Fatigue and Fracture

Fatigue, How and Why

Physics of Fatigue

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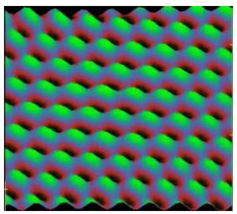
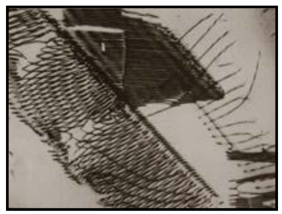
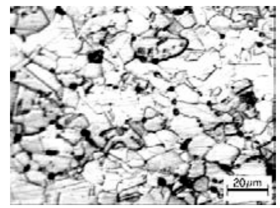
Fatigue, How and Why

- **Physics of Fatigue**
- Material Properties
- Similitude
- Fatigue Calculator

Size Scale for Studying Fatigue

Atoms	Dislocations	Crystals	Specimens	Structures
				

10^{-10} 10^{-8} 10^{-6} 10^{-4} 10^{-2} 10^{0} 10^{2}

Understand the physics on this scale (10^{-6} to 10^{-1})

Model the physics on this scale (10^{-2} to 10^{1})

Use the models on this scale (10^{0} to 10^{2})

The Fatigue Process

- Crack nucleation
- Small crack growth in an elastic-plastic stress field
- Macroscopic crack growth in a nominally elastic stress field
- Final fracture

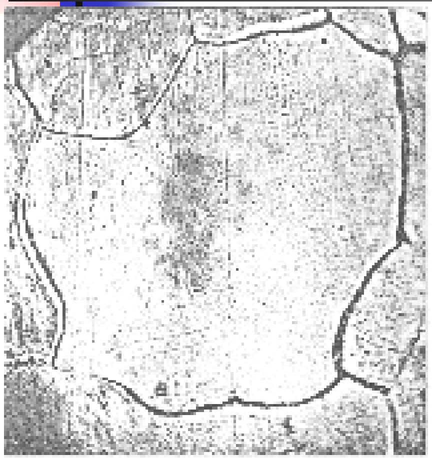
Mechanisms Crack Nucleation

Nucleation in Slip Bands inside Grain

Nucleation at Grain Boundaries

Nucleation at Inclusions

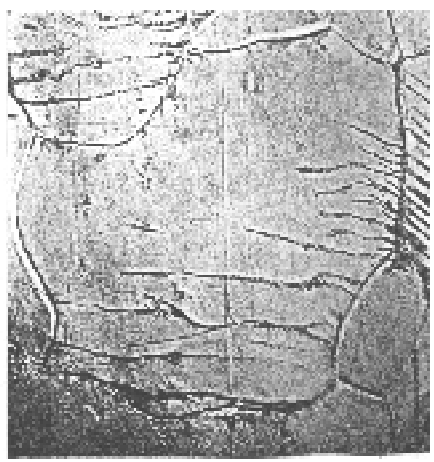
1903 - Ewing and Humfrey



N = 1,000

N = 2,000

N = 10,000

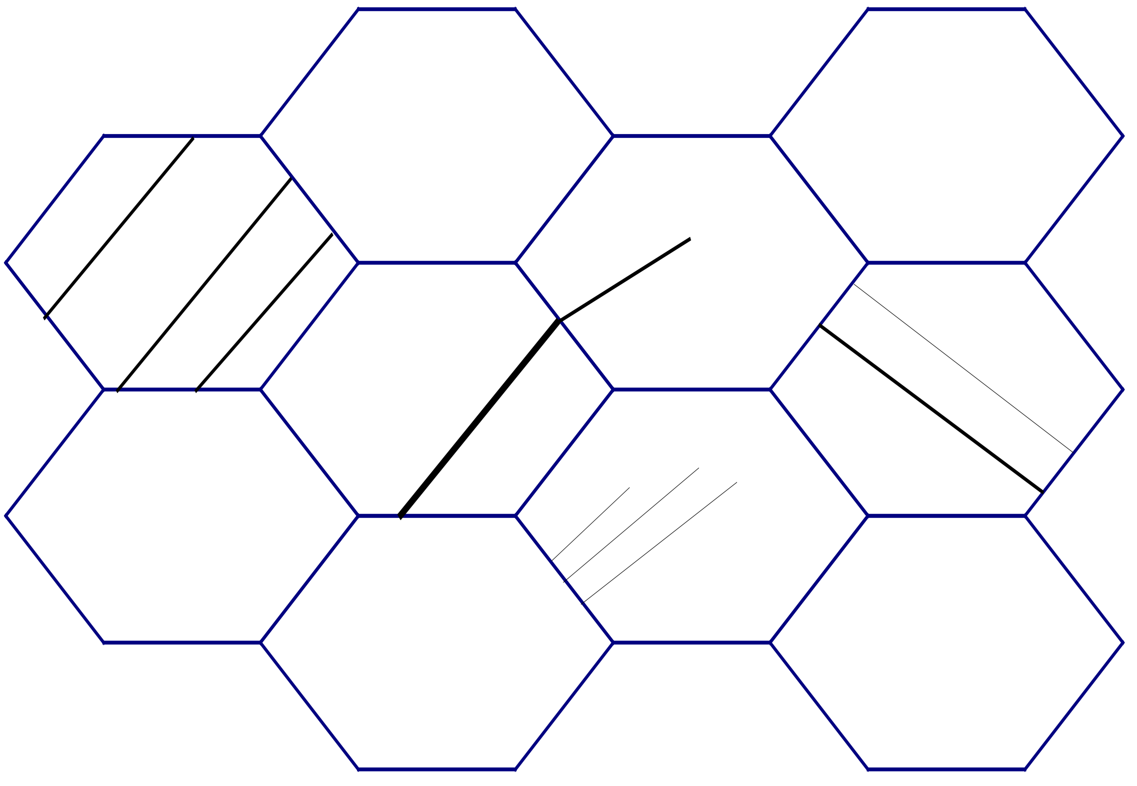


N = 40,000 N_f = 170,000

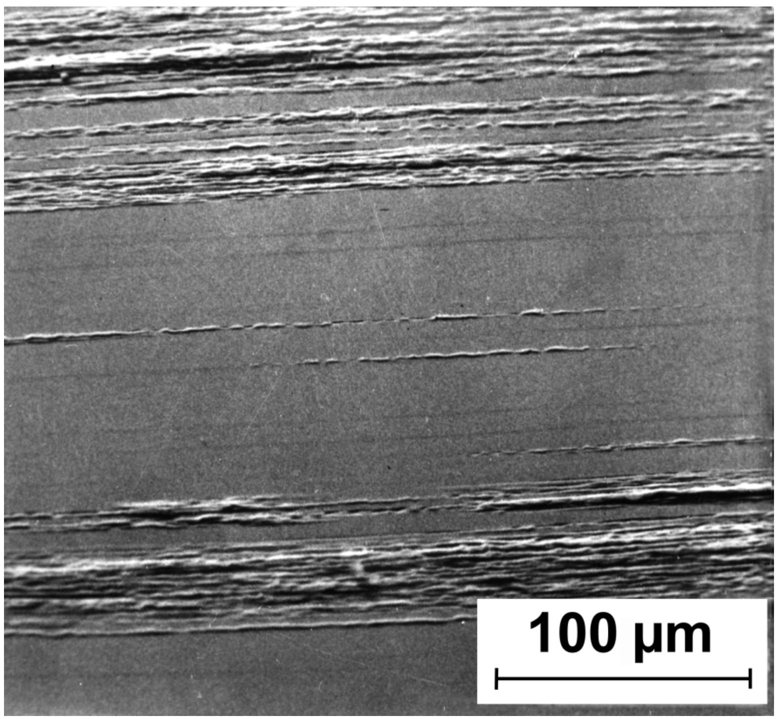
Cyclic deformation leads to the development of slip bands and fatigue cracks

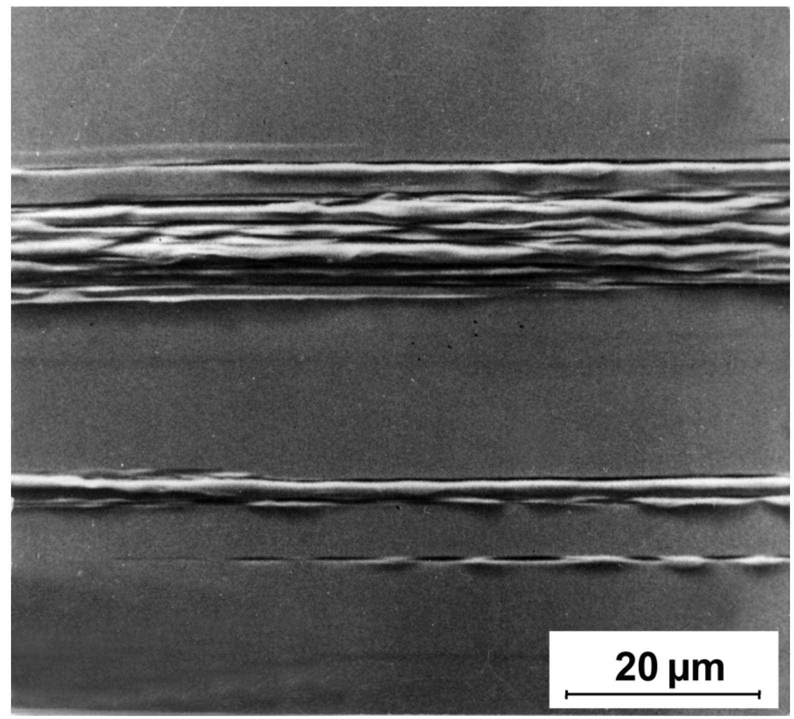
Ewing, J.A. and Humfrey, J.C. “The fracture of metals under repeated alterations of stress”, *Philosophical Transactions of the Royal Society*, Vol. A200, 1903, 241-250

