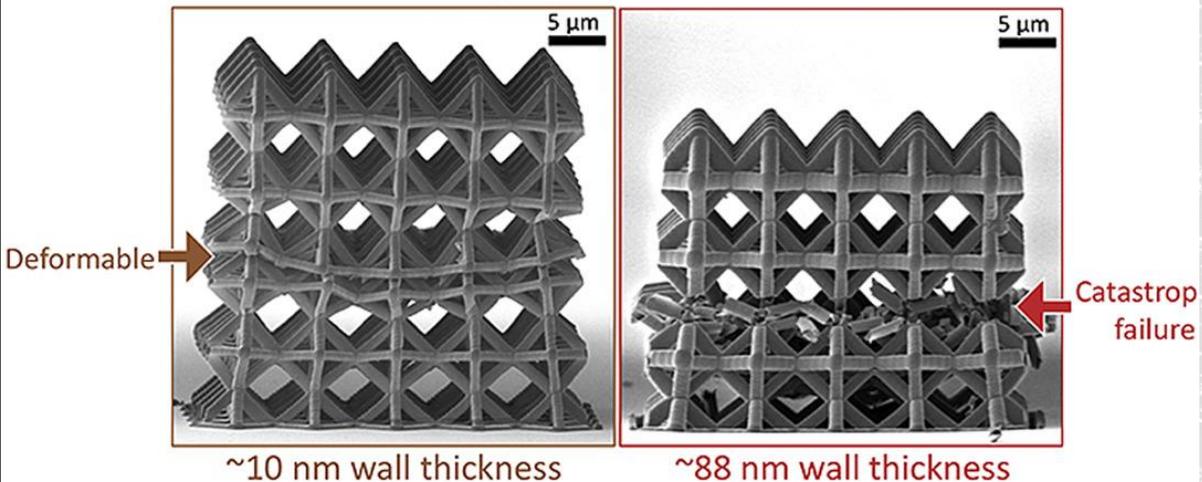


After compression to ~33% strain



Deformability in hollow metallic glass nanolattices is achieved by decreasing the wall thickness of the nanolattice beams. Nano-architecting in this way enables the “smaller is more deformable” material size effect first observed in metallic glasses nanopillars to be proliferated to larger nanolattice structures as long as the characteristic nanolattice dimension, the wall thickness, is kept below a critical value ~50 nm.

FRATURA DOS METAIS

AULA I: INTRODUÇÃO

Prof. Cassius Terra Ruchert

cassiusterra@usp.br

NESTA AULA

Introdução:

- Tipos de falhas nos materiais
- Desenho e seleção de materiais
- Desafios tecnológicos
- Importância das fraturas na economia



INTRODUÇÃO

Conceitos:

- Strain \neq deformation ; deformação = \sum strain
- Stress \neq strength (em desenho $\sigma_{\text{desenho/medido}} < \sigma_{\text{falha}}$ (deformação excessiva ou fratura))
- Falhas: por deformação ou fratura

Estudo de deformações e fratura de materiais: Estudo mecânico dos materiais

- Casos especiais:
 - Tensões biaxiais e triaxiais
 - Defeitos e trincas
 - Carregamentos aplicados por períodos longos de tempo
 - Forças aplicadas e retiradas repetidamente

TIPOS DE FALHAS NO MATERIAIS

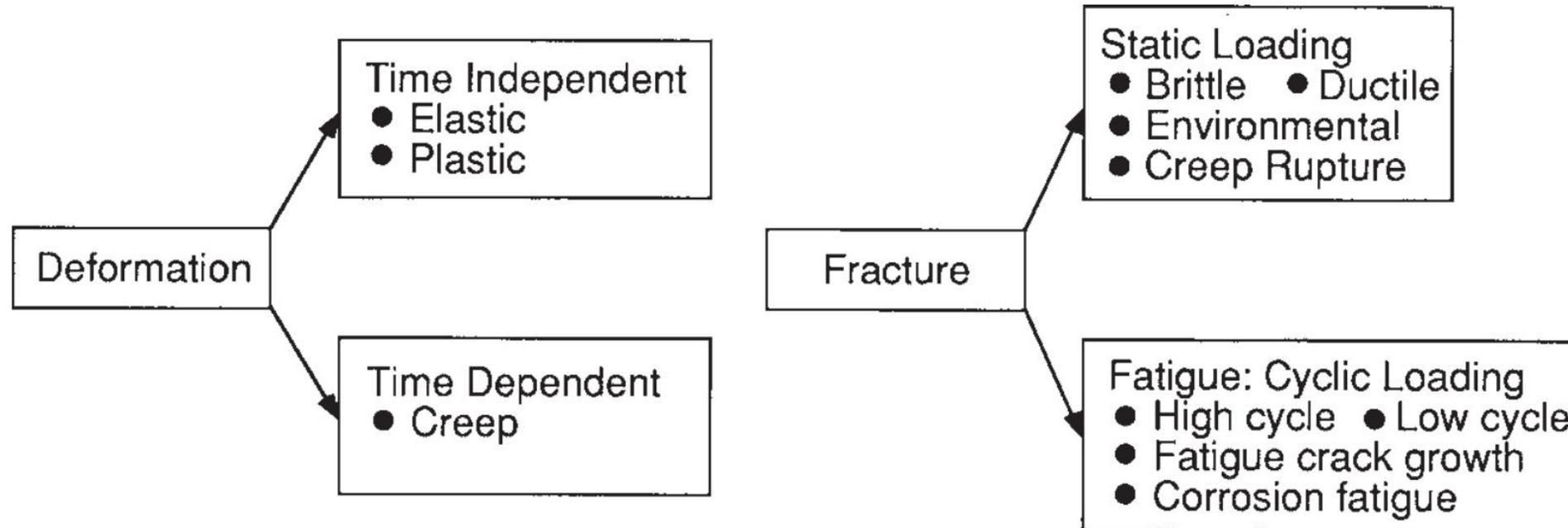


Figure 1.1 Basic types of deformation and fracture.

