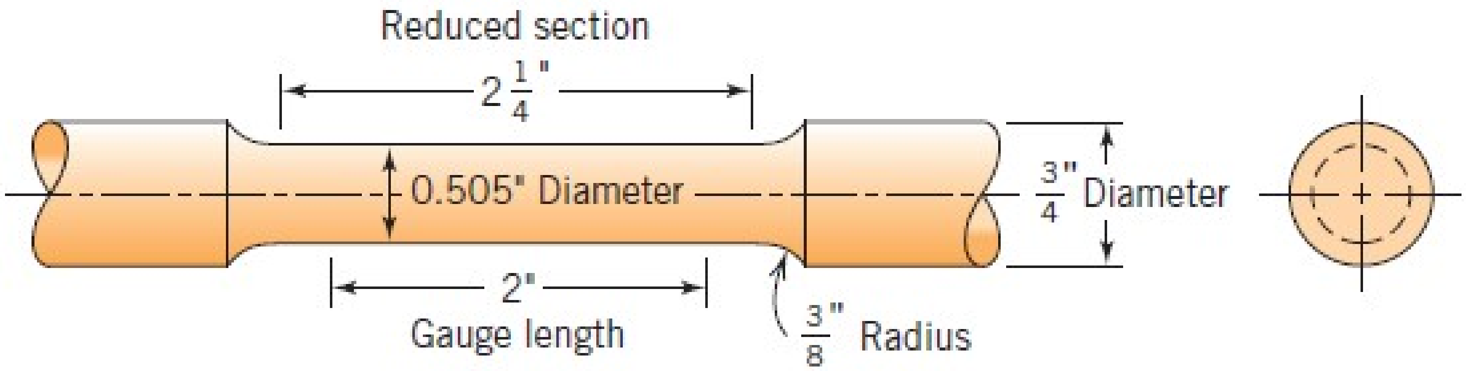
Propriedades Mecânicas

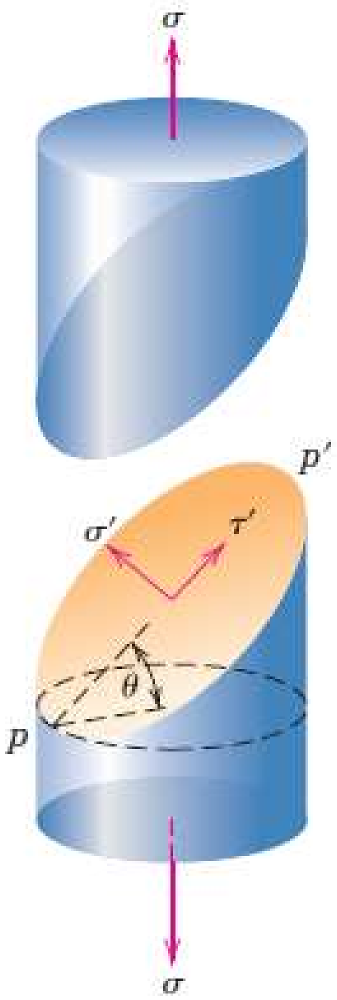
Ensaio de Tração



$$\sigma = \frac{F}{A_0}$$

$$\epsilon = \frac{l_i - l_0}{l_0} = \frac{\Delta l}{l_0}$$

Tração



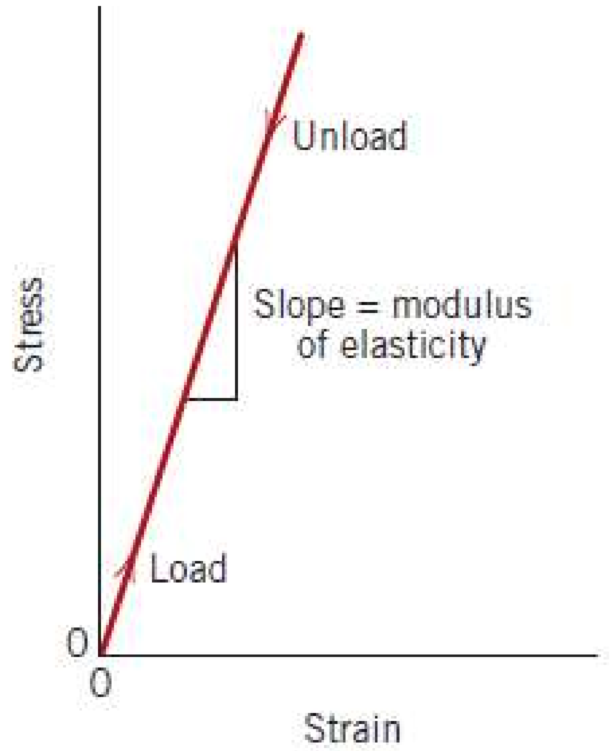
$$\sigma' = \sigma \cos^2 \theta = \sigma\left(\frac{1 + \cos 2\theta}{2}\right)$$

$$\tau' = \sigma \sin \theta \cos \theta = \sigma\left(\frac{\sin 2\theta}{2}\right)$$

Deformação elástica

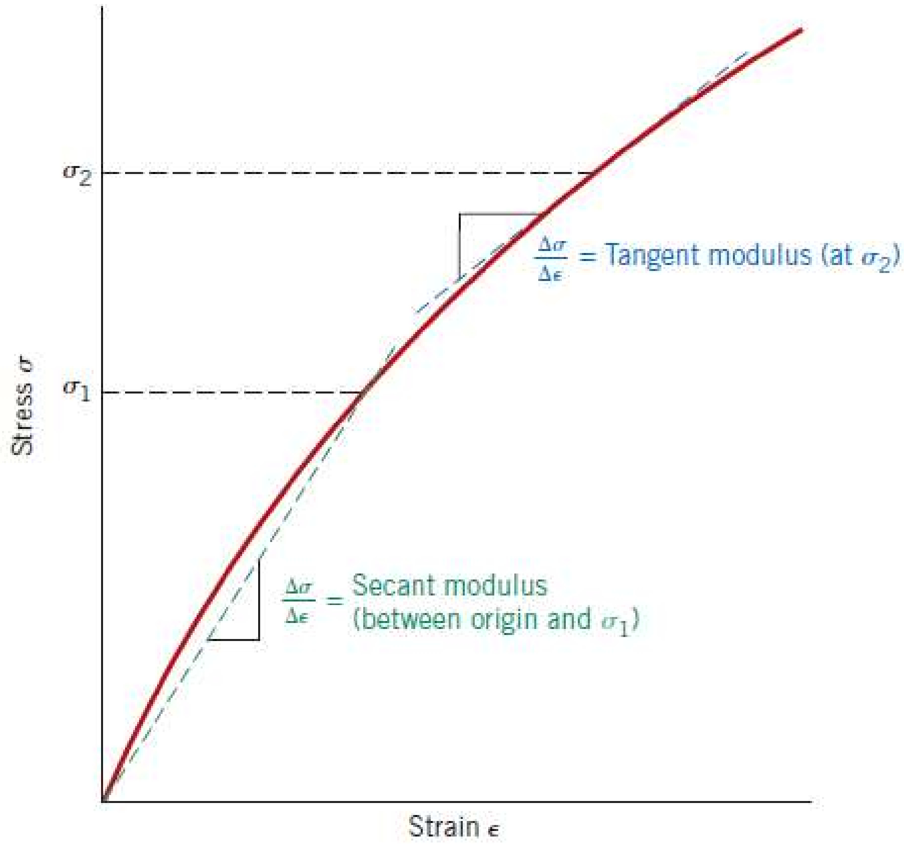
- Regime elástico linear (lei de Hook)

