



IIT ROORKEE



NPTEL ONLINE
CERTIFICATION COURSE

Failure Analysis and Prevention

General Procedure of Failure Analysis: Determination of type of fracture

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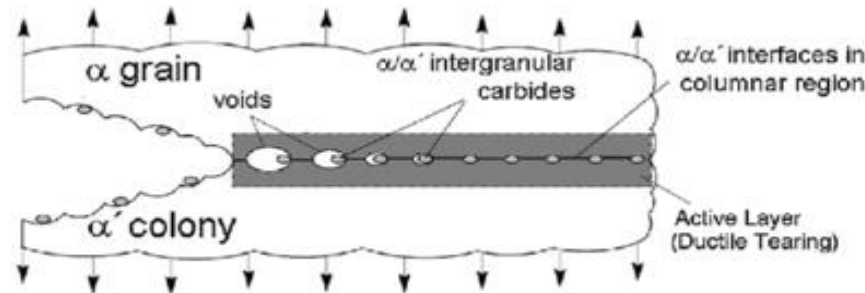
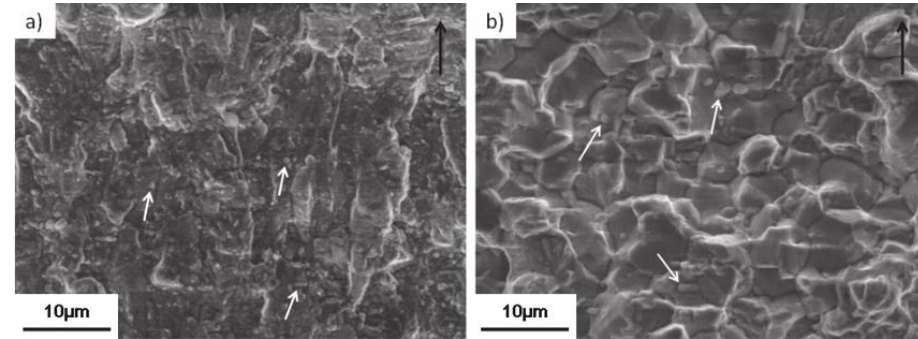
Type of fracture

- Based on micro-mechanisms of the fracture not macro-level changes
- Crack propagation for fracture
 - Trans-granular:
 - Intergranular



Crack propagation

- Based on crack propagation
 - Trans-granular: cleavage
 - Inter-granular: Poor phases at GB, precipitation of specific species at GB, Creep, SCC, HIC

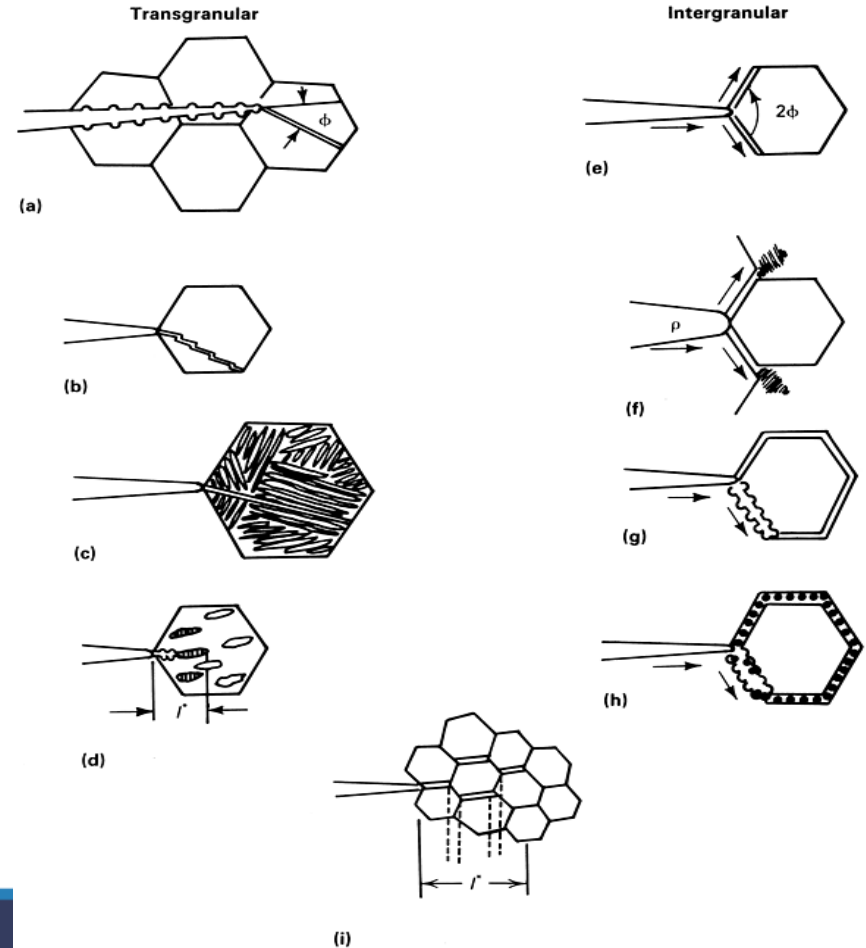


Micro-mechanisms

- Ductile fracture: dimple fracture: high energy and fracture tough system
- Brittle fracture: cleavage facets, & inter-granular : low energy and brittle systems

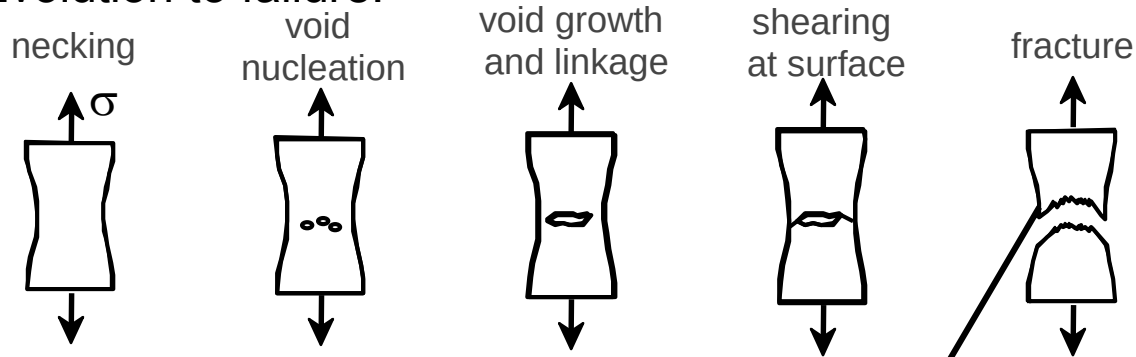


Micro-mechanism



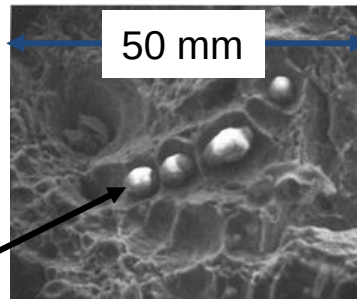
Moderately Ductile Failure

- Evolution to failure:

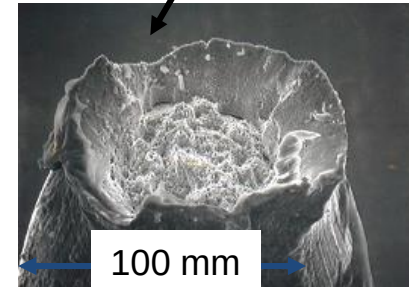


- Resulting fracture surfaces (steel)

Inclusion particles serve as void nucleation sites.