TIPOS DE FALHAS NO MATERIAIS

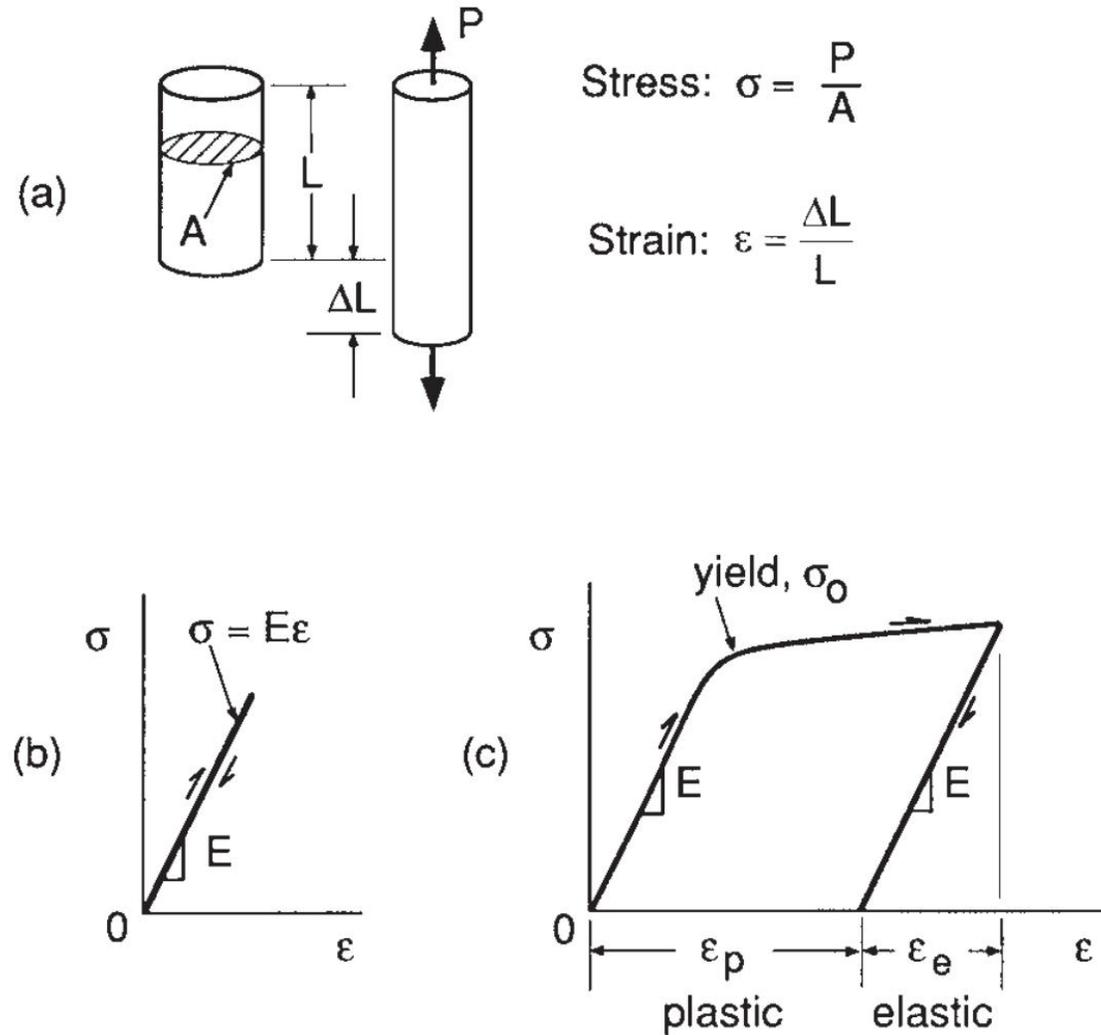
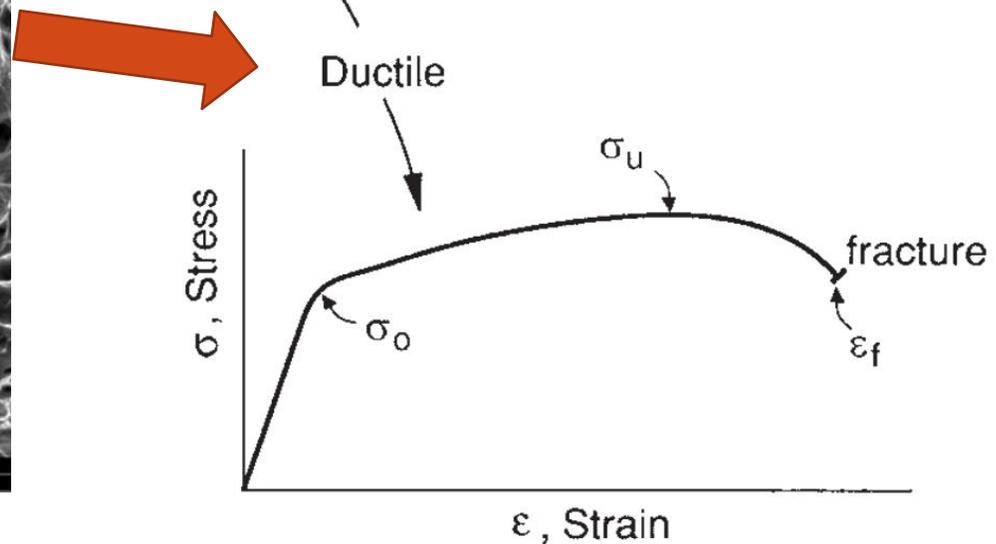
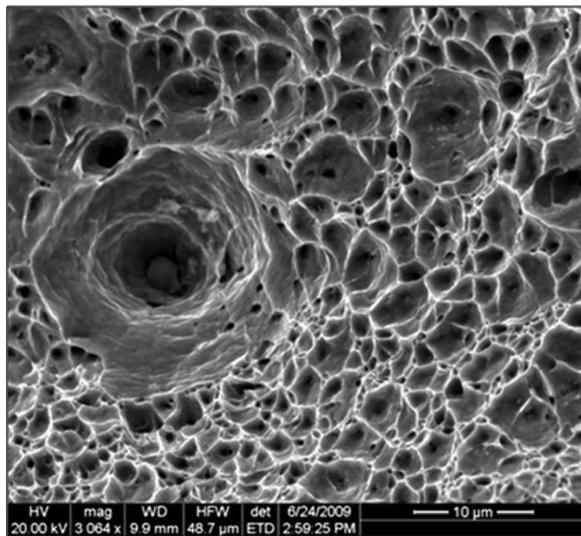
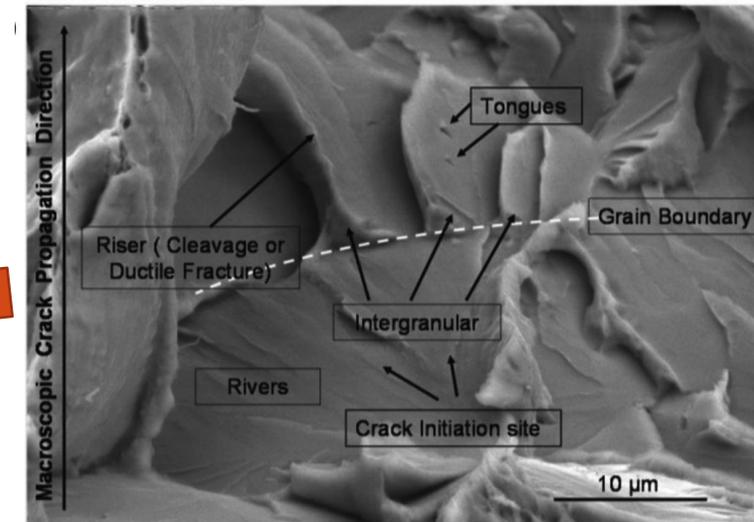
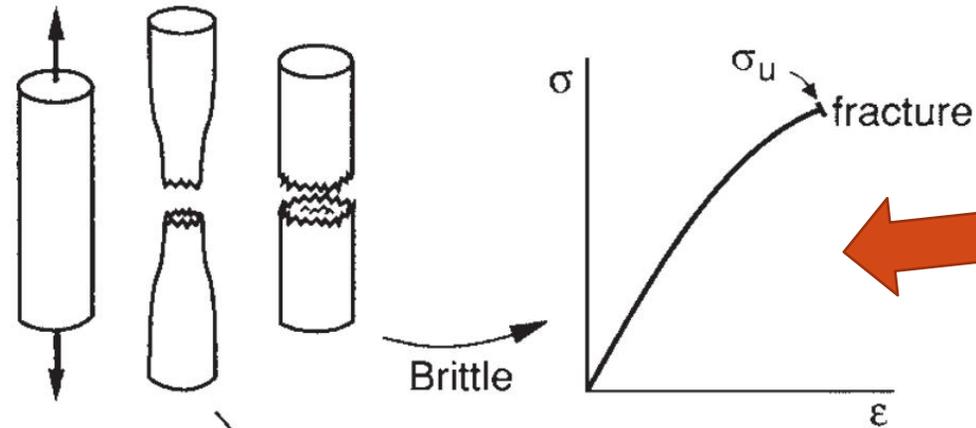


Figure 1.2 Axial member (a) subject to loading and unloading, showing elastic deformation (b) and both elastic and plastic deformation (c).

DEFORMAÇÃO ELÁSTICA E PLÁSTICA



<https://doi.org/10.1016/j.actamat.2015.12.034>

Figure 1.3 Tension test showing brittle and ductile behavior. There is little plastic deformation for brittle behavior, but a considerable amount for ductile behavior.

DEFORMAÇÃO POR FLUÊNCIA (CREEP)

