metal effect on lubricant film thickness and friction using a mixed lubrication deterministic model
19th Tech Meeting – Flex-Fuel, tiagoegm@gmail.com

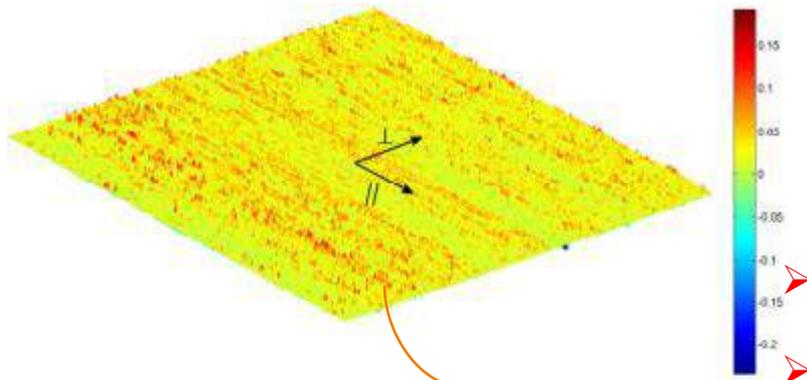
Lyon 2015 - Tribological response of fresh and used engine oils: the effect of surface texturing, roughness and fuel type