$$\sigma = E\epsilon$$

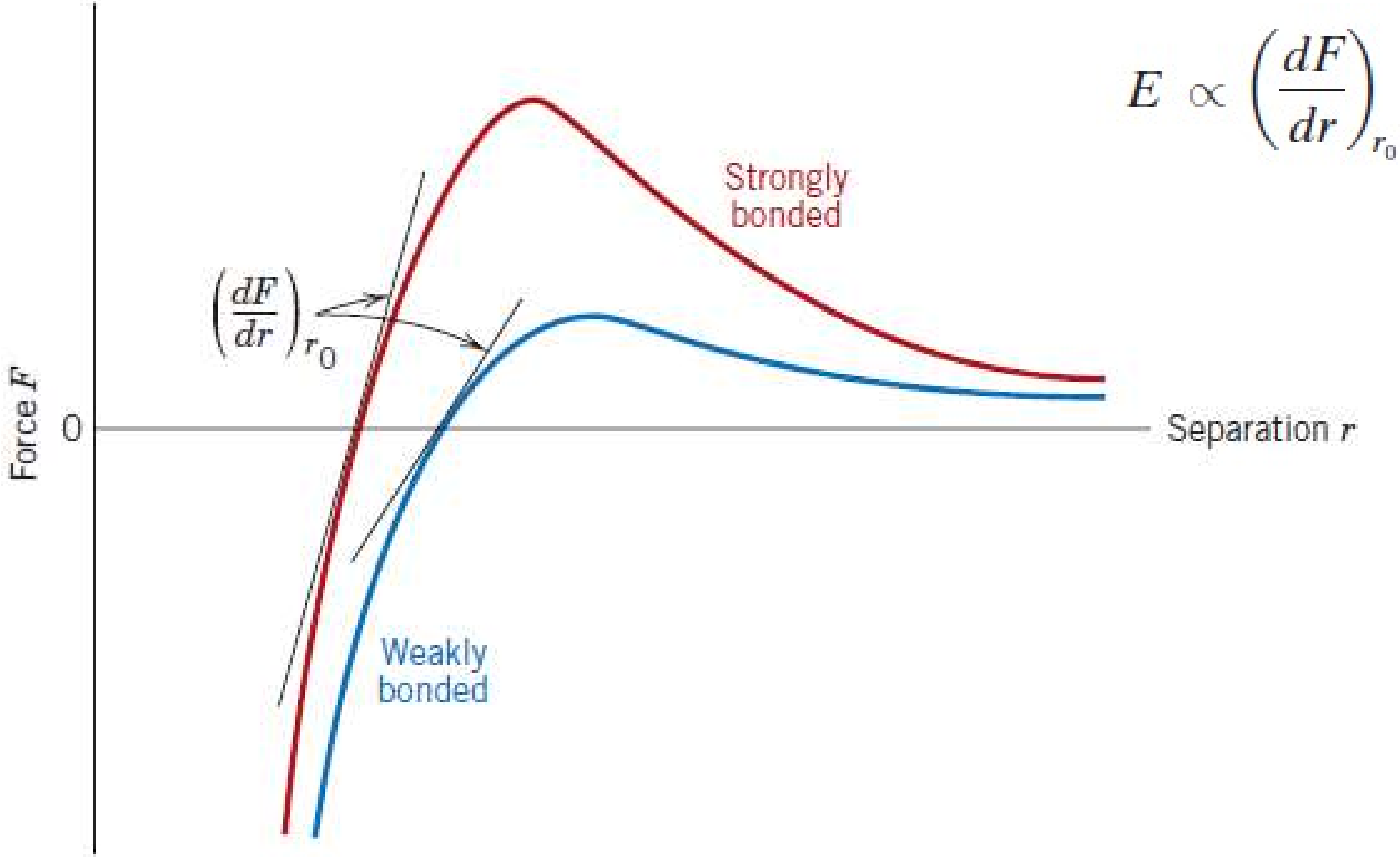


Deformação elástica

- Regime elástico não linear



Origem do módulo de elasticidade



Outras propriedades elásticas

- Módulo de cisalhamento

$$\tau = G\gamma$$

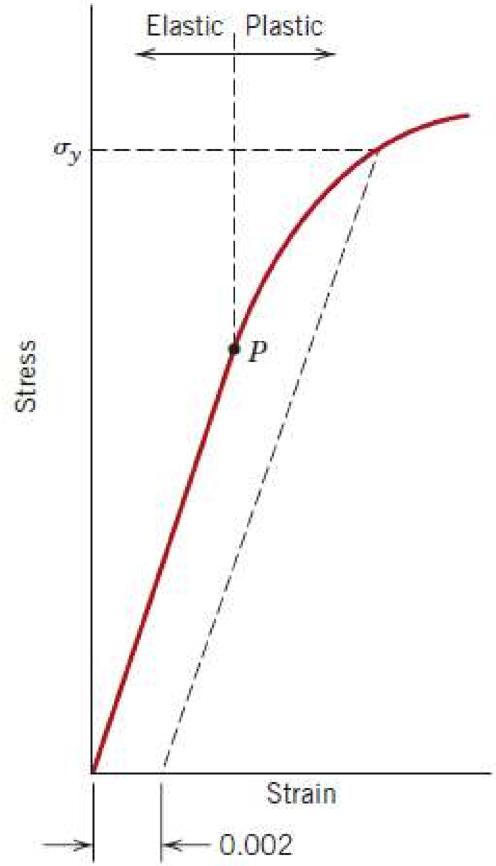
- Razão de Poisson

$$\nu = -\frac{\epsilon_x}{\epsilon_z} = -\frac{\epsilon_y}{\epsilon_z}$$

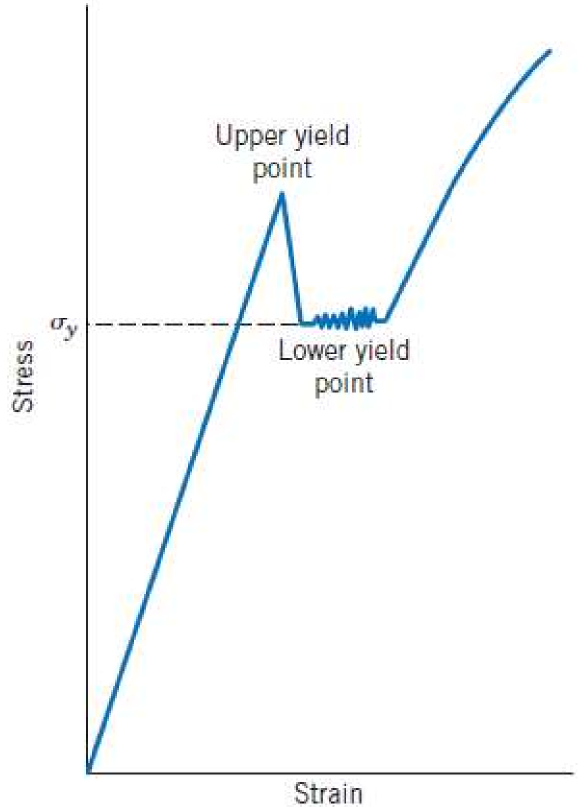
  - p/ material isotrópico

$$E = 2G(1 + \nu)$$

Deformação plástica

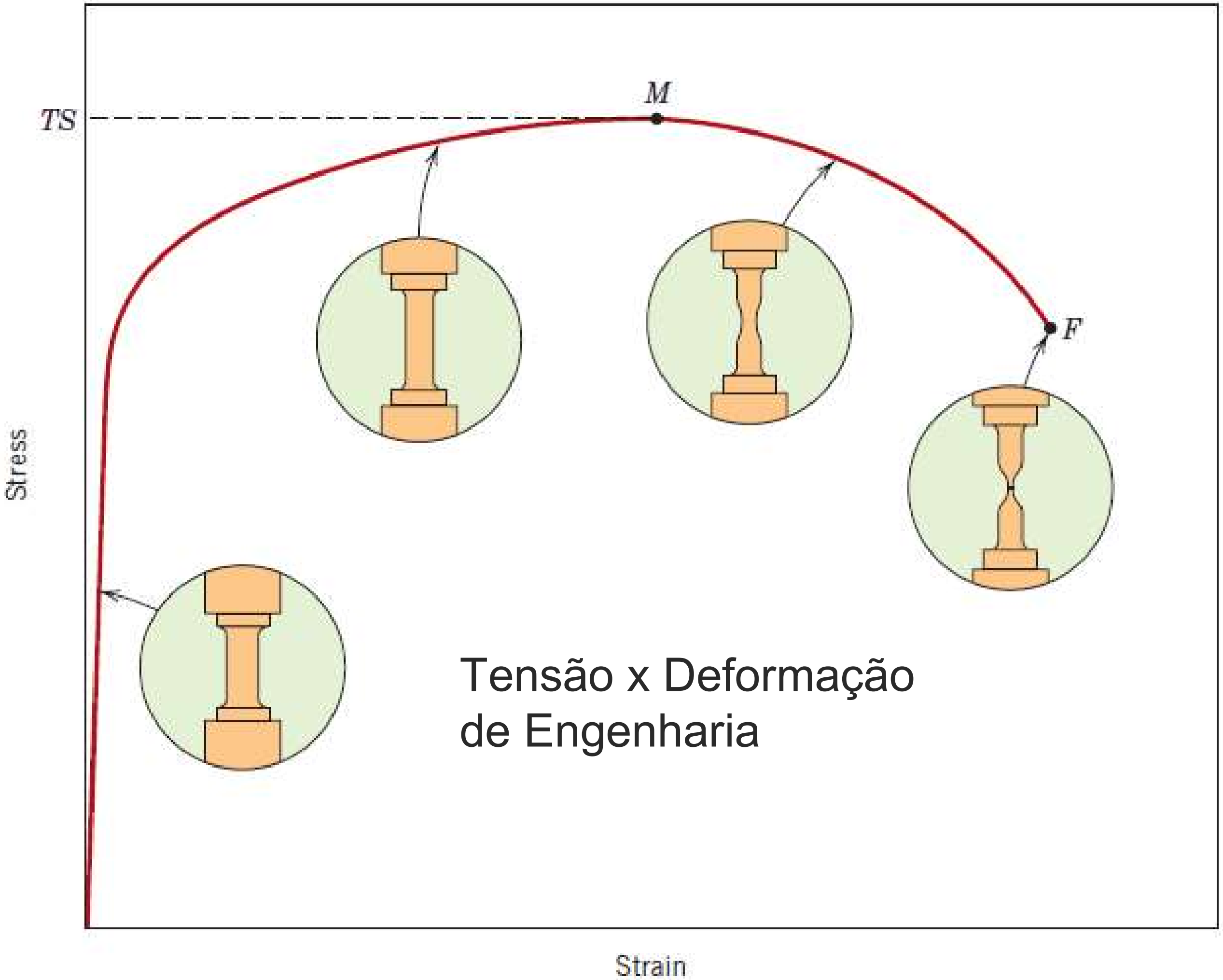


Limite não definido

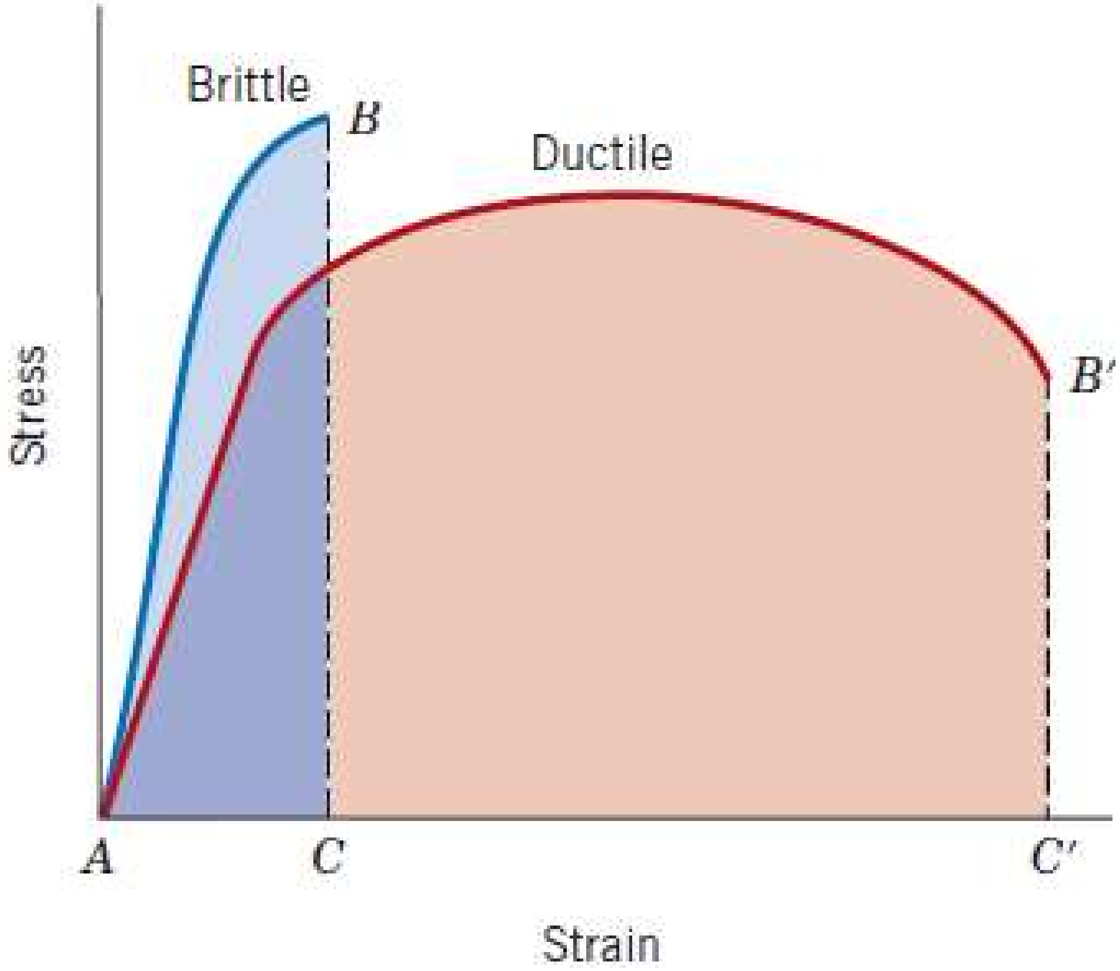


Limite bem definido

Tensão x Deformação p/ um metal típico



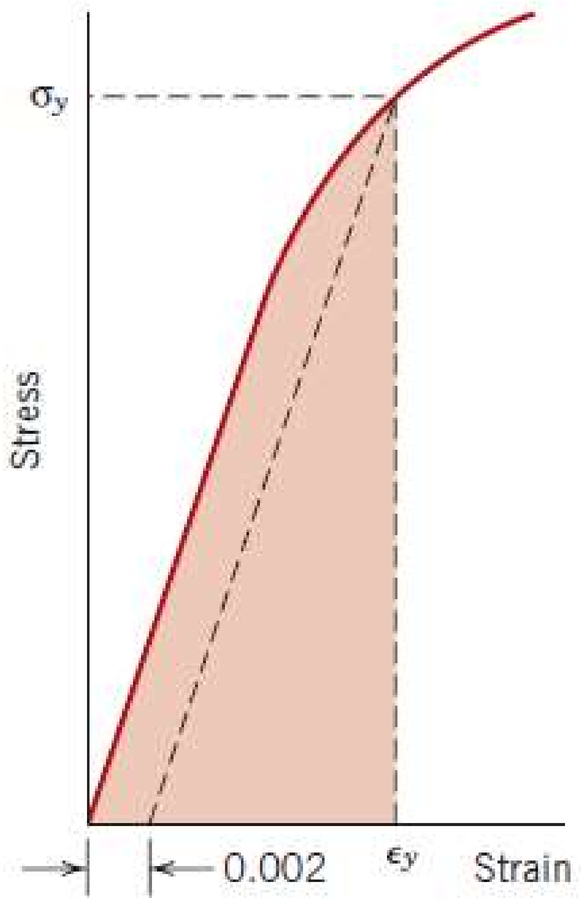
Ductilidade



$$\%EL = \left(\frac{l_f - l_0}{l_0}\right) \times 100$$

$$\%RA = \left(\frac{A_0 - A_f}{A_0}\right) \times 100$$

Resiliência

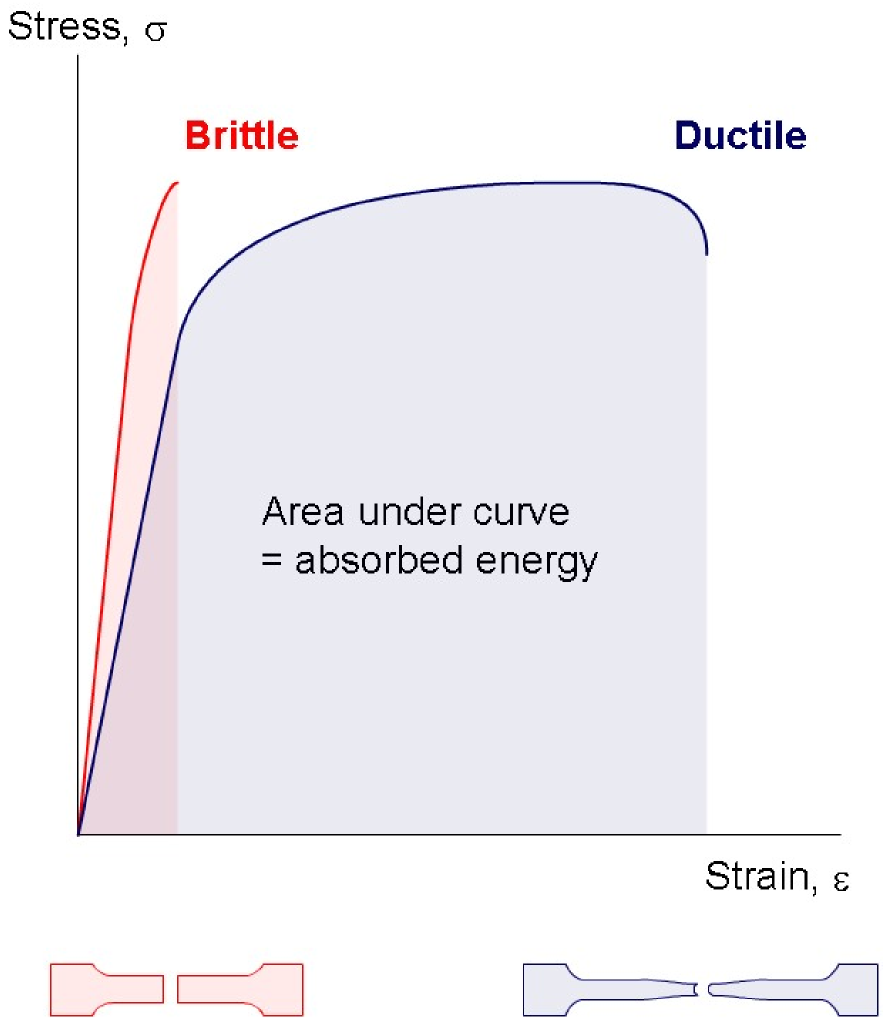


$$U_r = \int_0^{\epsilon_y} \sigma \, d\epsilon$$

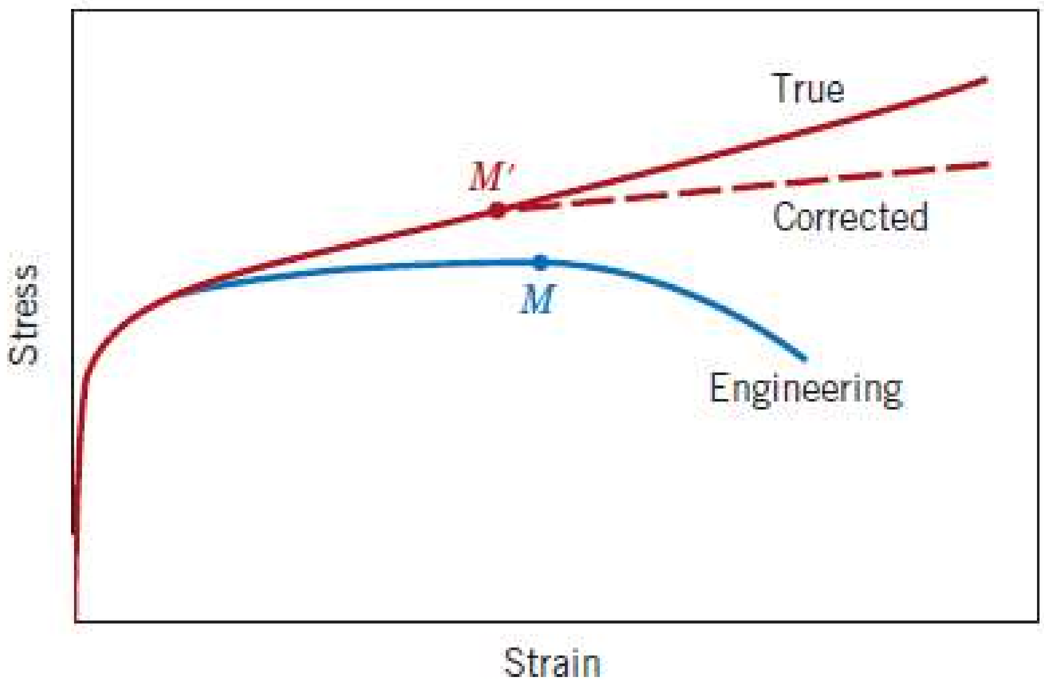
$$U_r = \tfrac{1}{2}\sigma_y \epsilon_y$$

$$U_r = \tfrac{1}{2}\sigma_y \epsilon_y = \tfrac{1}{2}\sigma_y\left(\frac{\sigma_y}{E}\right) = \frac{\sigma_y^2}{2E}$$