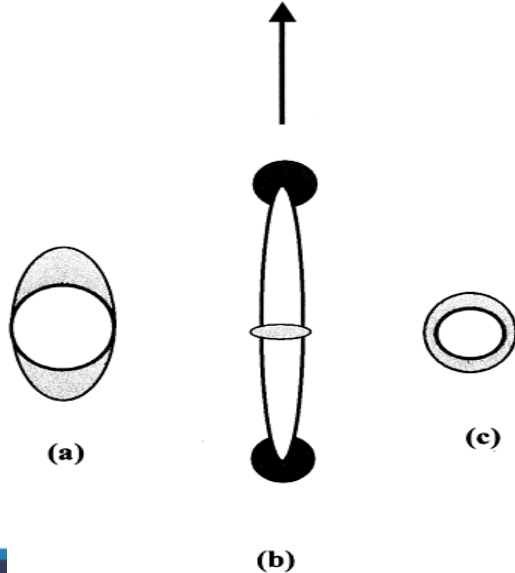
From V.J. Colangelo and F.A. Heiser, *Analysis of Metallurgical Failures* (2nd ed.), Fig. 11.28, p. 294, John Wiley and Sons, Inc., 1987. (Orig. source: P. Thornton, *J. Mater. Sci.*, Vol. 6, 1971, pp. 347-56.)



Fracture surface of tire cord wire loaded in tension. Courtesy of F. Roehrig, CC Technologies, Dublin, OH. Used with permission.

Three ways of void Formation

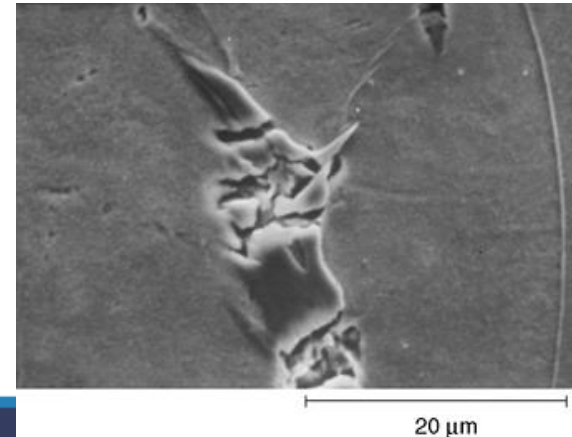
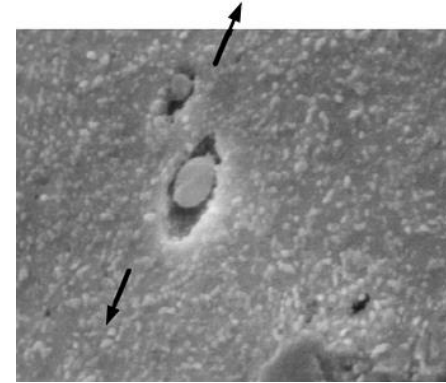
- Inclusion
- Needle fracture
- Triaxial stress state



- Hole formation around an often weakly bonded particle
- Cracking of a particle
- Growth from a pre-cracked particle
- Cracking in a matrix of limited ductility in which faceted particles cause stress concentration in the matrix (faceted nitride inclusions in a high-strength, low-alloy, or HSLA, steel)

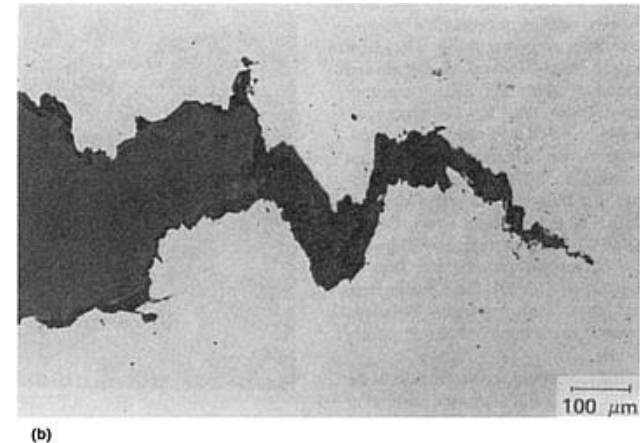
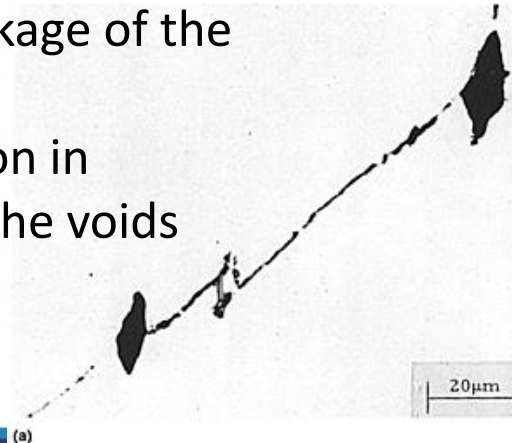
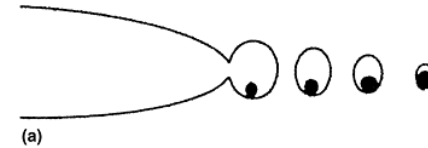
Debonding at MnS inclusion and Fe₃C

- In steels, these inclusions fall into three general groups:
- Stringer types that are sulfides and additional phases
- Spheroidal types (oxides and sulfides)
- Faceted types (nitrides)



Void growth and coalescence

- The incipient cracks (voids) associated with the particles may grow by two mechanisms, depending on particle size and spacing:
 - Growth of an incipient crack by enlargement and linkage of the voids
 - Slip band deformation in ligaments between the voids



Ductile tearing

- For large particles relatively closely spaced, and especially in the presence of constraint, void coalescence typically occurs on the plane of maximum normal stress.
- This mechanism of void coalescence is referred to as pure ductile tearing

