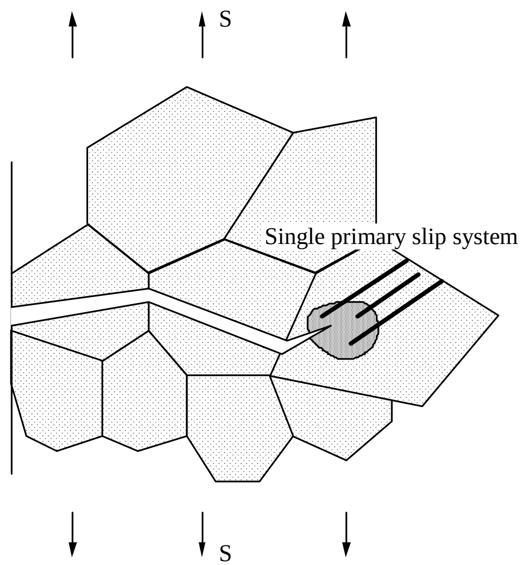
Fatigue Overview



F. V. Lawrence

Fatigue Overview

- History of Fatigue
- Fatigue Overview
- The Process of Fatigue

Fatigue-prone Machine

Welded Ship - 2 sink each day

Service Enviromnent?

Determining Service Stresses

In Better Days

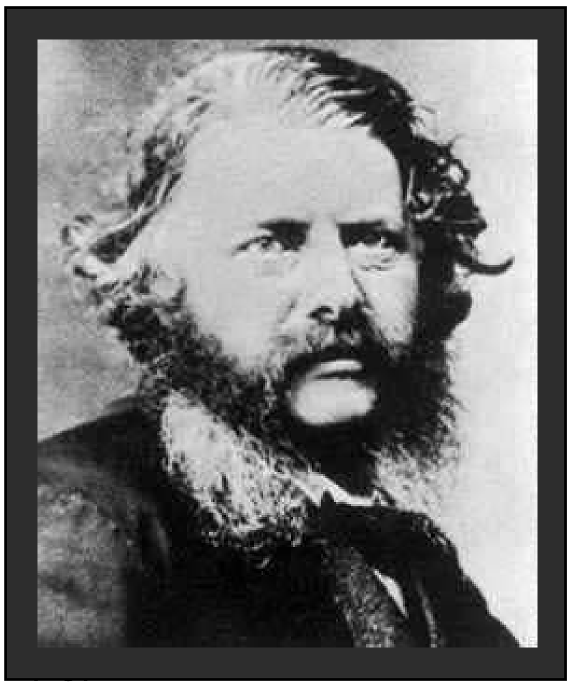
When is the next short course?

Early History

1829	**Albert**	**Effects of repeated loads**
1839	**Poncelet**	**“Fatigue”**
1843	**Rankine**	**Effect of stress concentrations**
1860	**Wöhler**	**Systematic investigations**
1886	**Bauschinger**	**Reversed deformation effects**
1903	**Ewing & Humfrey**	**Nucleation of “fatigue” cracks**
1910	**Basquin**	**Endurance limit**

1844 - Rankine

Stress Concentrations- Railroad Axles, the Versailles Accident



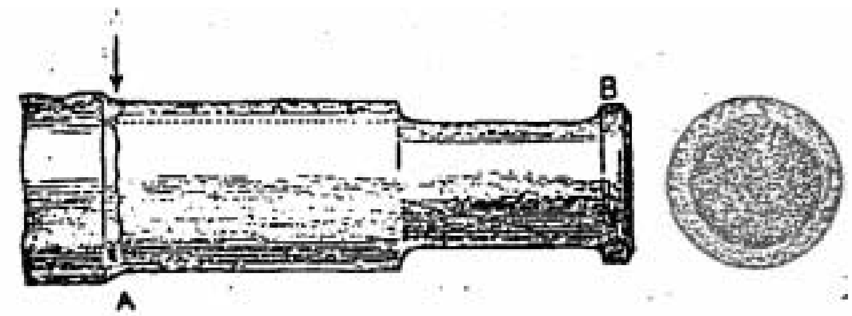
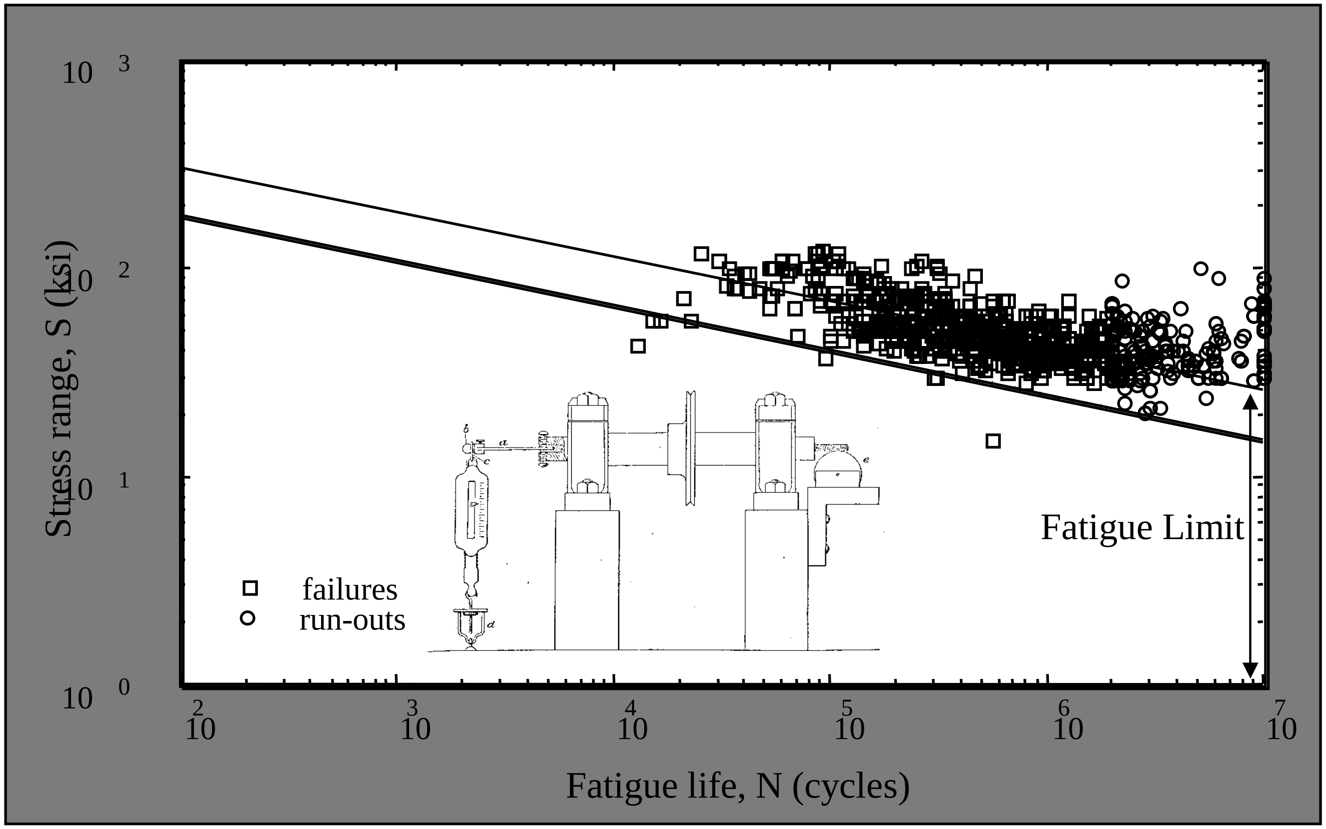


Fig 1. Classic appearance of a fatigue cracked railway axle from Glynn, 1844.