Limite de CO₂/km no 2012
130gCO₂/km

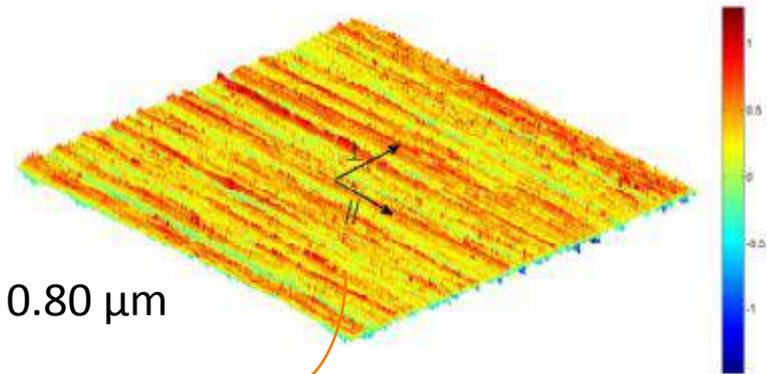


Holmberg;Andersson;Erdemir, 2012

Smooth Surface – $Sq=0.02 \mu\text{m}$

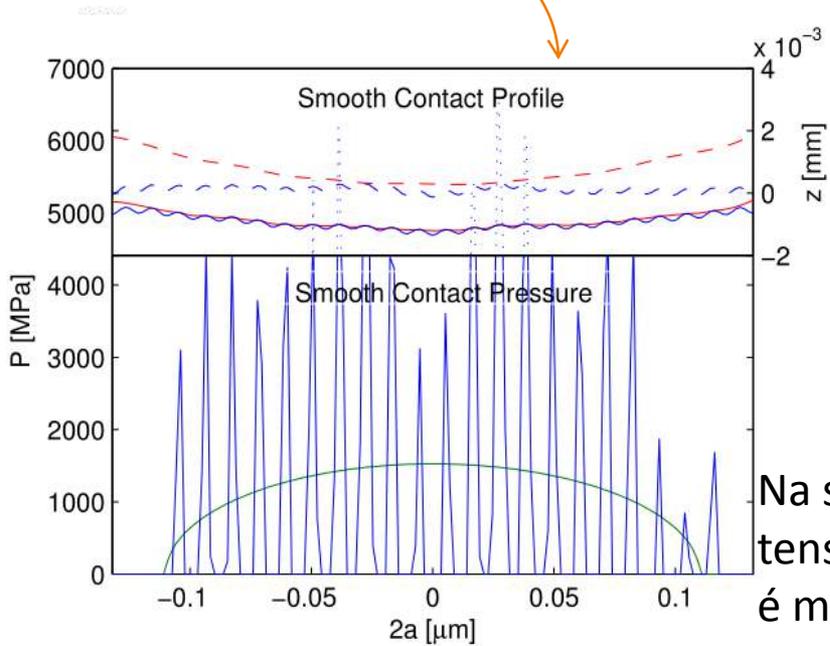


Rough Surface – $Sa=0.40 \mu\text{m}$

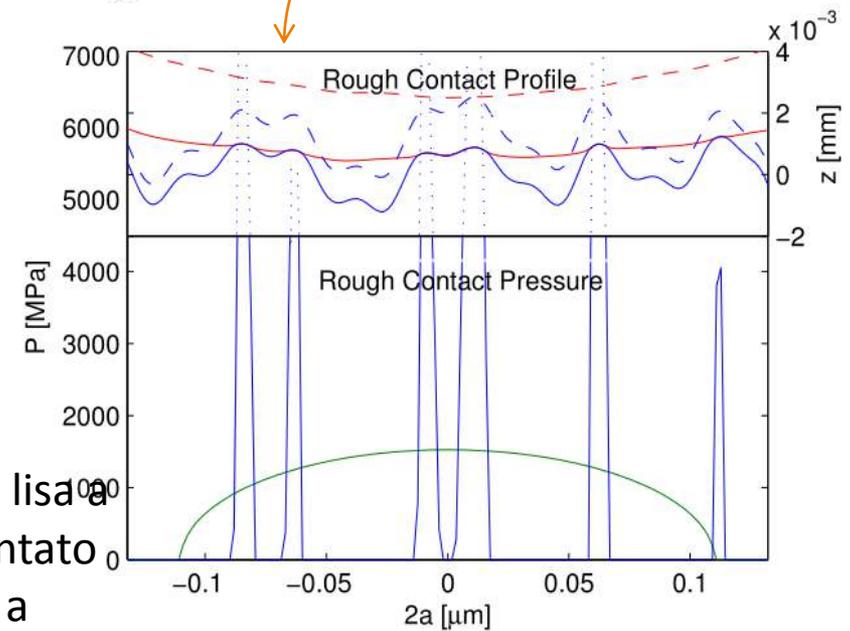


Sa 0.18 – 0.80 μm

H 450 – 650 HV



$P_0 < H$
Elastic Field