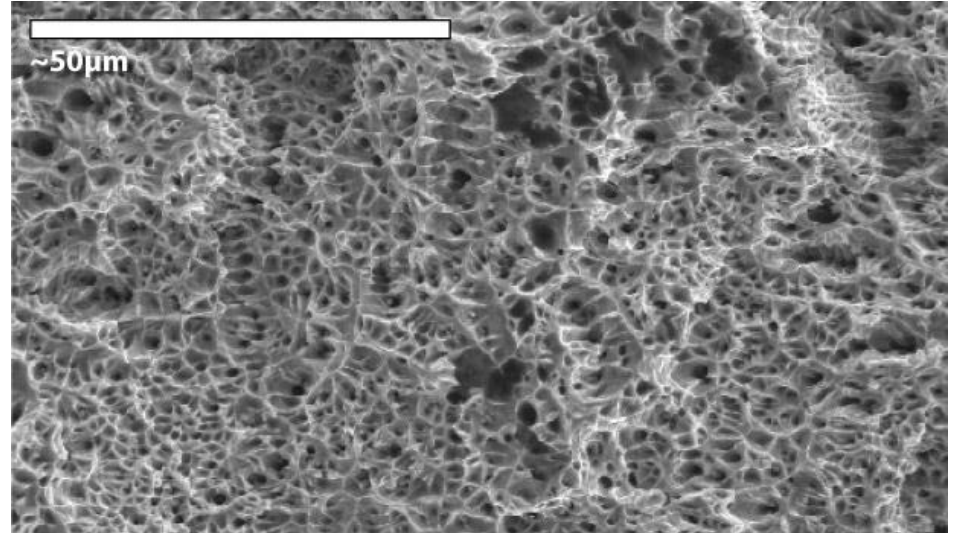
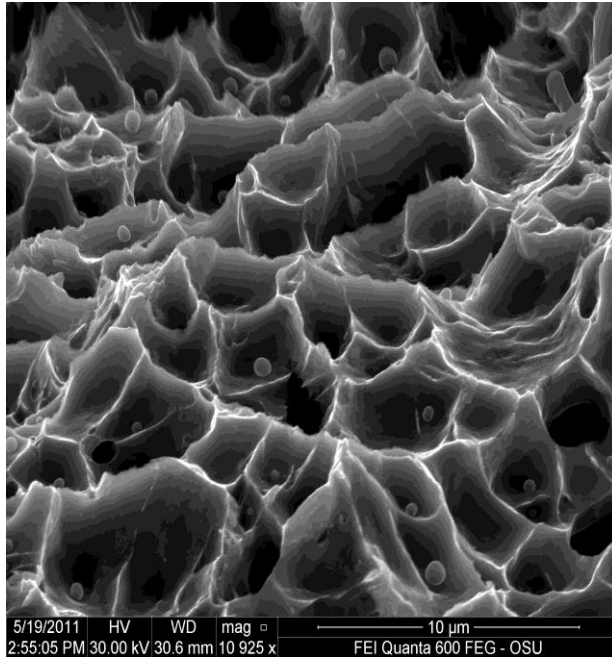


Cracking in ductile fracture

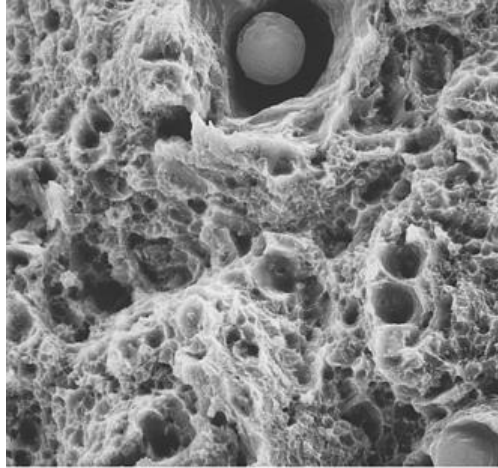
- Microscale ductile crack propagation are recognized, depending on whether growth of incipient cracks occurs on a plane of maximum normal stress or on a plane of high shear stress:
 - Pure ductile tearing by void coalescence, usually on the plane of maximum normal stress
 - Zig-zag slip deformation on planes of high shear stress between voids



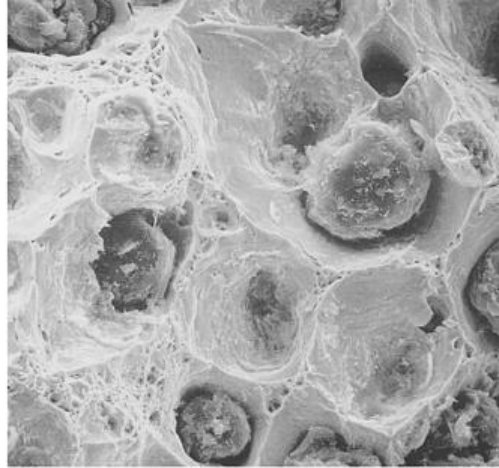
Dimple: Ductile overload fracture



Overload fracture

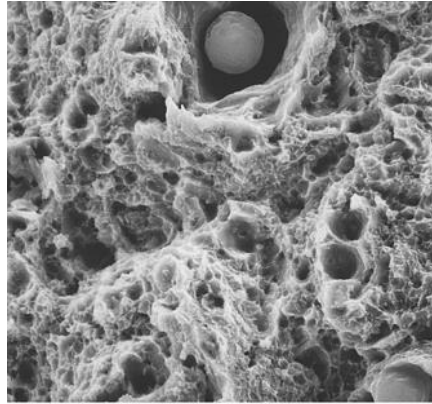


(a)

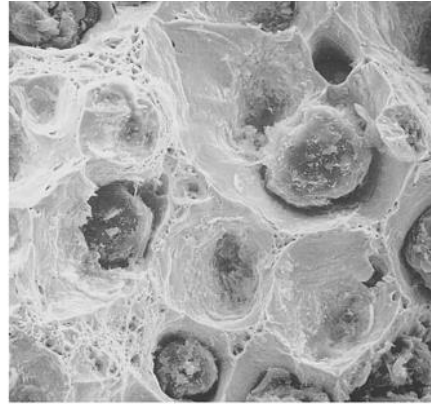


(b)

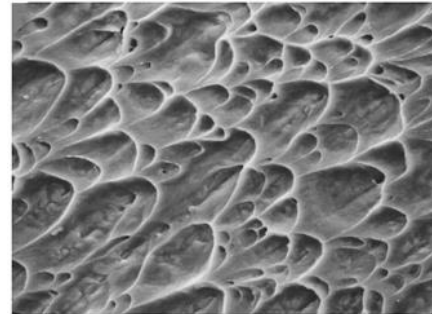
Overload fracture



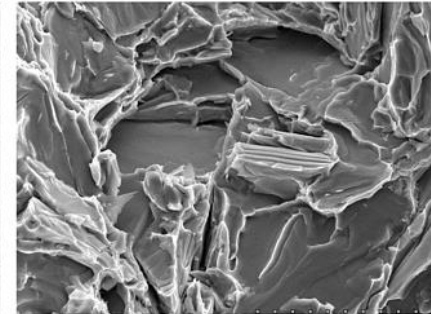
(a)



(b)