Tenacidade


Stress, σ
Brittle
Ductile
Area under curve
= absorbed energy
Strain, ε

Tensão e Deformação Verdadeiras em Tração



p/ metais: $\sigma_T = K\epsilon_T^n$

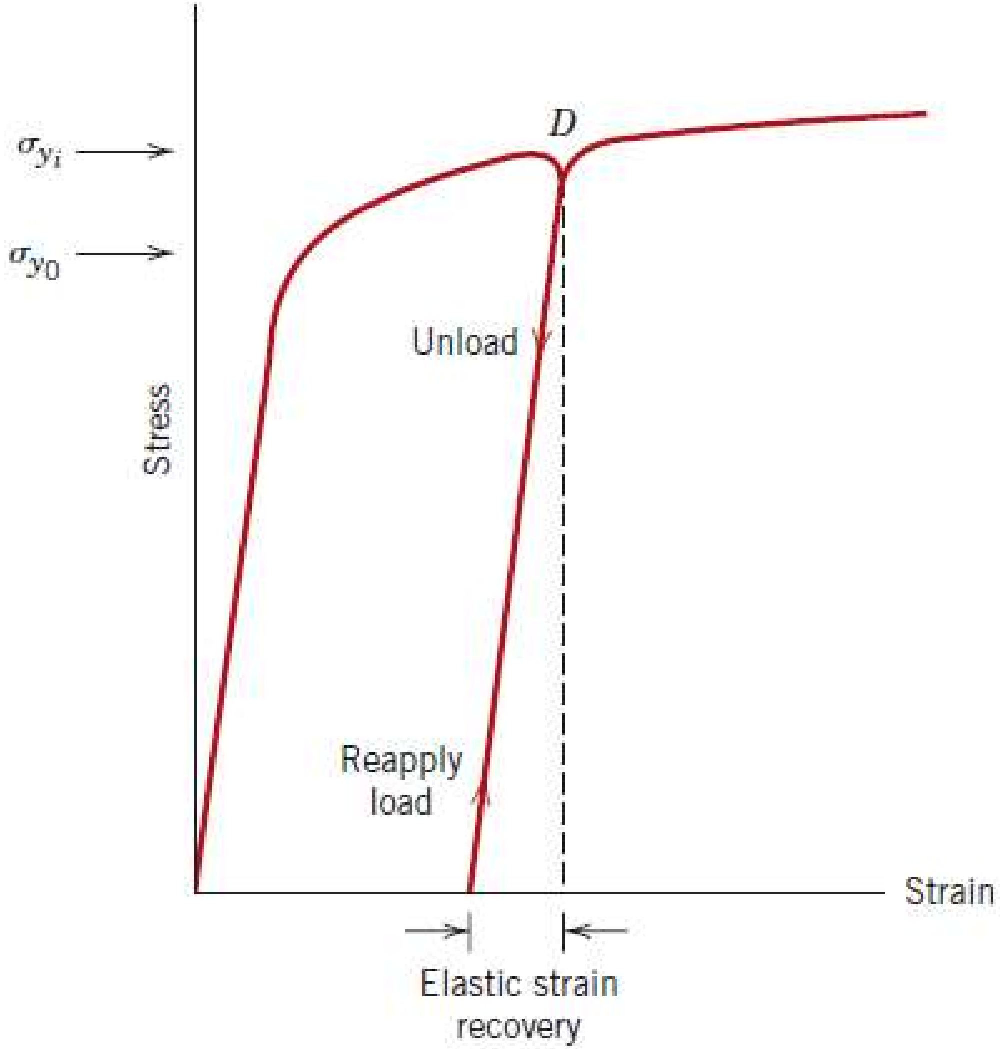
$$\sigma_T = \frac{F}{A_i}$$

$$\epsilon_T = \ln\frac{l_i}{l_0}$$

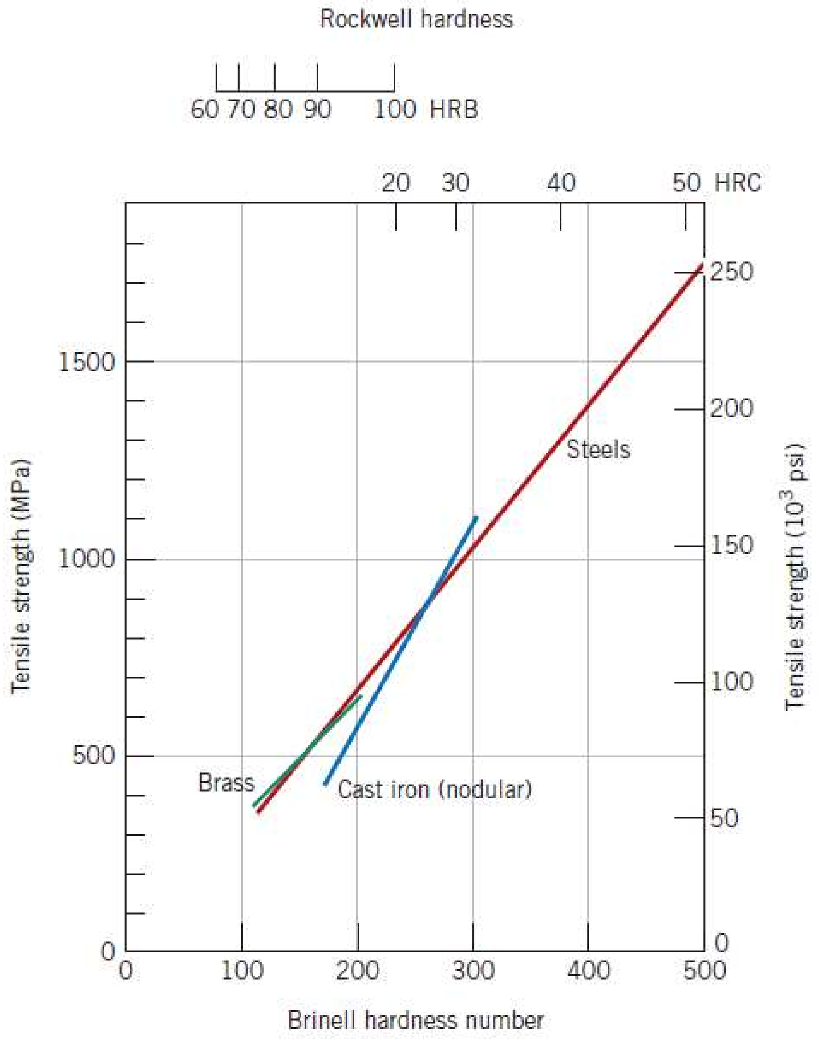
$$\sigma_T = \sigma(1 + \epsilon)$$

$$\epsilon_T = \ln(1 + \epsilon)$$

Encruamento de metais

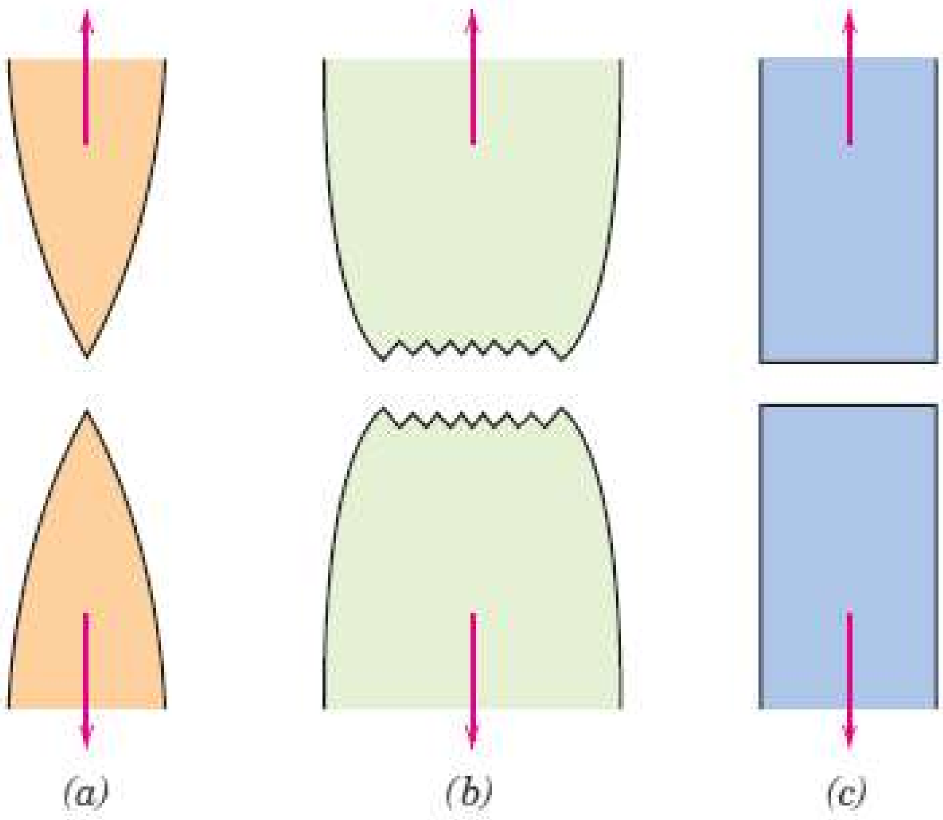


Dureza

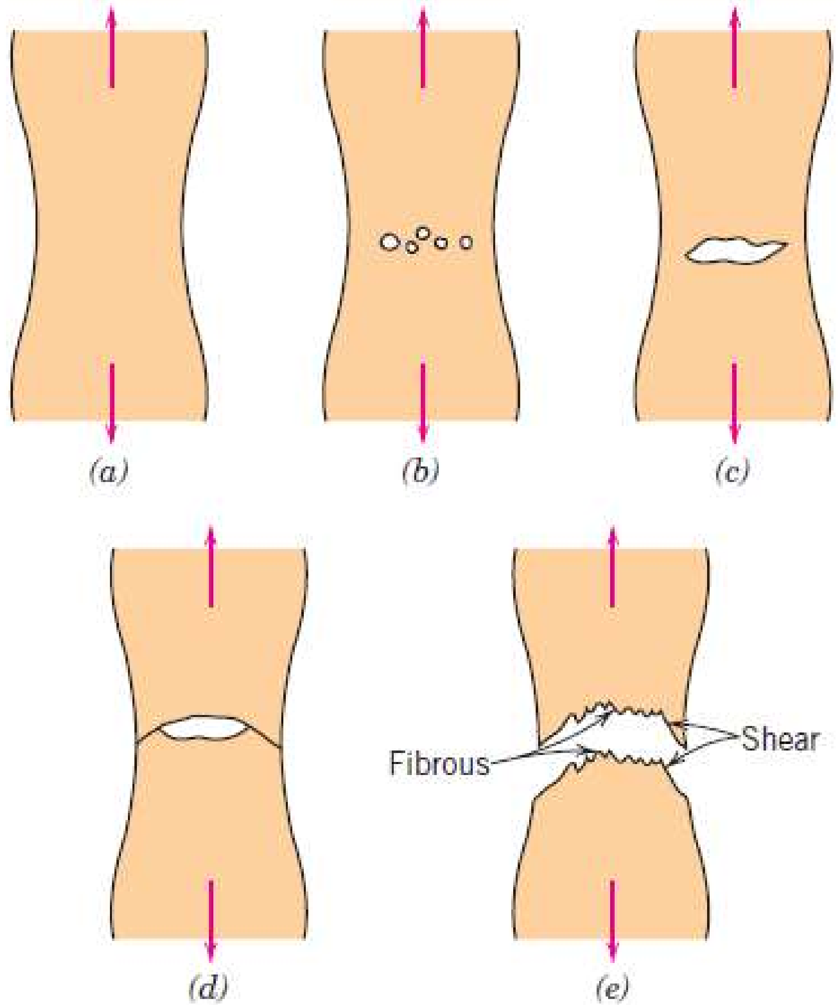


Rockwell hardness
60 70 80 90 100 HRB
20 30 40 50 HRC
Tensile strength (MPa)
0
500
1000
1500
Tensile strength (10³ psi)
0
50
100
150
200
250
Steels
Brass
Cast iron (nodular)
0
100
200
300
400
500
Brinell hardness number

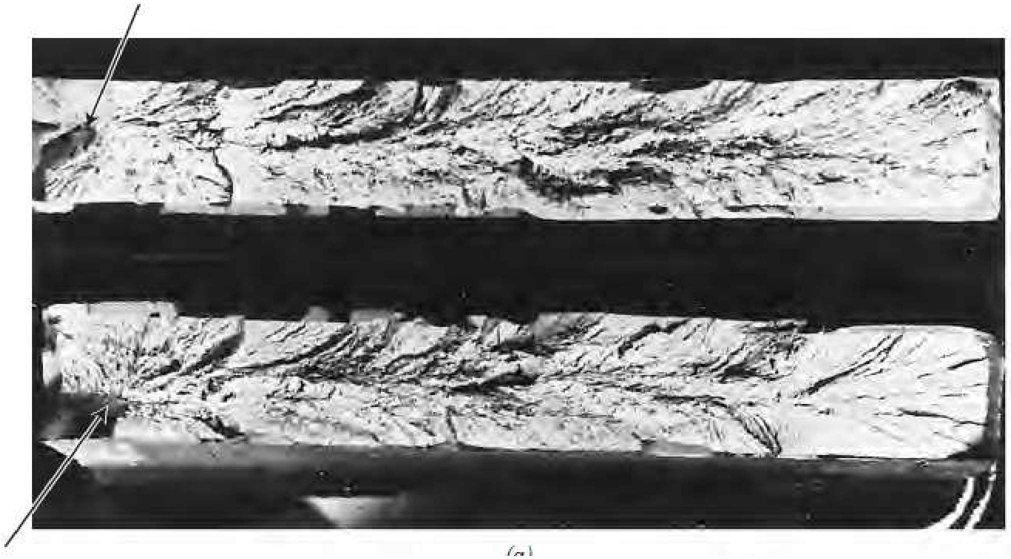
Fratura dúctil ou frágil



Fratura “taça – cone” (dúctil)