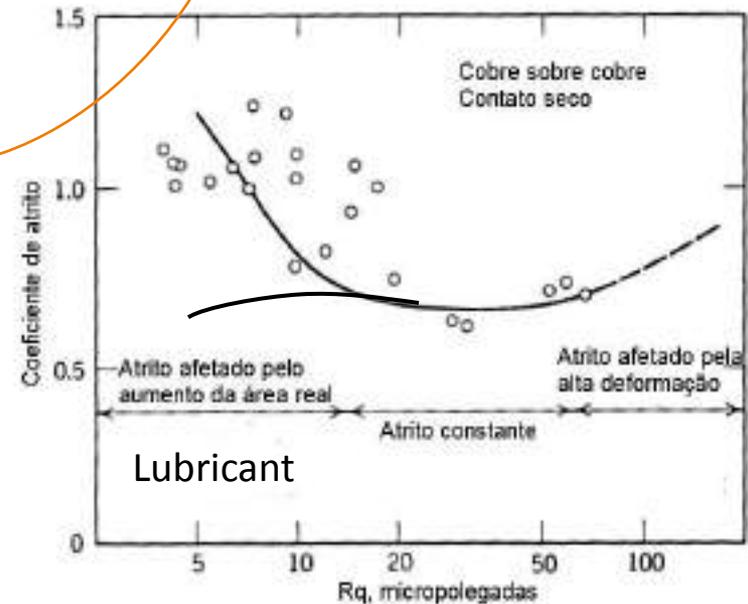
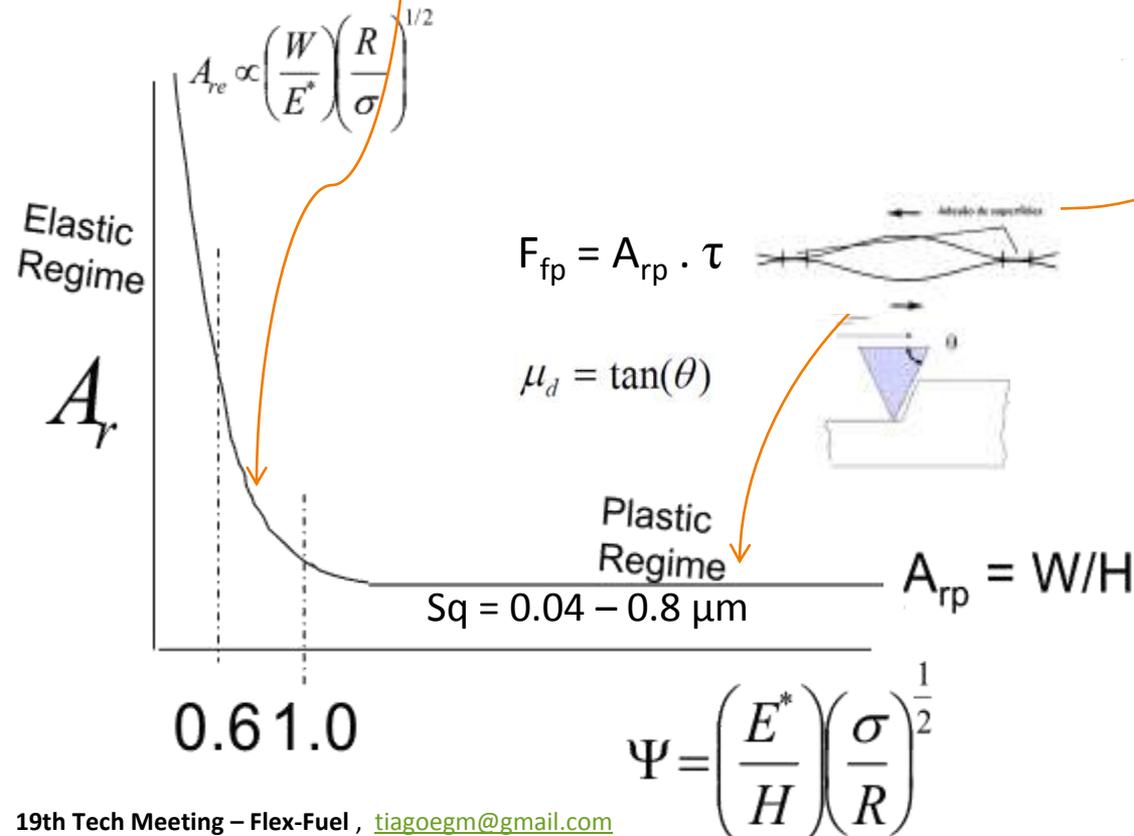
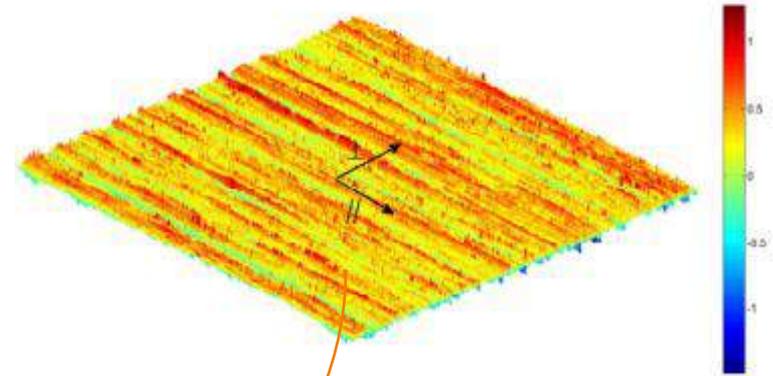
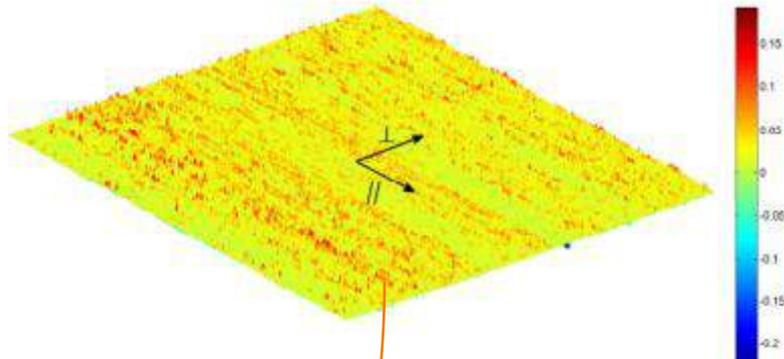