Crack Nucleation



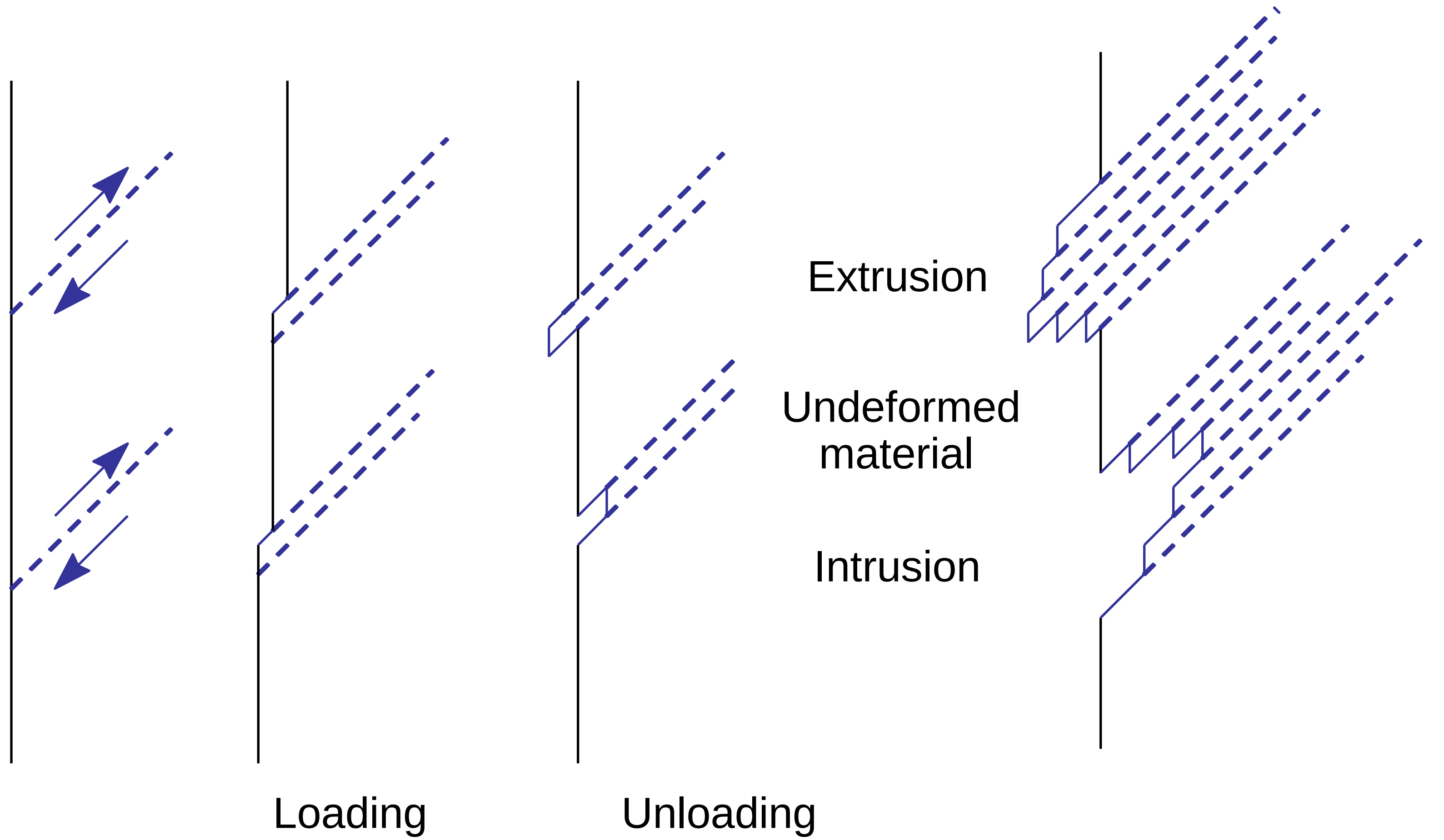
Slip Band in Copper



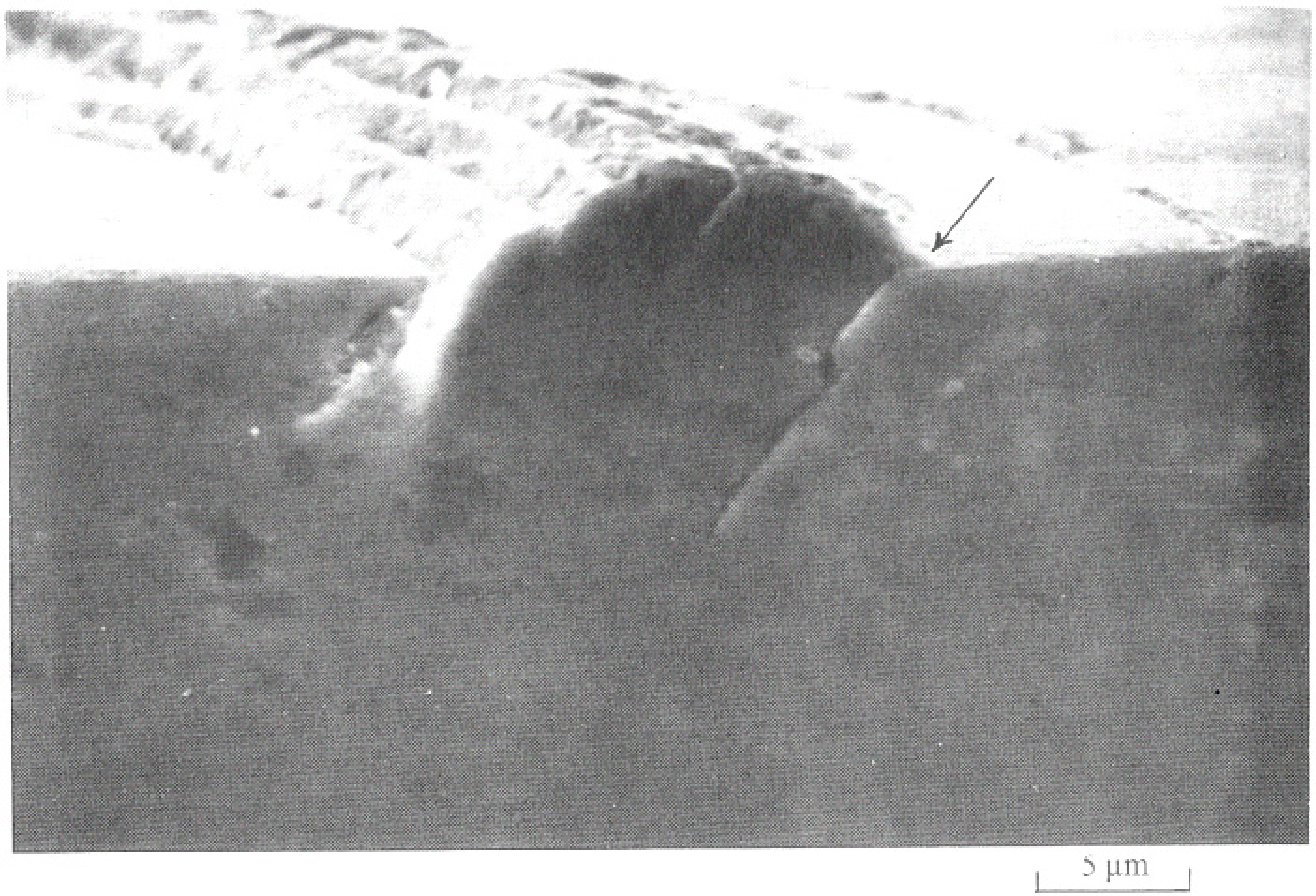


Polak, J. Cyclic Plasticity and Low Cycle Fatigue Life of Metals, Elsevier, 1991

Slip Band Formation

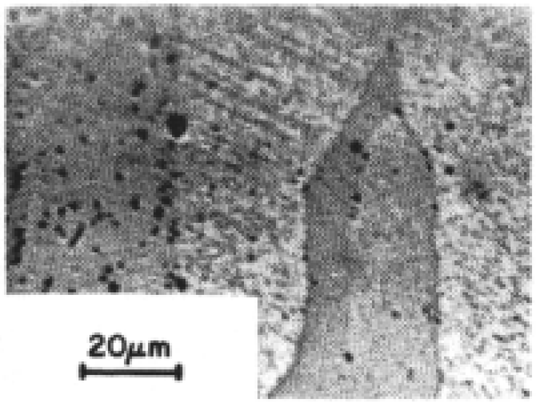


Slip Bands

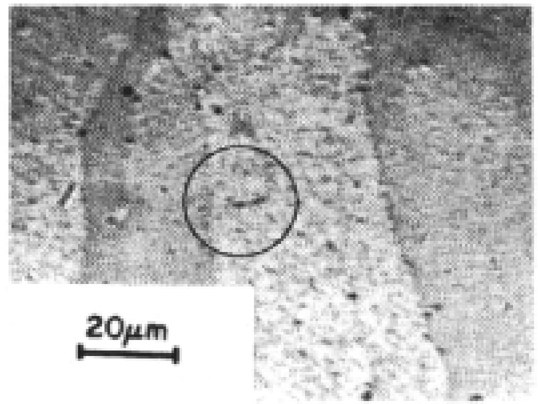


Ma, B-T and Laird C. “Overview of fatigue behavior in copper sinle crystals –II Population, size, distribution and growth Kinetics of stage I cracks for tests at constant strain amplitude”, Acta Metallurgica, Vol 37, 1989, 337-348

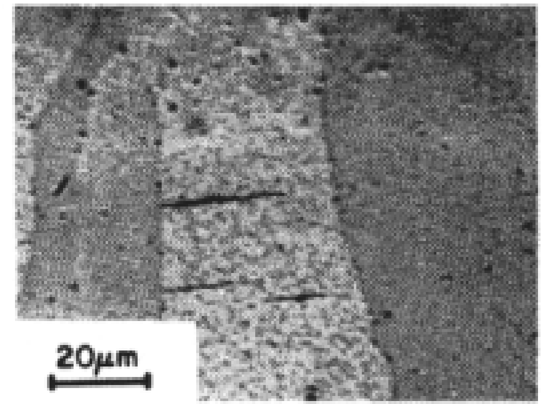
2124-T4 Cracking in Slip Bands



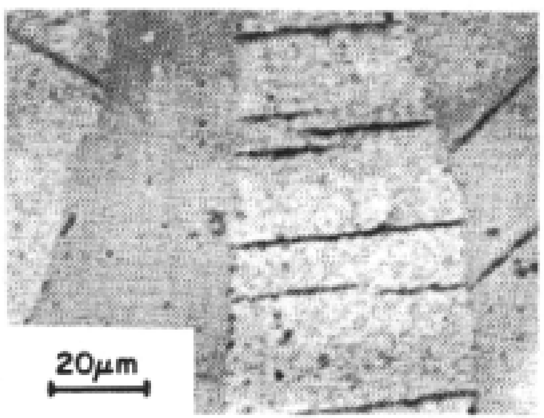
N = 60 (a)



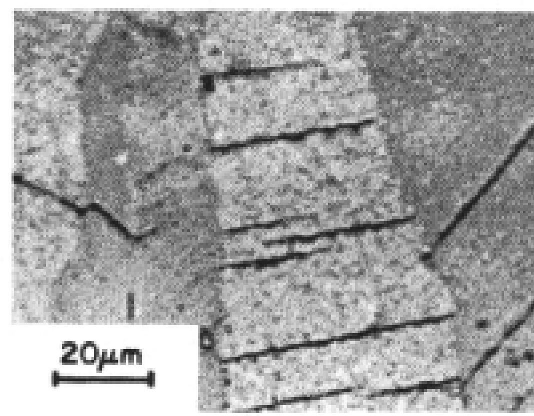
N = 240 (b)



N = 300 (c)



N = 1200 (d)

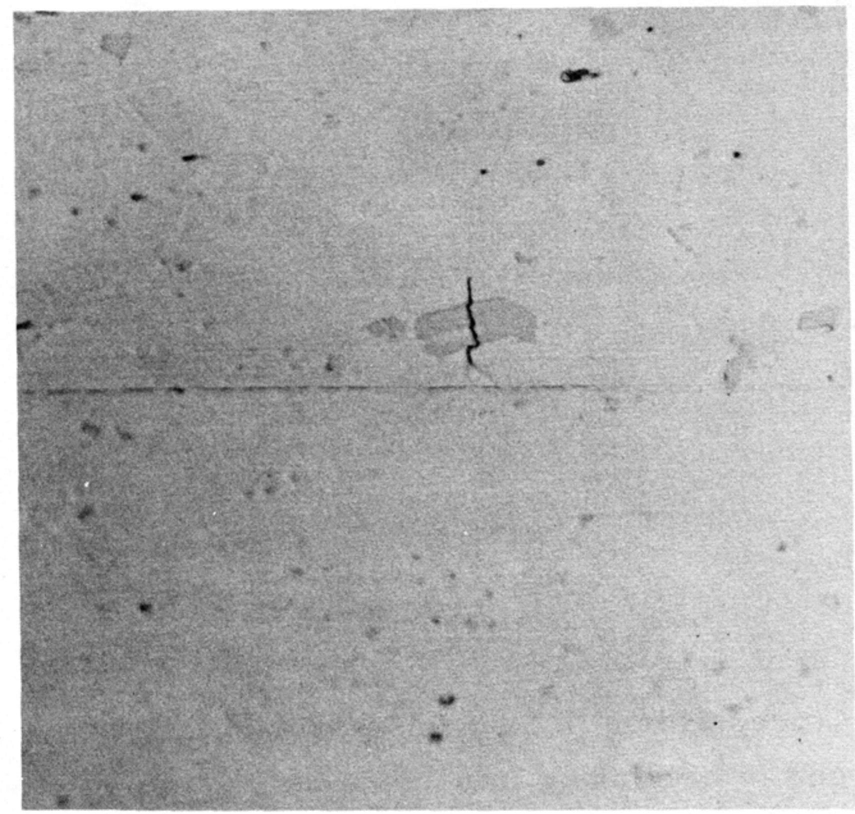


N = 2000 (e)

Crack at Particle

Material: BS L65 Aluminum

Loading: 63 ksi, R=0 for 500,000+ cycles, followed by 68 ksi, R=0 to failure. Cracks found during 68 ksi loading.



S. Pearson, "Initiation of Fatigue Cracks in Commercial Aluminum Alloys and the Subsequent Propagation of Very Short Cracks," RAE TR 72236, Dec 1972.

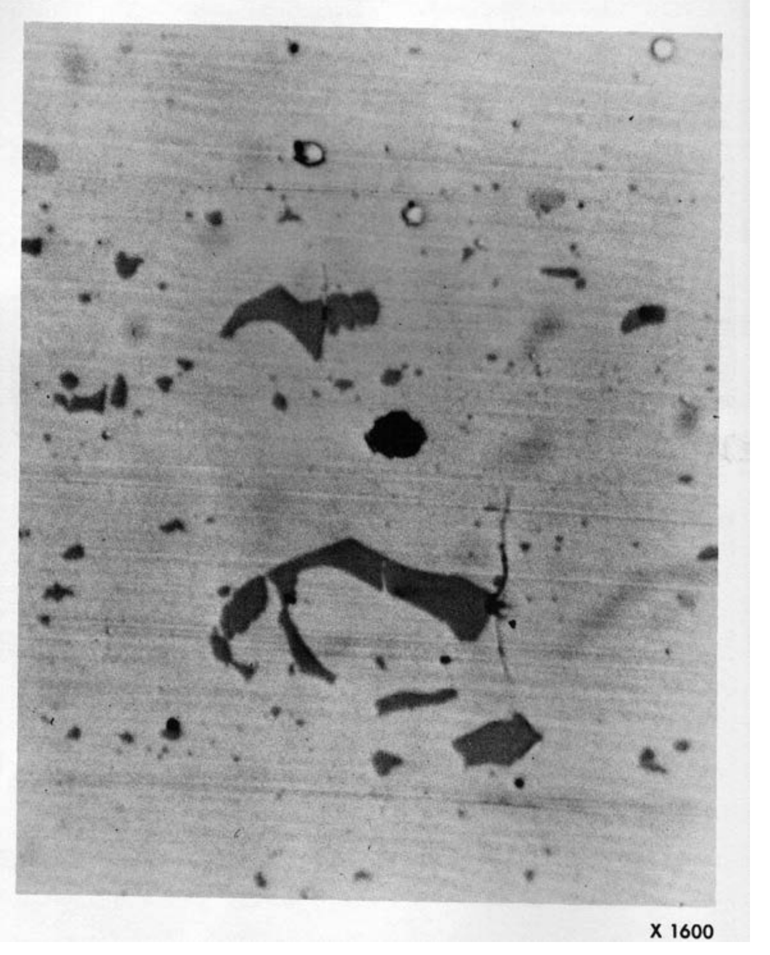
2219-T851 Cracked Particle

James & Morris, *ASTM STP 811 Fatigue Mechanisms: Advances in Quantitative Measurement of Physical Damage*, pp. 46-70, 1983.

Crack at Bonded Particle

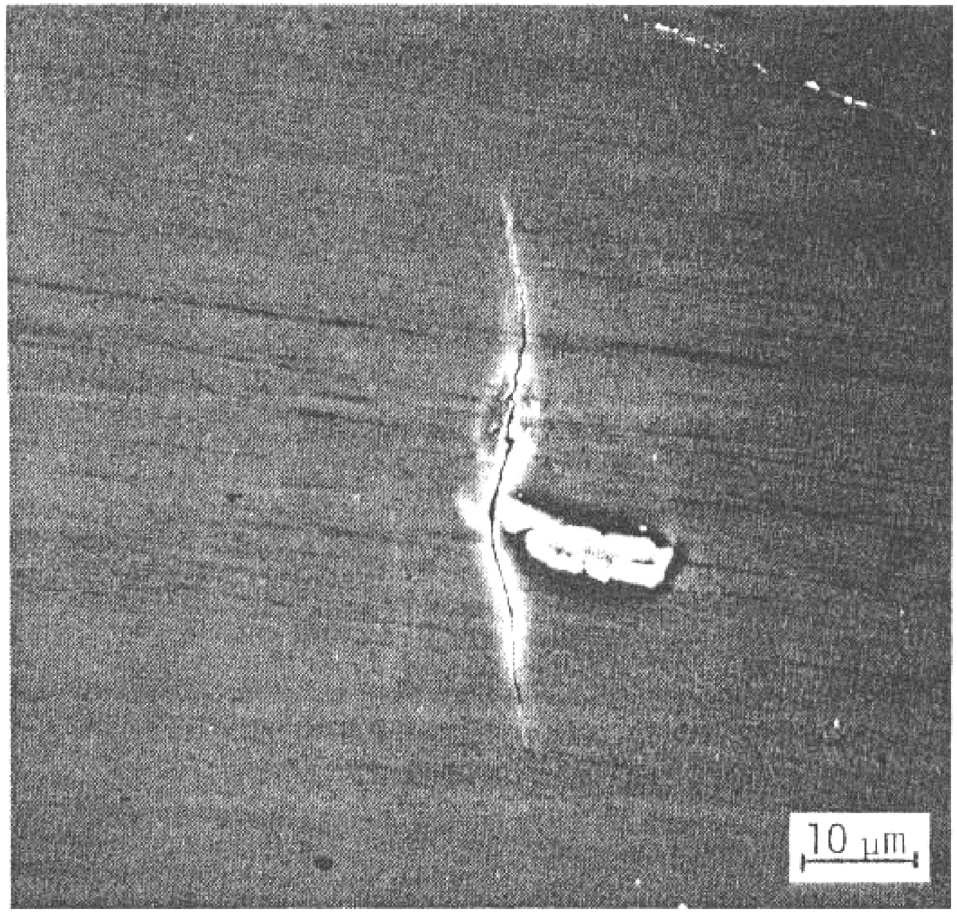
Material: BS L65 Aluminum

Loading: 63 ksi, R=0 for 500,000+ cycles, followed by 68 ksi, R=0 to failure. Cracks found during 68 ksi loading.