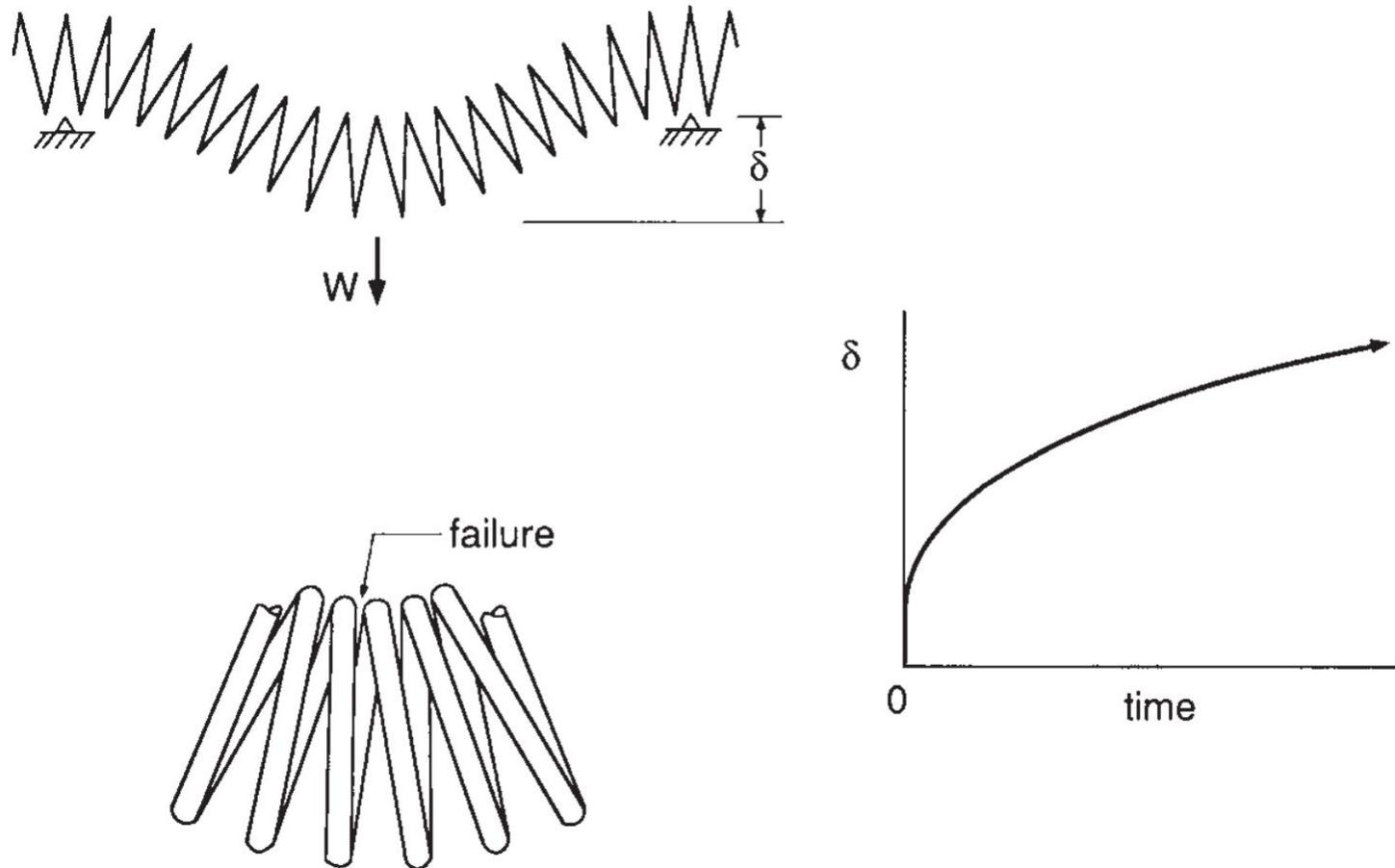
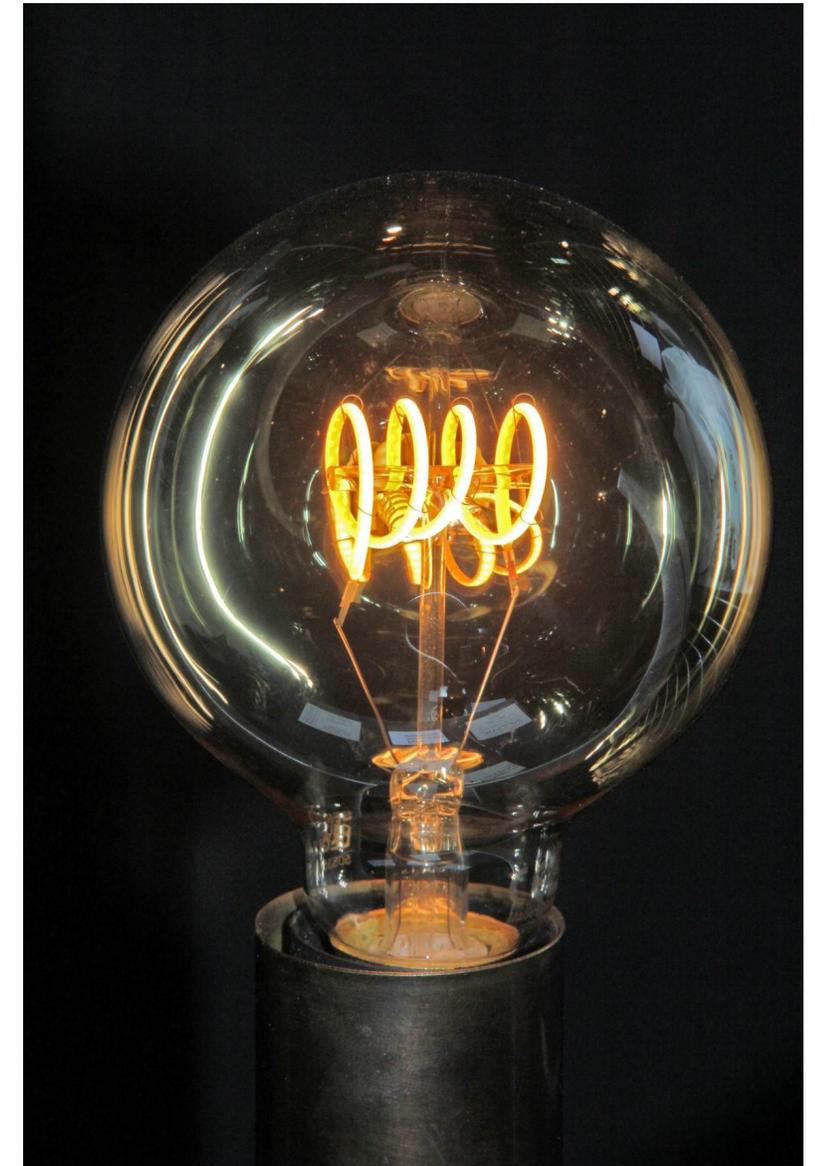


Figure 1.4 A tungsten lightbulb filament sagging under its own weight. The deflection increases with time due to creep and can lead to touching of adjacent coils, which causes bulb failure.



<https://pxhere.com/en/photo/1194379>

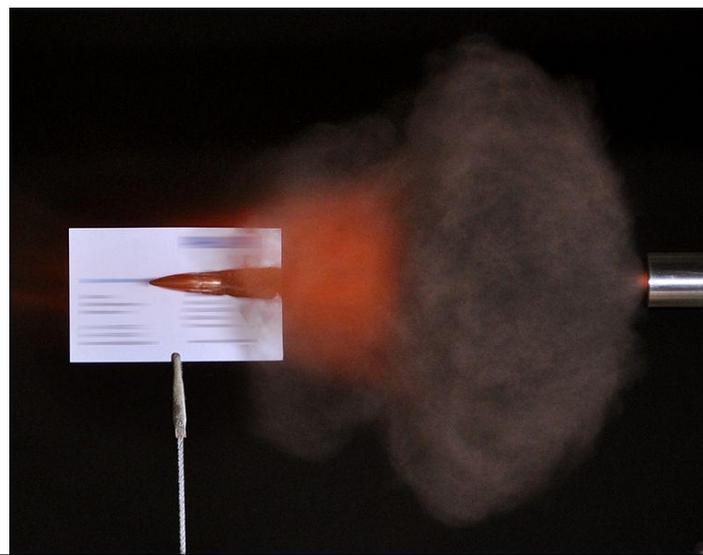
FRATURA SUB CARREGAMENTO ESTÁTICO OU IMPACTO

- Carregamento estático



<https://www.maxpixel.net/Envelope-Cargo-Port-Loading-Container-Transport-2539942>

- Impacto: carregamento aplicado rapidamente



[https://commons.wikimedia.org/wiki/File:.308_Winchester_bullet_\(150_grain_FMJ\).JPG](https://commons.wikimedia.org/wiki/File:.308_Winchester_bullet_(150_grain_FMJ).JPG)

TRINCAS OU DEFEITOS AFIADOS

Estudado pela “mecânica da da fratura”

- Propriedades : tenacidade à fratura (K_{IC}, CTOD, integral J)

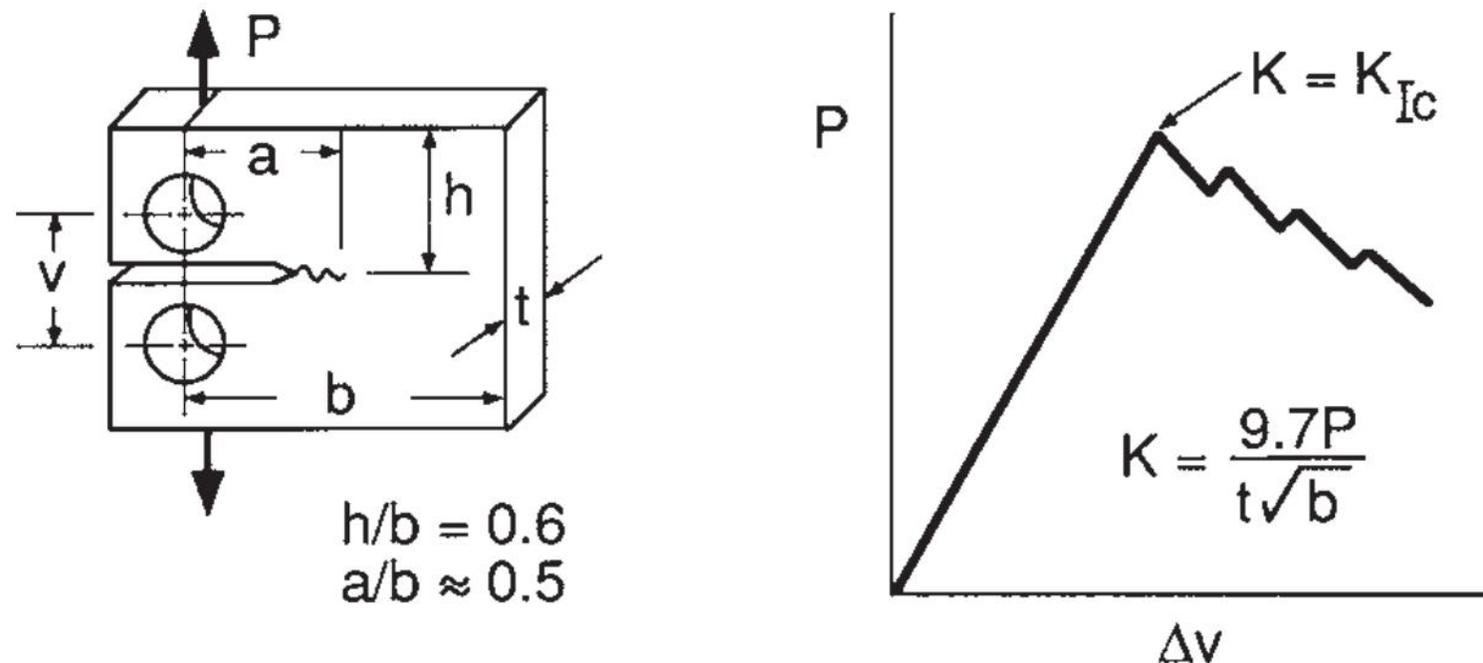


Figure 1.5 Fracture toughness test. K is a measure of the severity of the combination of crack size, geometry, and load. K_{IC} is the particular value, called the *fracture toughness*, where the material fails.