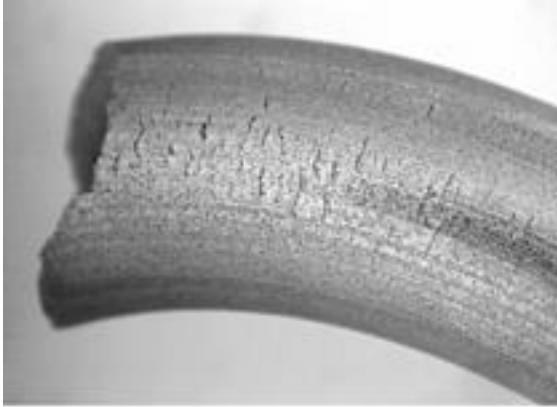


(c)

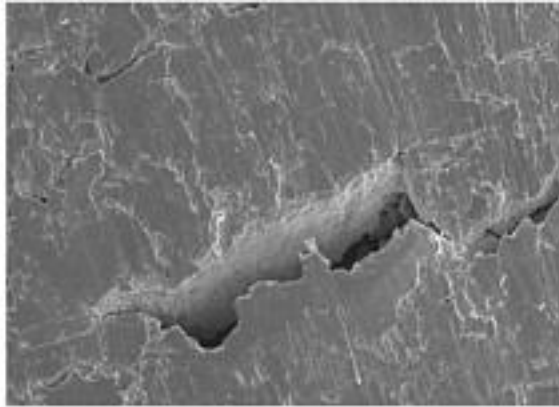


(d)

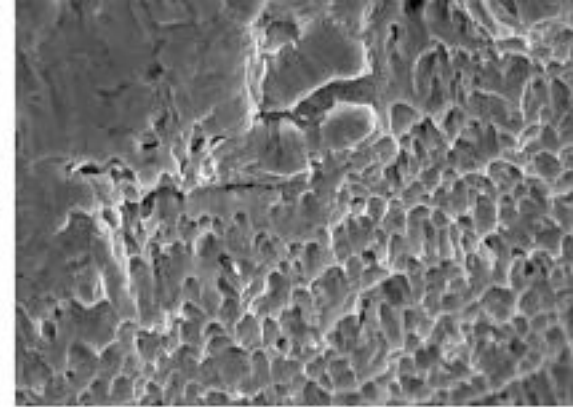
Bend cracks



(a)

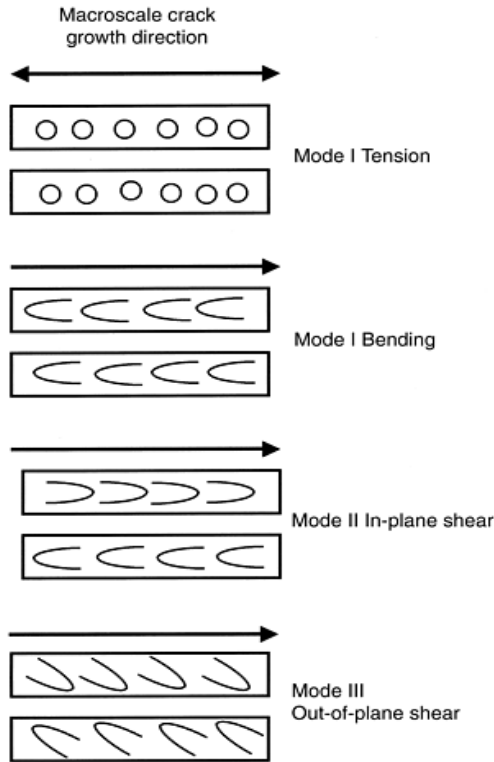


(b)



(c)

Dimple morphology and loading

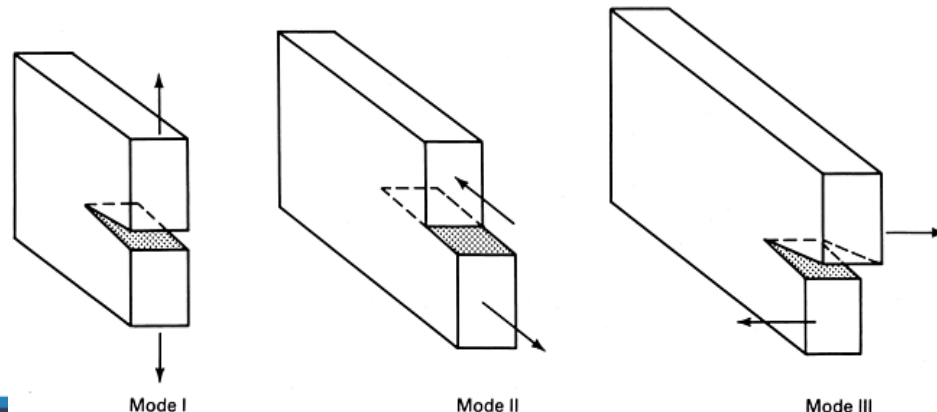


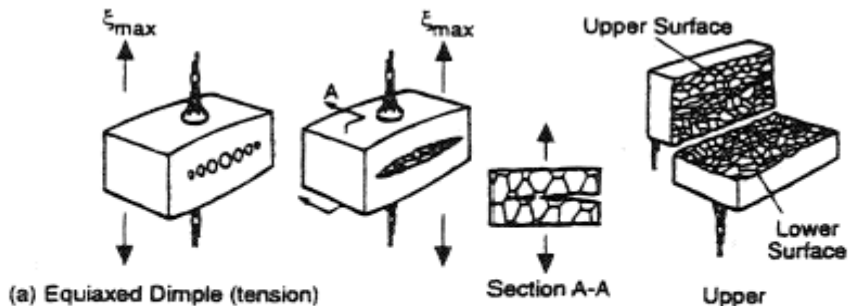
Dimples are equiaxed for axial loading (mode I, opening mode)

Dimples are elongated in shear loading (mode II or mode III)

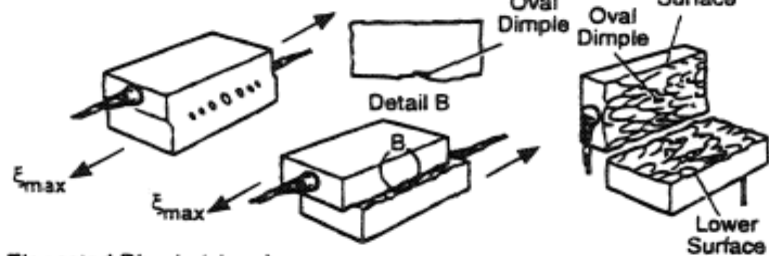
Dimples are elongated and point in the same direction on both sides of the fracture surface from bending loading