William John Macquorn Rankine
Born: 2 July 1820 in Edinburgh, Scotland
Died: 24 Dec 1872 in Glasgow, Scotland

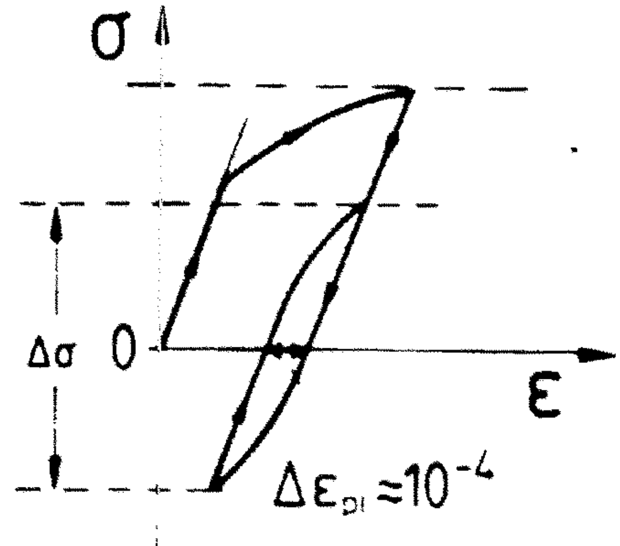
1860 - Wöhler



Stress-Life (SN) Diagrams

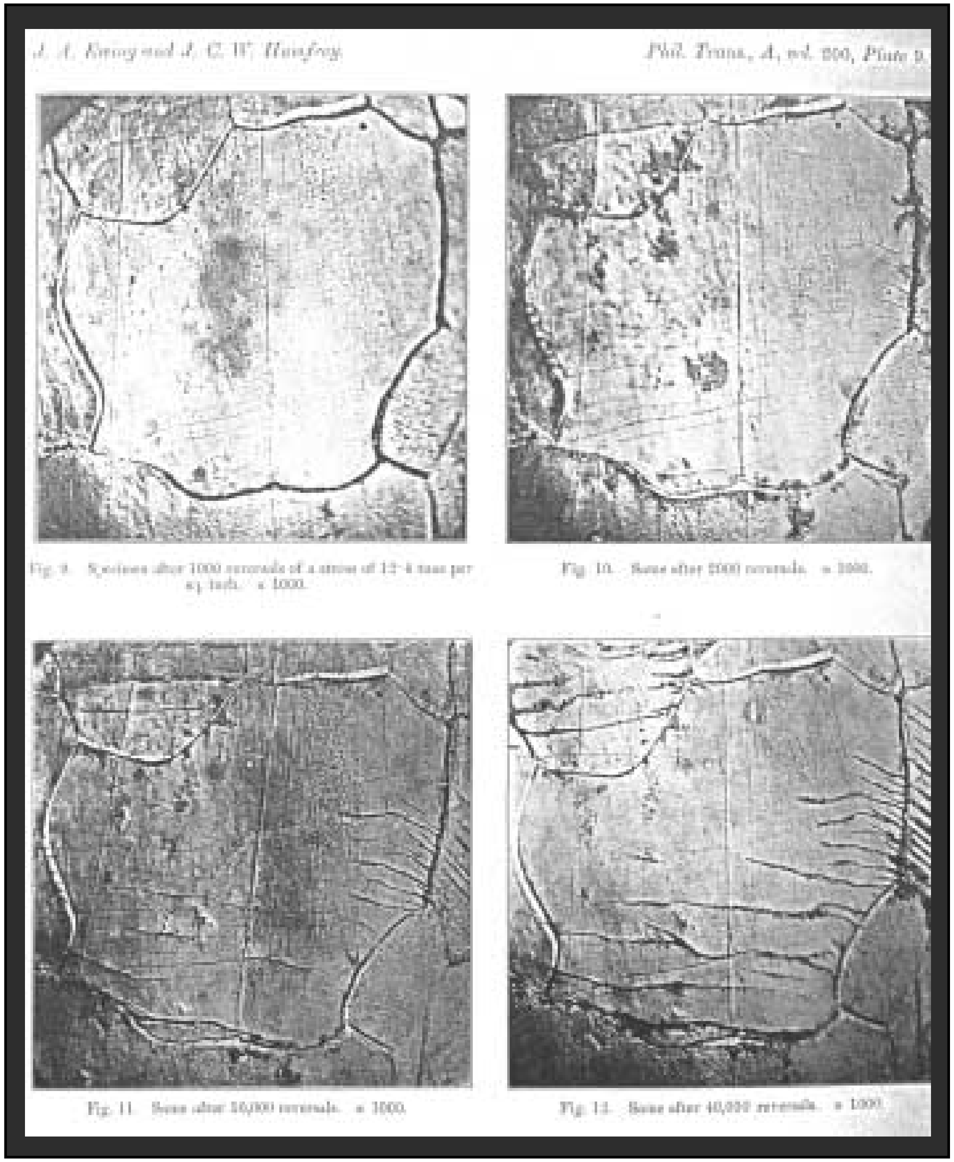
1886 - Bauschinger

Fig. 1: Portrait of Johann Bauschinger, born on June 11, 1834, and died on November 25, 1893.



