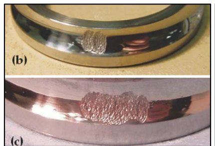
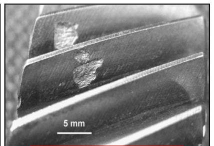
Rolling Contact Fatigue

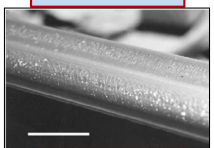
The rolling motion between the rolling elements and raceway produces complex, localized, alternating contact stresses within the material



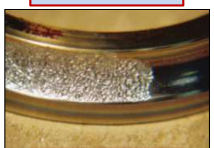
RCF in ball bearing (Arakere et al., 2009)



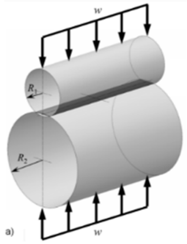
RCF in helical gear (Olver, 2005)



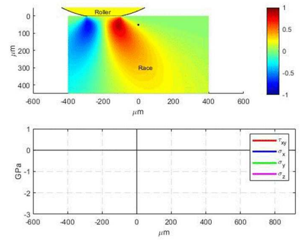
RCF in railways (Kalousek, 2002)



RCF in ball bearing (Rosado et al., 2009)



Over-rolling components



Stress History at Material Point

What makes RCF Unique and Challenging to Study?

- Difficult to observe the failure progression using non-destructive techniques even in laboratory settings
- Small contact dimensions, thus stresses are highly localized usually a few grains in dimensions
- Multi-axial states of stress
- Significant compressive hydrostatic stresses: Mode I crack growth inhibited
- Stress/strain history during rolling contact cycle is non-proportional
- Principal stress directions continually change as contact passes over the material

Analytical Modeling Approach:

Continuum Damage Mechanics – *Damage Rate Equation(s)*

Expression for change in damage (D) over change in cycles (N) $\frac{dD}{dN} = f(\sigma, D, c_1, c_2, \dots, c_n)$ → Calibrate using a material's torsion fatigue data

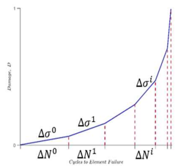
material constants

Elastic Damage Law

$$\frac{dD}{dN} = \left[\frac{\Delta\tau}{\sigma_r(1-D)}\right]^m$$

– Integrating the eq. above –

$$\Delta\tau = \frac{\sigma_r}{(m+1)^{1/m}} N_f^{-1/m} \quad (1)$$



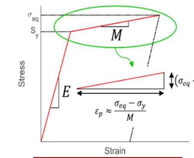
Equating (1) and (3) yields: m, σ_r

Elastic-Plastic Damage Law

$$\frac{dD}{dN} = \left[\frac{\sigma_{vm}^2 R_v}{2ES_0(1-D)^2}\right]^q \dot{p}$$

– Integrating the eq. above –

$$\sigma_{vm} = \frac{(2ES_0)^{\frac{1}{2}}}{[(2q+1)\Delta\varepsilon_p]^{1/q}} \frac{1}{\sqrt{R_v}} N_f^{-\frac{1}{2q}} \quad (2)$$

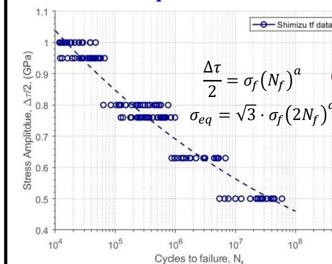


Equating (2) and (4) yields: q, S_0

Calibration of CDM via S-N Curve

Torsional Fatigue: rapid assessment of a material's performance vs shear

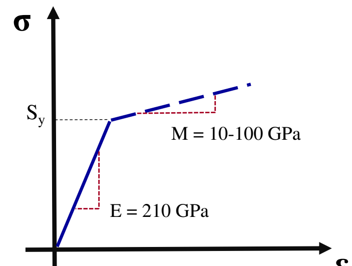
Basquin's Law:



$$\frac{\Delta\tau}{2} = \sigma_f (N_f)^a \quad (3)$$

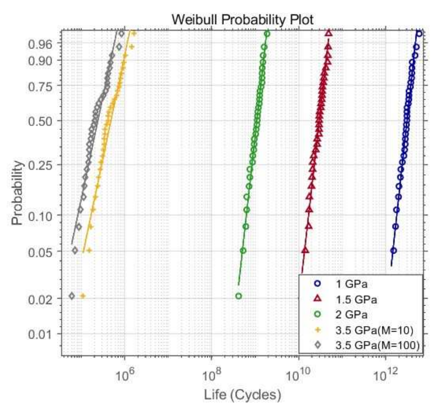
$$\sigma_{eq} = \sqrt{3} \cdot \sigma_f (2N_f)^a \quad (4)$$

Elastic linear kinematic plastic Model



Stress-strain curve for ELKP material.

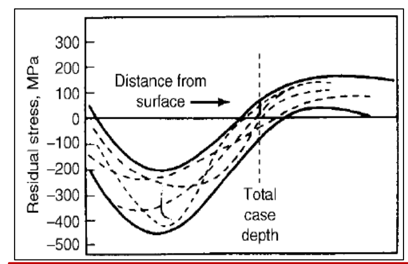
Parameter	Value
Material grain diameter	10μm
Undamaged Elastic Modulus	210GPa
Poisson's Ratio	0.3
σ_r	5.97GPa
m	11.1
q (M=10GPa & 100GPa)	3.97
S_0 (M= 10GPa)	86 MPa
S_0 (M= 100GPa)	43 MPa



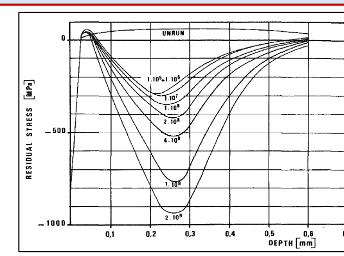
Hertzian Pressure	3.5 GPa M=100 GPa	3.5 GPa M= 10GPa	2 GPa	1.5 GPa	1 GPa
L_{10} lives	$0.8e^5$	$1.7e^5$	$6.2e^8$	$3.3e^{10}$	$3.4e^{12}$

Cased Carburized Steel

- Machine components such as bearings, cams, etc. are commonly made from cased carburized steels and subject to RCF
- Heat treatments during case carburization introduce residual stresses (RS) in the material
- Retained austenite transformation is accompanied by volume expansion inducing residual stresses
- Compressive residual stresses improves fatigue resistance & life



Typical RS distribution in case carburized steel



Evolution of RS due to RA transformation