Dimples are either elongated or equiaxed in combined axial and bending

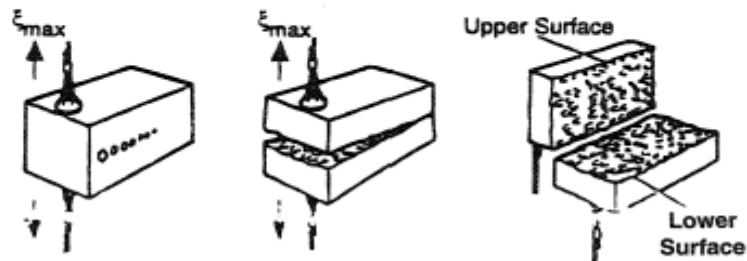




(a) Equiaxed Dimple (tension)

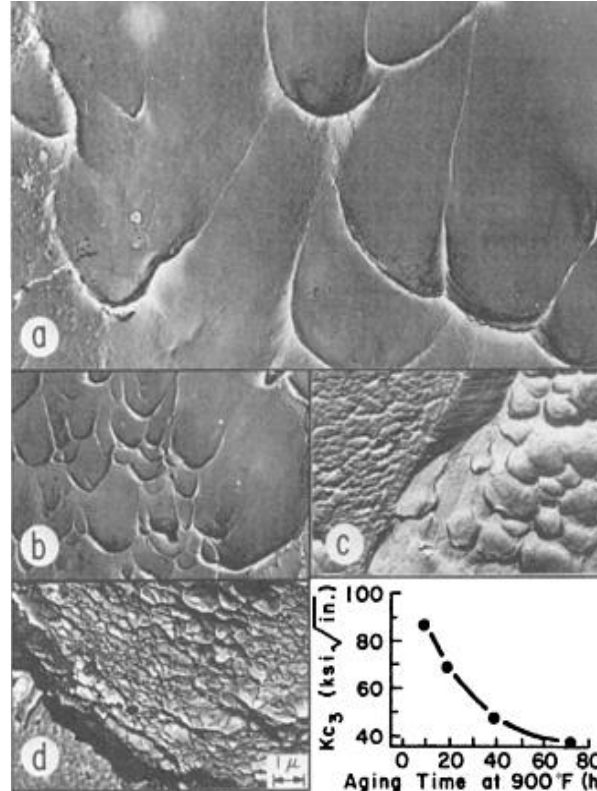


(b) Elongated Dimple (shear)



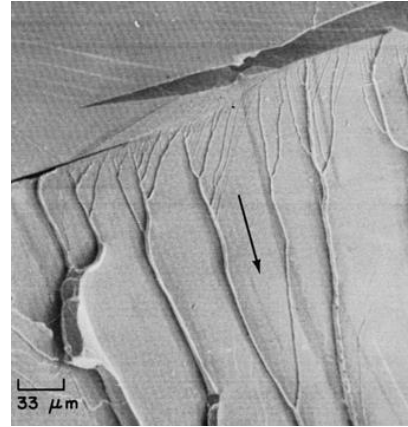
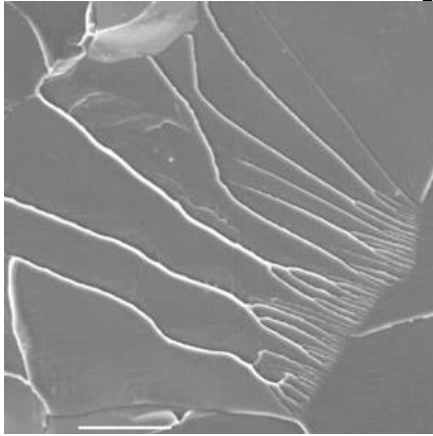
(c) Elongated Dimple (tension tearing)