Cyclic behavior of materials
Bauschinger effect

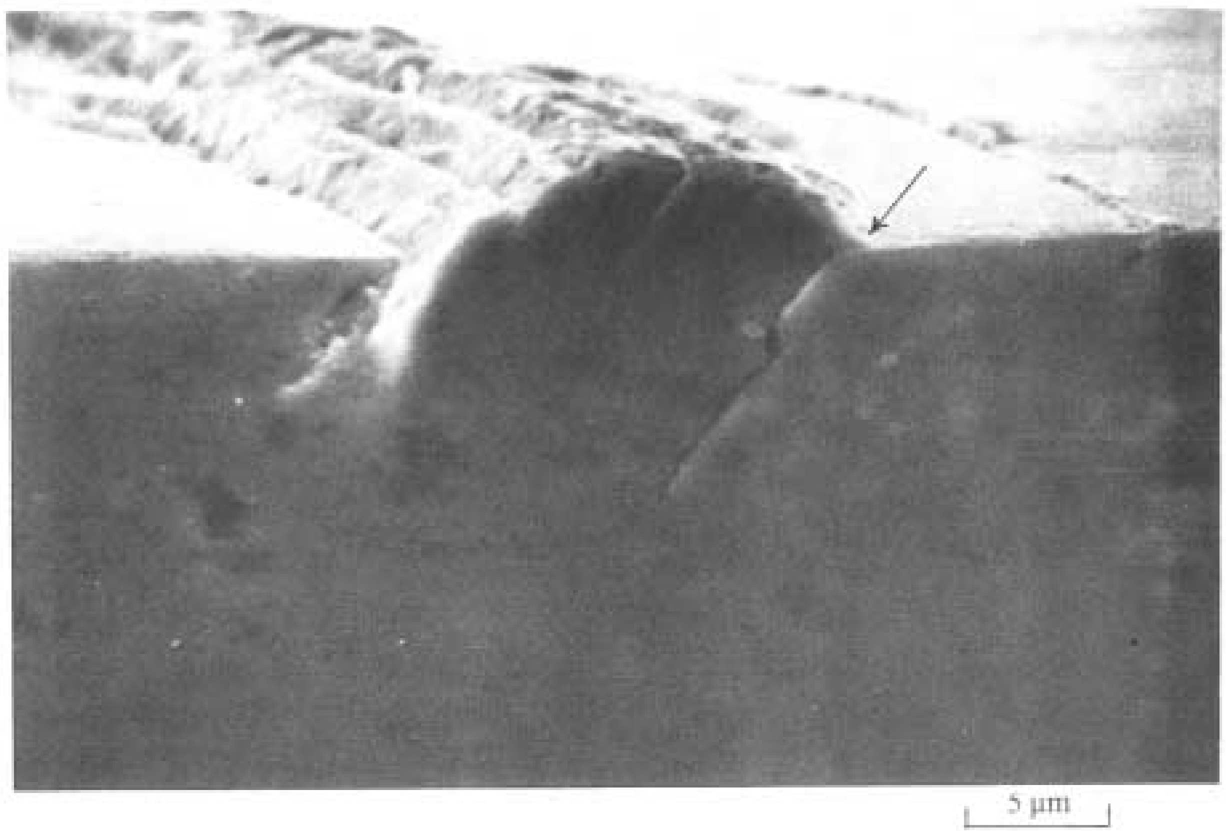
1903 - Ewings and Humphries



Cyclic deformation leads to the development (initiation) of fatigue cracks….

Mosaic structure

Origins of Fatigue Cracks



Surface roughening through cyclic plastic strains leads to the development of fatigue cracks

Recent Developments

1945	**Miner**	**Accumulation of fatigue “damage”**
1954	**Coffin & Manson**	**Plastic strains cause fatigue**
1961	**Paris**	**Growth of fatigue cracks correlated with ^{2}K**
1970	**Elber**	**Crack closure**
1975	**Pearson**	**Behavior of small cracks**

1954 - Coffin and Manson

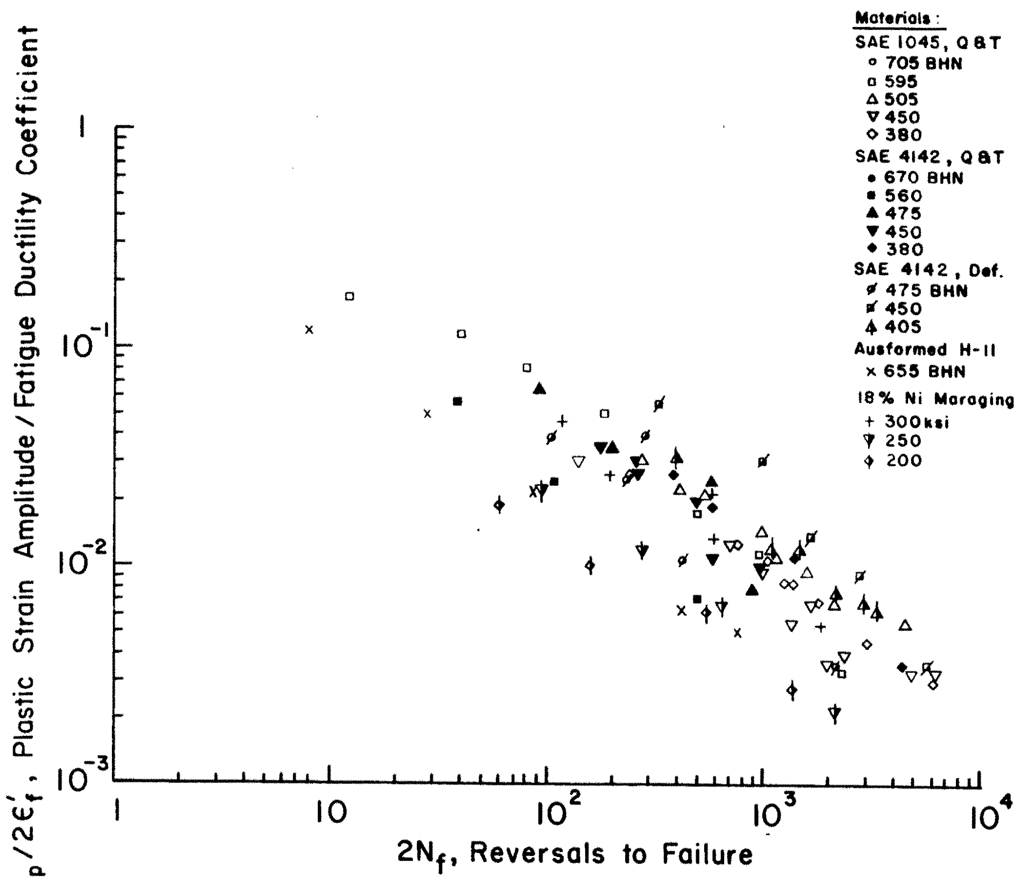
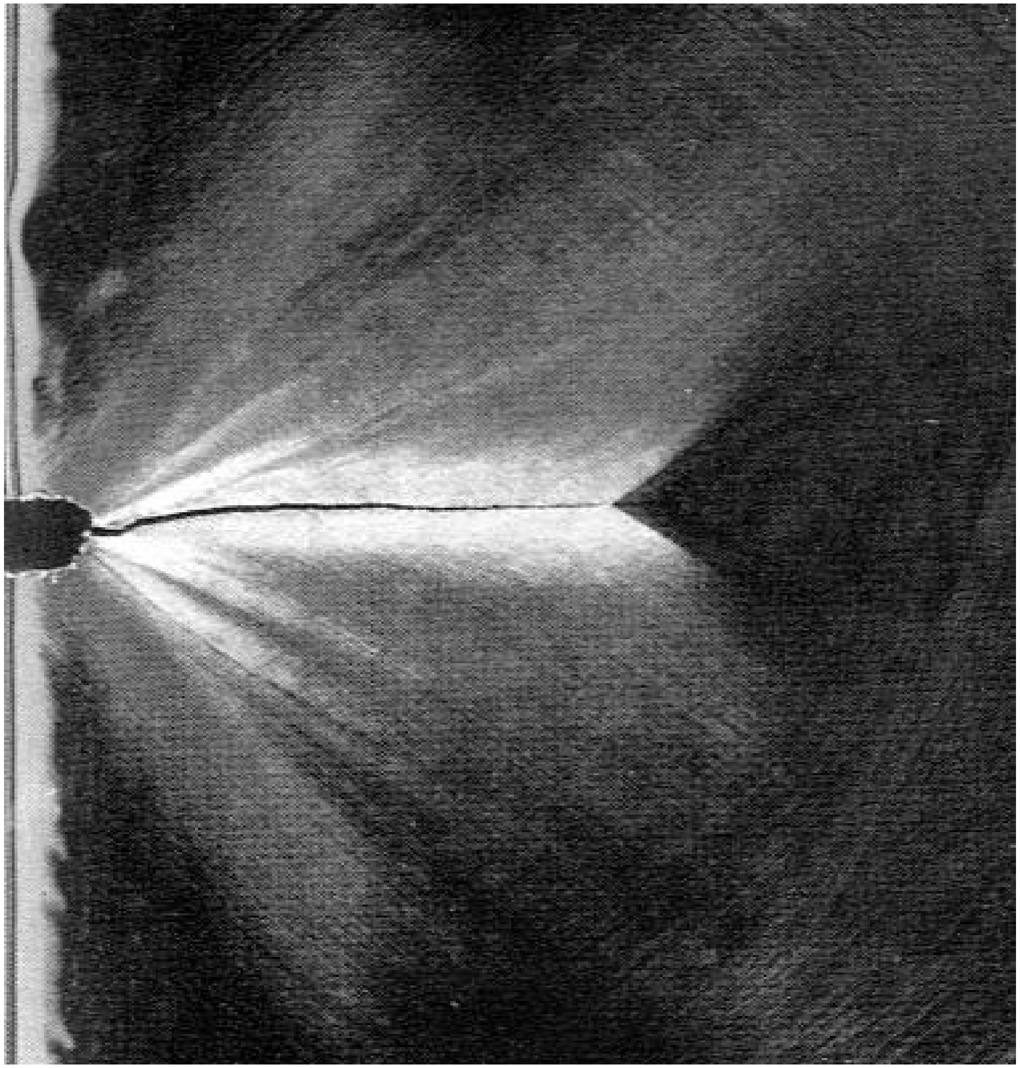


Fig. 27b Dimensionless Plastic Strain Amplitude – Fatigue Life Plot for Hardened Steels

Plastic strains cause the accumulation of "fatigue damage."