TENACIDADE À FRATURA VS CAPACIDADE DE DEFORMAÇÃO

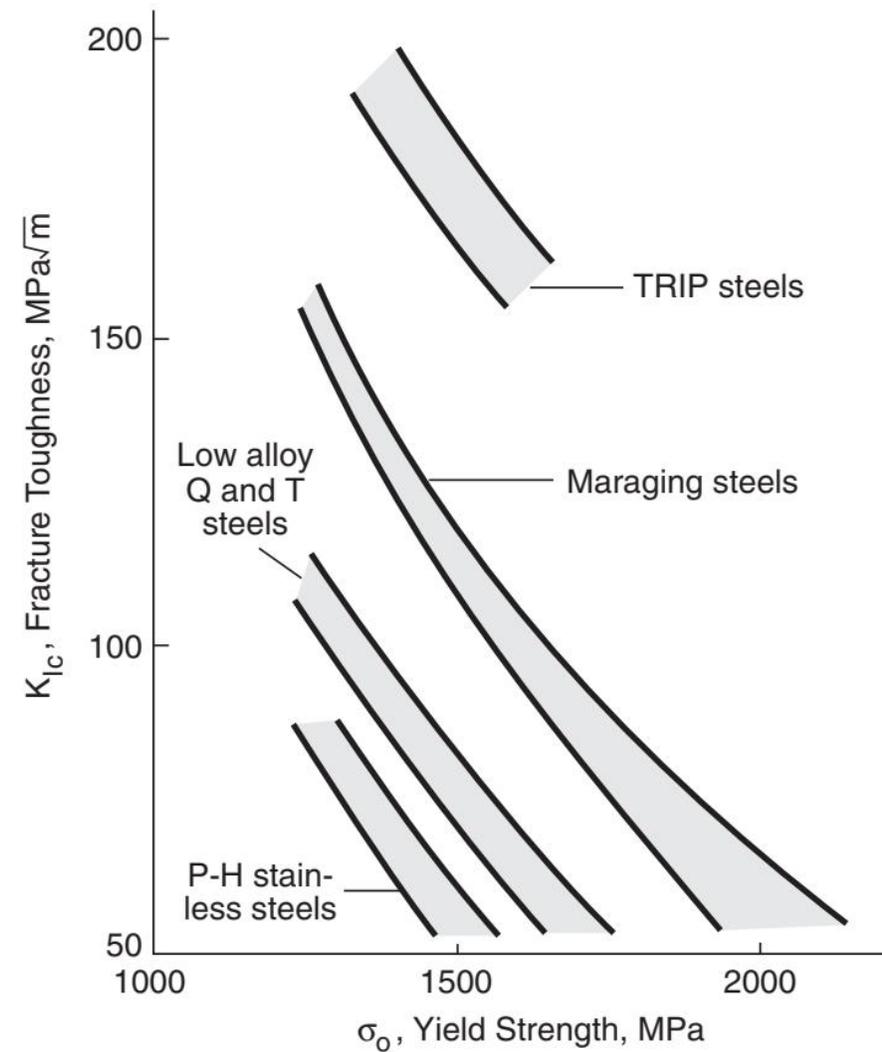
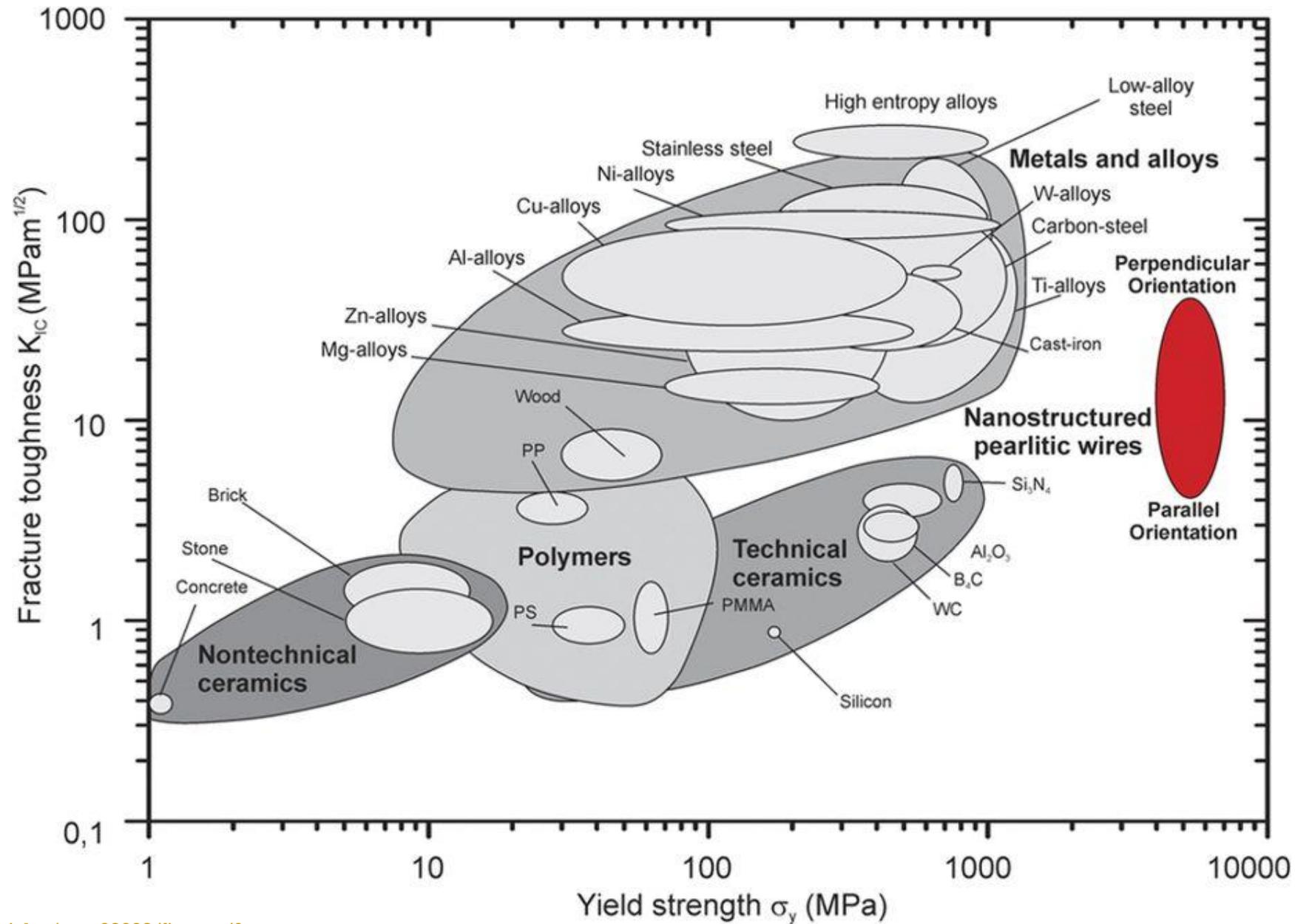


Figure 1.6 Decreased fracture toughness, as yield strength is increased by heat treatment, for various classes of high-strength steel. (Adapted from [Knott 79]; used with permission.)