Spacing of dimples and ppt time

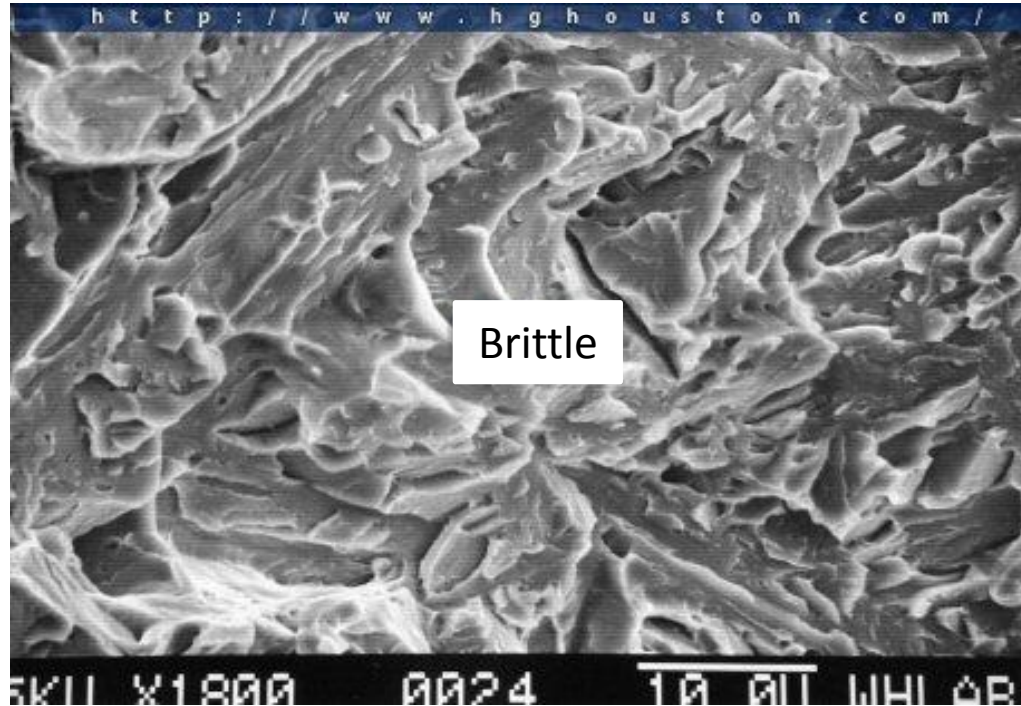


(a) Solution annealed; (b) aged 10 h; (c) aged 20 h; (d) aged 72 h

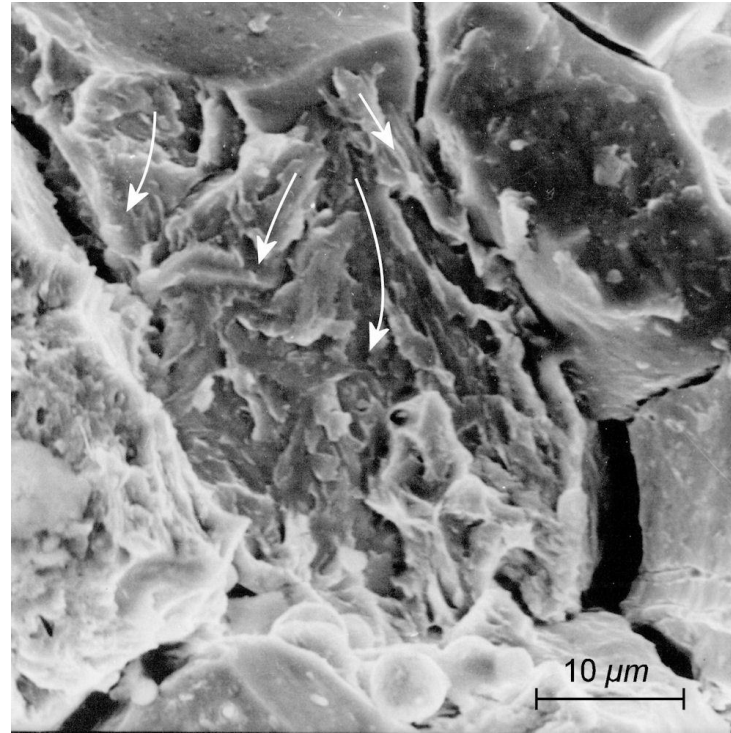
River pattern or fan pattern



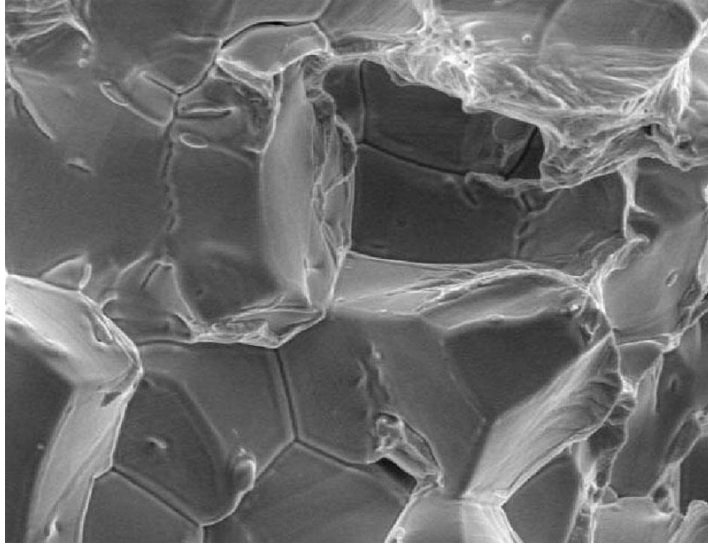
Faceted: brittle cleavage fracture



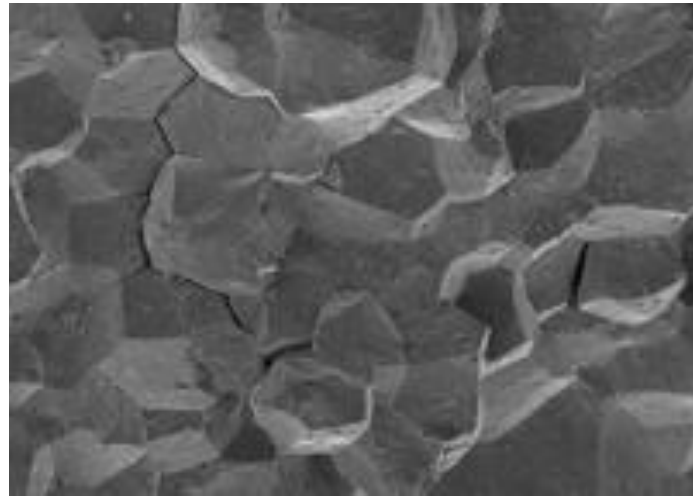
Faceted: SCC fracture (rare)



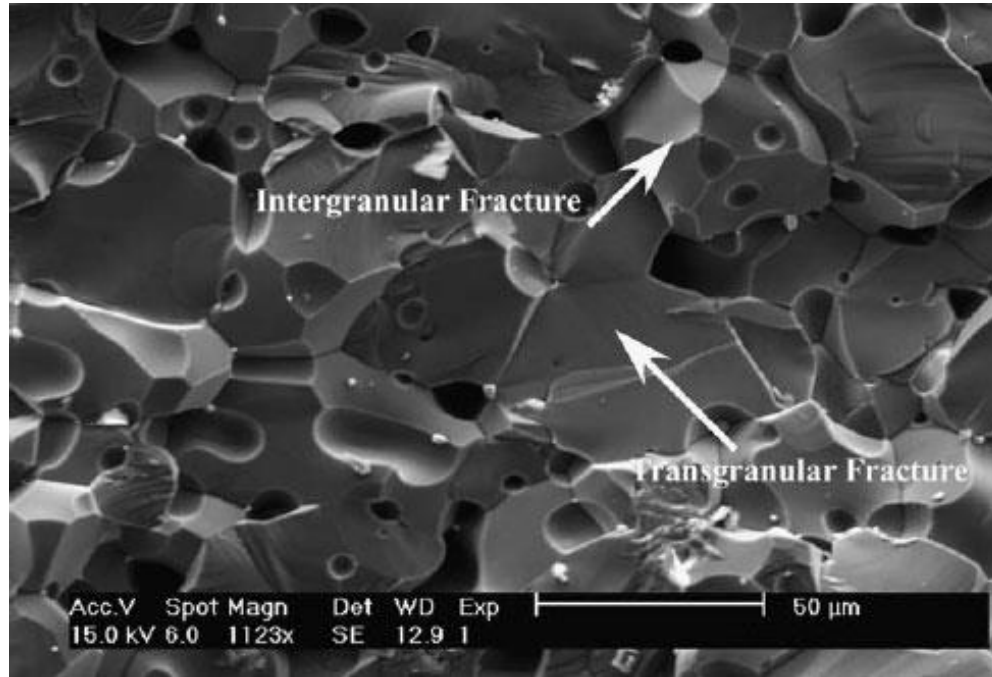
IG fracture with smooth GB



- Improper thermal processing
- Environment assisted fracture
- High temperature or corrosion