1961 - Paris

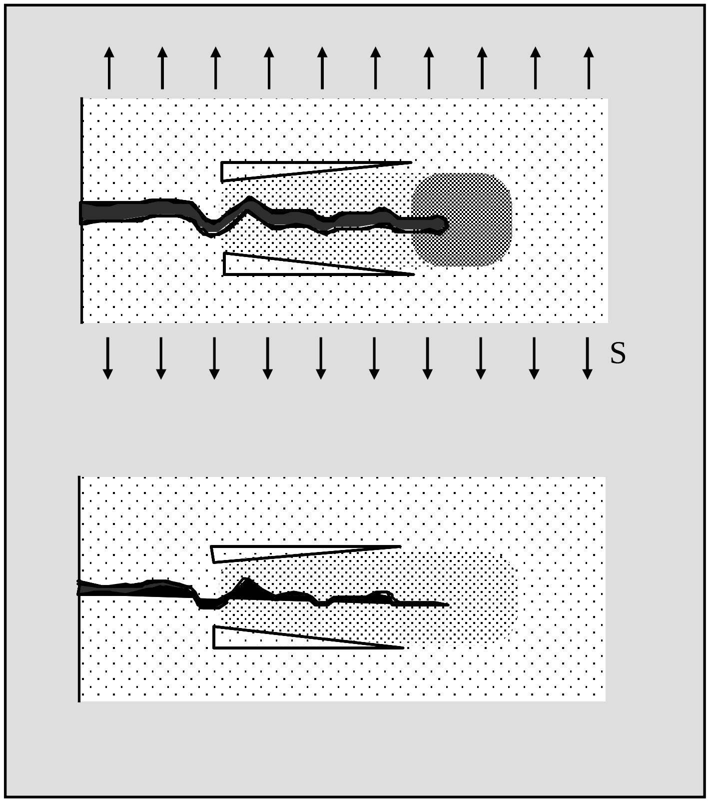


Growth of fatigue cracks related to the range in stress

intensity factor.

$$da/dN = C(\Delta K)^n$$

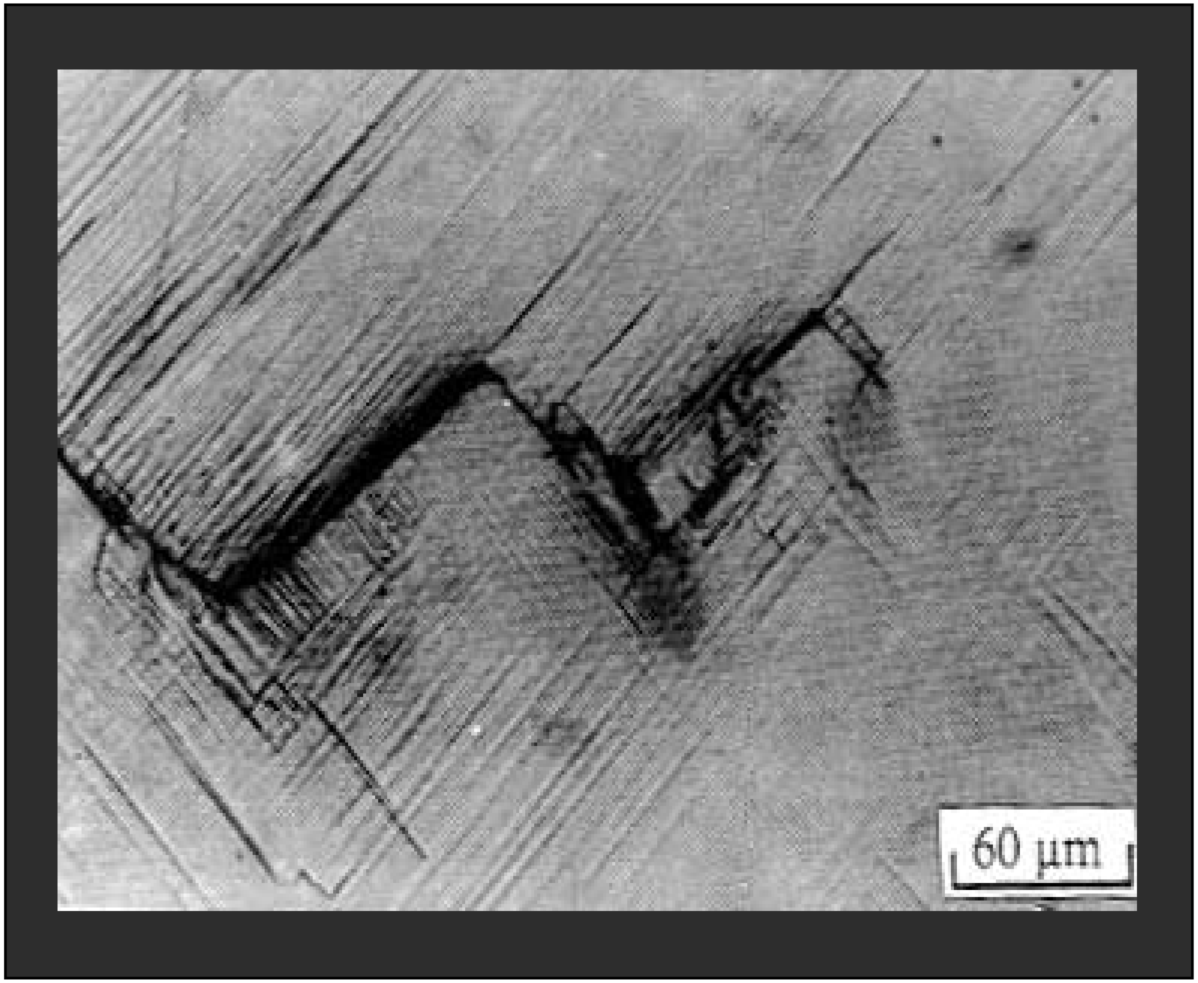
1970 - Elber



Critical importance of crack closure and the phenomena which cause it.