FRATURA ASSISTIDA PELO MÉDIO

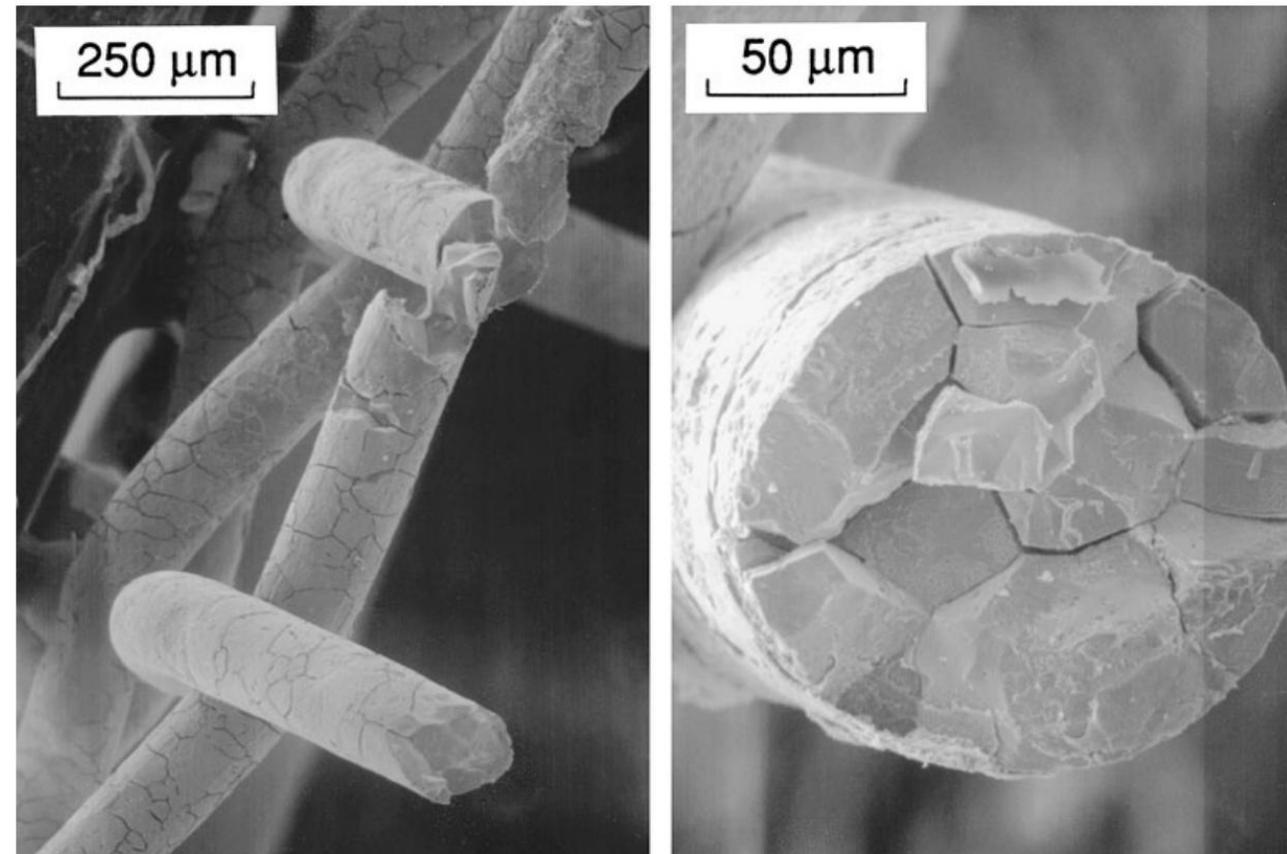


Figure 1.7 Stainless steel wires broken as a result of environmental attack. These were employed in a filter exposed at 300°C to a complex organic environment that included molten nylon. Cracking occurred along the boundaries of the crystal grains of the material. (Photos by W. G. Halley; courtesy of R. E. Swanson.)

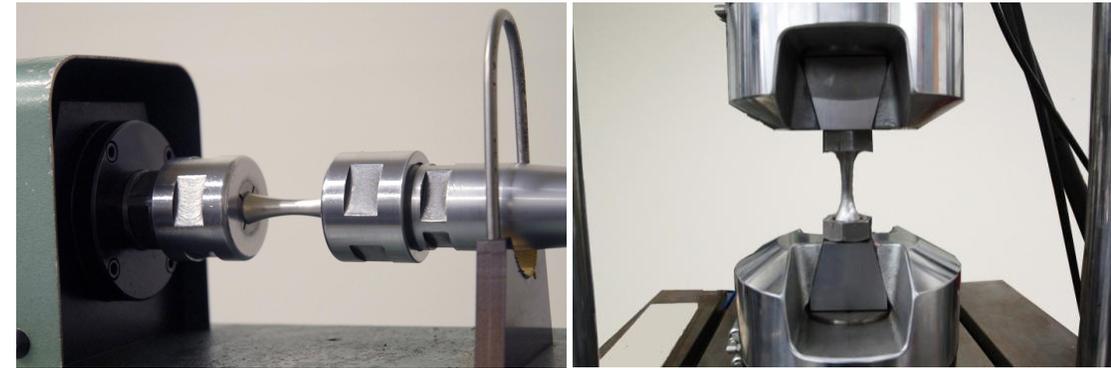
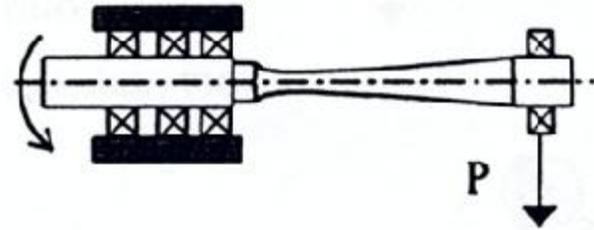
FADIGA SUB CARREGAMENTO CÍCLICOS

- Peças desenhadas sob este critério: equipamentos, veículos, estruturas.



Figure 1.10 Main mast region of a helicopter, showing inboard ends of blades, their attachment, and the linkages and mechanism that control the pitch angles of the rotating blades. The cylinder above the rotors is not ordinarily present, but is part of instrumentation used to monitor strains in the rotor blades for experimental purposes. (Photo courtesy of Bell Helicopter Textron, Inc., Ft. Worth, TX.)

FADIGA SUB CARREGAMENTO CÍCLICOS



<https://www.imrtest.com/tests/fatigue-testing>

DOI: 10.4236/jmmce.2011.1011078

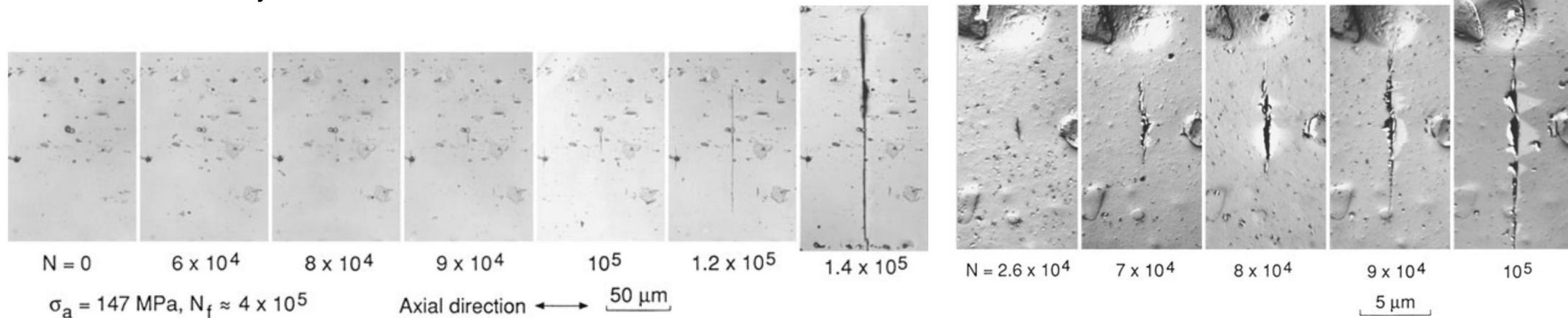
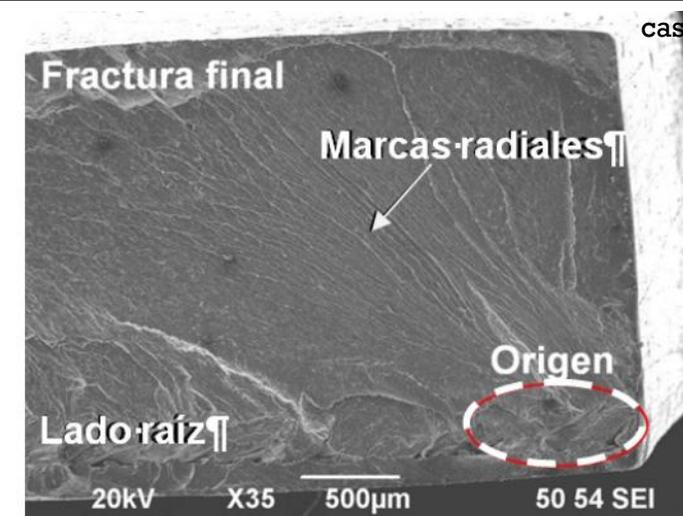


Figure 1.8 Development of a fatigue crack during rotating bending of a precipitation-hardened aluminum alloy. Photographs at various numbers of cycles are shown for a test requiring 400,000 cycles for failure. The sequence in the bottom row of photographs shows more detail of the middle portion of the sequence in the top row. (Photos courtesy of Prof. H. Nisitani, Kyushu Sangyo University, Fukuoka, Japan. Published in [Nisitani 81]; reprinted with permission from *Engineering Fracture Mechanics*, Pergamon Press, Oxford, UK.)

FRATURA DE FADIGA



Figure 1.9 Fatigue failure of a garage door spring that occurred after 15 years of service. (Photo by R. A. Simonds; sample contributed by R. S. Alvarez, Blacksburg, VA.)



a.)

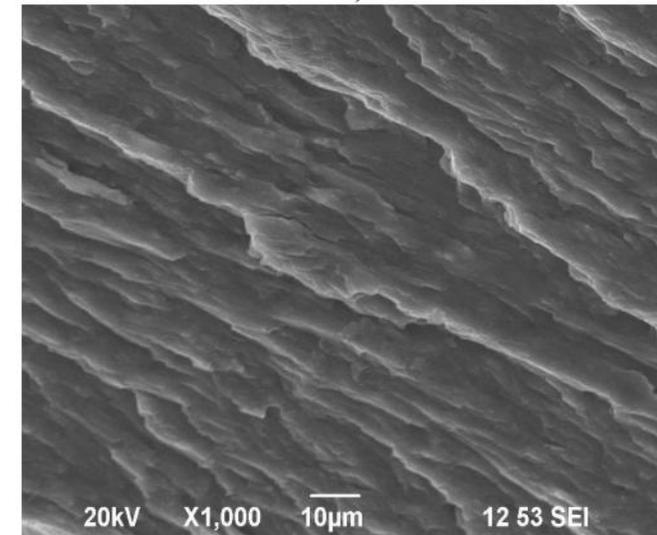


Figura 9. Micrografías SEM típica de superficies de fractura a fatiga de uniones por SFA con zona de falla 1. Muestra 1121. a.) Inicio de grieta a partir de un defecto de raíz; b.) Detalle de estrías paralelas en la zona de crecimiento debidas a fatiga

J.A.D. Avila, A.F. Franco, H.E. Jaramillo, Evaluación de la resistencia de a la tensión y la fatiga de uniones soldadas por fricción agitación de la aleación de magnesio AZ31B, Rev. Latinoam. Metal. y Mater. 32 (2012) 71–78. <http://www.rlmm.org/ojs/index.php/rlmm/article/view/148>.