$P_0 > H$
Elastic field (macro)
Plastic field (micro)

Na superfície lisa a tensão de contato é menor que a dureza (do mais mole). A casca do ovo não quebra

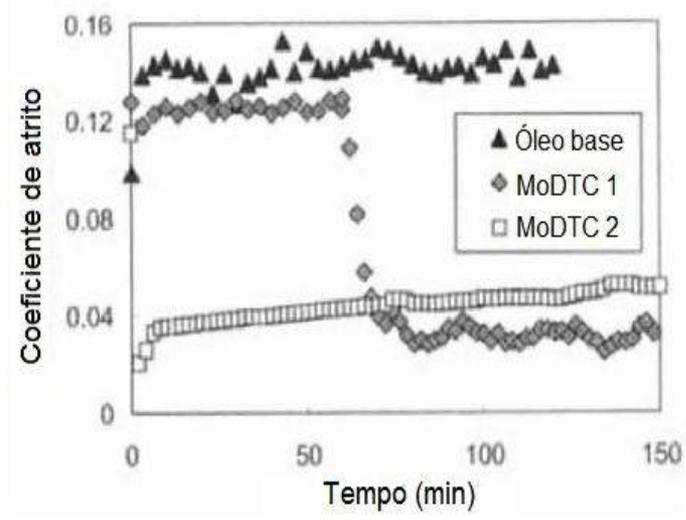
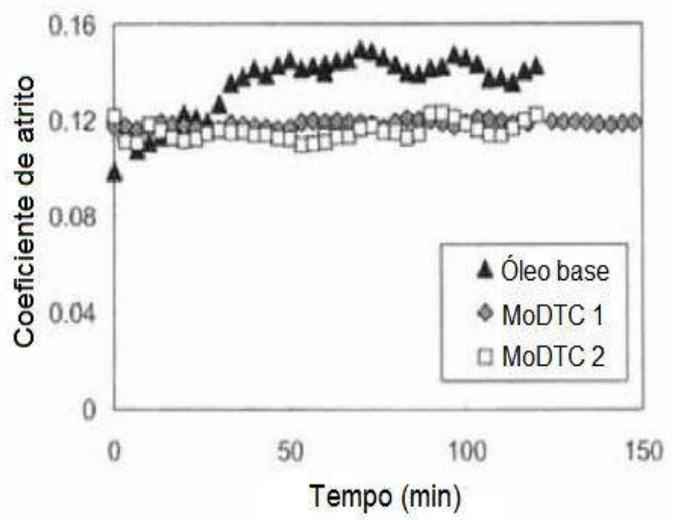
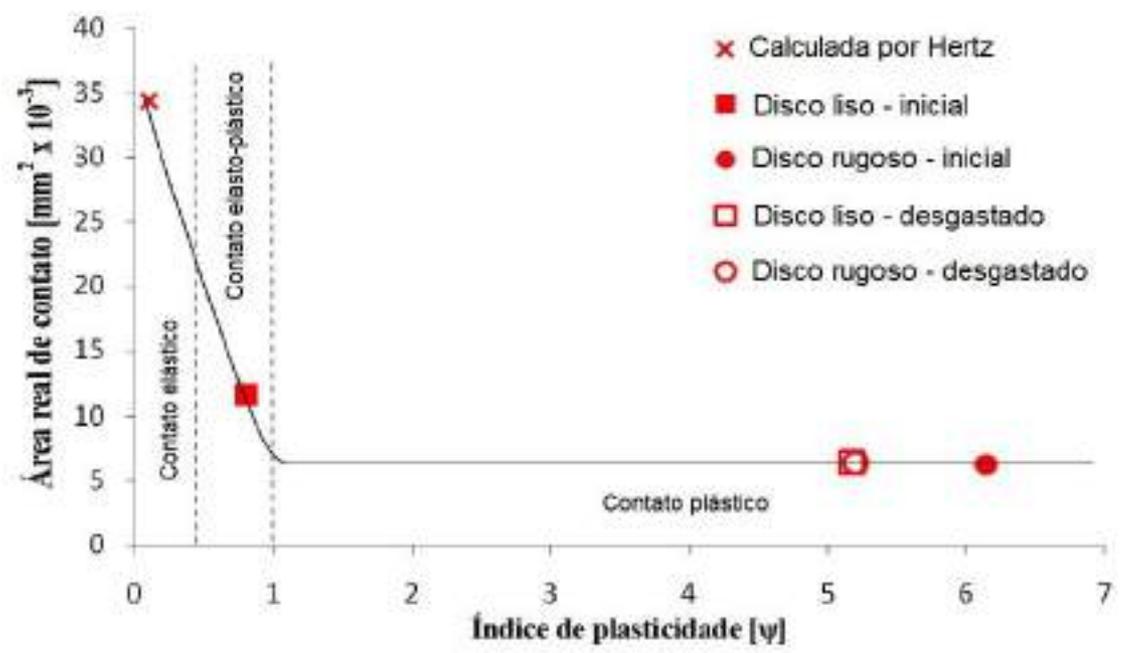
Smooth Surface – $Sq=0.02 \mu\text{m}$