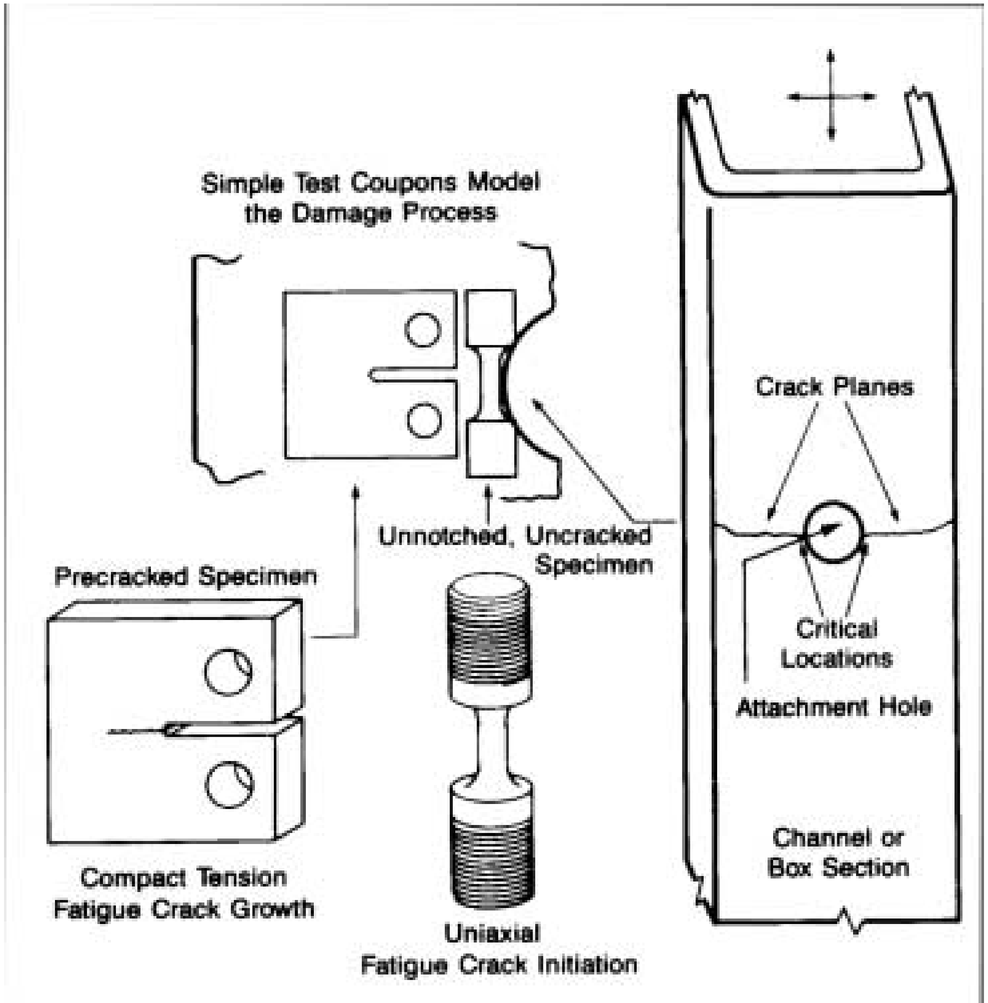
Crack open
Crack closed

1975 - Pearson



Surprising behavior of small fatigue cracks

1980's - UIUC



Development of the local strain approach.

Fatigue caused by notch-root stresses and strains.

Fatigue life consists of both crack nucleation and growth.

Fatigue Mechanisms

- History of Fatigue
- Fatigue Overview
- The Process of Fatigue

Surface Effects in Fatigue

Surface finish	**Reducing surface roughness reduces the notch root stresses. Smoother is better!**
Designed-in notches	**Designed-in notches are a major source of fatigue problems; notches are sites of stress and strain concentration.**
Fabrication defects	**Fabrication defects particularly crack-like (planar) as opposed to rounded (volumetric) defects are very damaging when oriented perpendicular to the applied stress.**
Absolute size	**Because most of fatigue life is spent in making a very small crack a little bigger, larger bodies have shorter fatigue lives because of the larger spatial extent of the high stresses in their notch-root stress fields.**
Aggressive environments	**Chemical attack can create pits at which fatigue cracks start. Corrosion can greatly reduce the portion of fatigue life devoted to fatigue crack initiation and + growth and thus greatly reduce the fatigue strength at long lives.**

Material Property Effects

Tensile, yield strength	**Higher strength materials resist plastic deformation and hence have a higher fatigue strength at long lives. Most ductile materials perform better at very short fatigue lives.**
Temperature	**Temperature has little influence except for the ductile-to-brittle transition in BCC metals which phenomenon leads to a very much smaller final flaw size. At high temperatures, creep damage may be superposed on fatigue damage.**
Quality of Material	**Metallurgical defects such as inclusions, seams, internal tears, and segregated elements can initiate fatigue cracks.**
Rate of testing	**At high frequencies, the metal component may be self-heated by the imposed plastic deformation. At low frequencies, environmental effects may become more important.**

Stress Effects in Fatigue

Stress range	**The basic cause of plastic deformation and consequently the accumulation of fatigue damage.**
Mean and residual stress	**Tensile mean and residual stresses aid the formation and growth of fatigue cracks.**
Stress gradients	**Bending is a more favorable loading condition than axial loading because (surface initiating) fatigue cracks propagate into lower stress environments.**

It depends on who you are….

Example	Envir.	Life	Failure	Perspective
Welded bridge girder	NaCl, variable load histories	10^6	large crack	Large preexisting defects (?), life limited by fatigue crack growth.
Nuclear reactor pressure vessel	H_2O, high temps, constant amplitude load histories	10^5 to 10^8	small crack	Small preexisting defects, life limited by fatigue crack growth.
Automotive spot weld in sheet steel	Variable load histories	10^3 to 10^8	visible crack	Initiation of fatigue cracks important, only limited fatigue crack growth possible.
Engine crank shaft	Constant amplitude load histories	10^8	sudden, catastrophic failure	Initiation of fatigue cracks important.

Past Events, Future Behavior?

Design		Failure Analysis
An attempt to predict the future based on expectations: anticipated service loads, component design.		An attempt to explain the past based on evidence: metallography, fractography, computed loads, service records
Motive: save money but avoid premature fatigue failure.		Motive: assignment of blame, understand causes so future failure can be avoided.
Methods: fatigue testing, structural analysis, fatigue life prediction using empirical or analytical methods.		Methods: Fractography, materials tests, fracture mechanics.

Failure analysis

Analysis of past performance

Assignment of fault: Who's going to buy the new bridge?