ALOHA AIRLINES FLIGHT 243, APRIL 28, 1988



<http://www.staradvertiser.com/2018/04/27/photo-galleries/aloha-airlines-flight-243-april-28-1988/>

Figure 1.11 Fuselage failure in a passenger jet that occurred in 1988. (Photo courtesy of J. F. Wildey II, National Transportation Safety Board, Washington, DC; see [NTSB 89] for more detail.)

FADIGA DE ALTA E BAIXA CICLAGEM

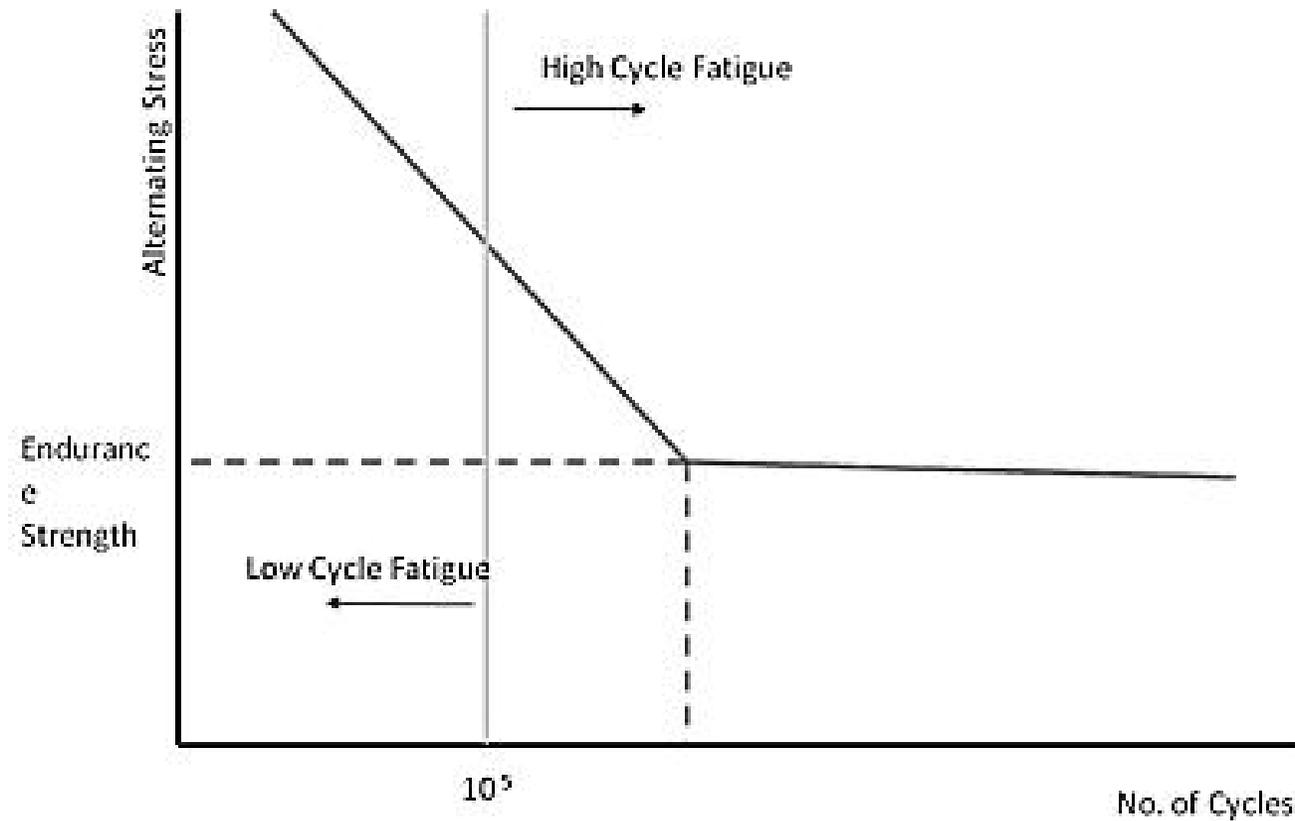


Fig1. *Low and High cycle Fatigue*

EFETOS COMBINADOS

- Fadiga + fluência (creep); ex. turbinas
- Fadiga + desgaste = fretting fatigue
- Fadiga + corrosão = corrosão fadiga
- Exposição ao meio ambiente:
 - Ambiente salino
 - Radiação ultravioleta (polímeros)
 - Radiação por nêutrons
 - Hidrogenio

DESENHO E SELEÇÃO DE MATERIAIS

- Segurança
- Durabilidade: capacidade do item de cumprir com o propósito de desenho num período de tempo determinado
 - Durabilidade baixa pode levar a falhas o mal funcionamento, afetando a segurança
 - Maior durabilidade evita a frequência de troca de peças, ajudando na conservação do meio ambiente.

NATUREZA GRADATIVA E ITERATIVO DO DESENHO

- Sínteses em cada etapa
- Assegurar segurança e durabilidade

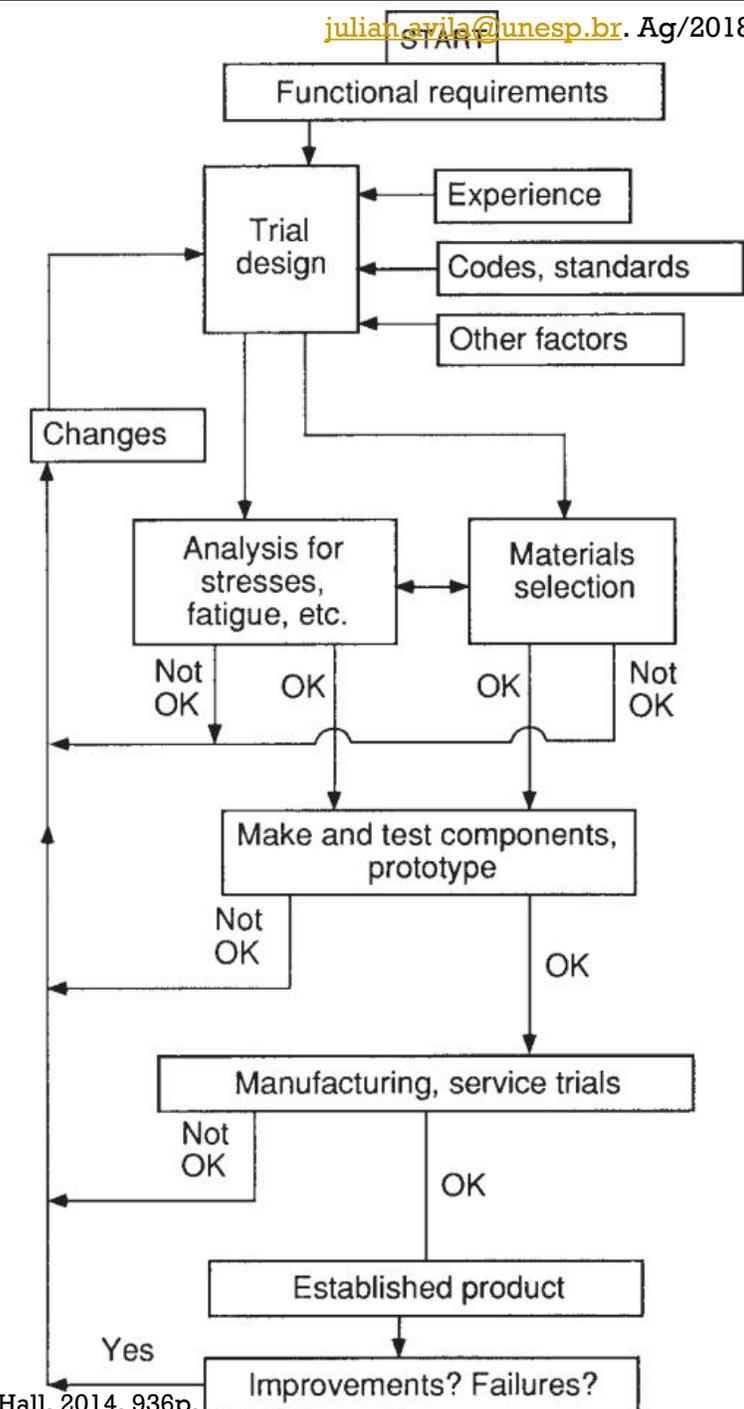


Figure 1.12 Steps in the design process related to avoiding structural failure. (Adapted from [Dowling 87]; used with permission; © Society of Automotive Engineers.)