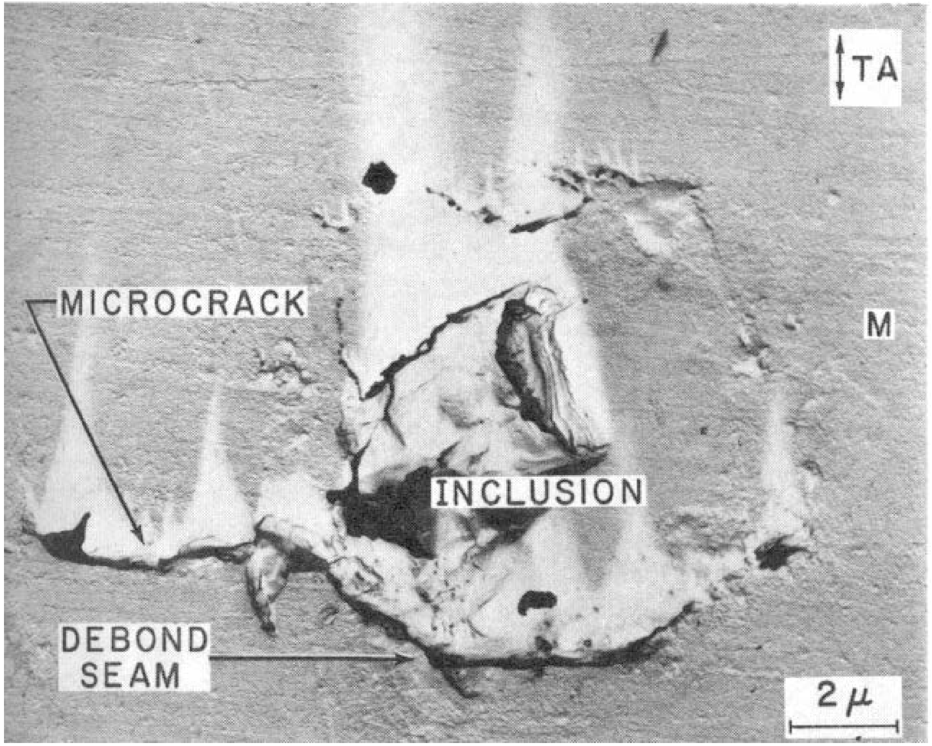


S. Pearson, "Initiation of Fatigue Cracks in Commercial Aluminum Alloys and the Subsequent Propagation of Very Short Cracks," RAE TR 72236, Dec 1972.

7075-T6 Cracking at Inclusion

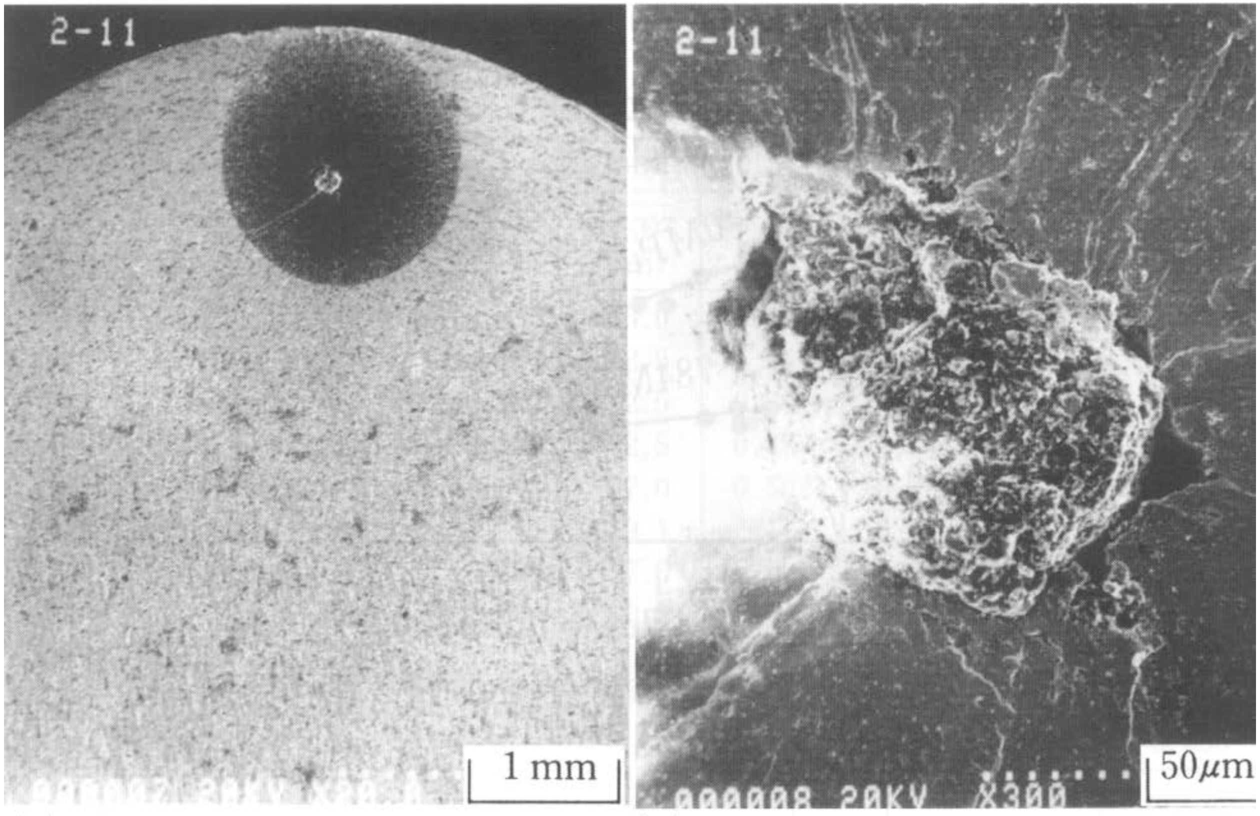


Crack Initiation at Inclusions



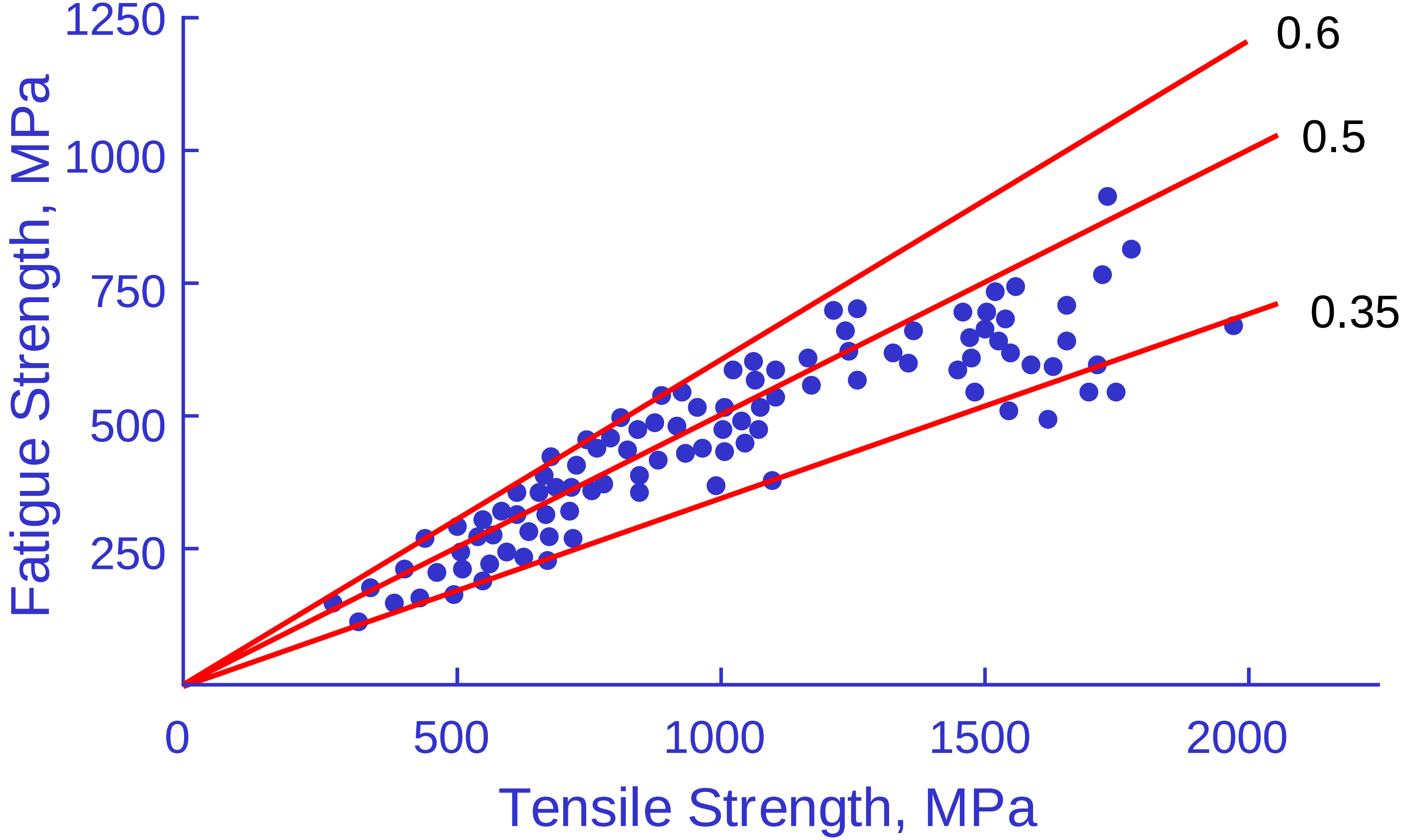
Langford and Kusenberger, “Initiation of Fatigue Cracks in 4340 Steel”, *Metallurgical Transactions*, Vol 4, 1977, 553-559

Subsurface Crack Initiation



Y. Murakami, Metal Fatigue: *Effects of Small Defects and Nonmetallic Inclusions*, 2002

Fatigue Limit and Strength Correlation

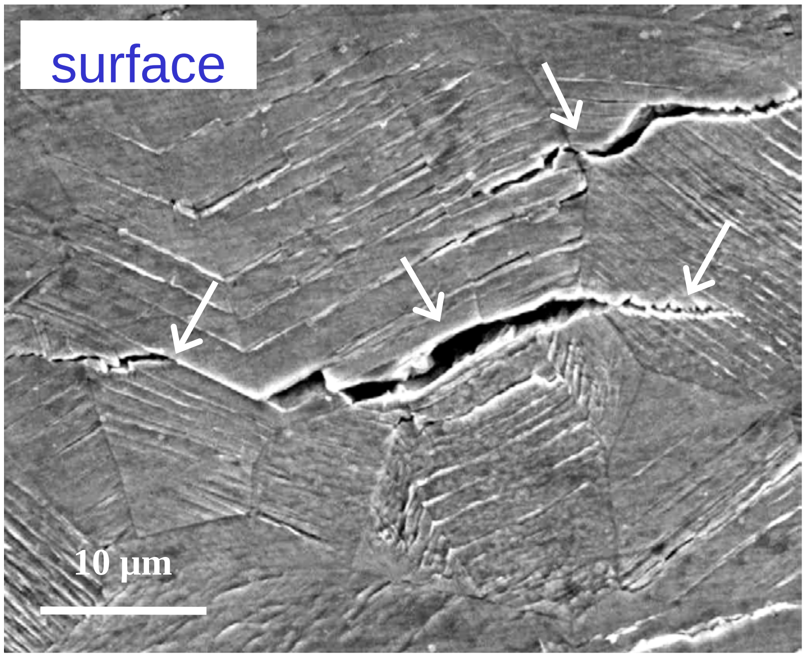


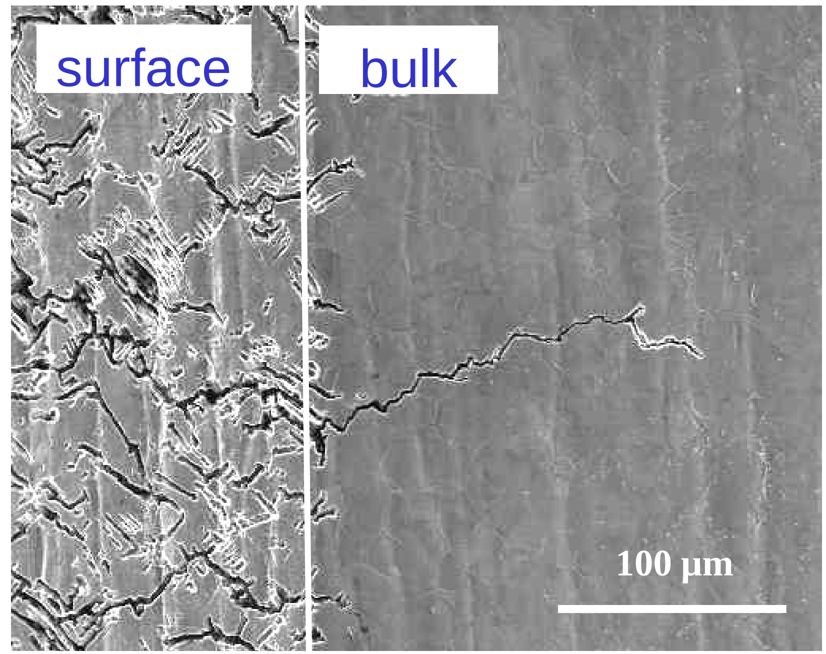
From Forrest, *Fatigue of Metals*, Pergamon Press, London, 1962