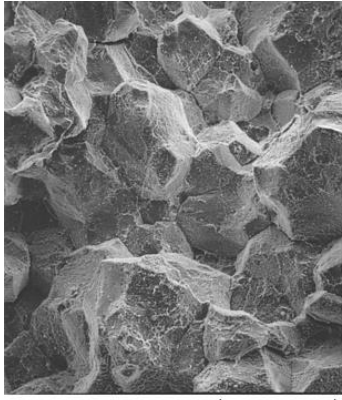


Mixed fracture with dimpled GB

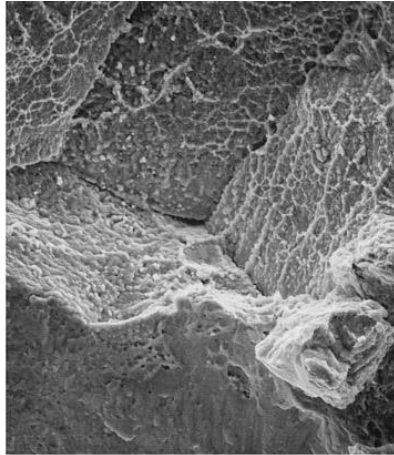


high temperature
poor materials
processing

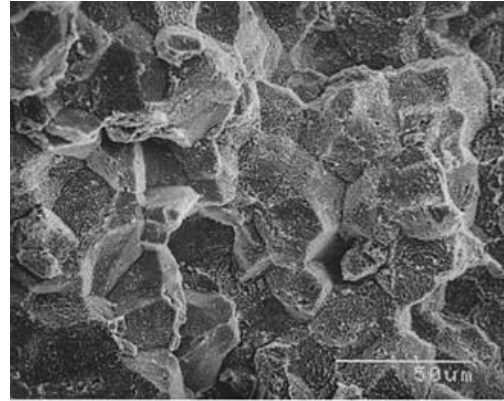
IG brittle and dimple



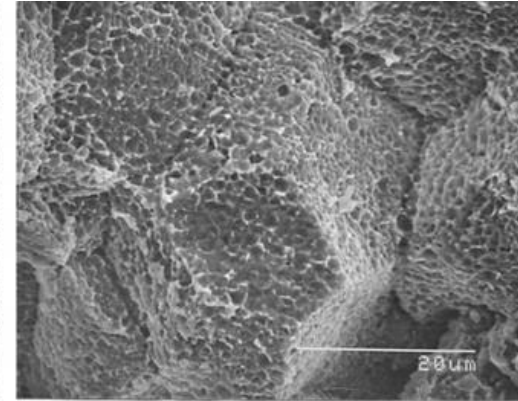
(a)



(b)

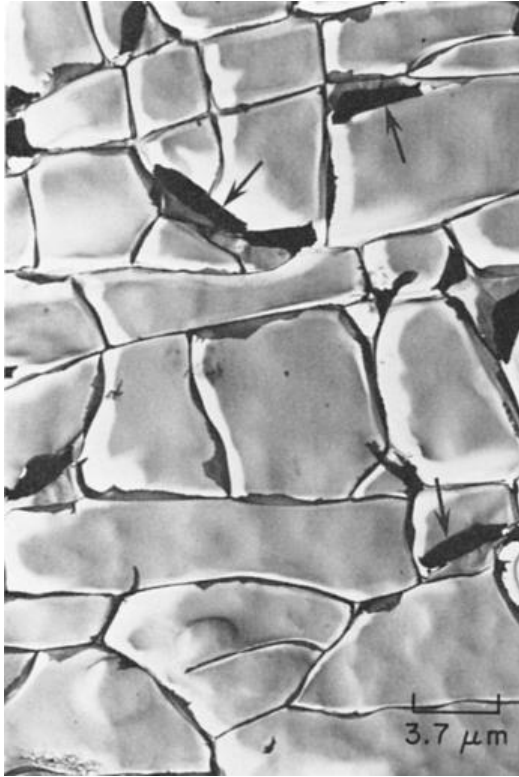


(a)



(b)

Mud cracks



- Liquid corrosion may be present
- IG fracture
- SCC

SCC

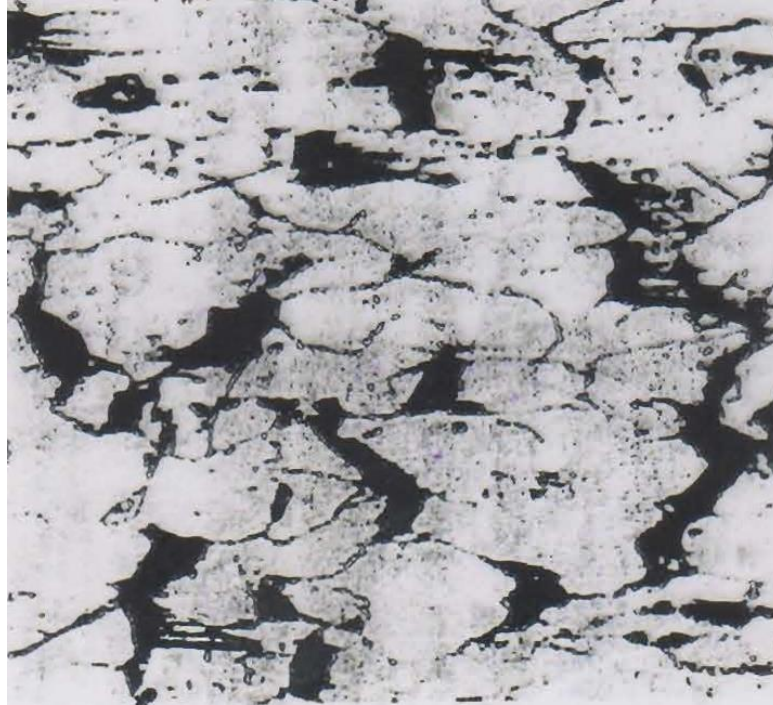


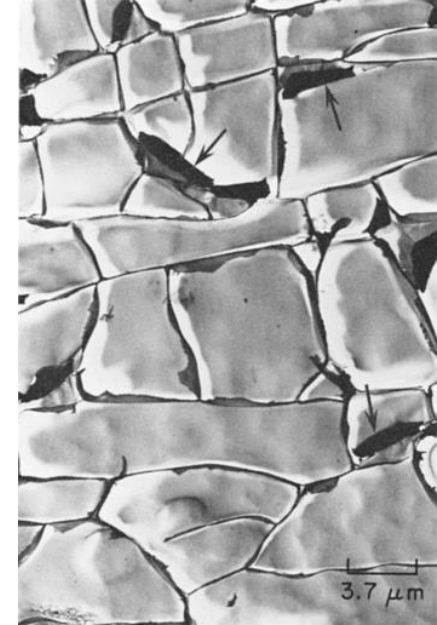
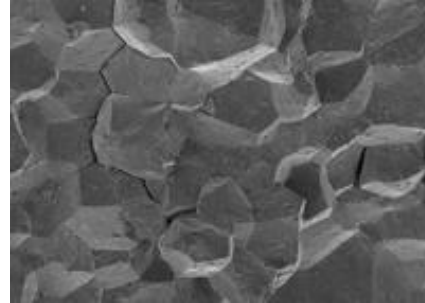
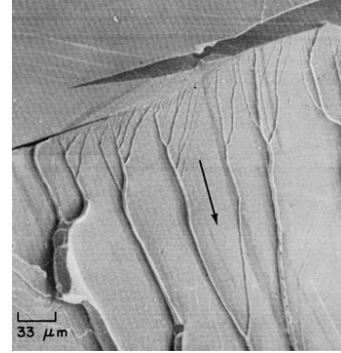
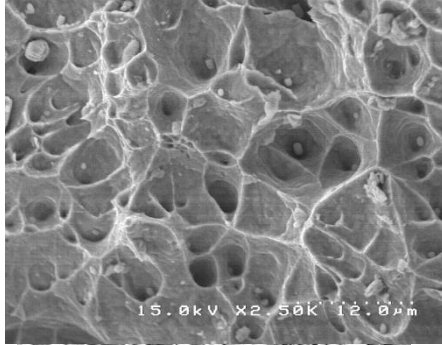
HIC