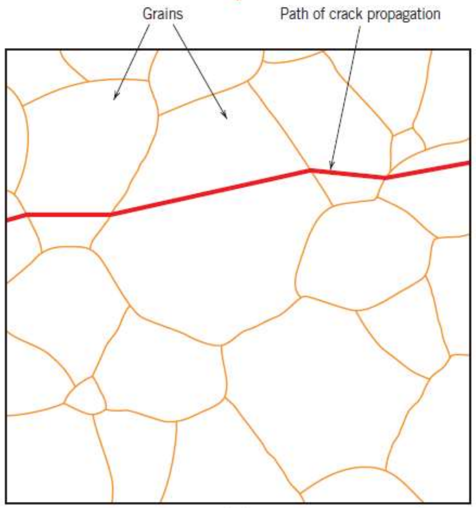


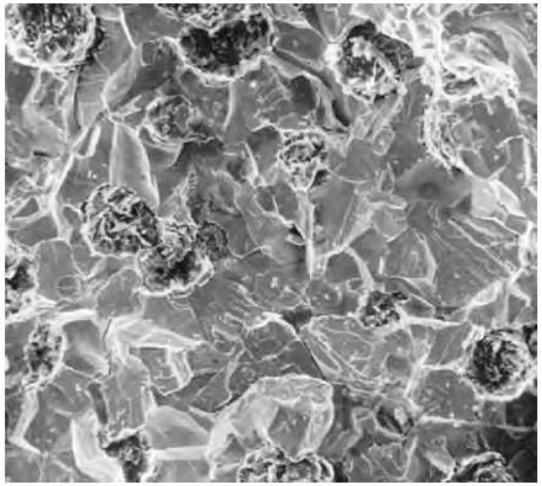
Fratura frágil



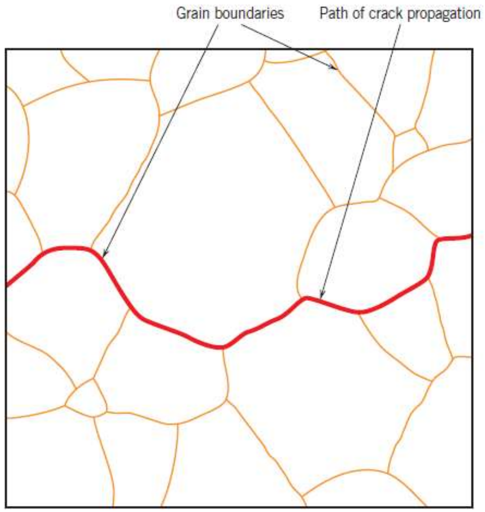
(a)

Fratura Transgranular e Intergranular



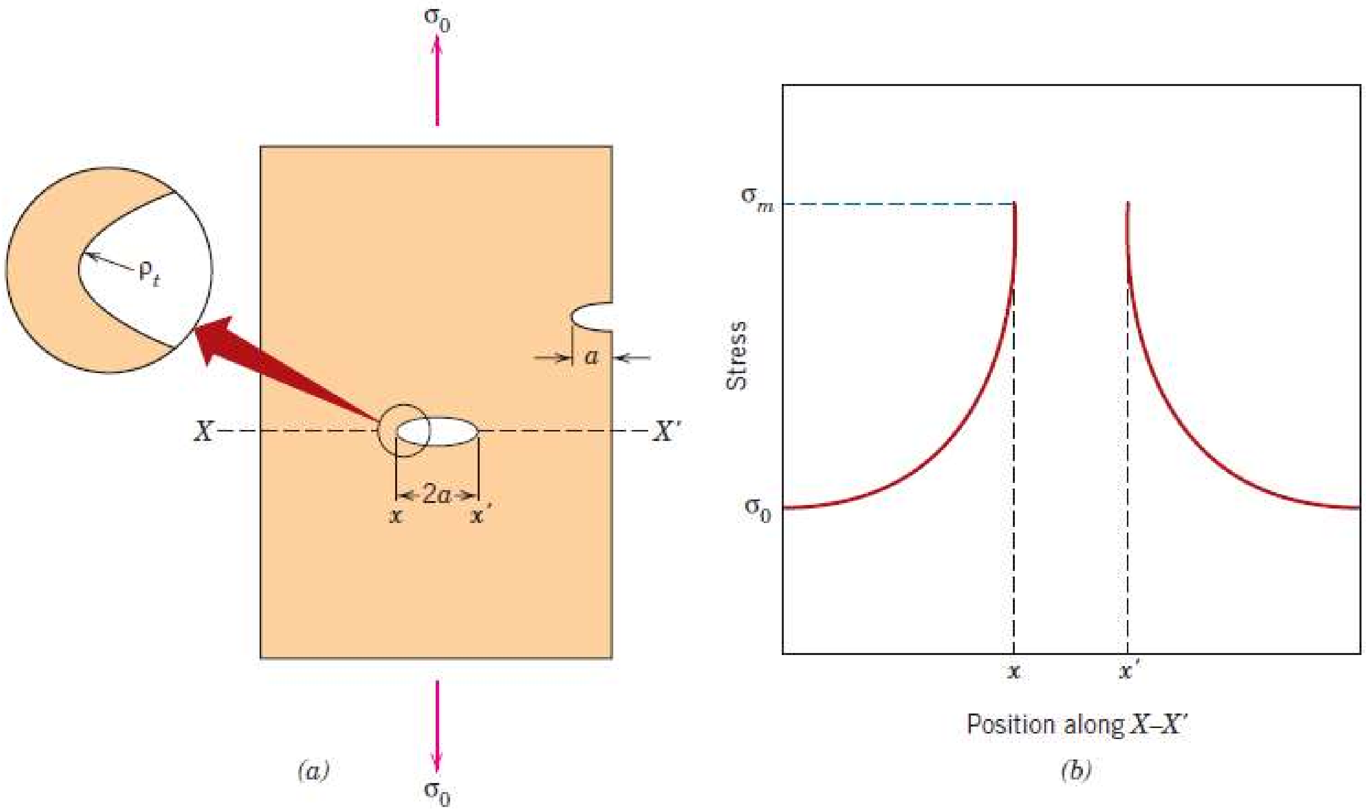


Transgranular



Intergranular

Concentração de tensão



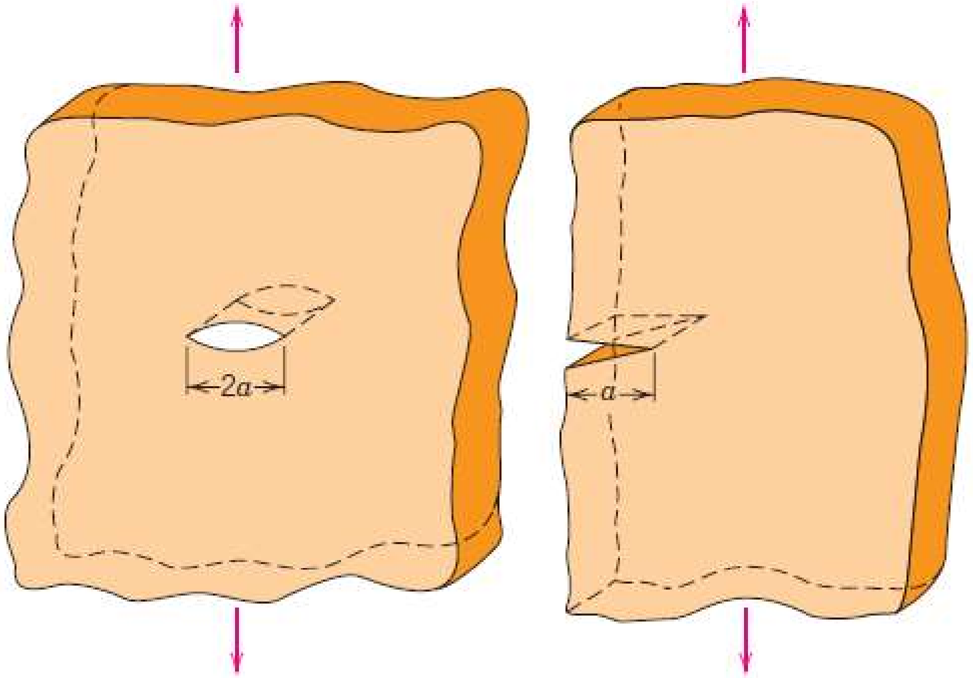
$$\sigma_m = 2\sigma_0\left(\frac{a}{\rho_t}\right)^{1/2}$$

$$K_t = \frac{\sigma_m}{\sigma_0} = 2\left(\frac{a}{\rho_t}\right)^{1/2}$$

Tenacidade à fratura

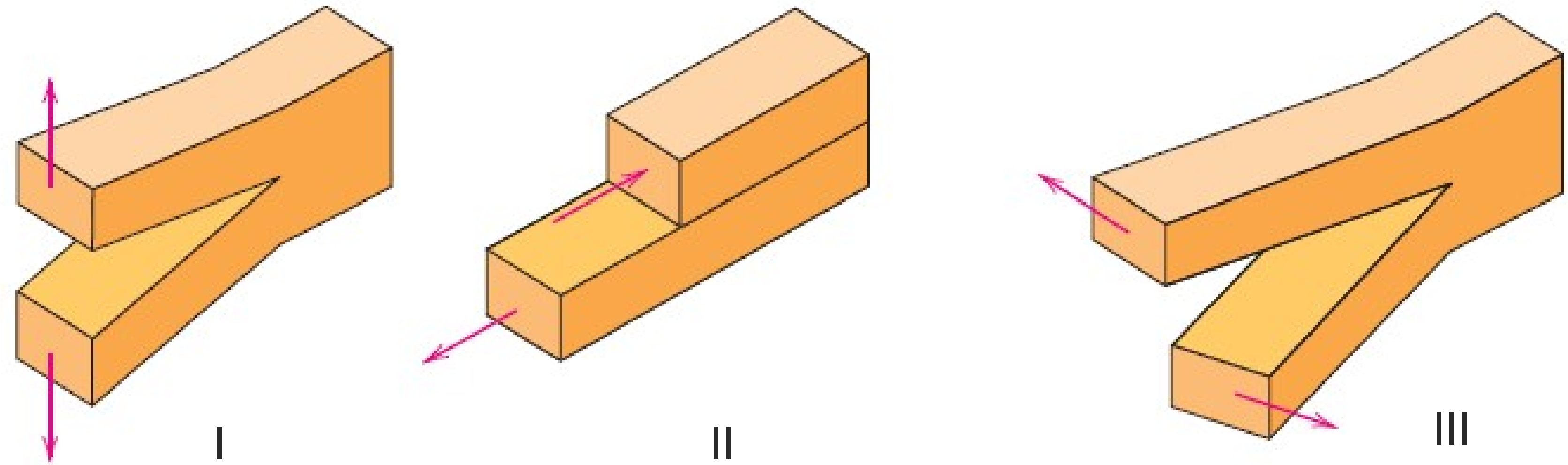
$$\sigma_c = \left(\frac{2E\gamma_s}{\pi a}\right)^{1/2}$$

$$K_c = Y\sigma_c\sqrt{\pi a}$$



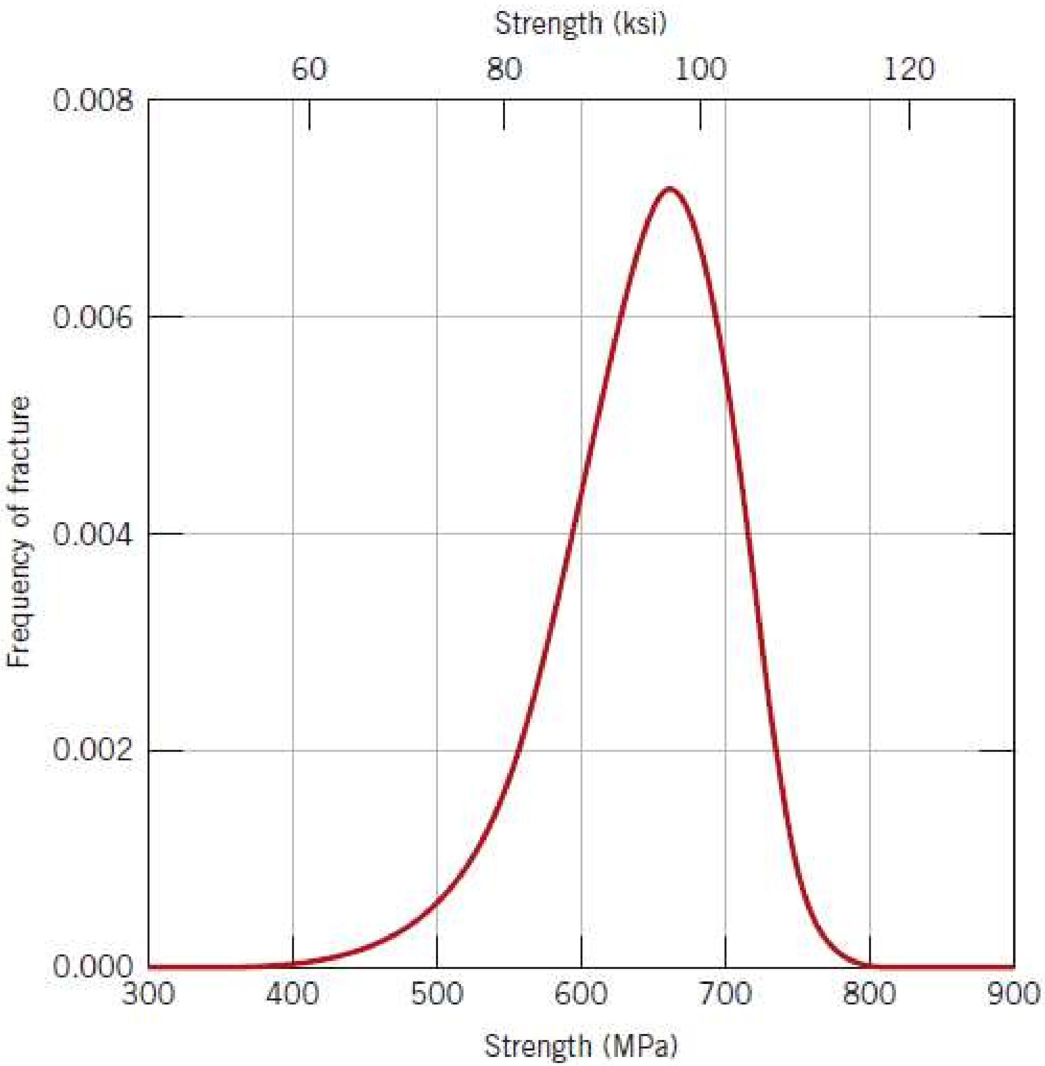
(a) (b)