FATOR DE SEGURANÇA

- Tensão permitida de desenho (fator de segurança)

$$X_1 = \frac{\text{stress causing failure}}{\text{stress in service}}$$

$$X_2 = \frac{\text{failure life}}{\text{desired service life}}$$

$$1,5 > X_1, X_2 < 3$$

- Fator de carga (força, momento, torque, etc)

$$(\text{load in service}) \times Y = \text{load causing failure}$$

PROTÓTIPOS E AVALIAÇÃO DE COMPONENTES

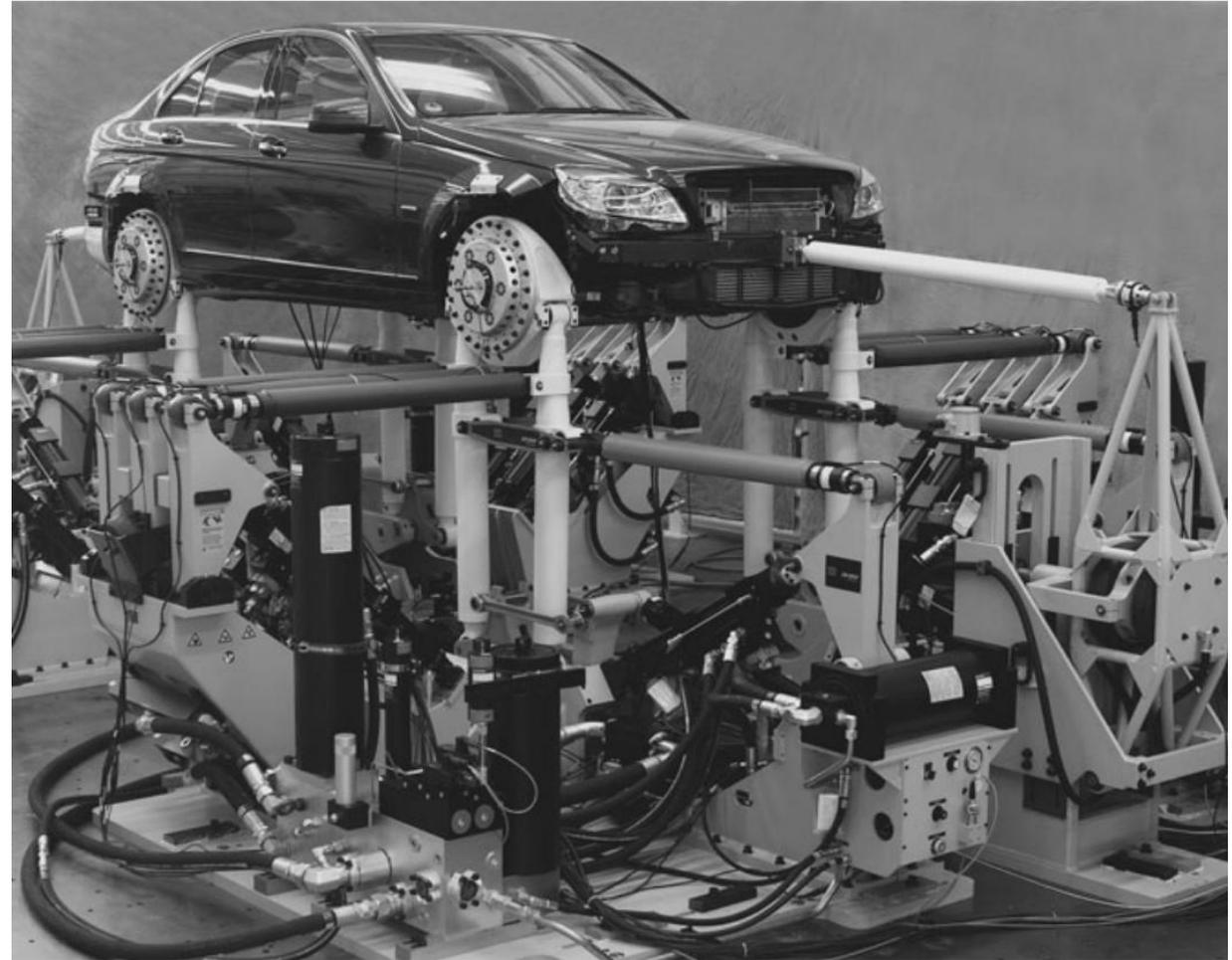


Figure 1.13 Road simulation test of an automobile, with loads applied at all four wheels and the bumper mounts. (Photo courtesy of MTS Systems Corp., Eden Prairie, MN.)

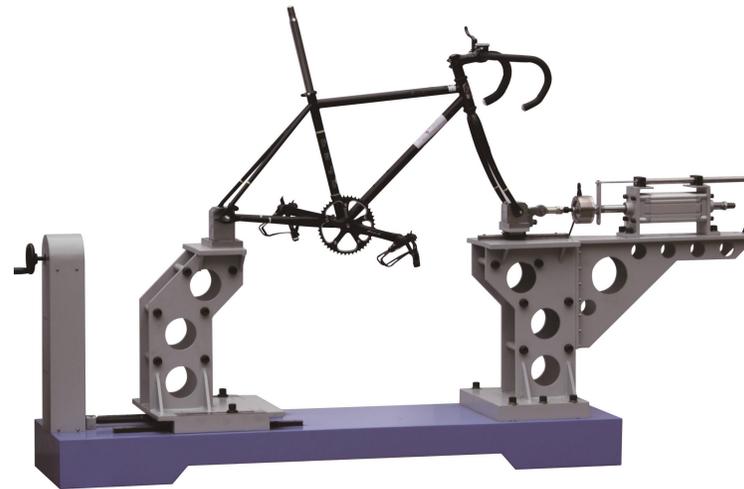
ESTRUTURAS DE ENSAIO DE FADIGA

Implante de cadeira



<http://www.instron.co.hu/hu-hu/testing-solutions/by-standard/iso/iso-7206-4>

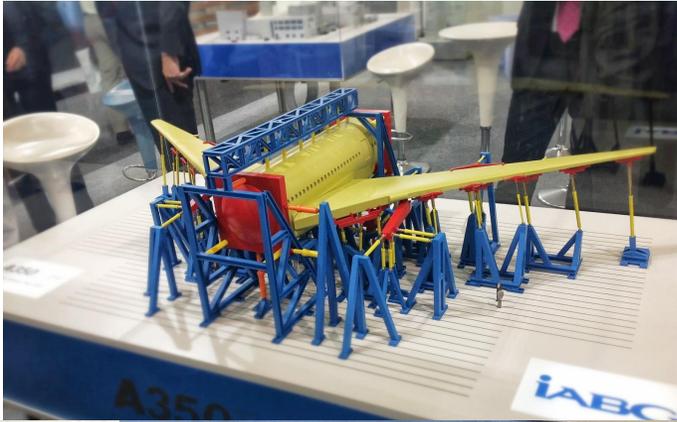
Bikes



<http://www.mytech.tw/en/product/MY-2708-C.html>



TESTE EM PARTES ESPECIFICAS - AVIÕES



<https://www.nlr.org/case/new-aircraft-materials-tested-limit/>



<http://bloga350.blogspot.com/2013/08/ef2-fatigue-test-at-iabg-waits-for-wings.html>

ACOMPANHAMENTO DOS PRODUTOS

- Após fabricação:
 - Revisões periódicas avaliando a estrutura dos equipamentos
 - Redesenho de partes segundo as cargas e meio ambiente de trabalho

DESAFIOS TECNOLÓGICOS



https://upload.wikimedia.org/wikipedia/commons/8/87/Elon_Musk%27s_Tesla_Roadster_%2840143096241%29.jpg



[https://commons.wikimedia.org/wiki/File:Roman_Bridge,_Ponte_da_Vila_Formosa,_Lusitania,_Portugal_\(12748924913\).jpg](https://commons.wikimedia.org/wiki/File:Roman_Bridge,_Ponte_da_Vila_Formosa,_Lusitania,_Portugal_(12748924913).jpg)

Table 1.1 Some Major Technological Advances from 1500 A.D., the Parallel Developments in Materials and Materials Testing, and Failures Related to Behavior of Materials

Source: [Herring 89], [Landgraf 80], [Timoshenko 83], [Whyte 75], *Encyclopedia Britannica*, news reports.