Rough Surface – $Sq=0.40 \mu\text{m}$



Rabinowicz, 1995

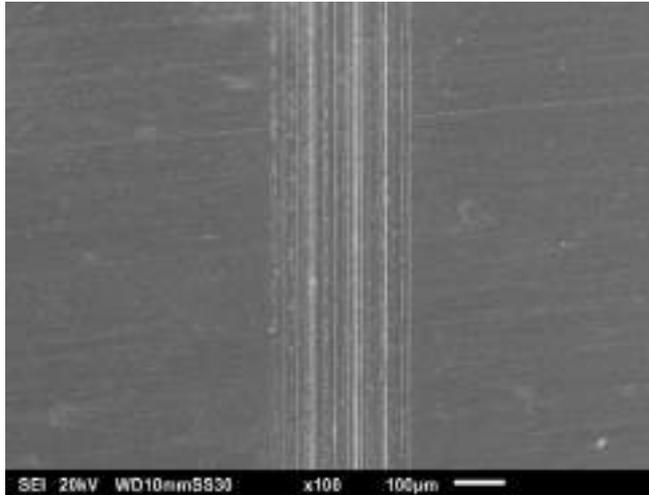
Área real vs índice de plasticidade



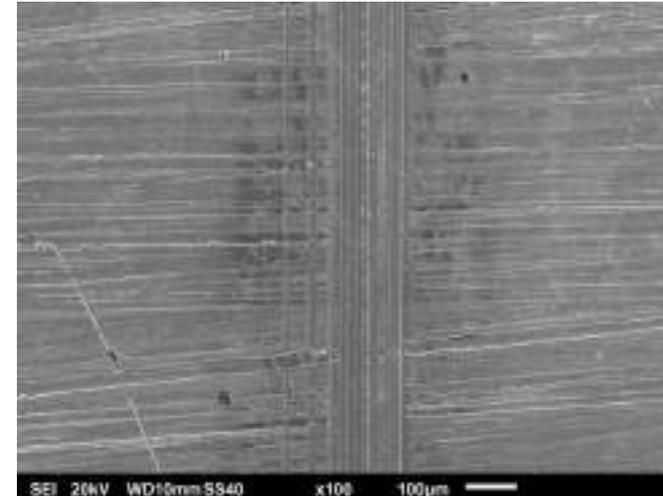
Graham, Spikes e Korcek, 2001

Mecânica do contato em amostras desgastadas

Disco liso – Óleo base



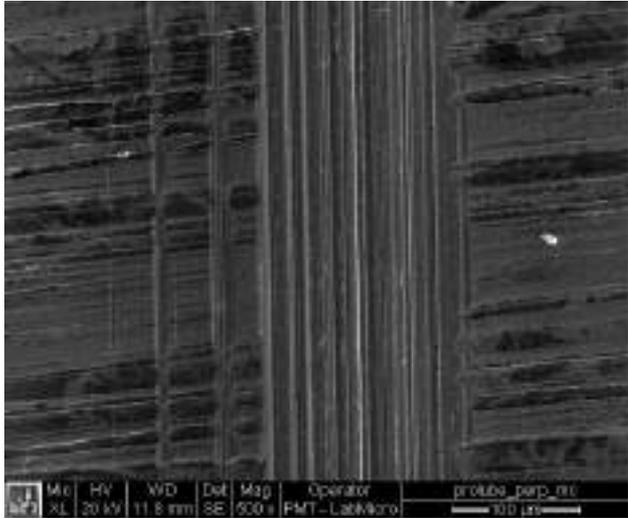
Disco rugoso – Óleo base



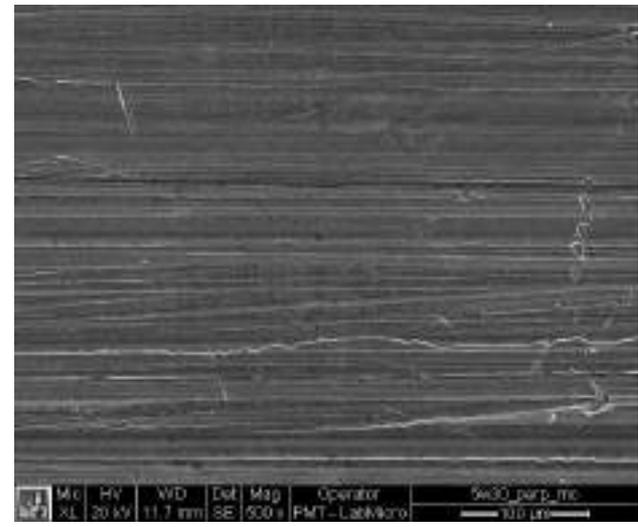
Tipo de superfície	Discos lisos	Discos lisos (desgastados)	Discos rugosos	Discos rugosos (desgastados)
Índice de plasticidade - ψ	0.9	5.2	6.1	5.3
Ângulo de ataque - $(\sigma/R)^{1/2}$	0.03	0.15	0.12	0.15
Sq [μm]	0,05	0.32	0,40	0.35
Espessura de filme específica - Λ	0.85	0,05	0,06	0,05