Crack Nucleation Summary

- Highly localized plastic deformation
- Surface phenomena
- Stochastic process

Surface Damage

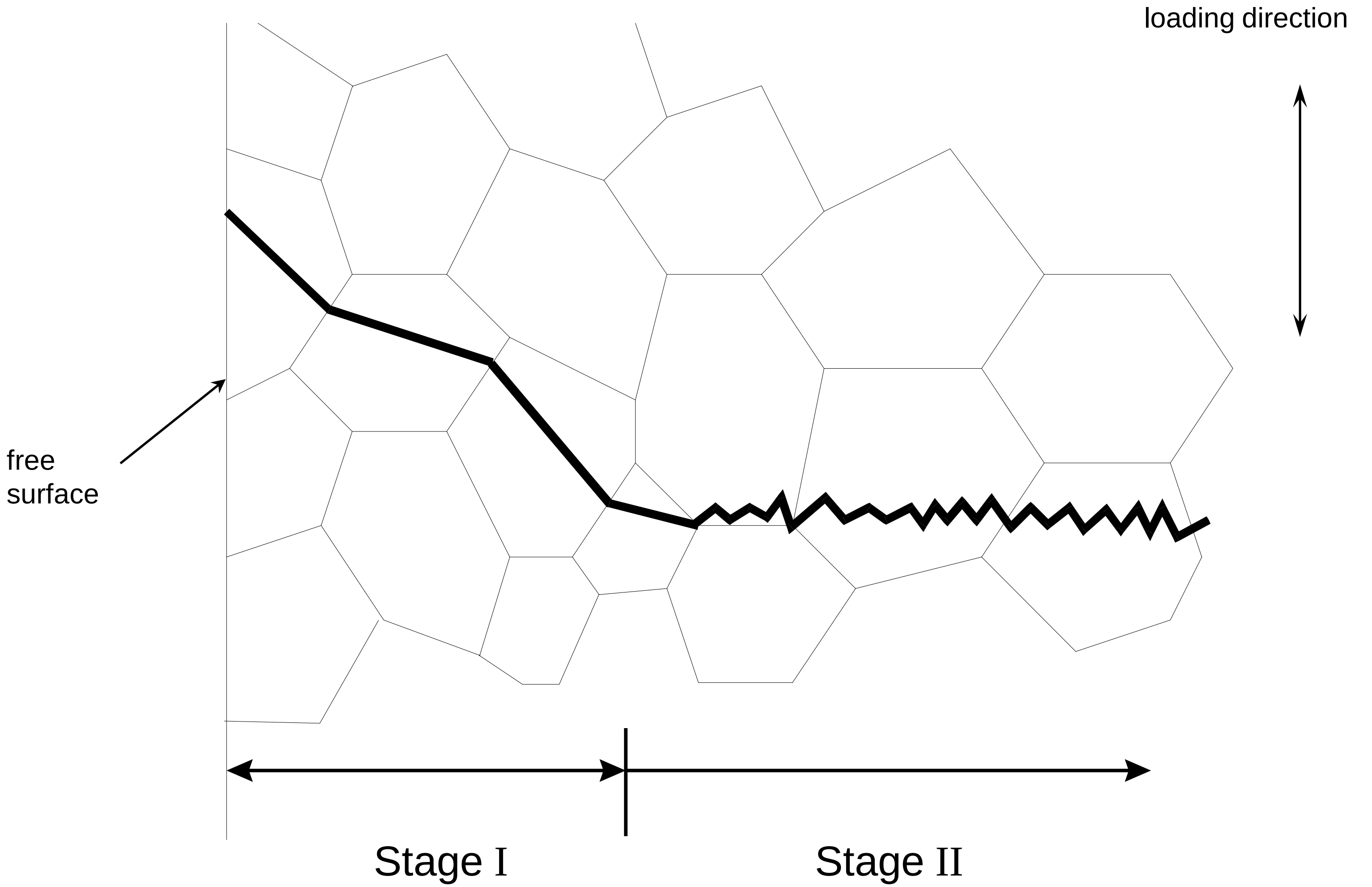




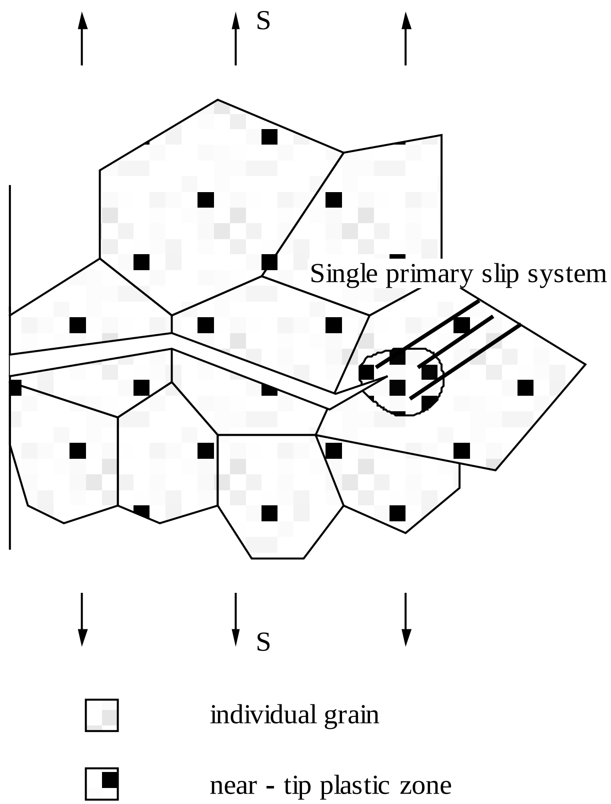
20-25 austenitic steel in symmetrical push-pull fatigue (20°C, $\Delta\varepsilon_p/2 = \pm 0.4\%$) : short cracks on the surface and in the bulk

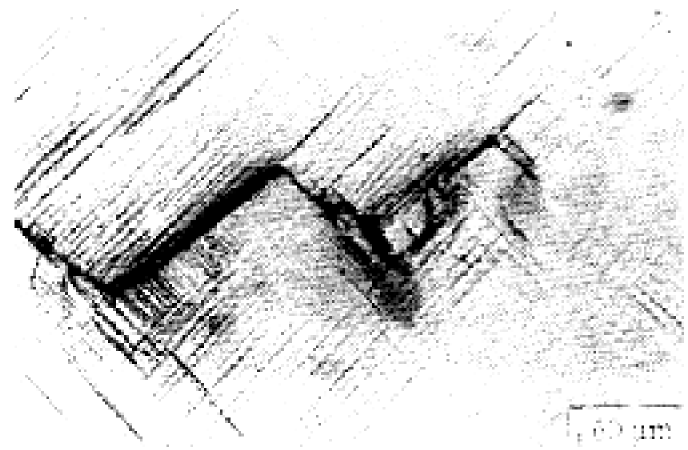
From Jacques Stolarz, Ecole Nationale Superieure des Mines
Presented at LCF 5 in Berlin, 2003

Stage I and Stage II



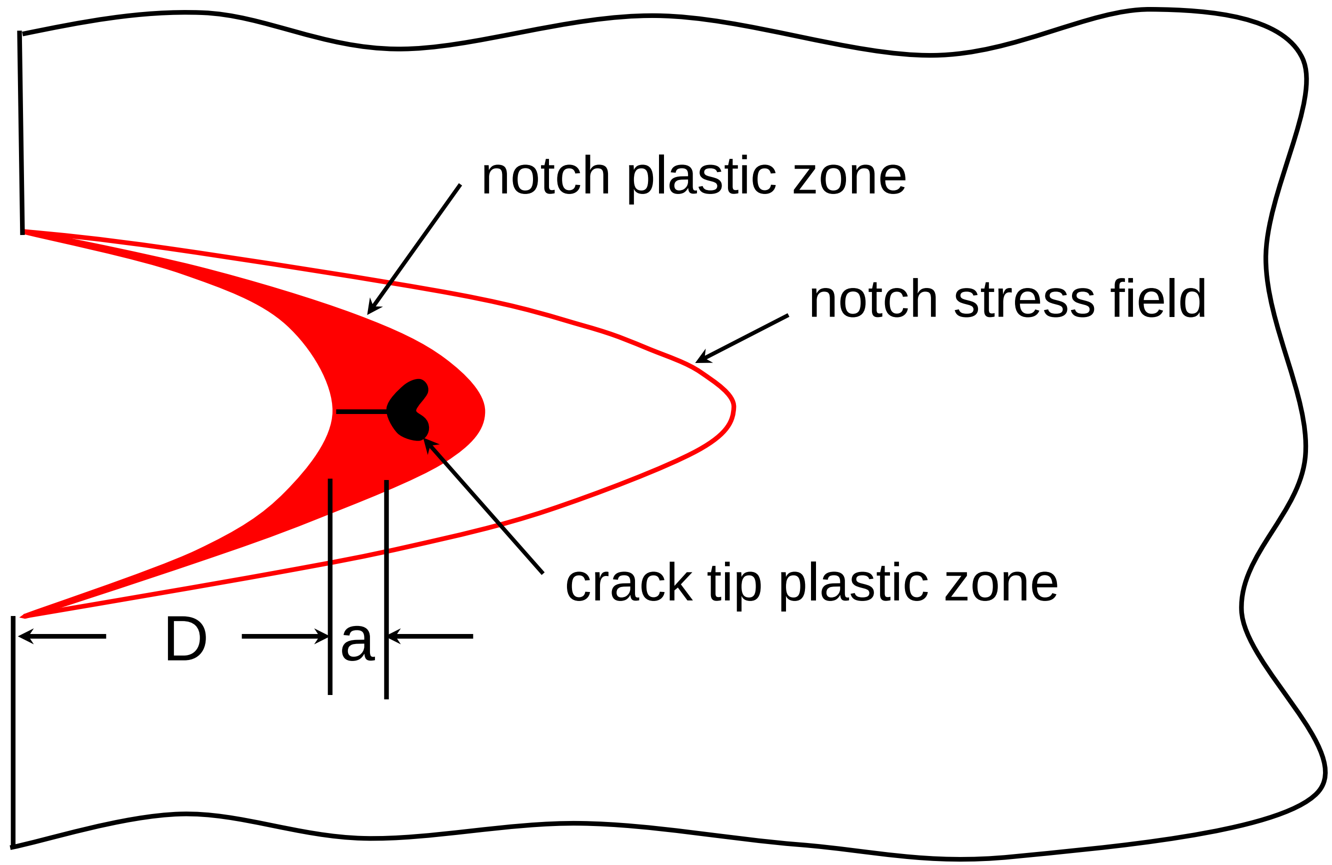
Stage I Crack Growth





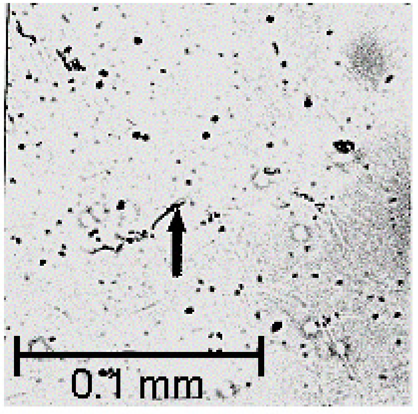
Stage I crack is strongly affected by slip characteristics, microstructure dimensions, stress level, extent of near tip plasticity