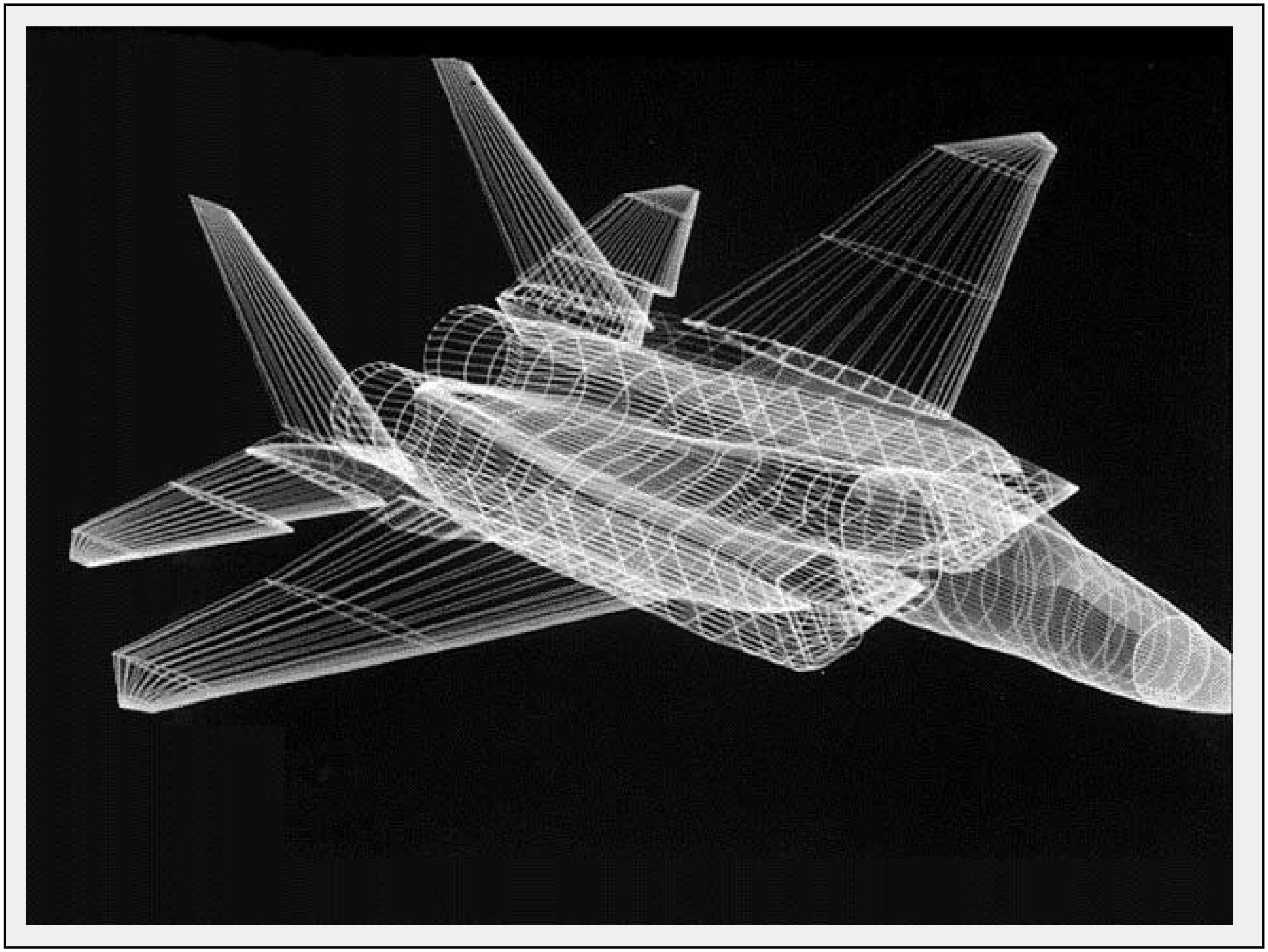
Silver point bridge failure

FCP

Failure analysis

Service life exhausted

Design



Avoidance of future problems

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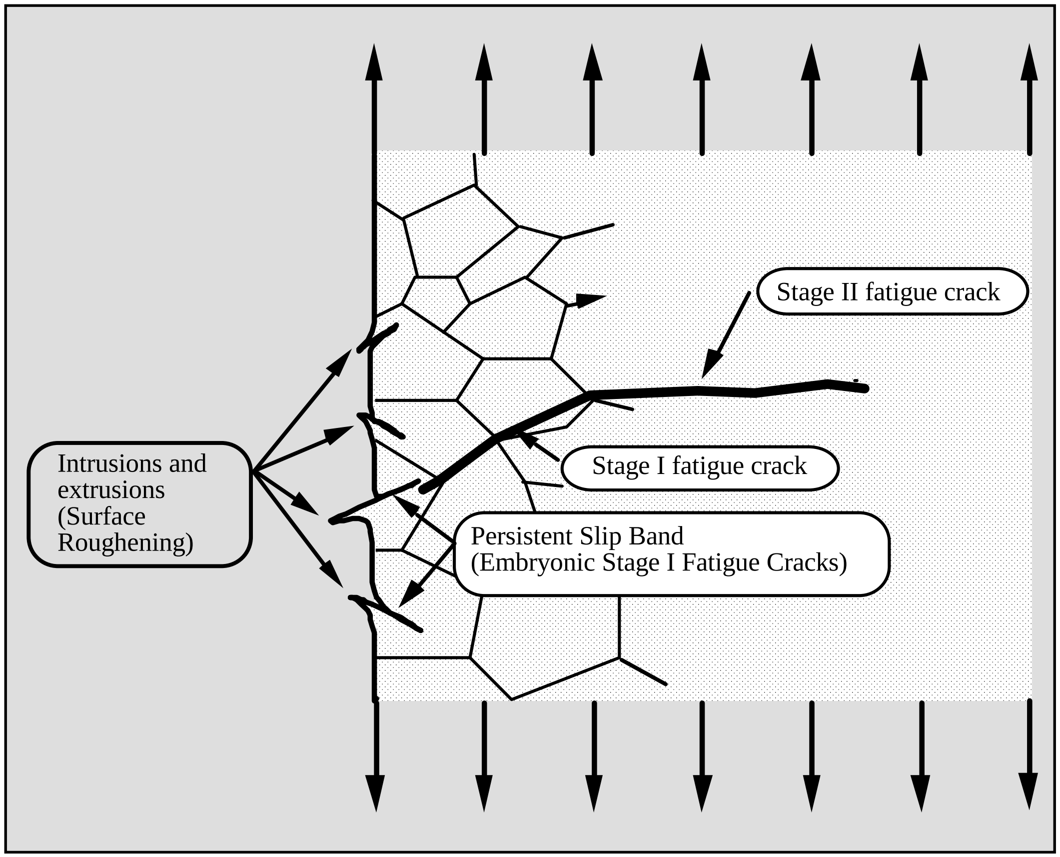
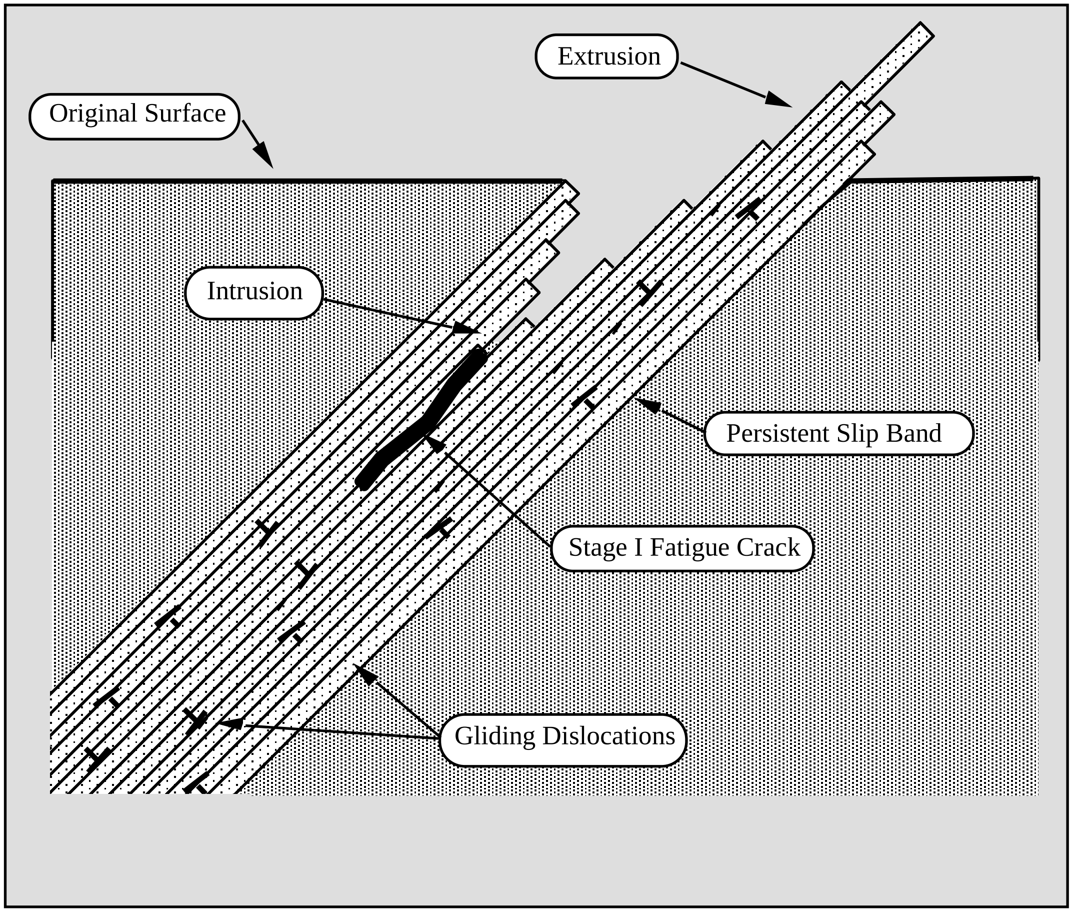
Process of fatigue