MEV em amostra de disco rugoso - perpendicular

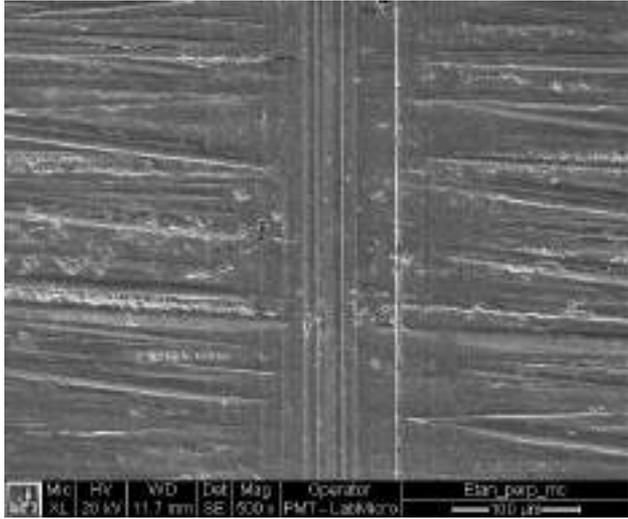
Disco rugoso – Óleo base



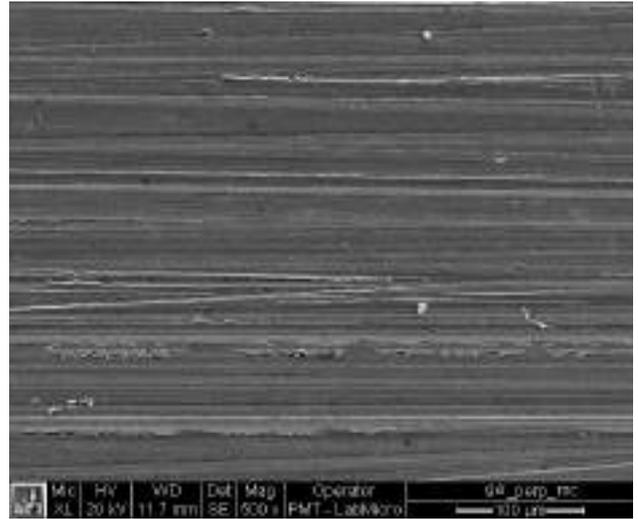
Disco rugoso – 5w30



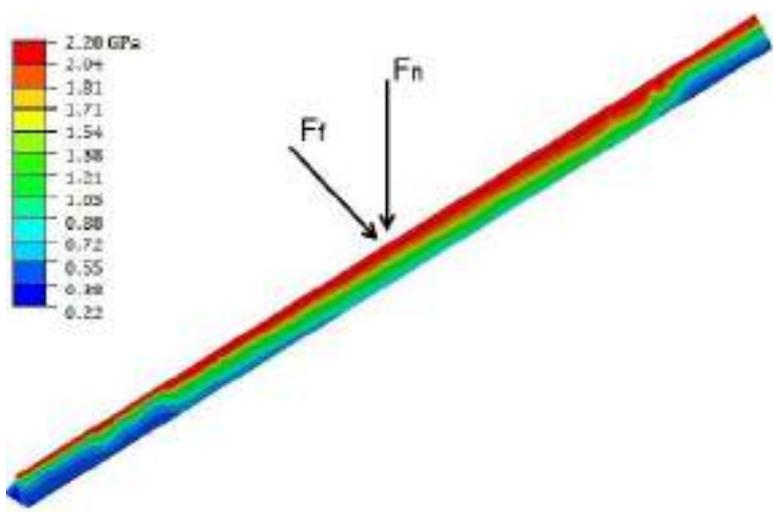
Disco rugoso – 5w30 E100



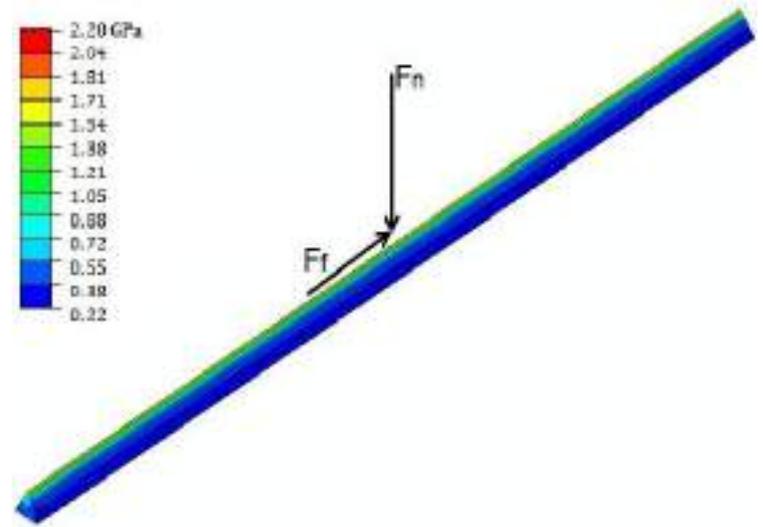
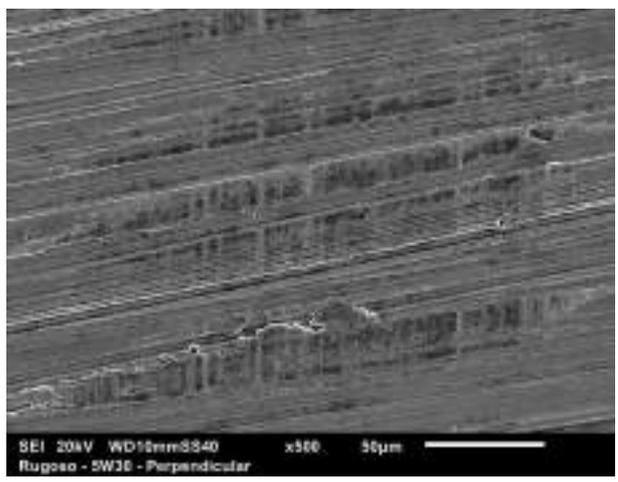
Disco rugoso – 5w30 E22



Efeito da direção de acabamento



Disco rugoso – 5W30 perpendicular



Disco rugoso – 5W30 paralelo