Small Cracks at Notches

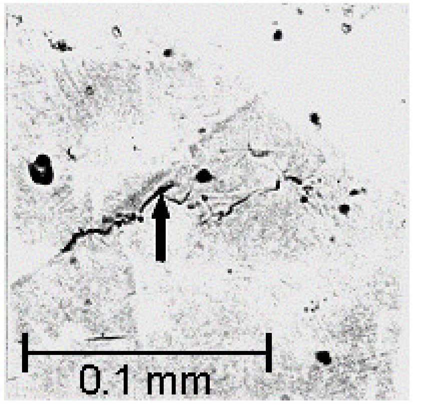


Crack growth controlled by the notch plastic strains

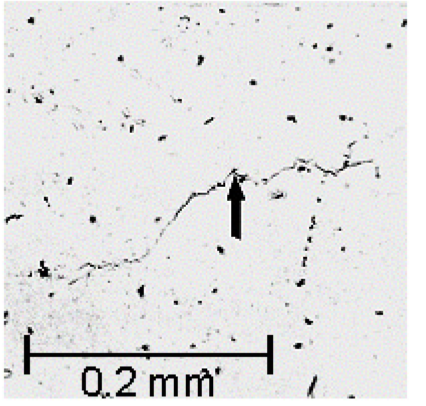
Small Crack Growth



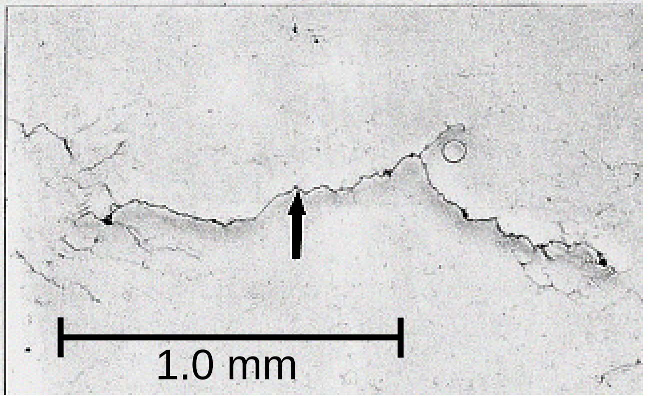
N = 160



N = 240



N = 520



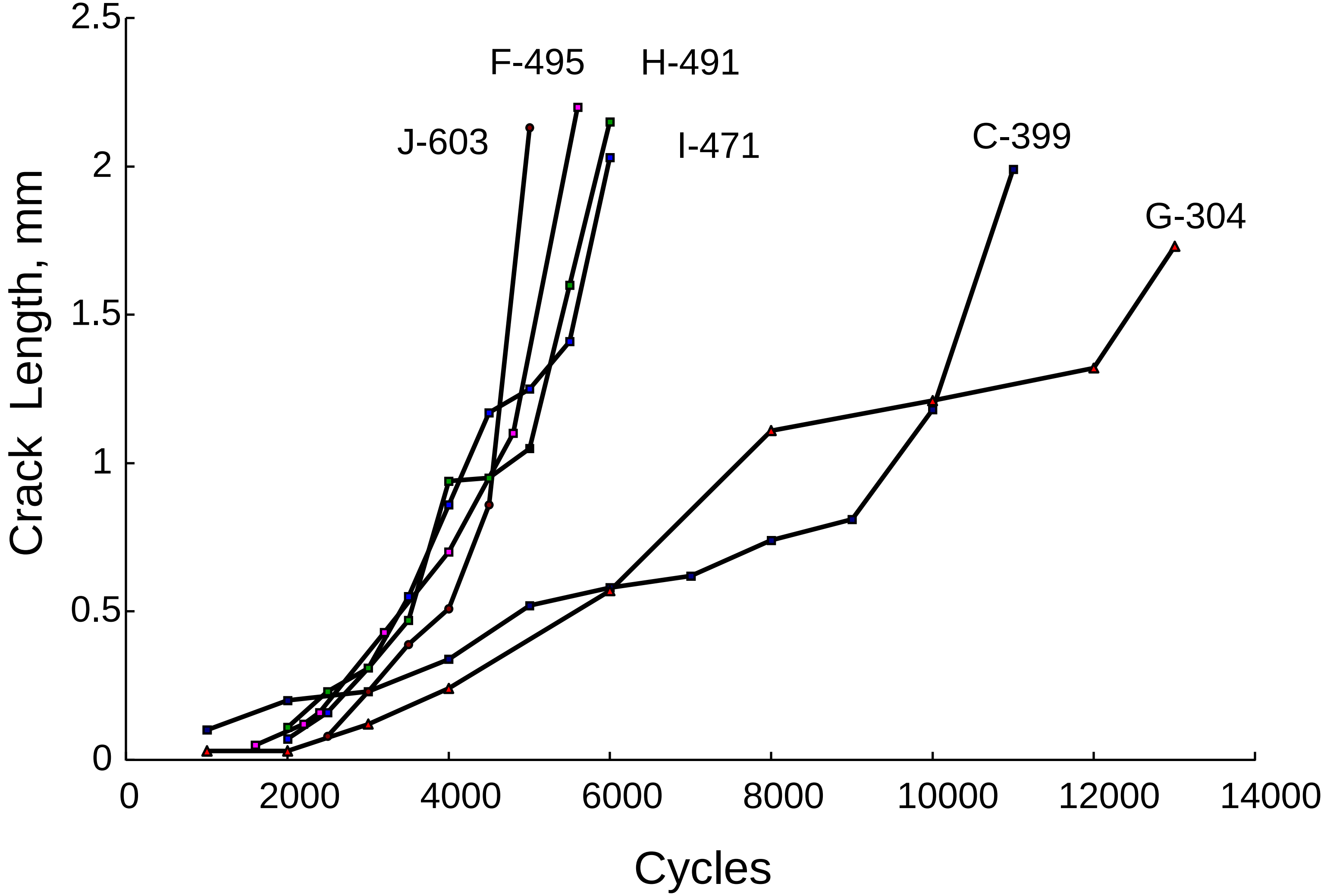
N = 900

Inconel 718

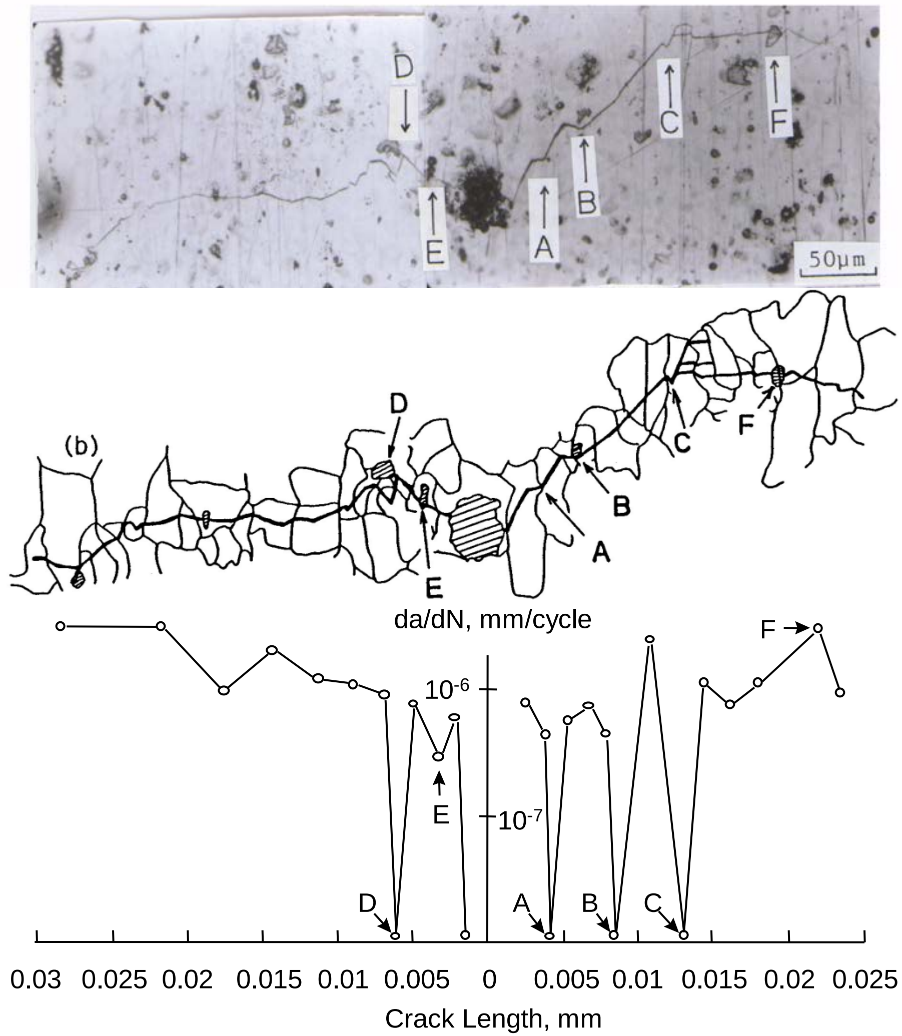
$\Delta\varepsilon = 0.02$

$N_f = 936$

Crack Length Observations

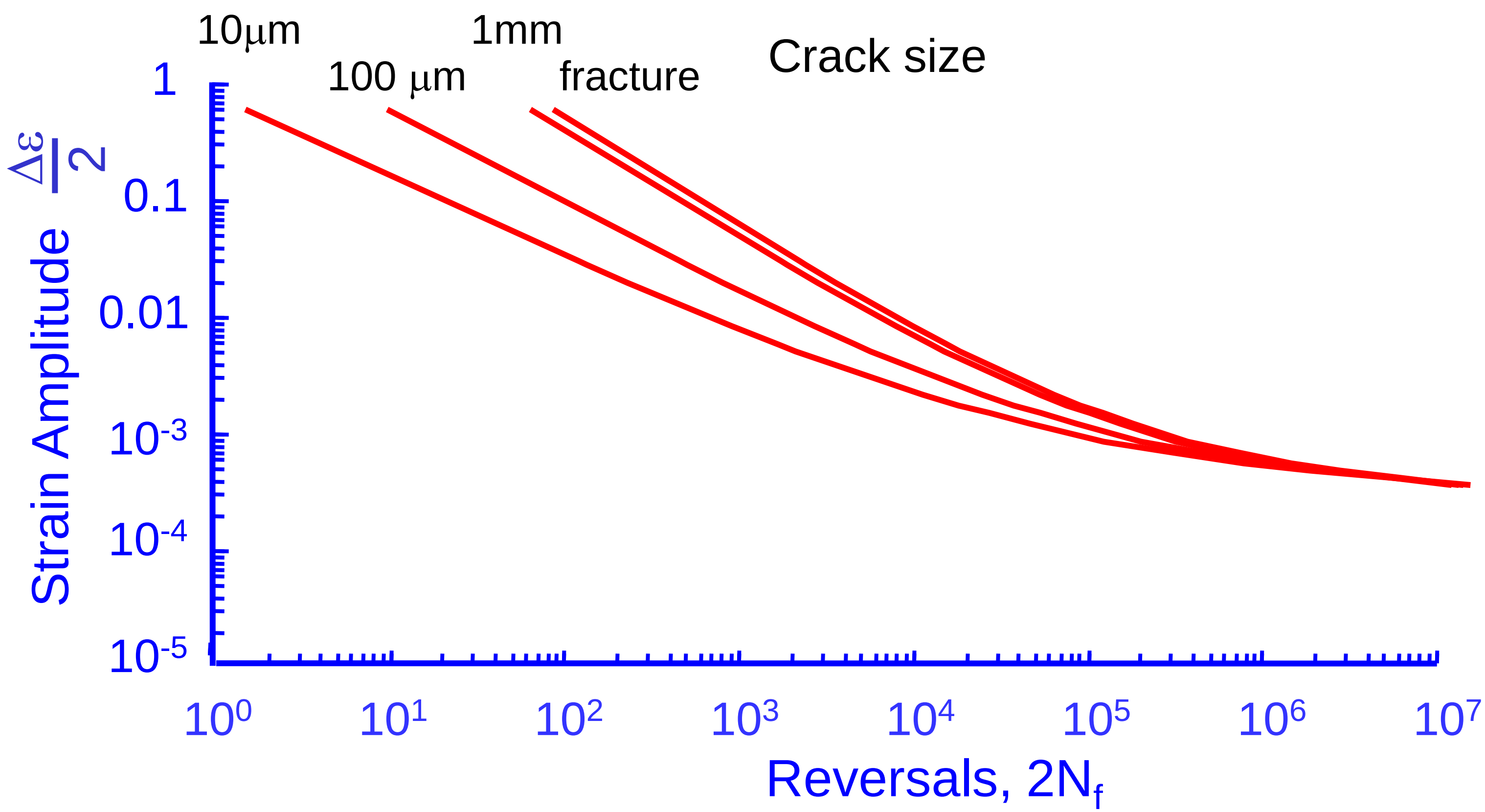


Crack - Microstructure Interactions



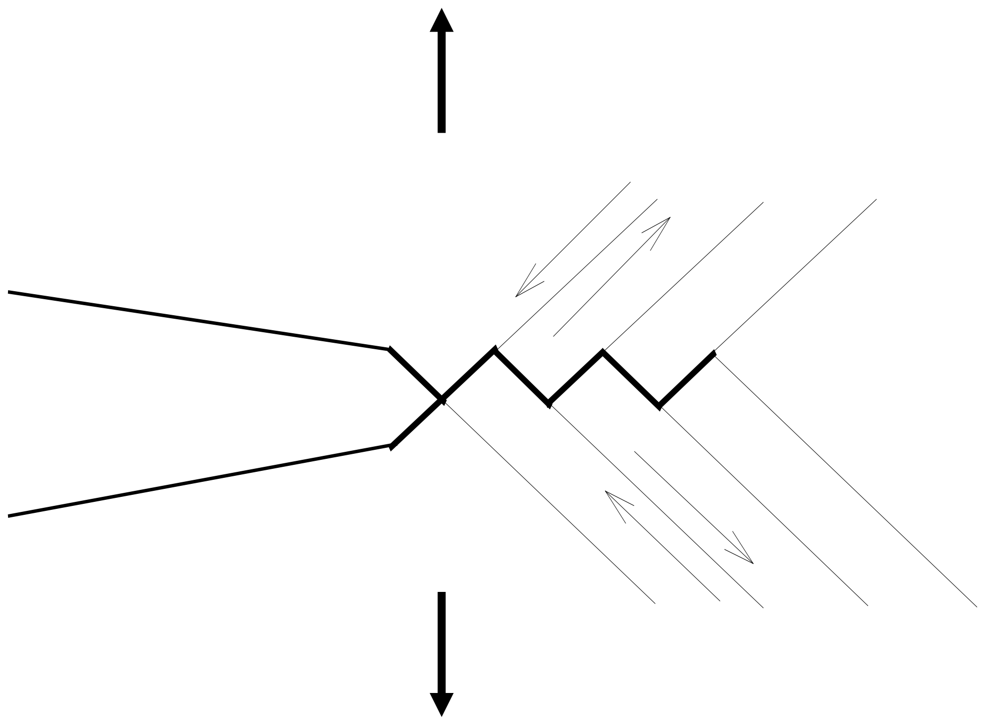
Akiniwa, Y., Tanaka, K., and Matsui, E.,"Statistical Characteristics of Propagation of Small Fatigue Cracks in Smooth Specimens of Aluminum Alloy 2024-T3, *Materials Science and Engineering*, Vol. A104, 1988, 105-115

Strain-Life Data



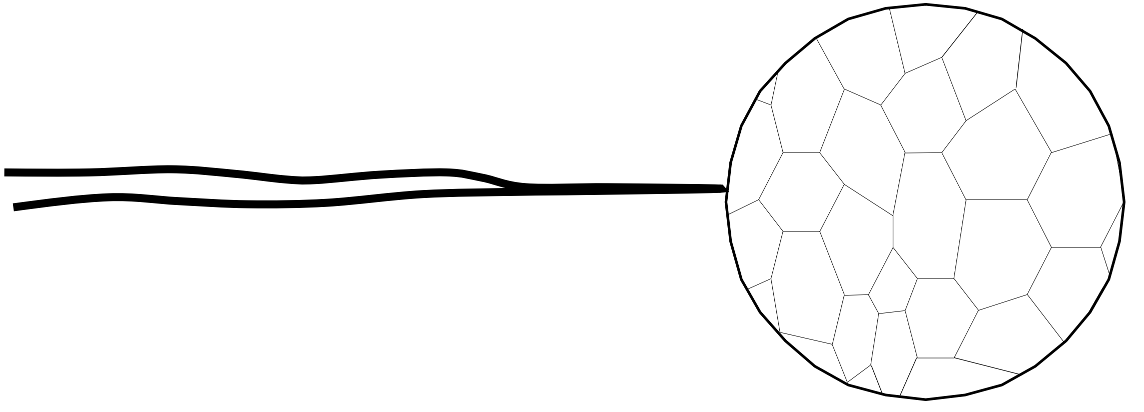
Most of the life is spent in microcrack growth in the plastic strain dominated region

Stage II Crack Growth



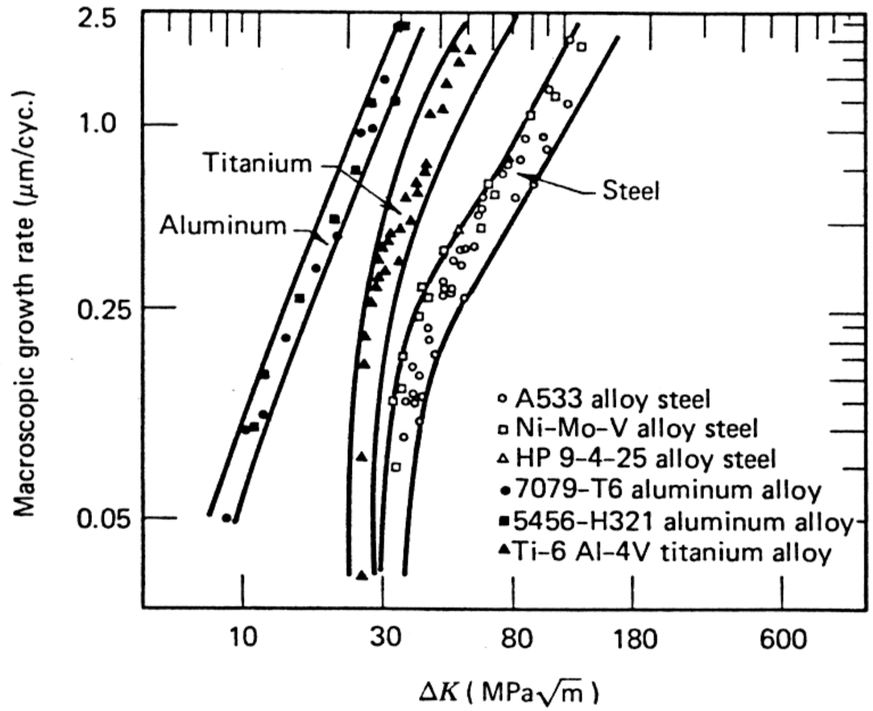
Locally, the crack grows in shear
Macroscopically it grows in tension

Long Crack Growth



Plastic zone size is much larger than the material microstructure so that the microstructure does not play such an important role.