Modos de fratura

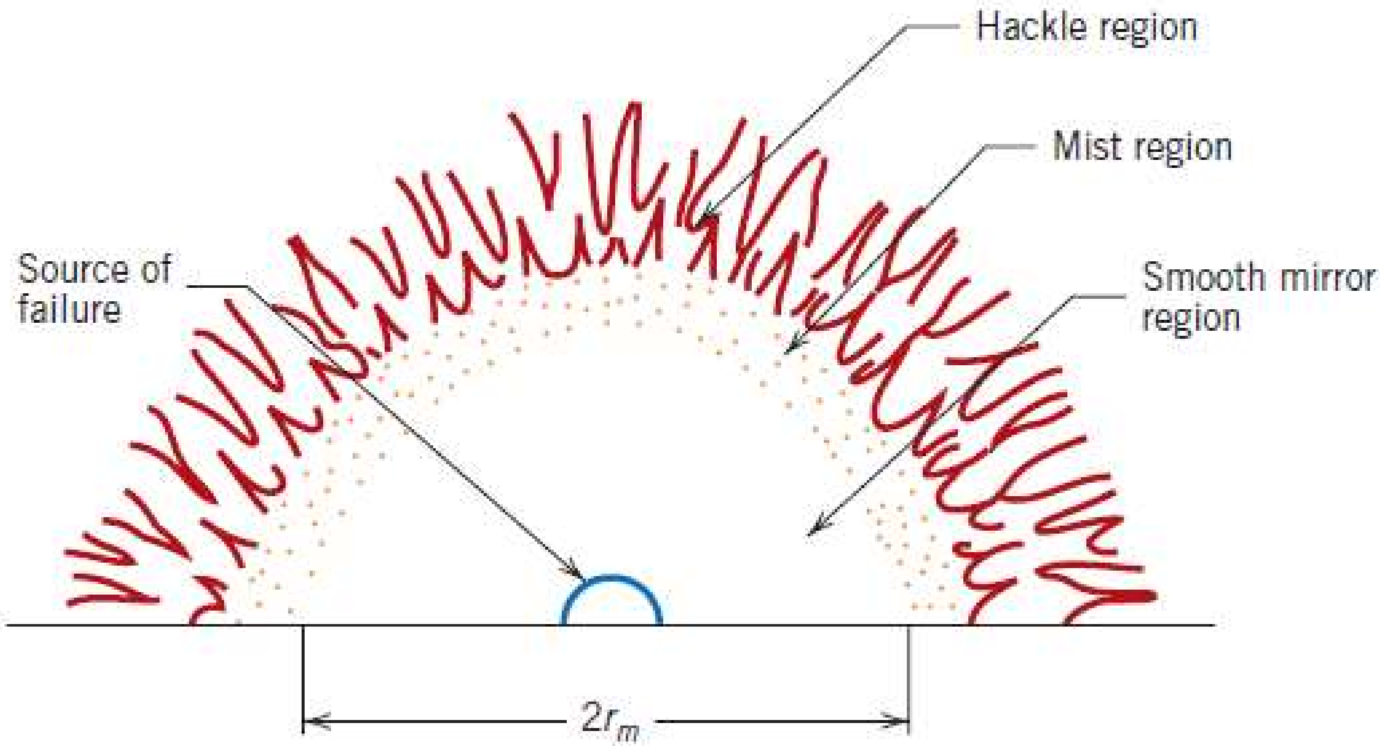


$$K_{Ic} = Y\sigma\sqrt{\pi a}$$

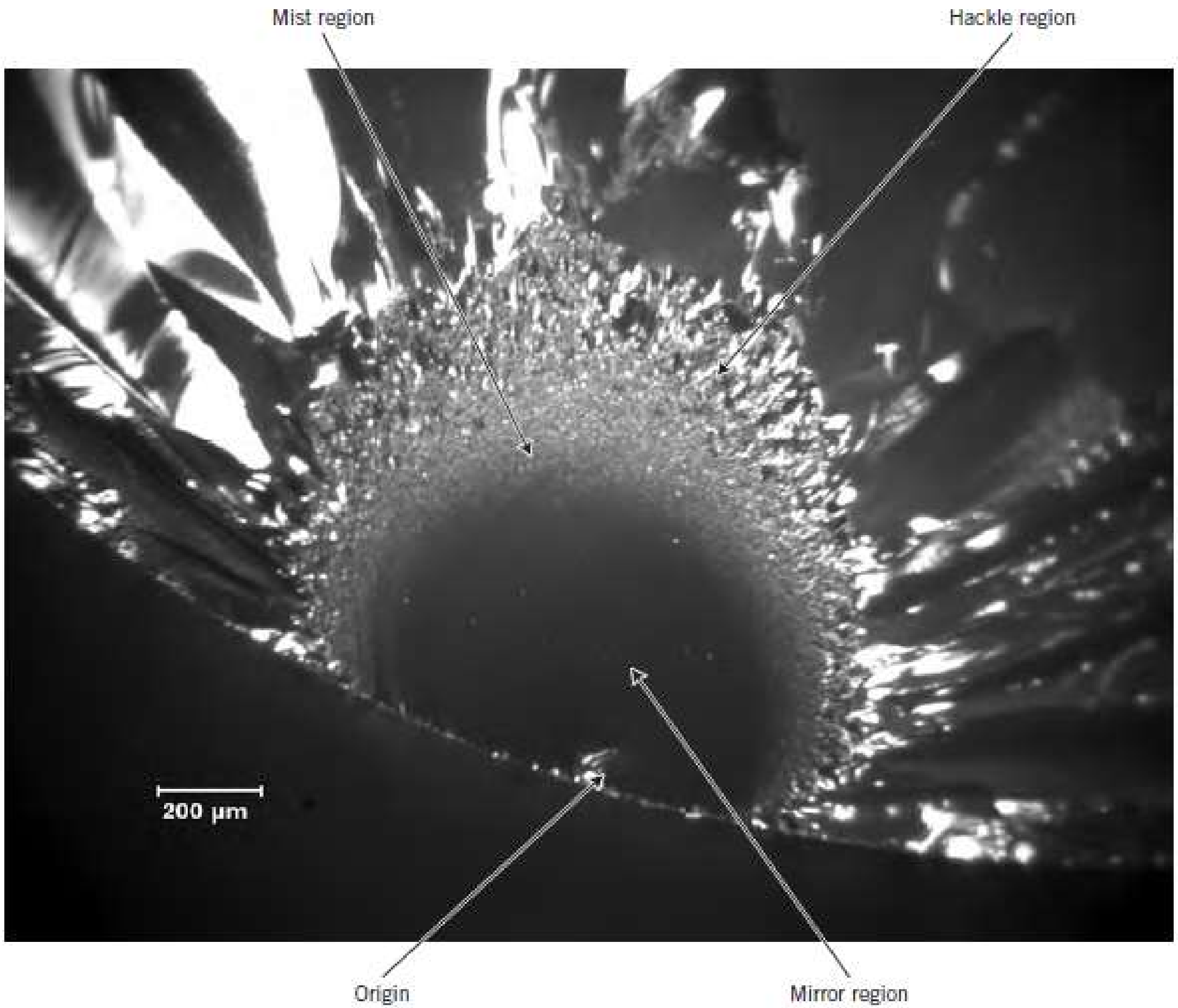
Distribuição estatística



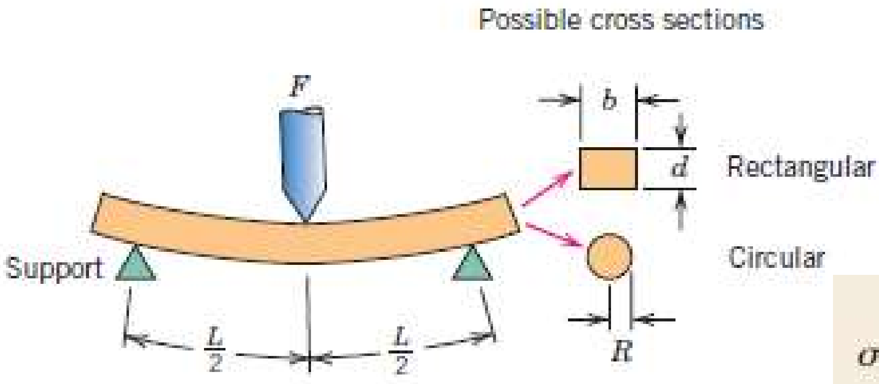
Fratura frágil de cerâmicas



Fratura frágil de cerâmicas



Ensaio de Flexão



$$\sigma_{fs} = \frac{3F_f L}{2bd^2}$$

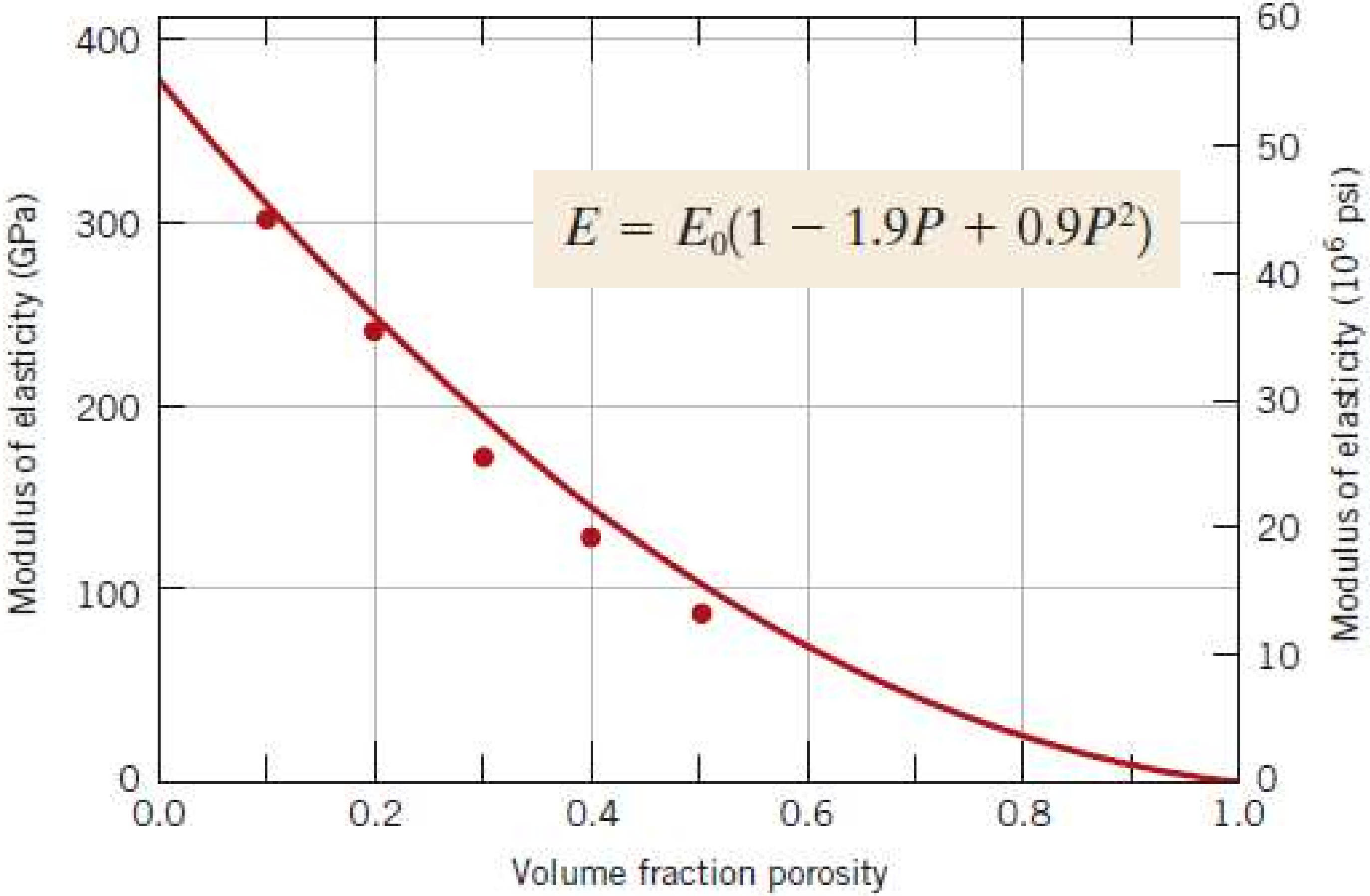
$$\sigma_{fs} = \frac{F_f L}{\pi R^3}$$

σ = stress = $\frac{Mc}{I}$

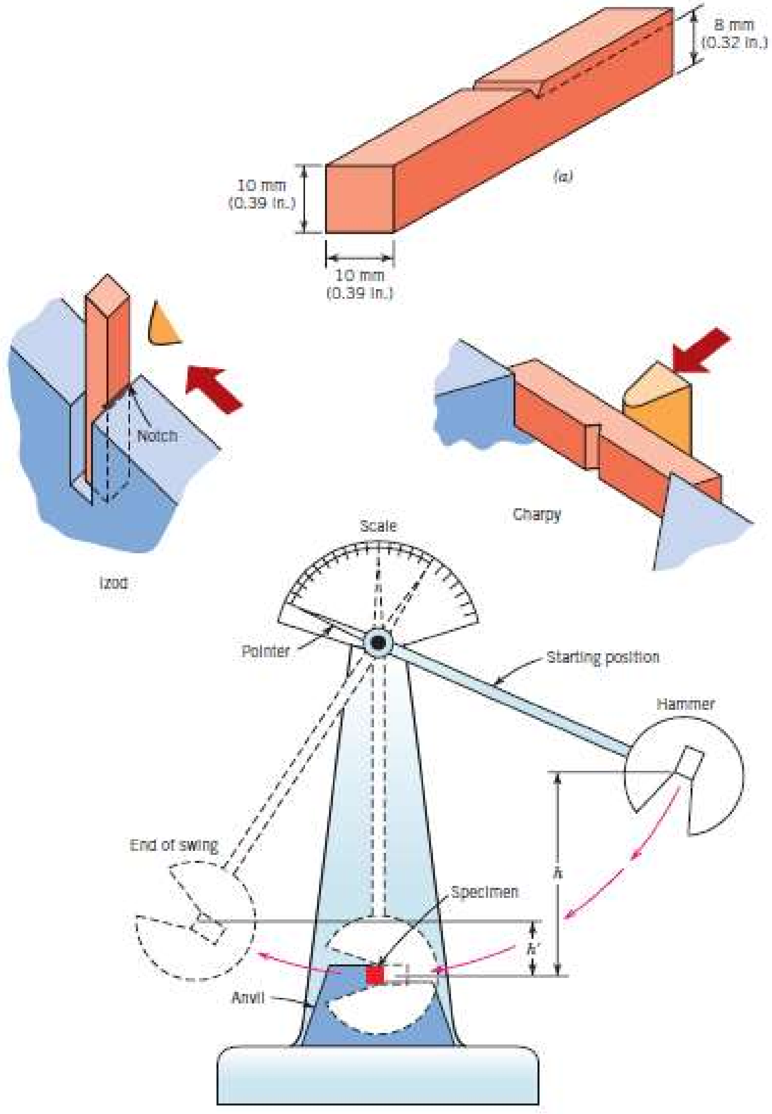
where M = maximum bending moment
c = distance from center of specimen to outer fibers
I = moment of inertia of cross section
F = applied load

	M	c	I	σ
Rectangular	$\frac{FL}{4}$	$\frac{d}{2}$	$\frac{bd^3}{12}$	$\frac{3FL}{2bd^2}$
Circular	$\frac{FL}{4}$	R	$\frac{\pi R^4}{4}$	$\frac{FL}{\pi R^3}$