Cyclic slip
Crack initiation
Stage I crack growth
Stage II crack growth
Failure

Intrusions and extrusions

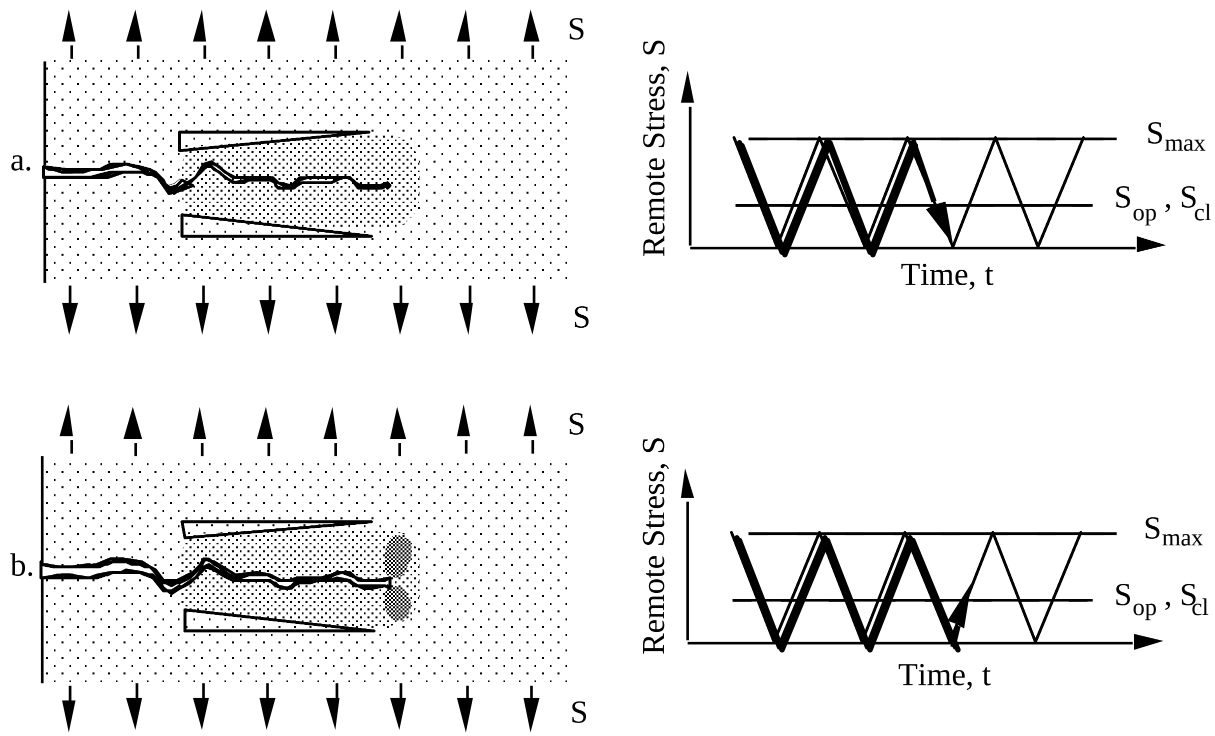


One mechanism for the development (initiation) of a fatigue crack

Intrusions and extrusions

Intrusions and extrusions on the surface of a Ni specimen

Fatigue crack growth



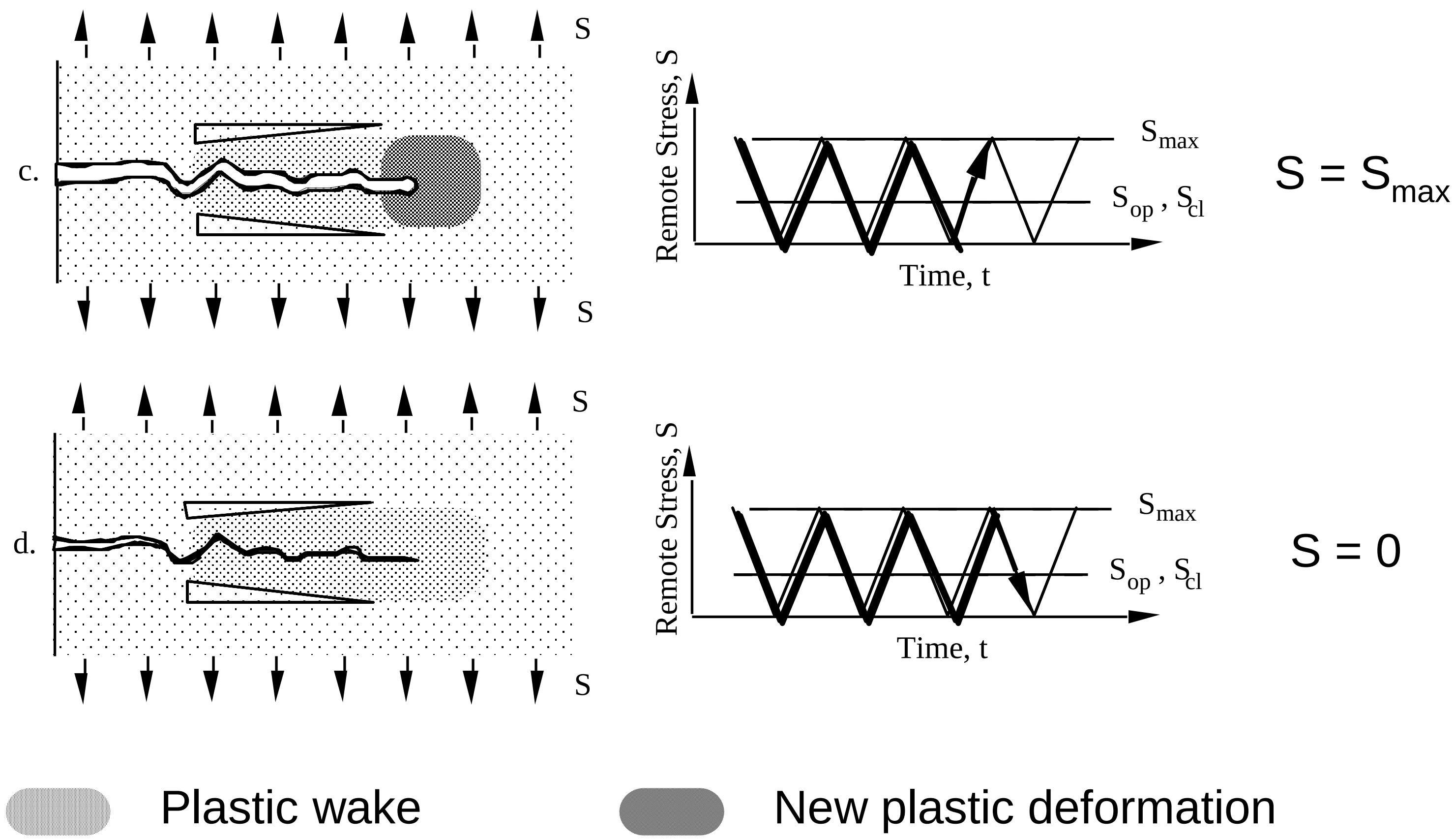
$S = 0$

$S = S_{op}$

Plastic wake