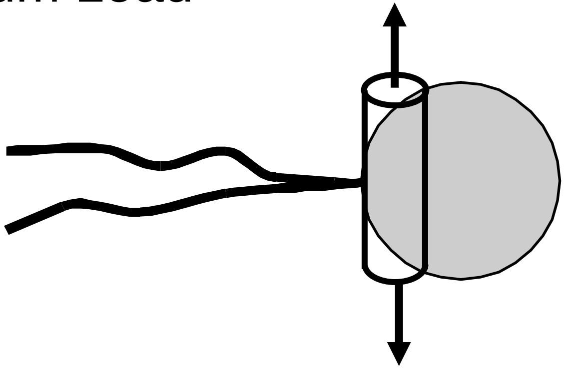
Crack Growth Rates of Metals

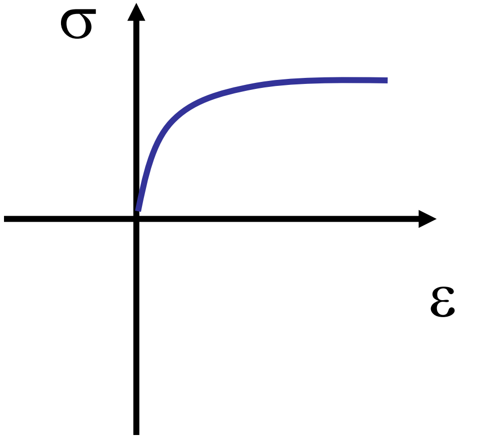


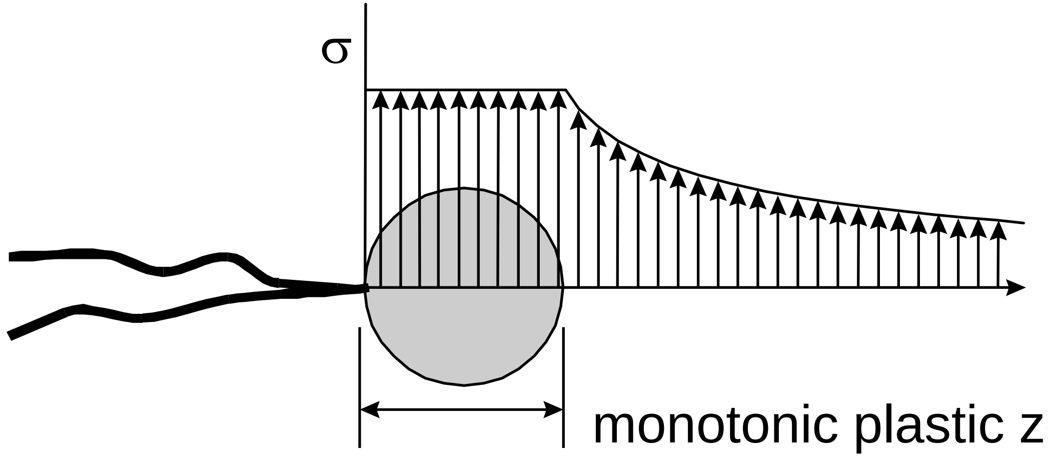
Material strength does not play a major role in fatigue crack growth

Stresses Around a Crack

Maximum Load

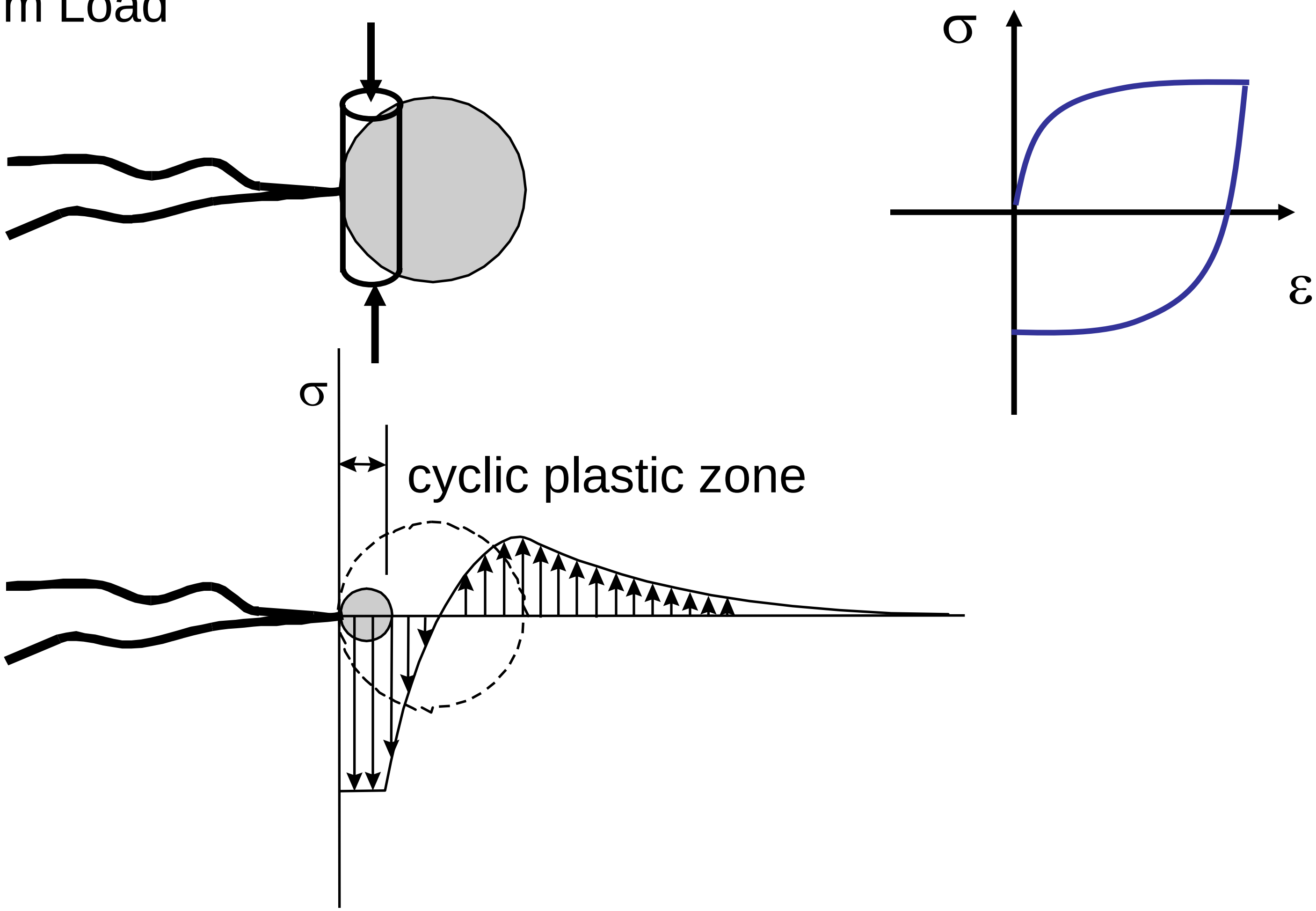




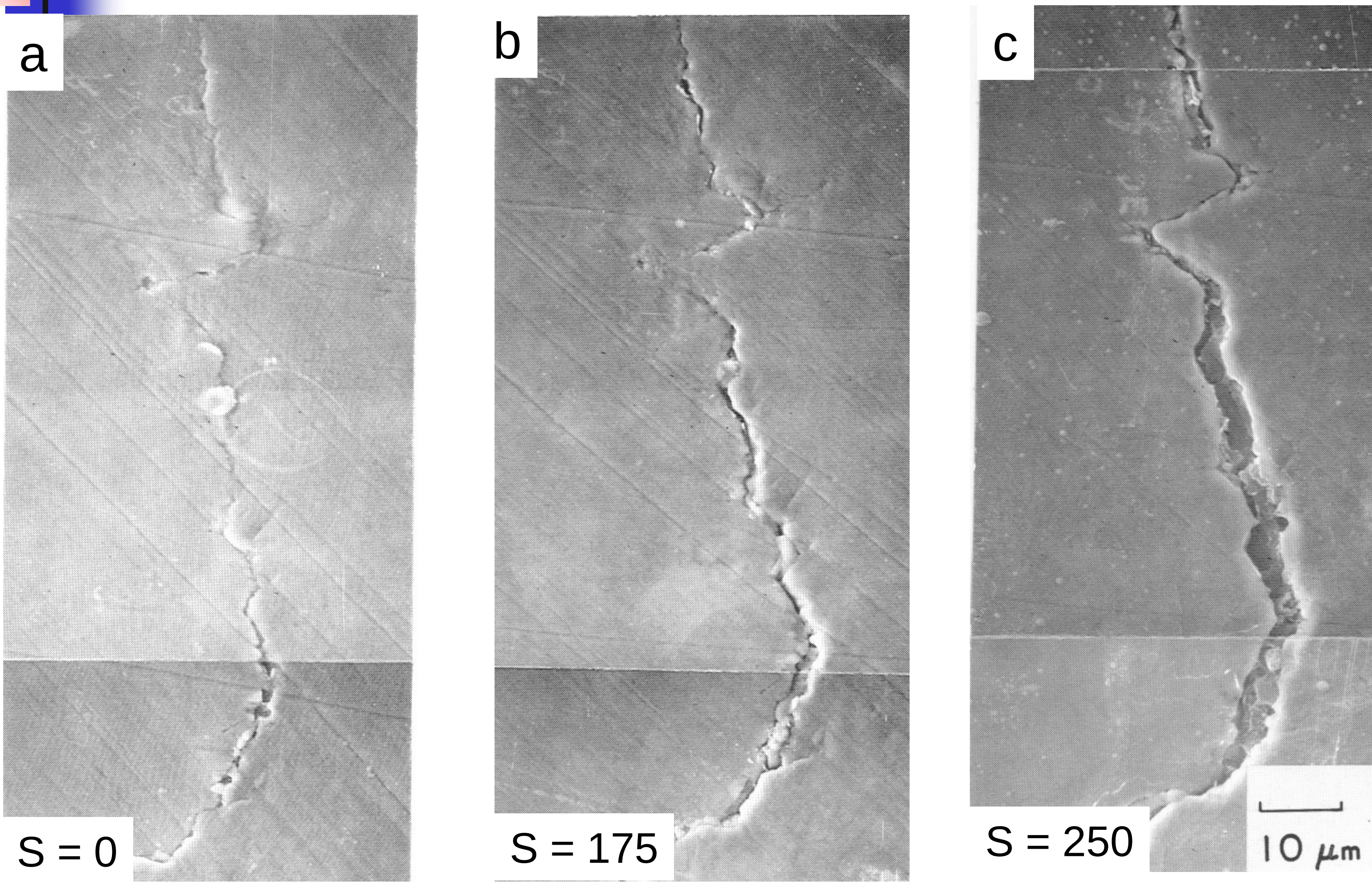


Stresses Around a Crack (continued)