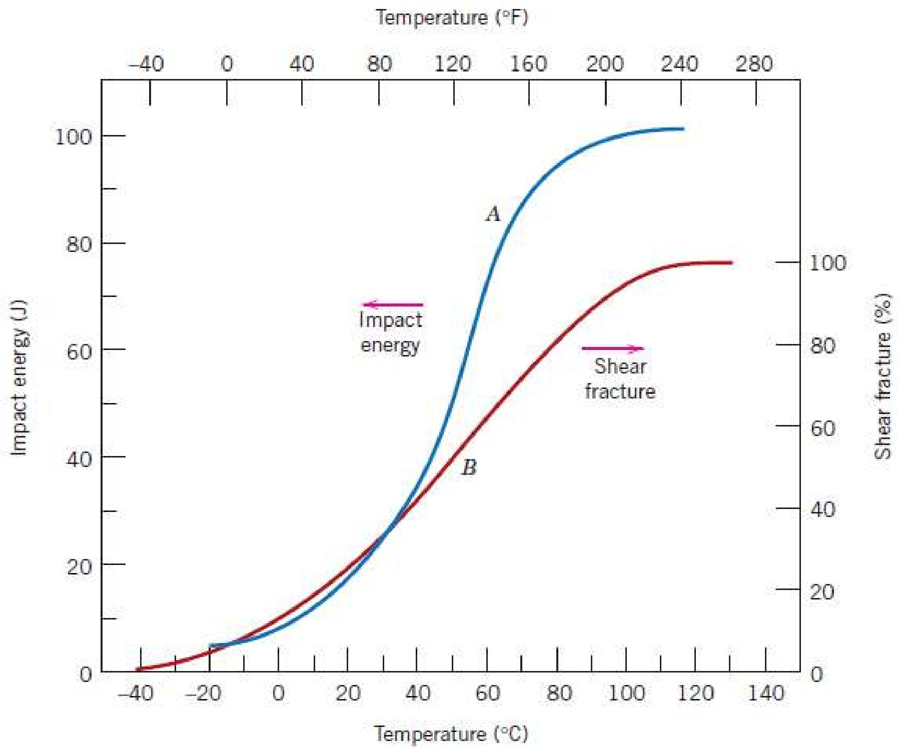
Influência de Porosidade em Cerâmicas

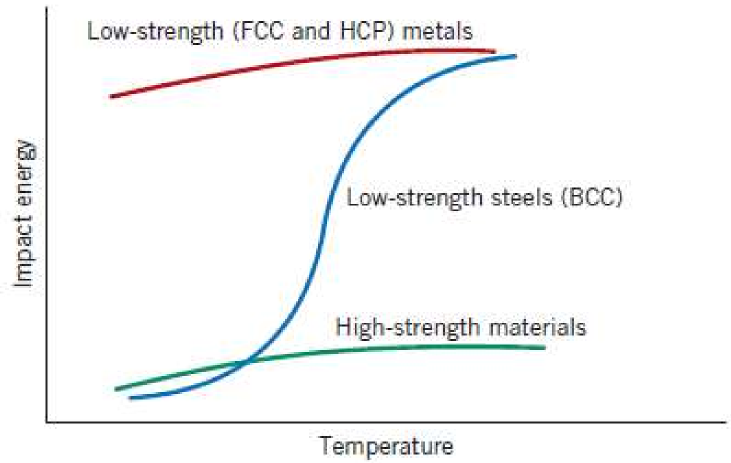


Ensaios de impacto

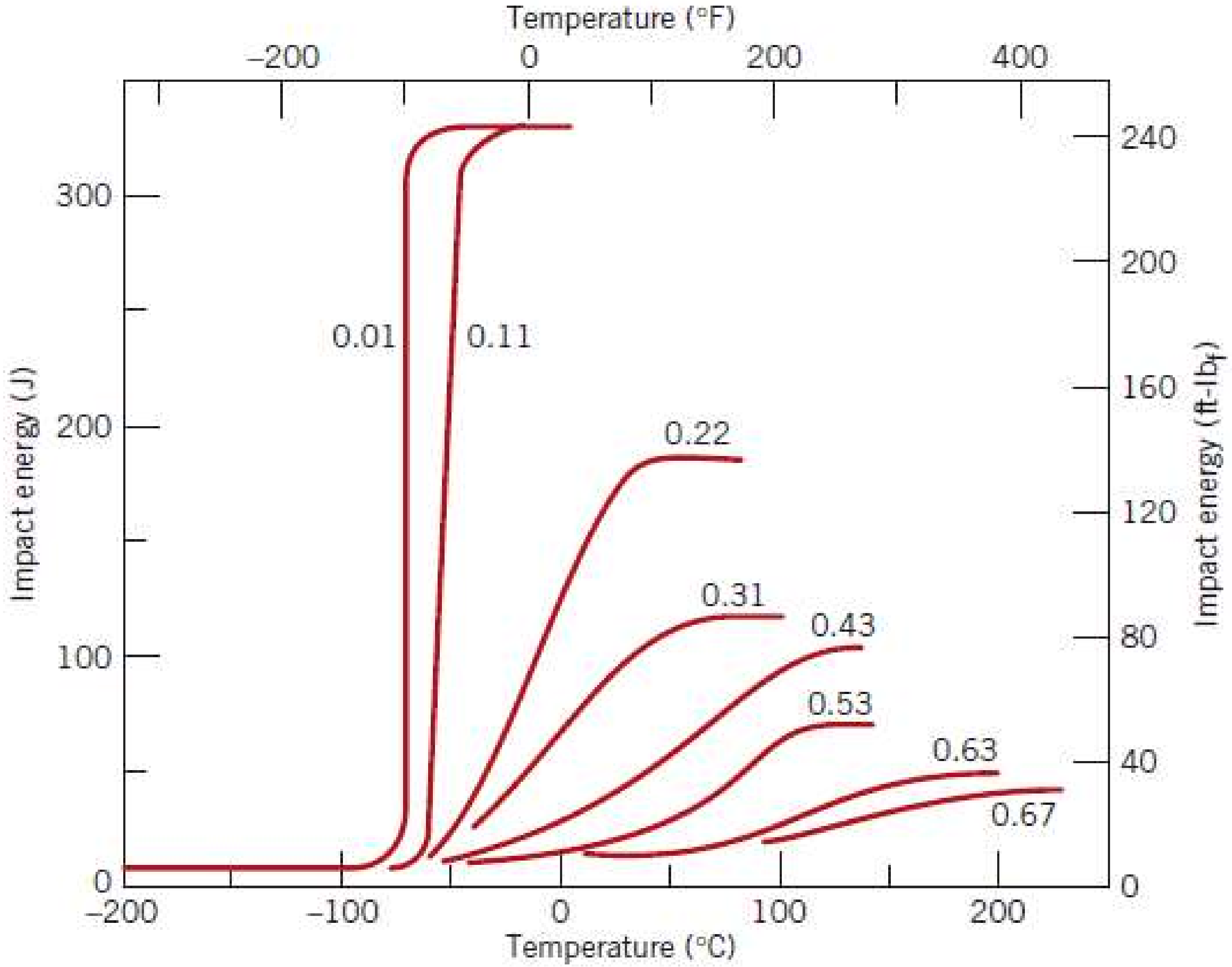


Transição frágil x dúctil

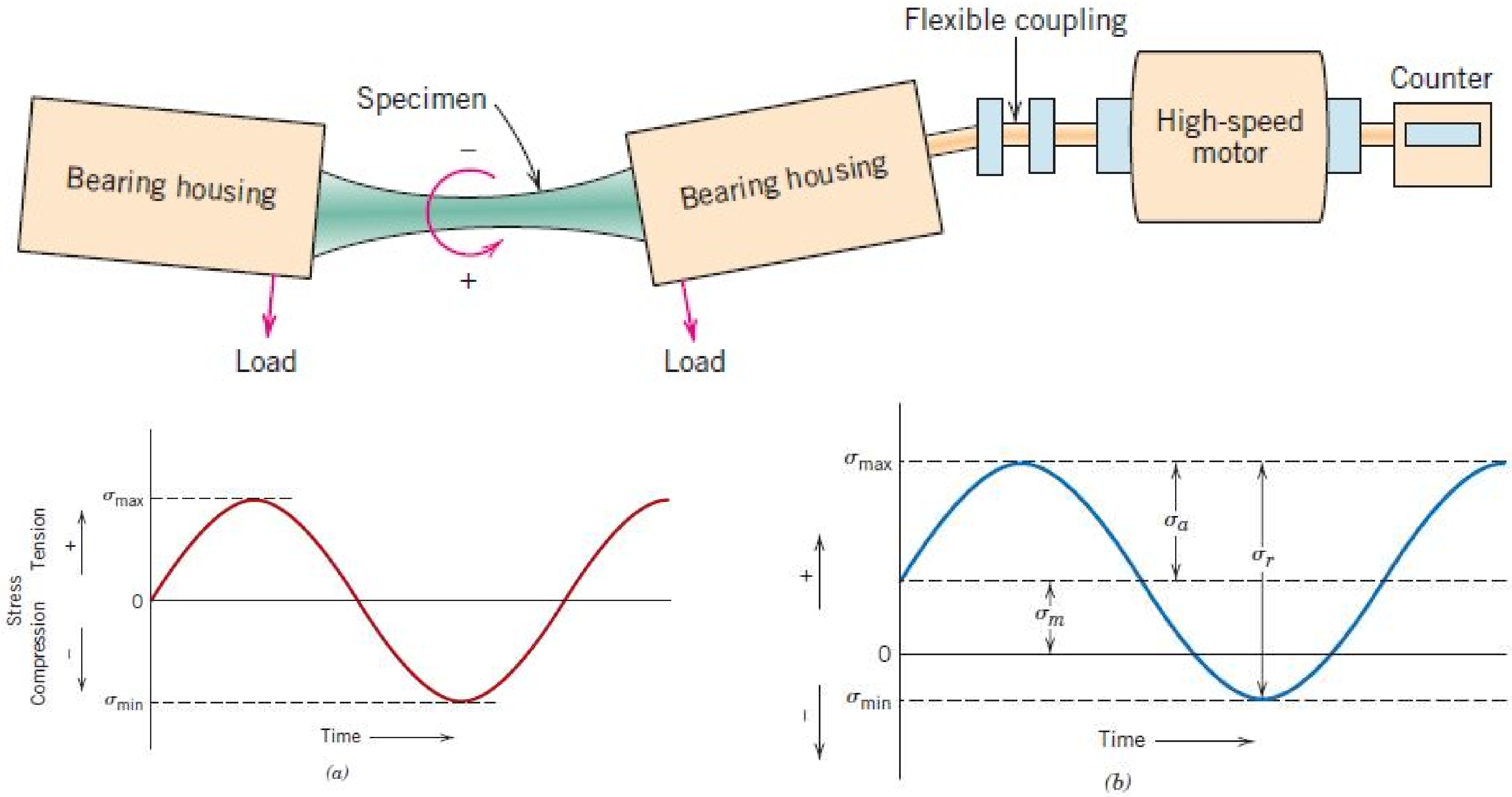




Transicão frágil x dúctil

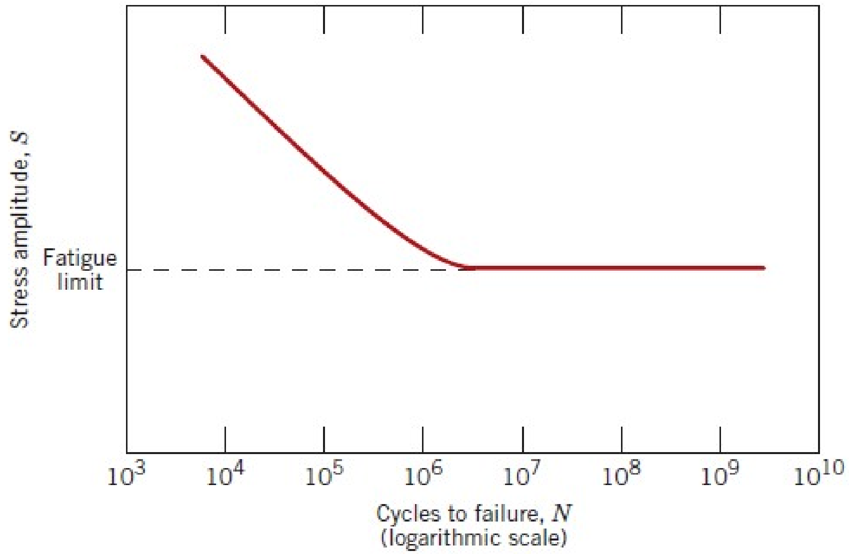


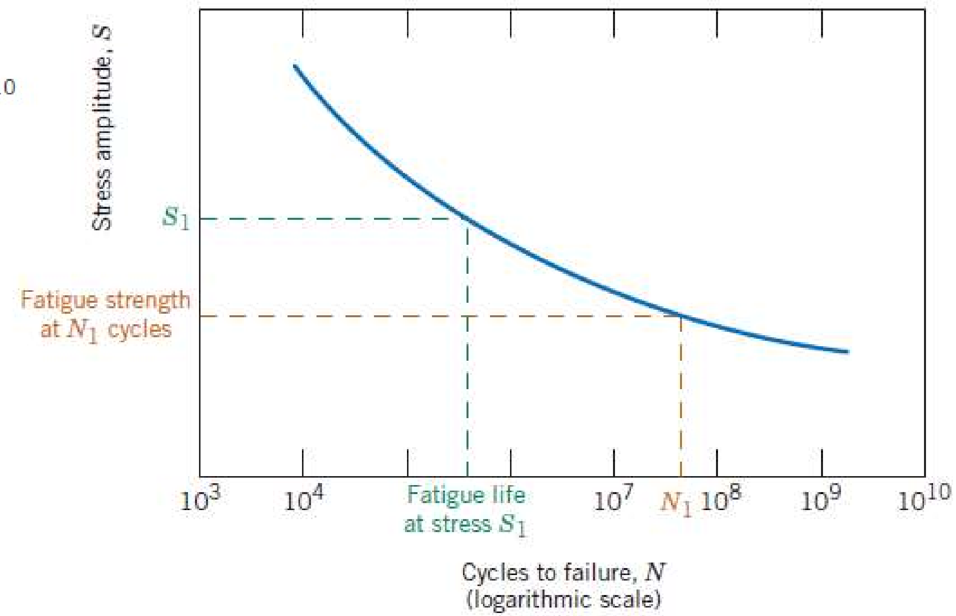
Fadiga



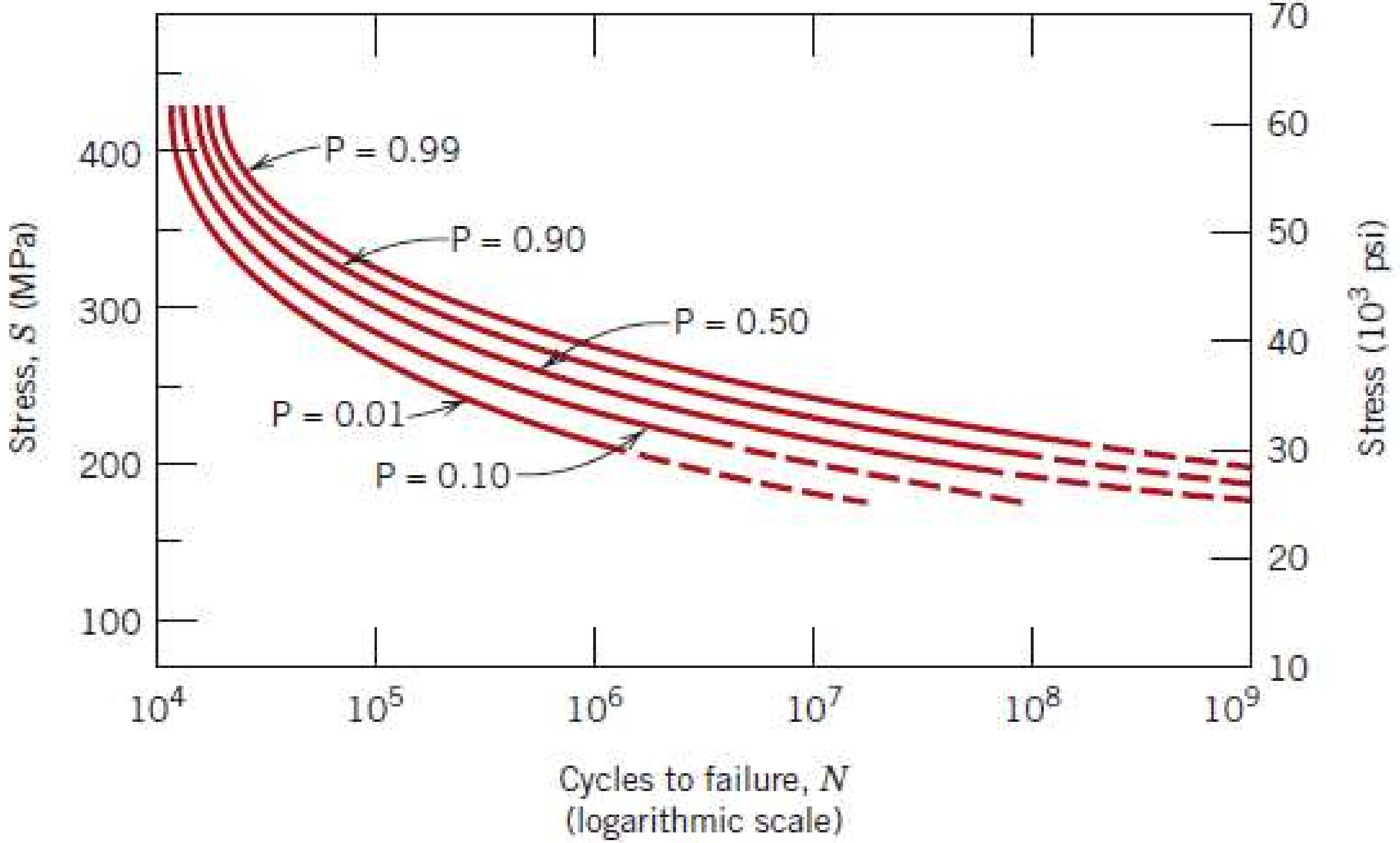
Flexible coupling
Specimen
Counter
High-speed motor
Bearing housing
Bearing housing
Load
Load
σmax
σmin
0
Stress
Tension
Compression
Time
(a)
σmax
σa
σr
σm
0
σmin
Time