Years	Technological Advance	New Materials Introduced	Materials Testing Advances	Failures
1500's 1600's	Dikes Canals Pumps Telescope	(Stone, brick, wood, copper, bronze, and cast and wrought iron in use)	Tension (L. da Vinci) Tension, bending (Galileo) Pressure burst (Mariotte) Elasticity (Hooke)	
1700's	Steam engine Cast iron bridge	Malleable cast iron	Shear, torsion (Coulomb)	
1800's	Railroad industry Suspension bridge Internal combustion engine	Portland cement Vulcanized rubber Bessemer steel	Fatigue (Wöhler) Plasticity (Tresca) Universal testing machines	Steam boilers Railroad axles Iron bridges
1900's 1910's	Electric power Powered flight Vacuum tube	Alloy steels Aluminum alloys Synthetic plastics	Hardness (Brinell) Impact (Izod, Charpy) Creep (Andrade)	Quebec bridge Boston molasses tank
1920's 1930's	Gas-turbine engine Strain gage	Stainless steel Tungsten carbide	Fracture (Griffith)	Railroad wheels, rails Automotive parts
1940's 1950's	Controlled fission Jet aircraft Transistor; computer Sputnik	Ni-base alloys Ti-base alloys Fiberglass	Electronic testing machine Low-cycle fatigue (Coffin, Manson) Fracture mechanics (Irwin)	Liberty ships Comet airliner Turbine generators
1960's 1970's	Laser Microprocessor Moon landing	HSLA steels High-performance composites	Closed-loop testing machine Fatigue crack growth (Paris) Computer control	F-111 aircraft DC-10 aircraft Highway bridges
1980's 1990's	Space station Magnetic levitation	Tough ceramics Al-Li alloys	Multiaxial testing Direct digital control	Alex. Kielland rig Surgical implants
2000's 2010's	Sustainable energy Extreme fossil fuel extraction	Nanomaterials Bio-inspired materials	User-friendly test software	Space Shuttle tiles Deepwater Horizon offshore oil rig

IMPORTÂNCIA ECONÔMICA DAS FRATURAS

- 1982, USA: \$119 billion dollars.

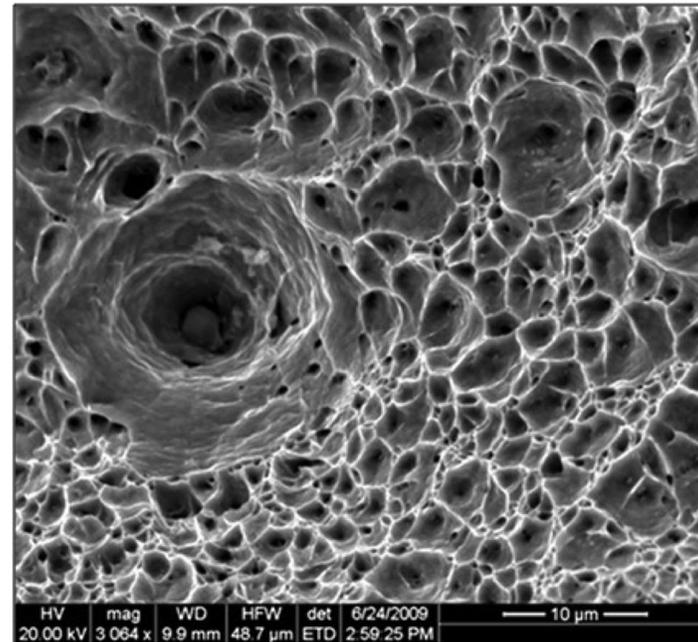
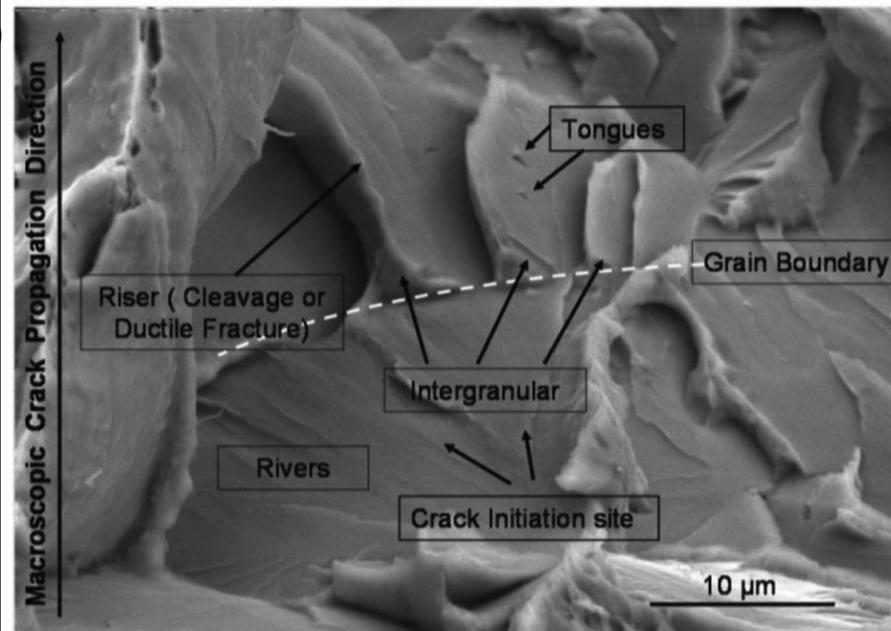
This was 4% of the gross national product (GNP) – PNB: produto nacional bruto

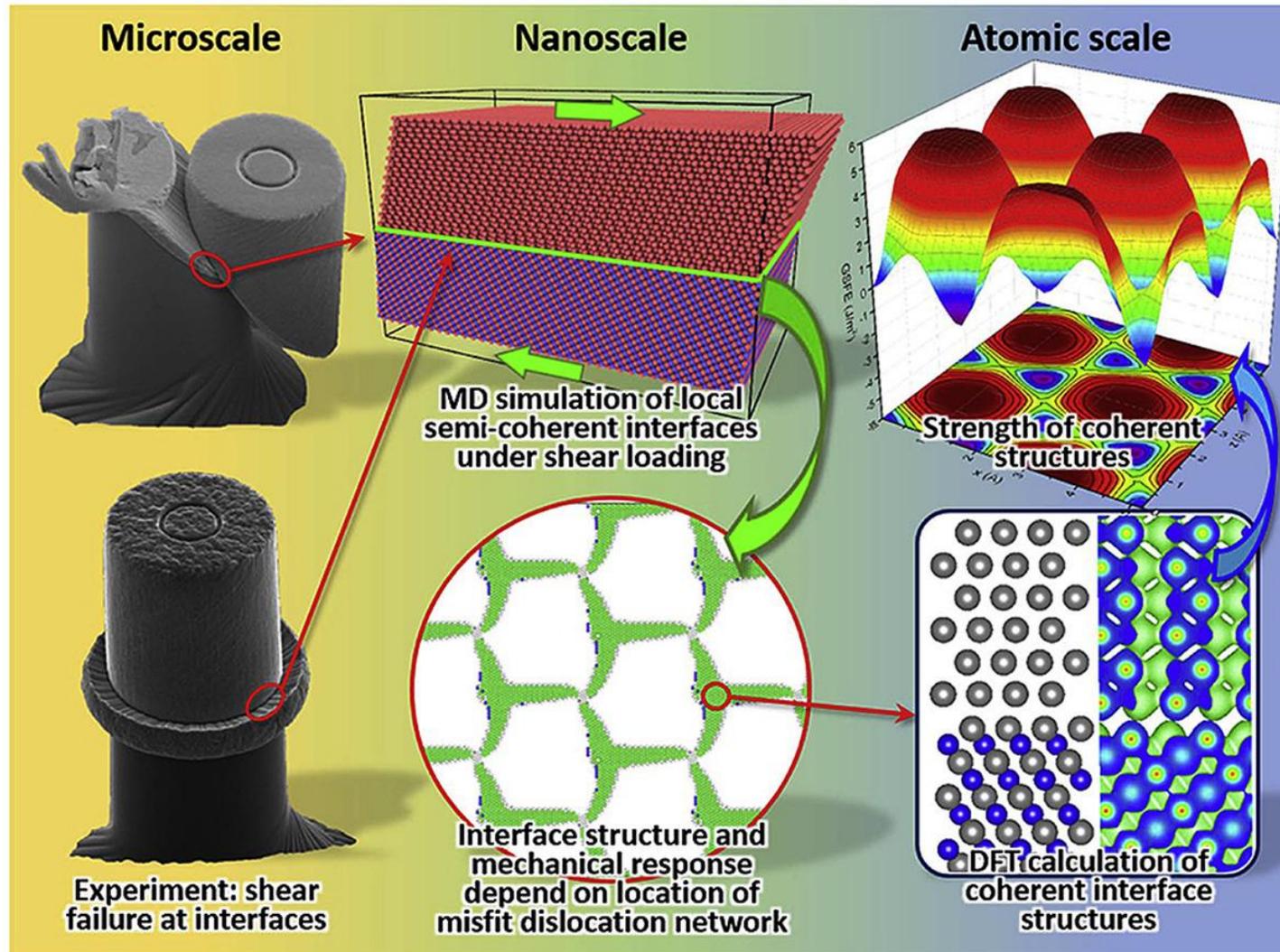
- 1991, Europe, 4% GNP
- USA, 10% partes de carros e 6% partes de aviões → Fadiga a maior causa de falhas
- Sugestões do relatório para evitar perdas por fraturas:
 - 1/3 melhor uso da tecnologia existente
 - 1/3 pesquisa e desenvolvimento de materiais e tecnologias
 - 1/3 a través de uma revolução de tecnologias ou materiais
- Exemplo atual:
 - PIB Brasil, 30/05/2018, R\$ 1,641 trilhão (1^{18}).
 - 4% → $R\$ 6,4 \cdot 1^{16} = 0,064 \cdot 1^{18} = \mathbf{0,064 \text{ trilhões} = 64.000,00 \text{ bilhões}}$ (1^{12})

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<http://www.rlmm.org/ojs/index.php/rlmm/article/view/148>.

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