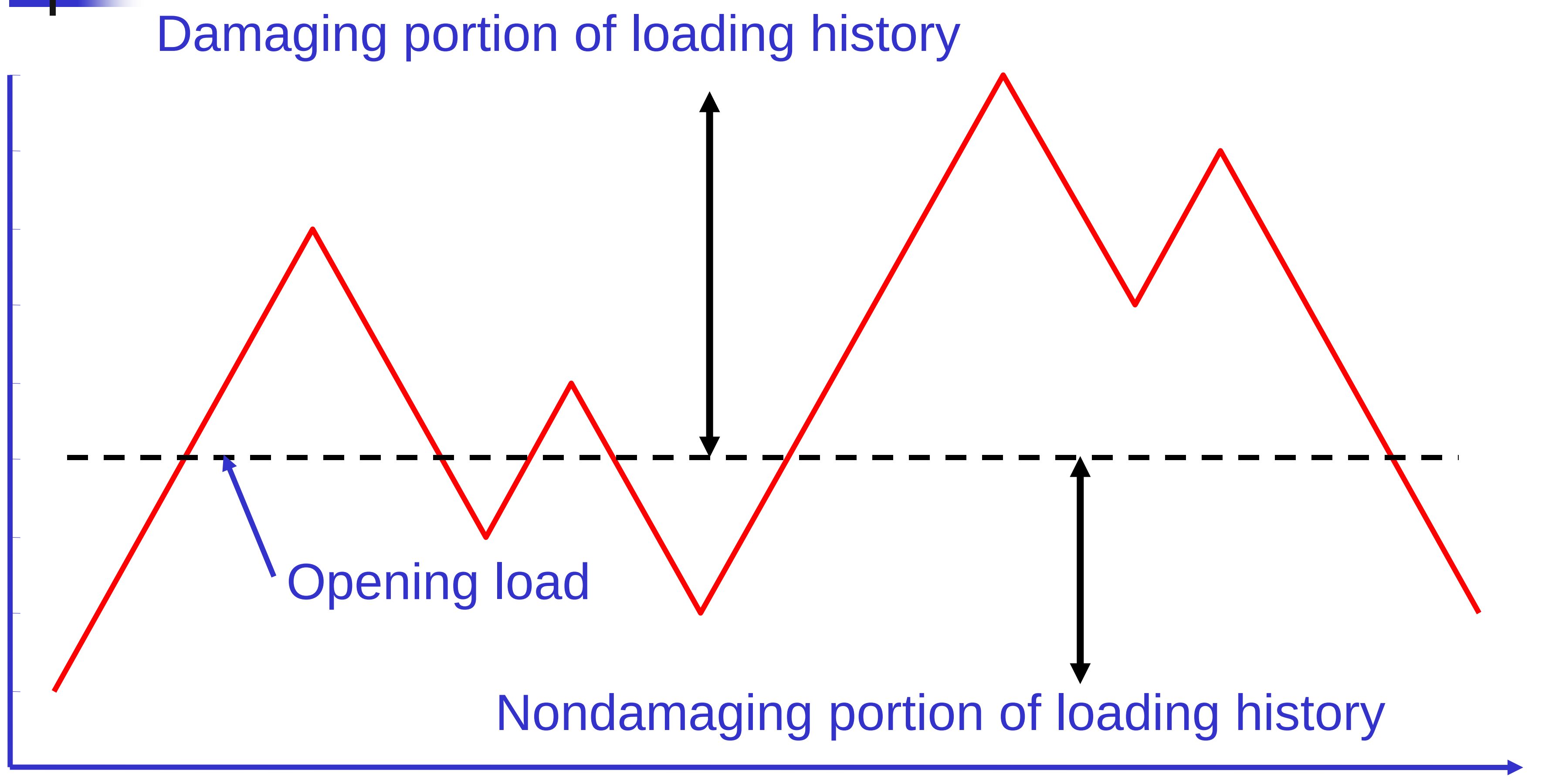
Minimum Load



Crack Closure



Crack Opening Load

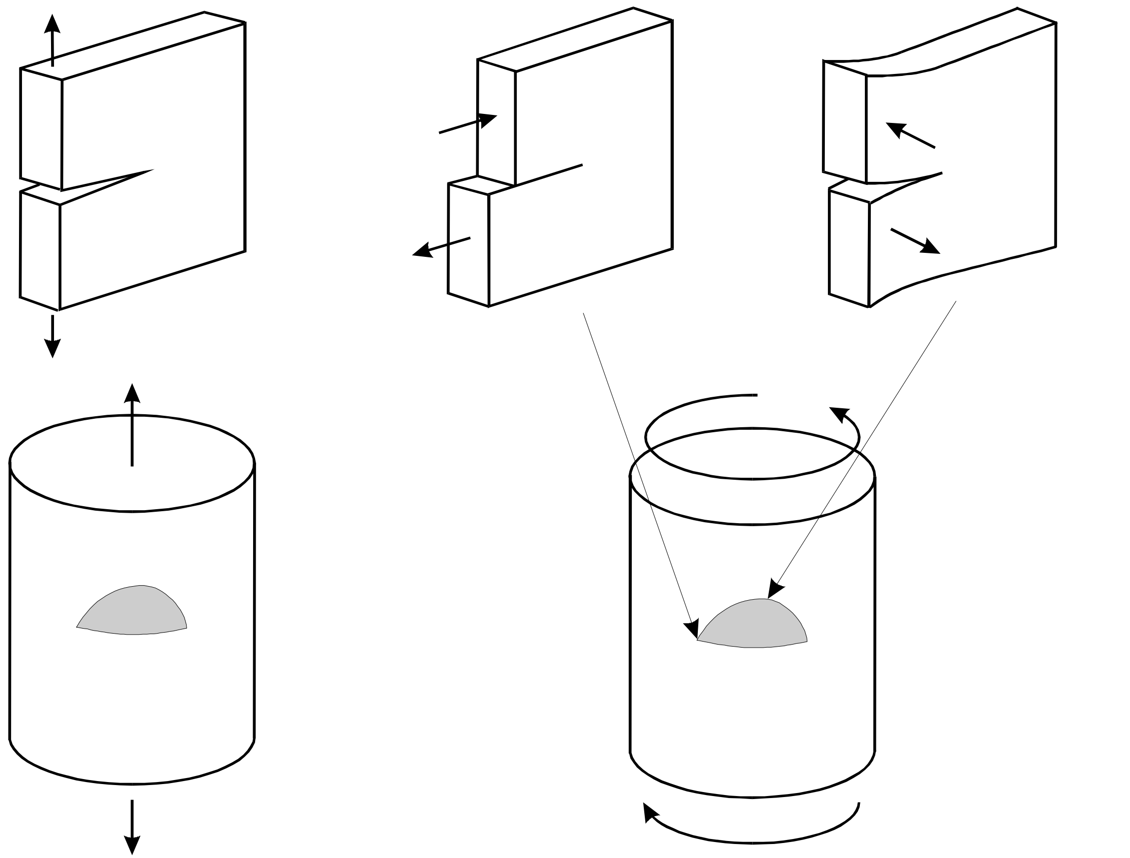


Mode I, Mode II, and Mode III

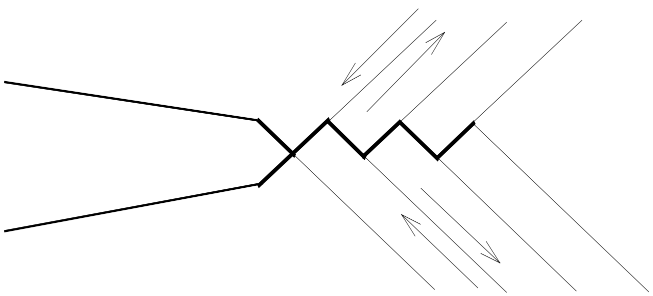
Mode I
opening

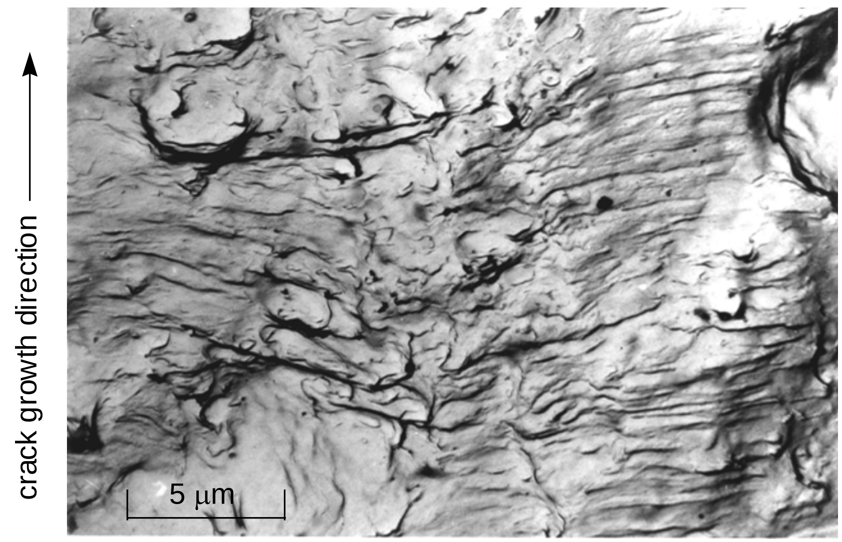
Mode II
in-plane shear

Mode III
out-of-plane shear

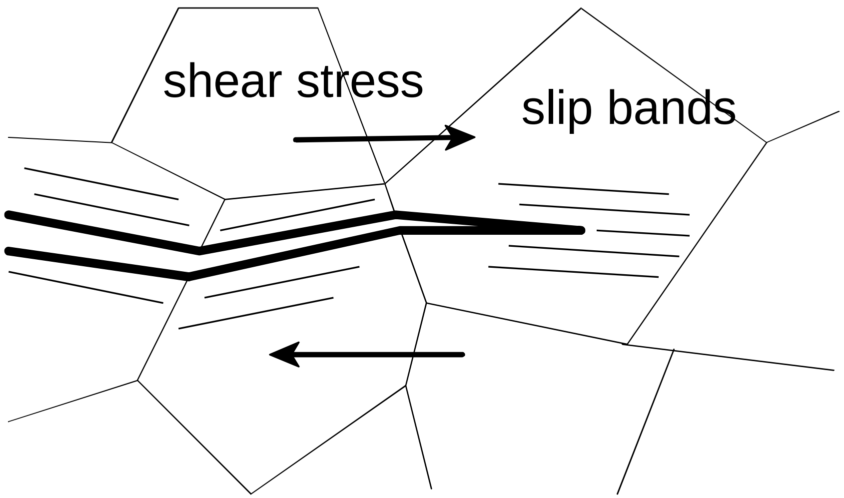


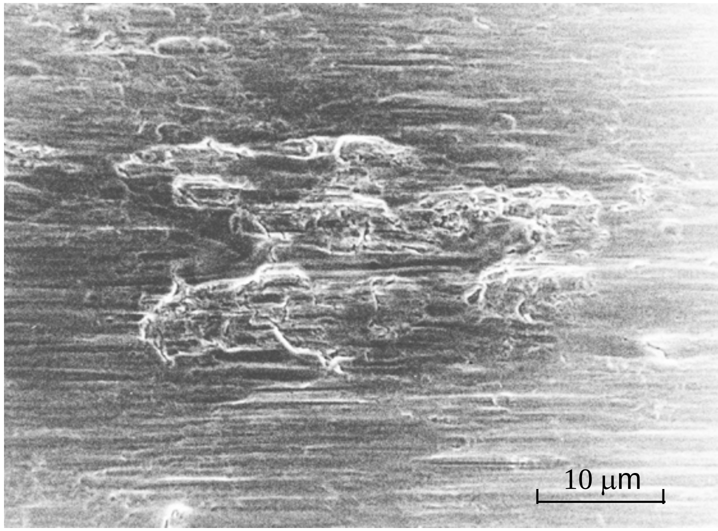
Mode I Growth





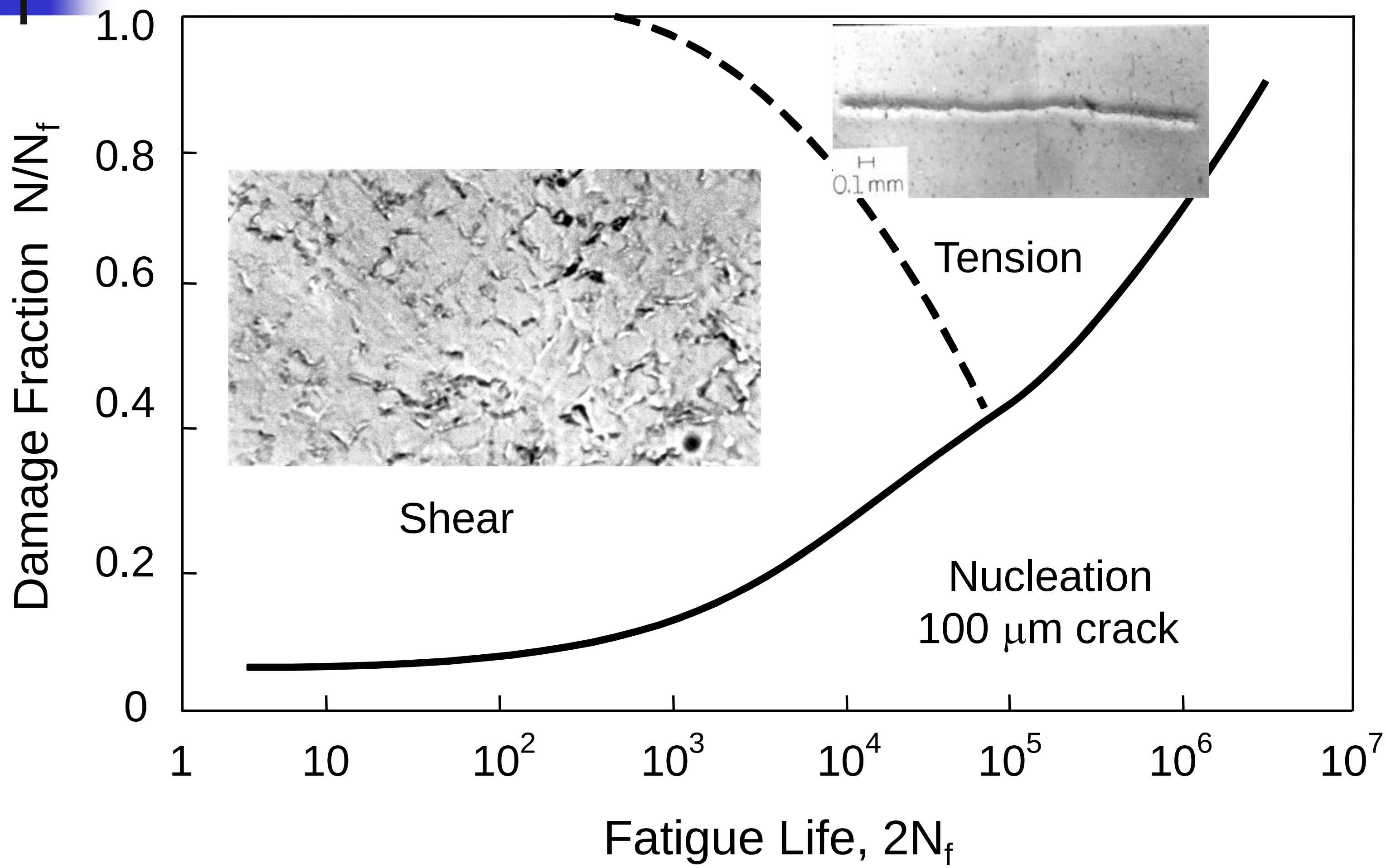
Mode II Growth



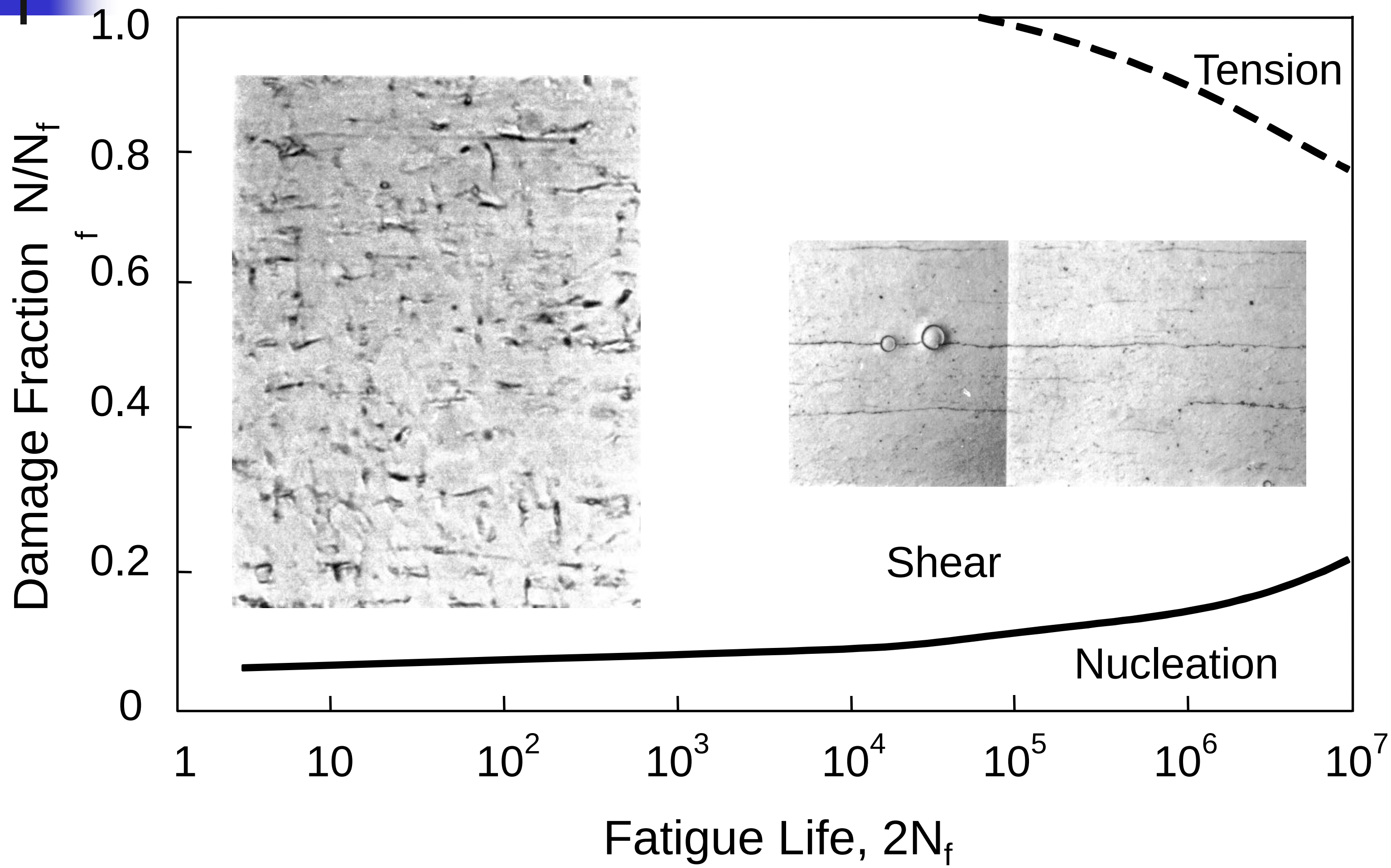


crack growth direction

1045 Steel - Tension



1045 Steel - Torsion



Things Worth Remembering

- Fatigue is a localized process involving the nucleation and growth of cracks to failure.
- Fatigue is caused by localized plastic deformation.
- Most of the fatigue life is consumed growing microcracks in the finite life region