(b)

Fadiga


Stress amplitude, S
Fatigue limit
10^3
10^4
10^5
10^6
10^7
10^8
10^9
10^10
Cycles to failure, N
(logarithmic scale)

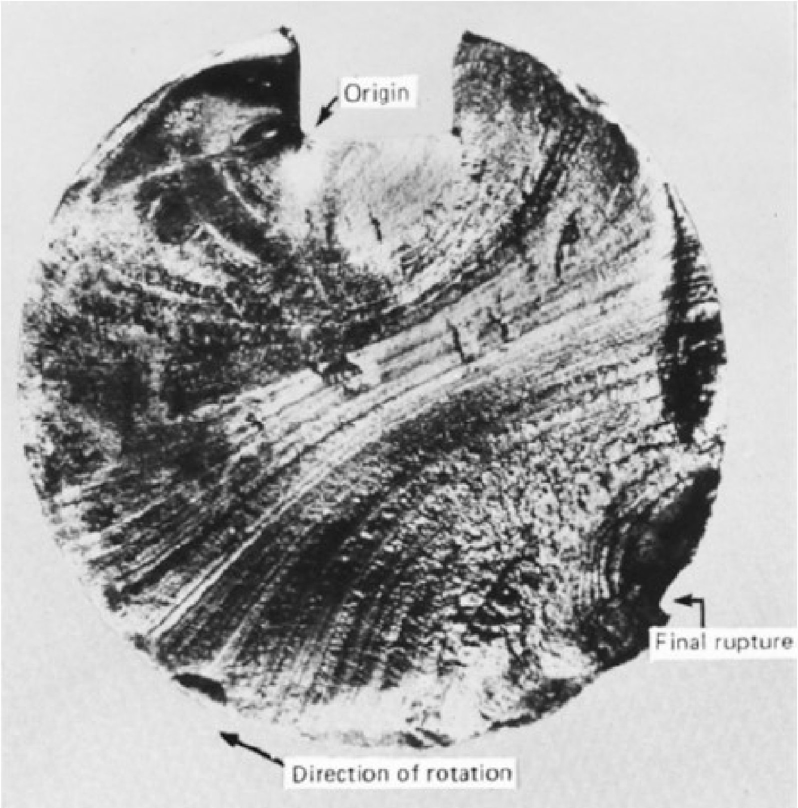

Stress amplitude, S
S1
Fatigue strength at N1 cycles
10^3
10^4
Fatigue life at stress S1
10^7
N1
10^8
10^9
10^10
Cycles to failure, N
(logarithmic scale)

Fadiga

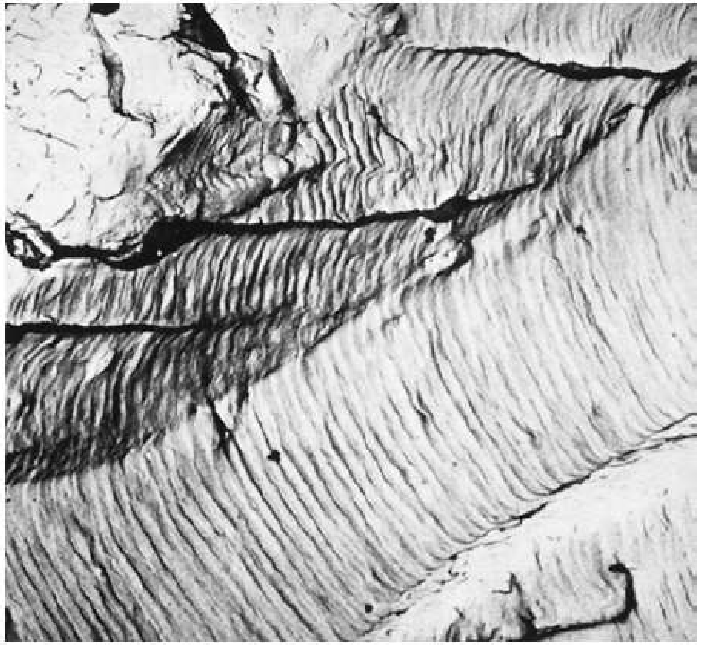


P = 0.99
P = 0.90
P = 0.50
P = 0.01
P = 0.10
400
300
200
100
Stress, S (MPa)
70
60
50
40
30
20
10
Stress (10³ psi)
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹
Cycles to failure, N
(logarithmic scale)