Creep cracking

- IG





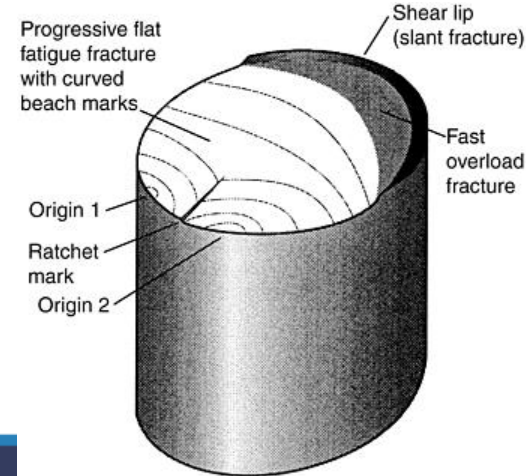
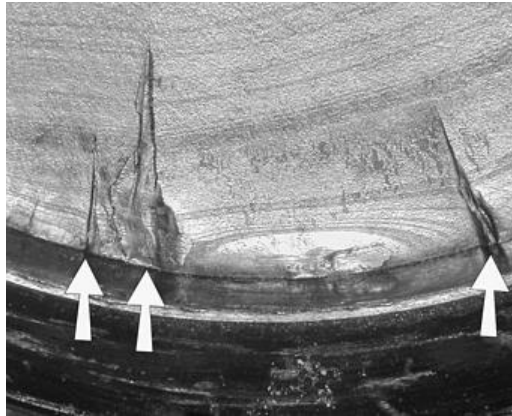
Causes of IGF

- Presence of grain-boundary precipitates
 - Thermal treatment or high temperature exposure leading **segregation** of certain impurities to the grain boundaries without an observable second phase
 - Stresses applied at elevated (**creep**-regime) temperatures
 - Environmentally assisted **weakening** of the grain boundaries
 - Additionally, grain size plays a role in causing a change in fracture mechanism



Fatigue Initiation

- Accumulation of local irreversible plastic deformation
- Creation of microscopic flaws
- Growth and coalescence of flaws to form one or more macroscopic cracks



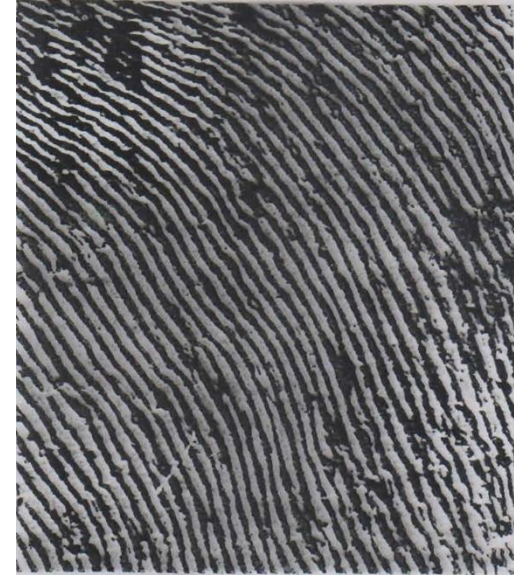
Striated ridges fracture: fatigue : constant / variable amplitude as per spacing



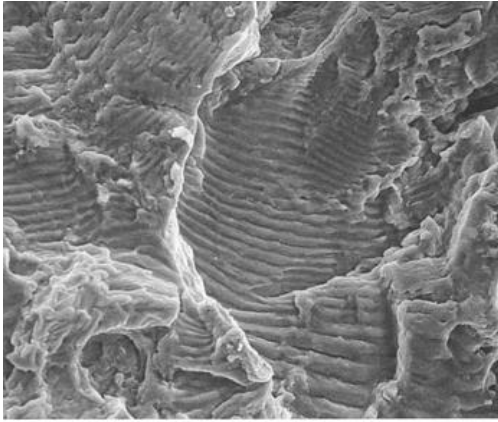
(a)



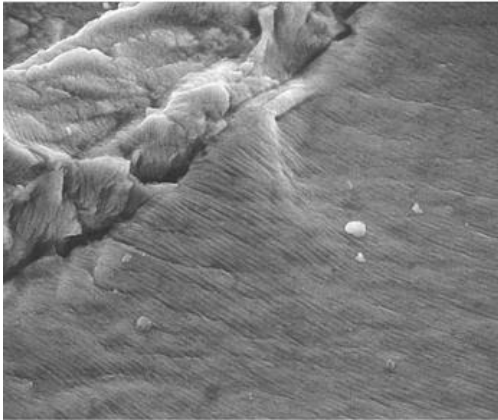
(b)



Coarse and fine

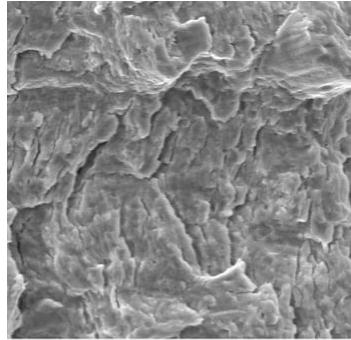


(a)

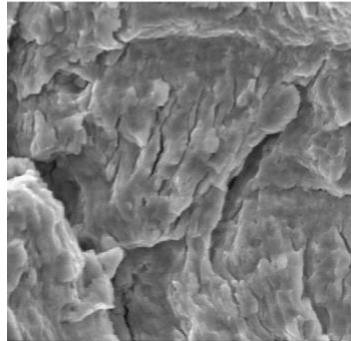


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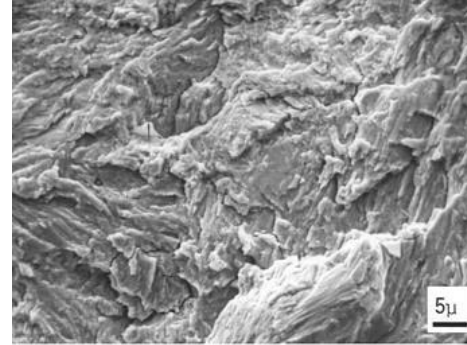
Poorly defined/ no striation



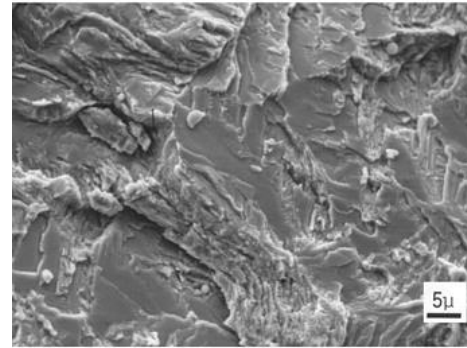
(a)



(b)



(a)



(b)