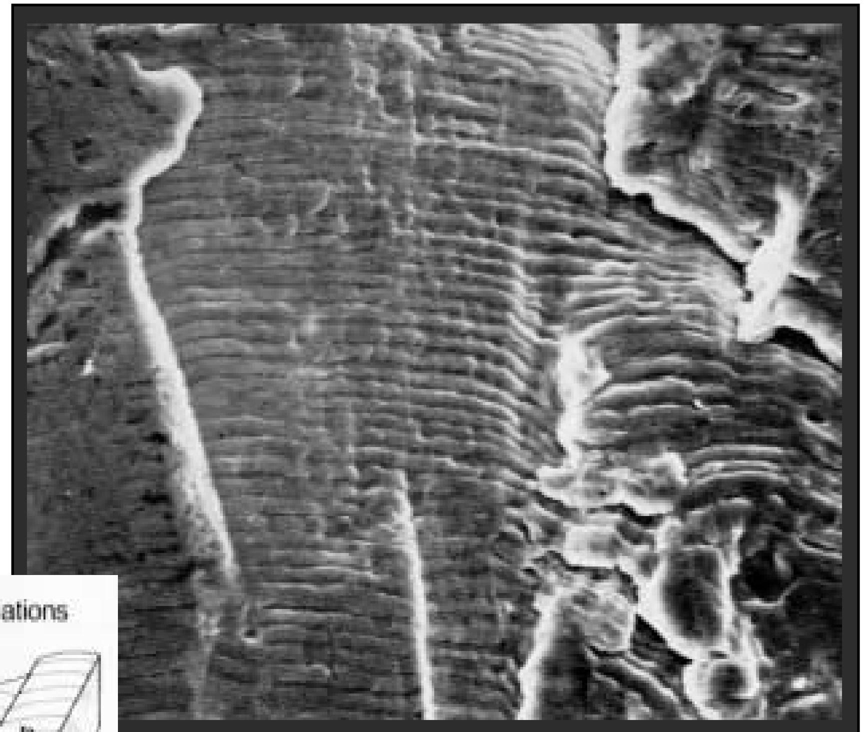
New plastic deformation

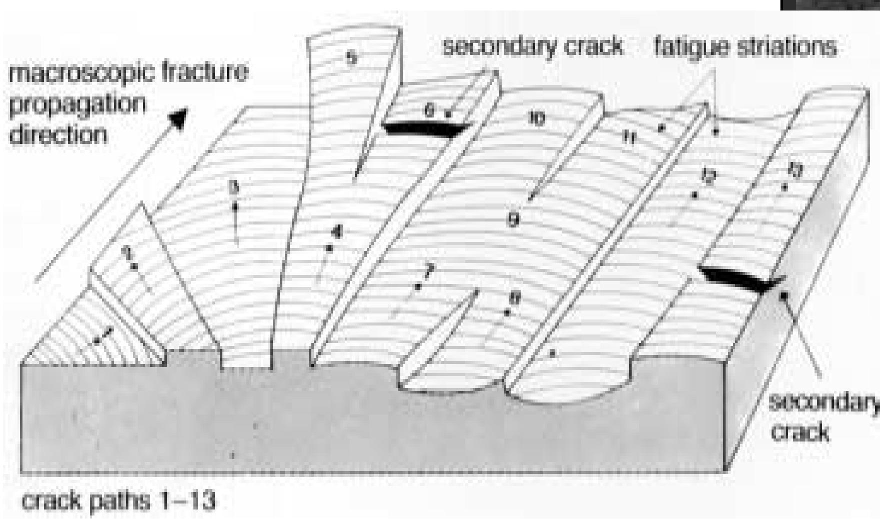
Fatigue crack growth



Fatigue fracture surface

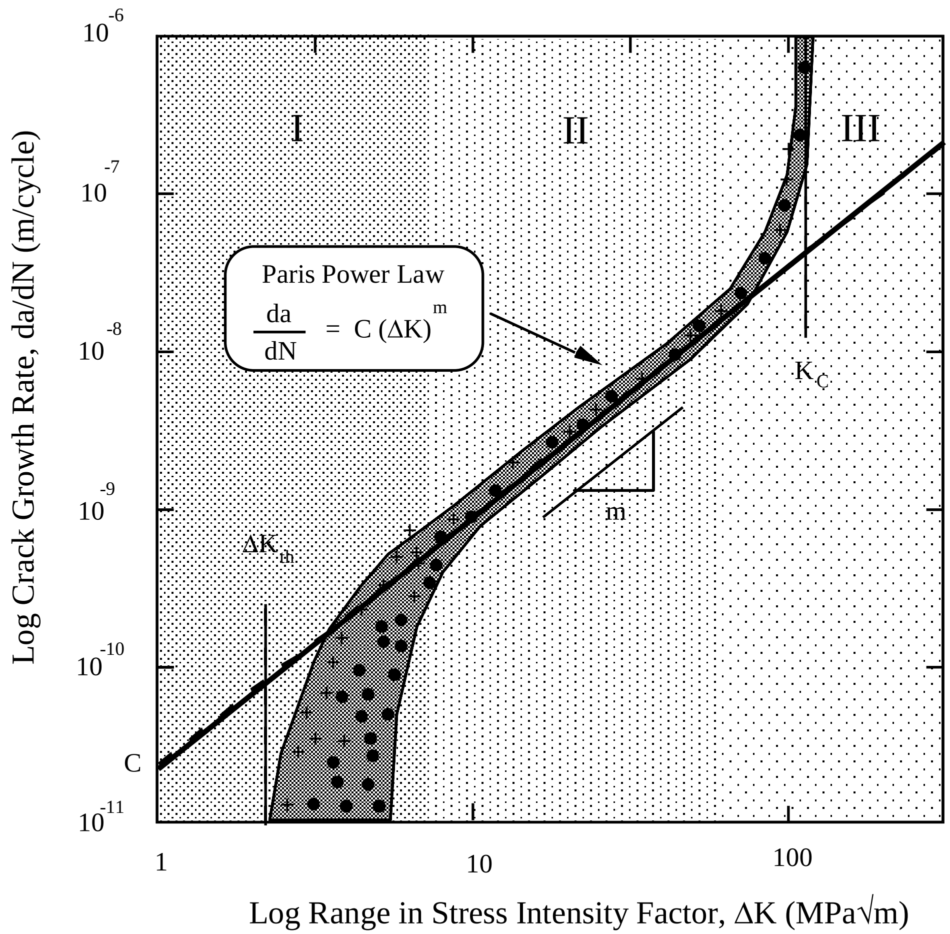
Scanning electron microscope image - striations clearly visible





Schematic drawing of a fatigue fracture surface

Paris Power Law



I Sensitive to microstructure and environment

II Paris power Law

III Approaching fracture when

Kmax ≈ KIC.