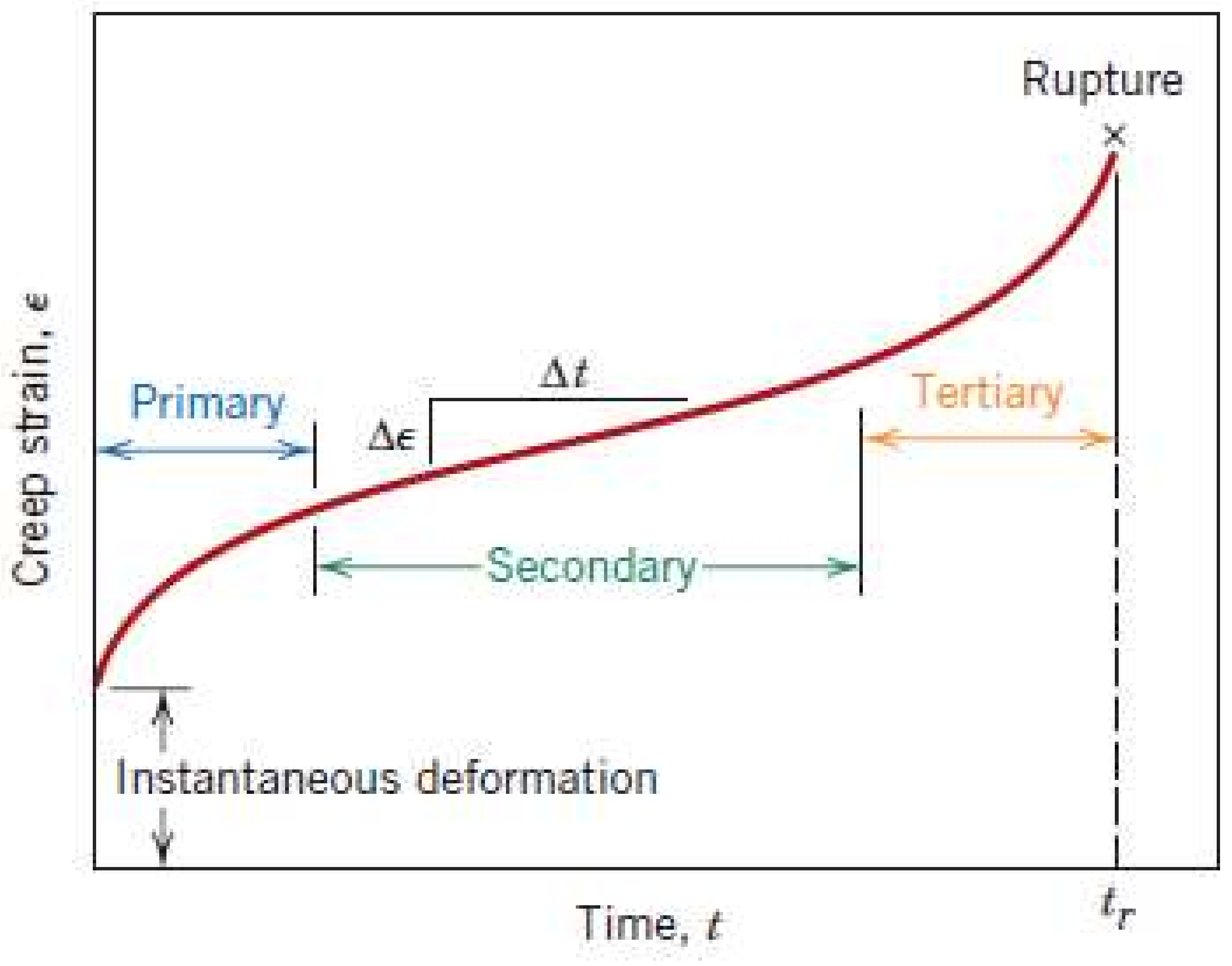
Nucleação e Propagação da Trinca



MEV

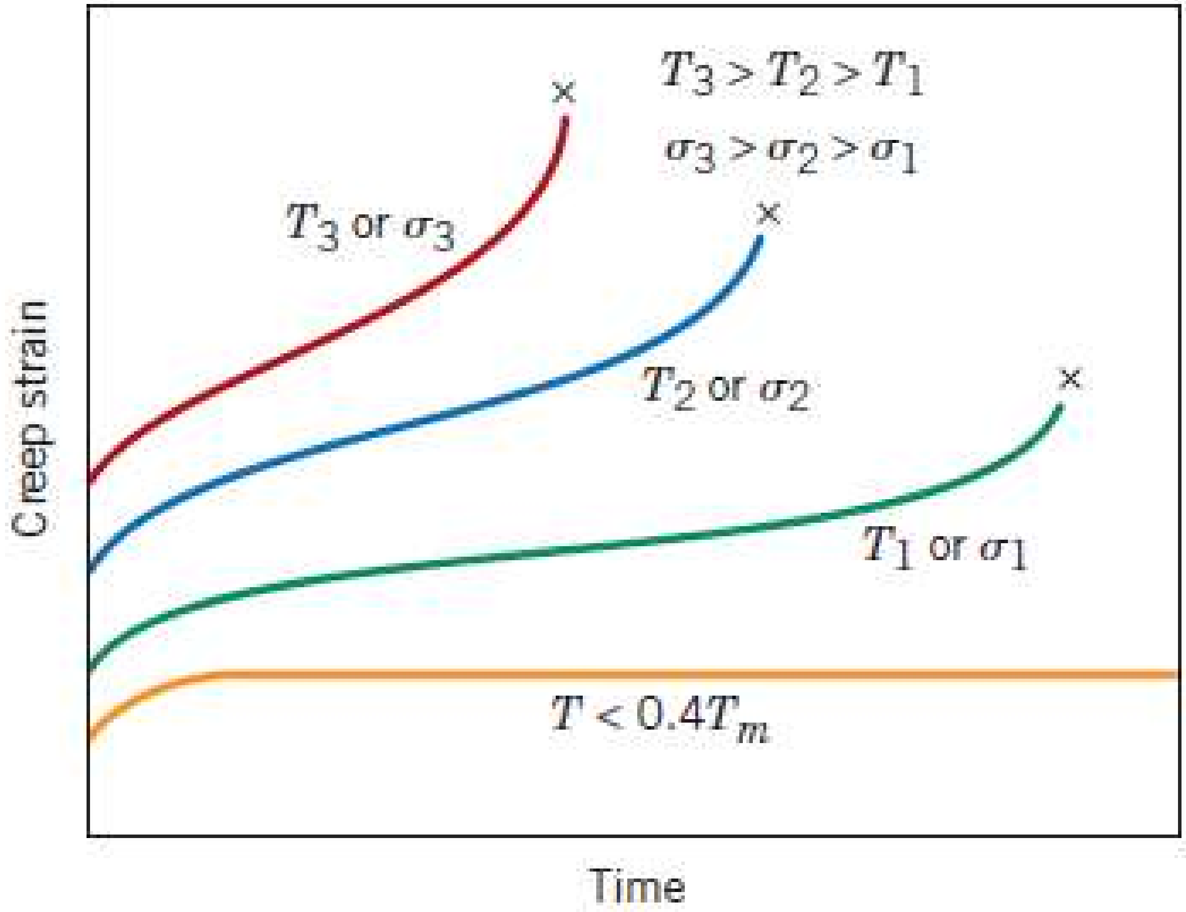


Fluência



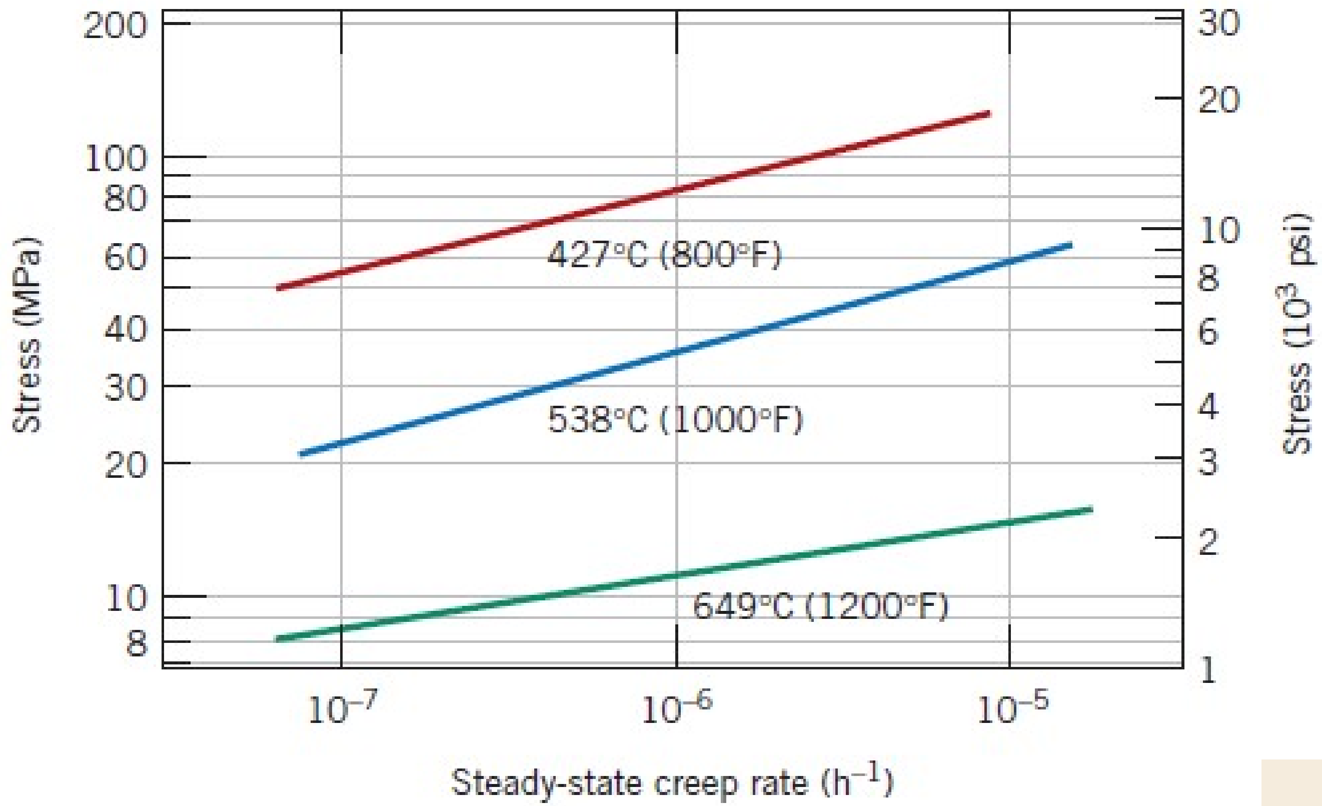
Rupture
Primary
Δt
Δϵ
Tertiary
Secondary
Instantaneous deformation
Creep strain, ϵ
Time, t
t_r

Fluência



$T_3 > T_2 > T_1$
$\sigma_3 > \sigma_2 > \sigma_1$
T_3 or σ_3
T_2 or σ_2
T_1 or σ_1
$T < 0.4T_m$
Creep strain
Time

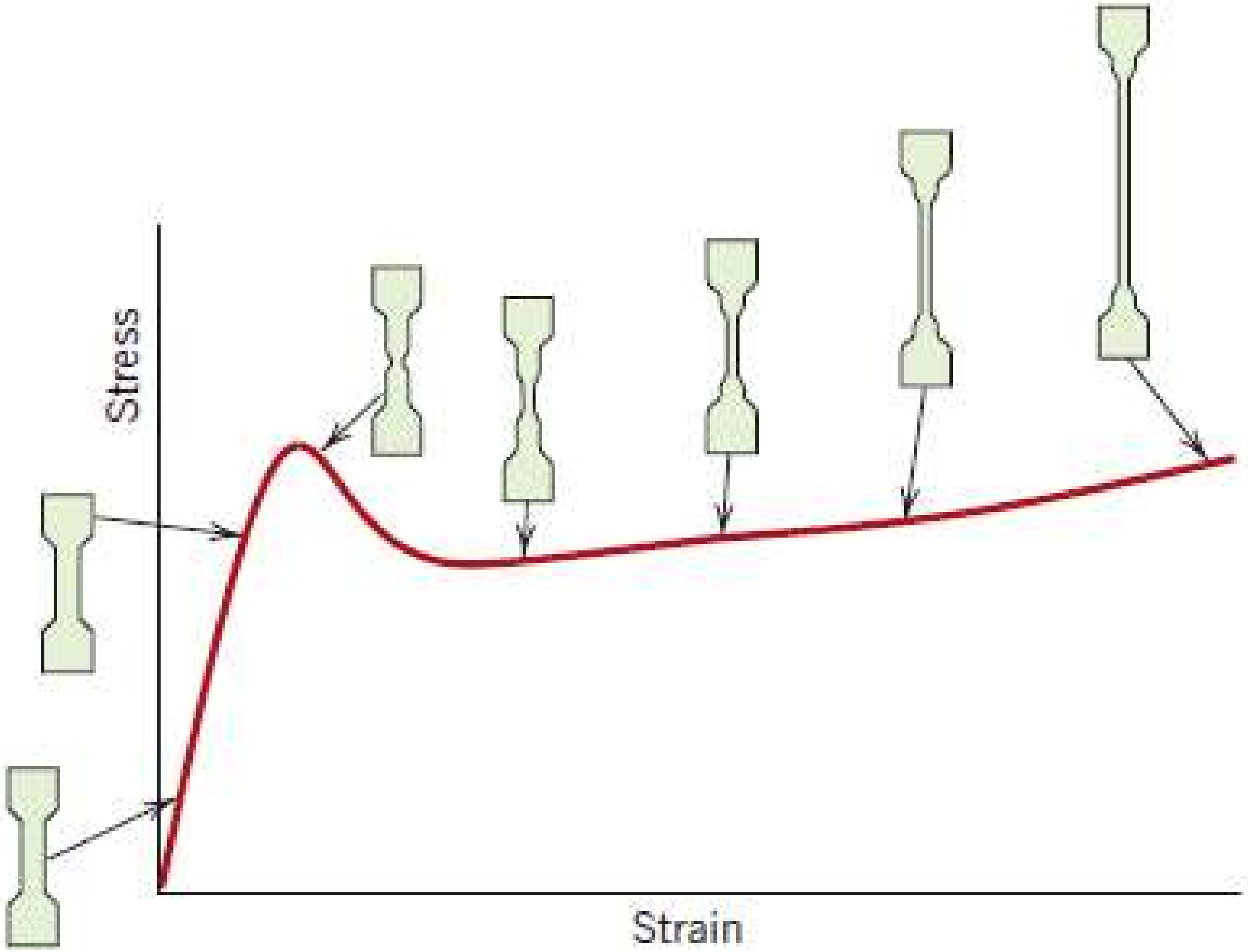
Fluência



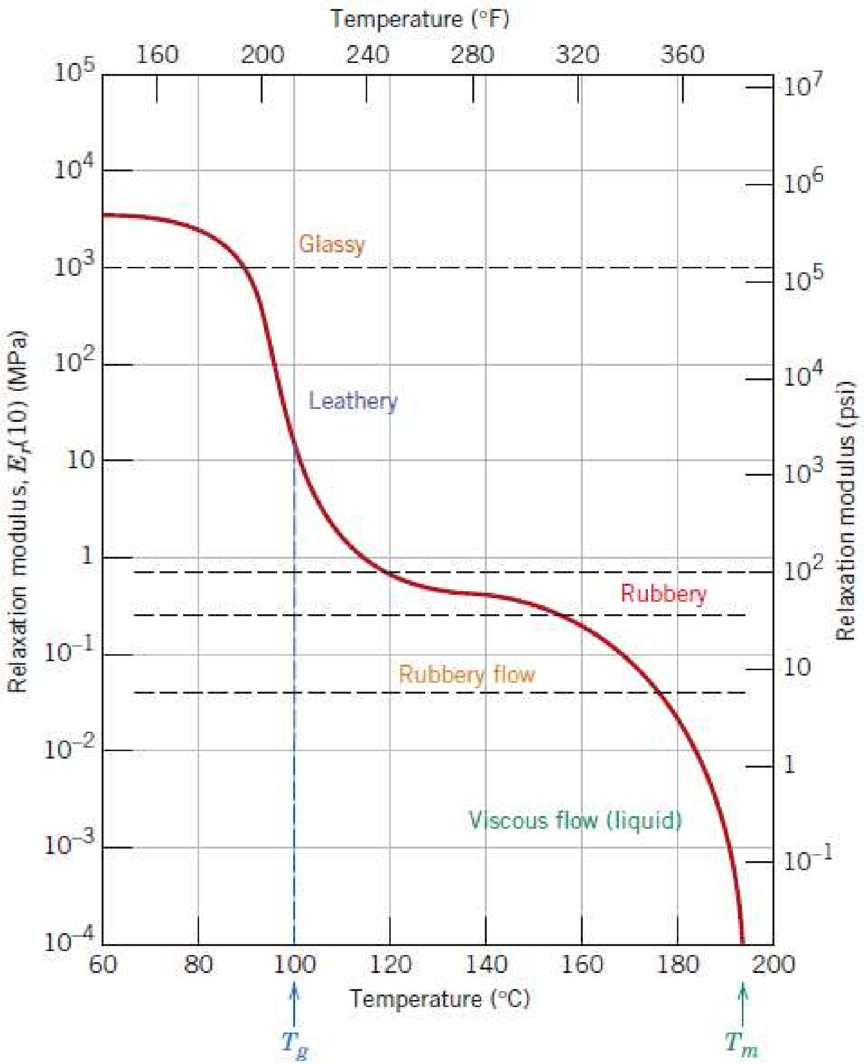
$$\dot{\epsilon}_s = K_1 \sigma^n$$

$$\dot{\epsilon}_s = K_2 \sigma^n \exp\left(-\frac{Q_c}{RT}\right)$$

Viscoelasticidade em Polímeros



Relaxação em Polímeros



$$E_r(t) = \frac{\sigma(t)}{\epsilon_0}$$

Módulo de Relaxação x Estrutura

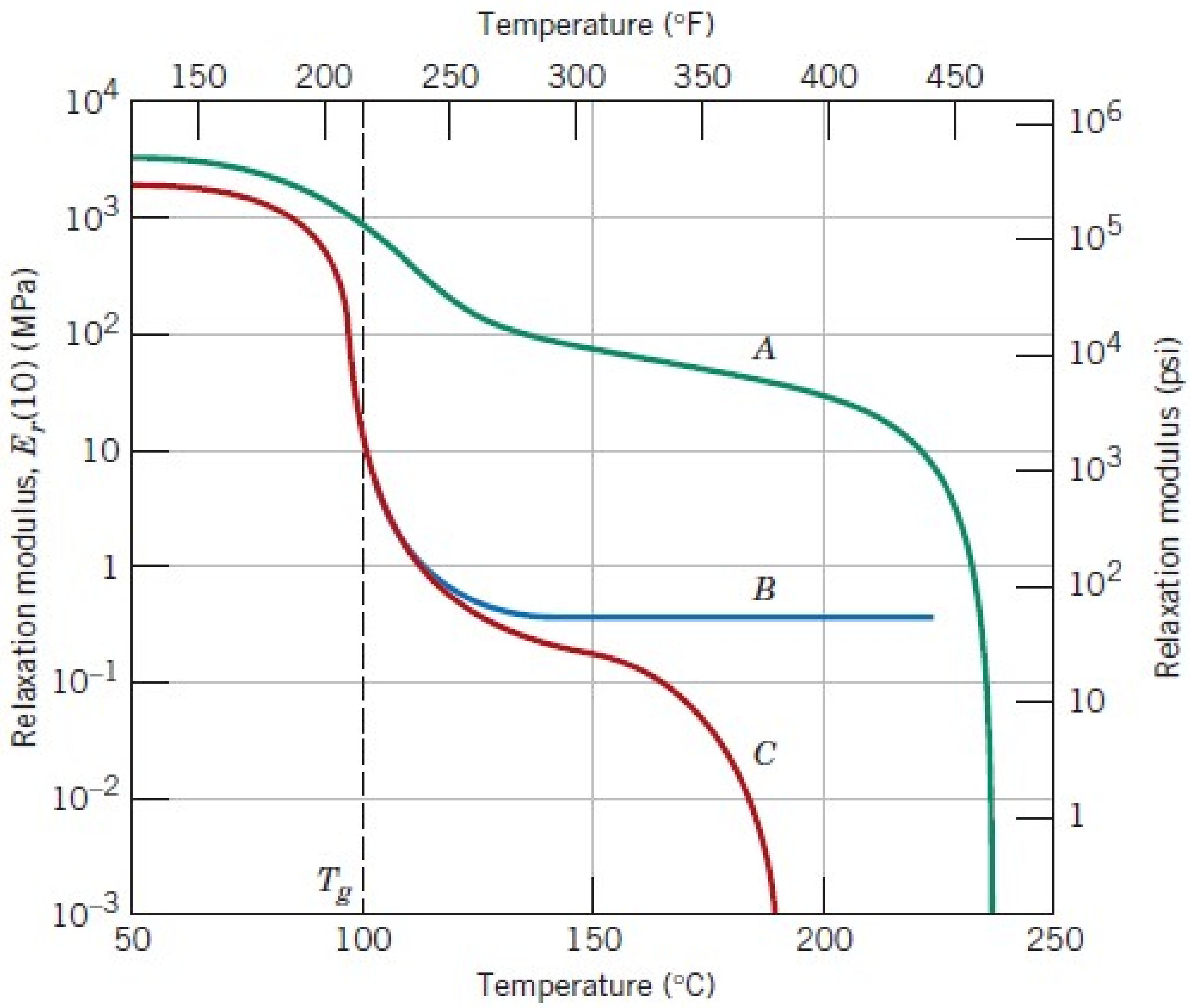


Figure 15.8 Logarithm of the relaxation modulus versus temperature for crystalline isotactic (curve *A*), lightly crosslinked atactic (curve *B*), and amorphous (curve *C*) polystyrene. (From A. V. Tobolsky, *Properties and Structures of Polymers.* Copyright © 1960 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.)