- Crack nucleation is dominate at long lives.

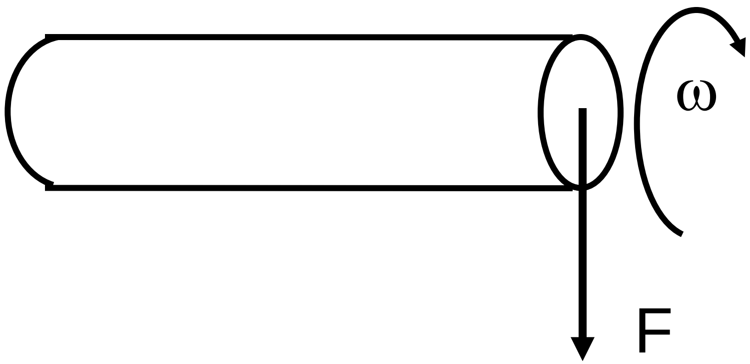
Fatigue, How and Why

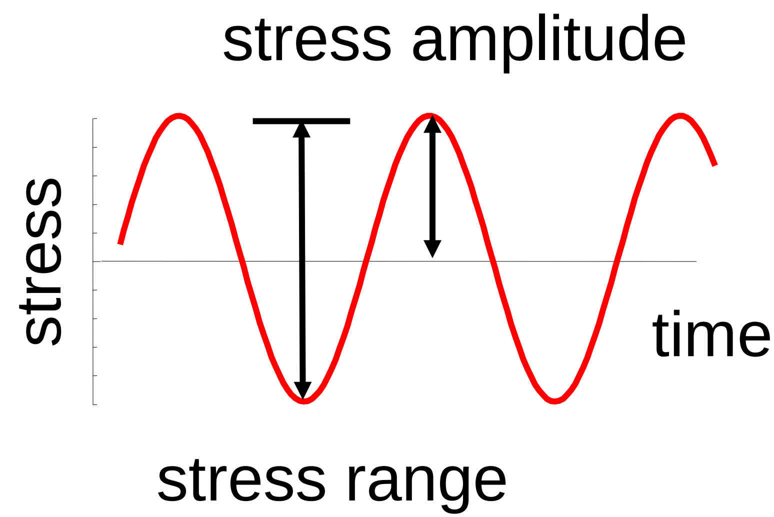
- Physics of Fatigue
- **Material Properties**
- Similitude
- Fatigue Calculator

Characterization

- Stress Life Curve
  - Fatigue Limit
- Strain Life Curve
  - Cyclic Stress Strain Curve
- Crack Growth Curve
  - Threshold Stress Intensity

Bending Fatigue

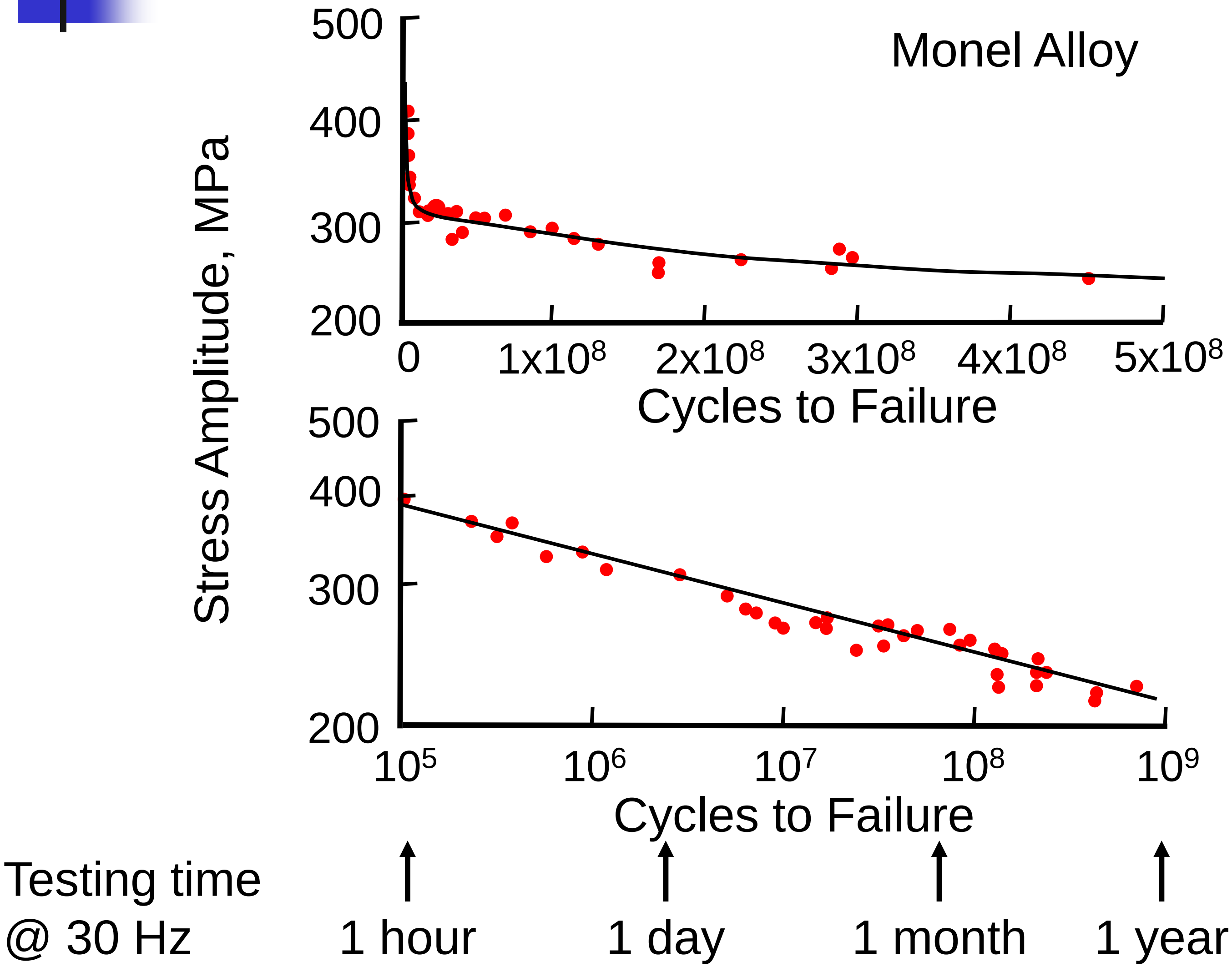




Bending stress:

$$\sigma = \frac{Mc}{I}$$

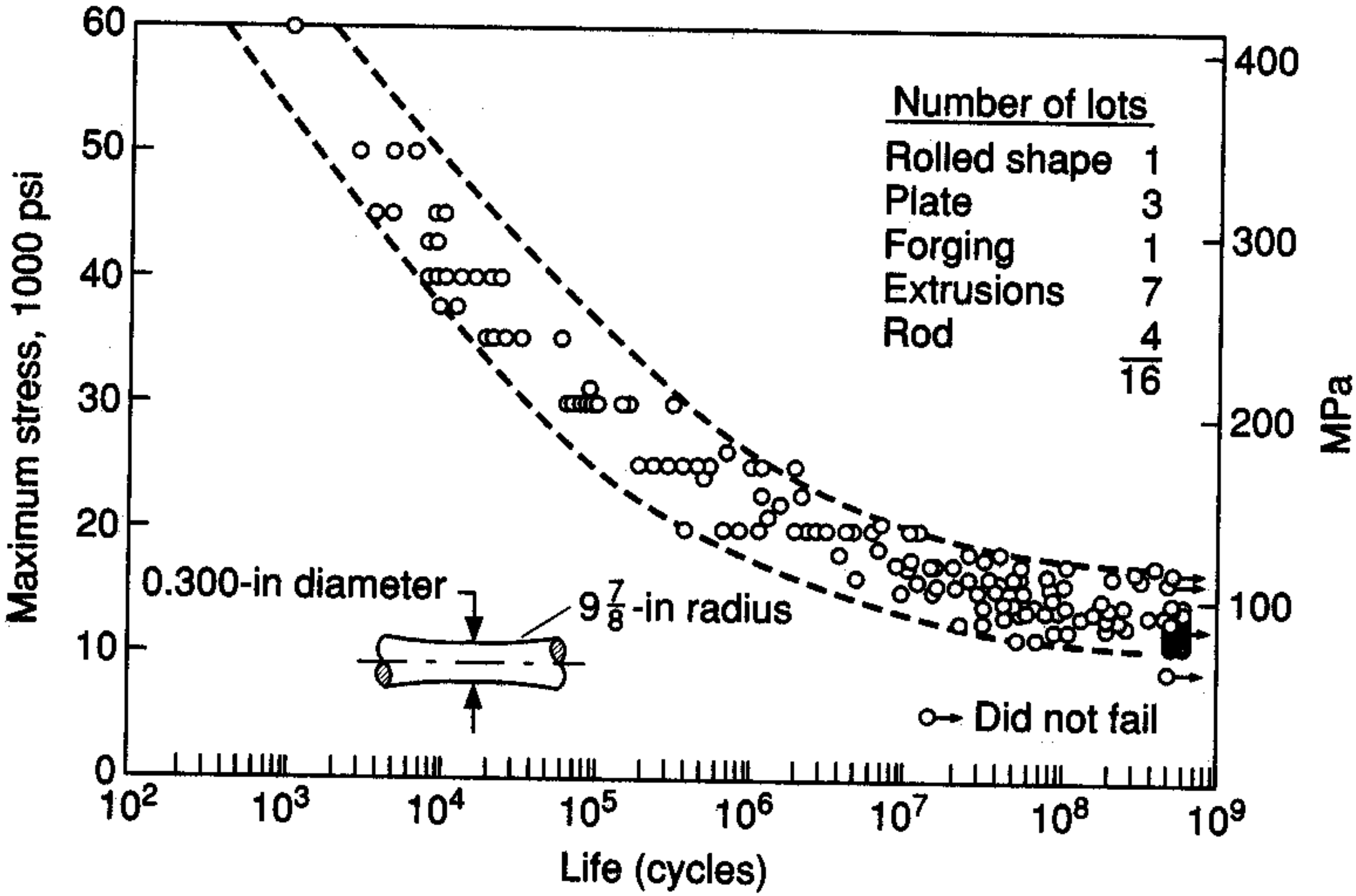
SN Curve


Monel Alloy
500
400
300
200
Stress Amplitude, MPa
0
1x10^8
2x10^8
3x10^8
4x10^8
5x10^8
Cycles to Failure
500
400
300
200
10^5
10^6
10^7
10^8
10^9
Cycles to Failure
Testing time
@ 30 Hz
1 hour
1 day
1 month
1 year

Fatigue Strength

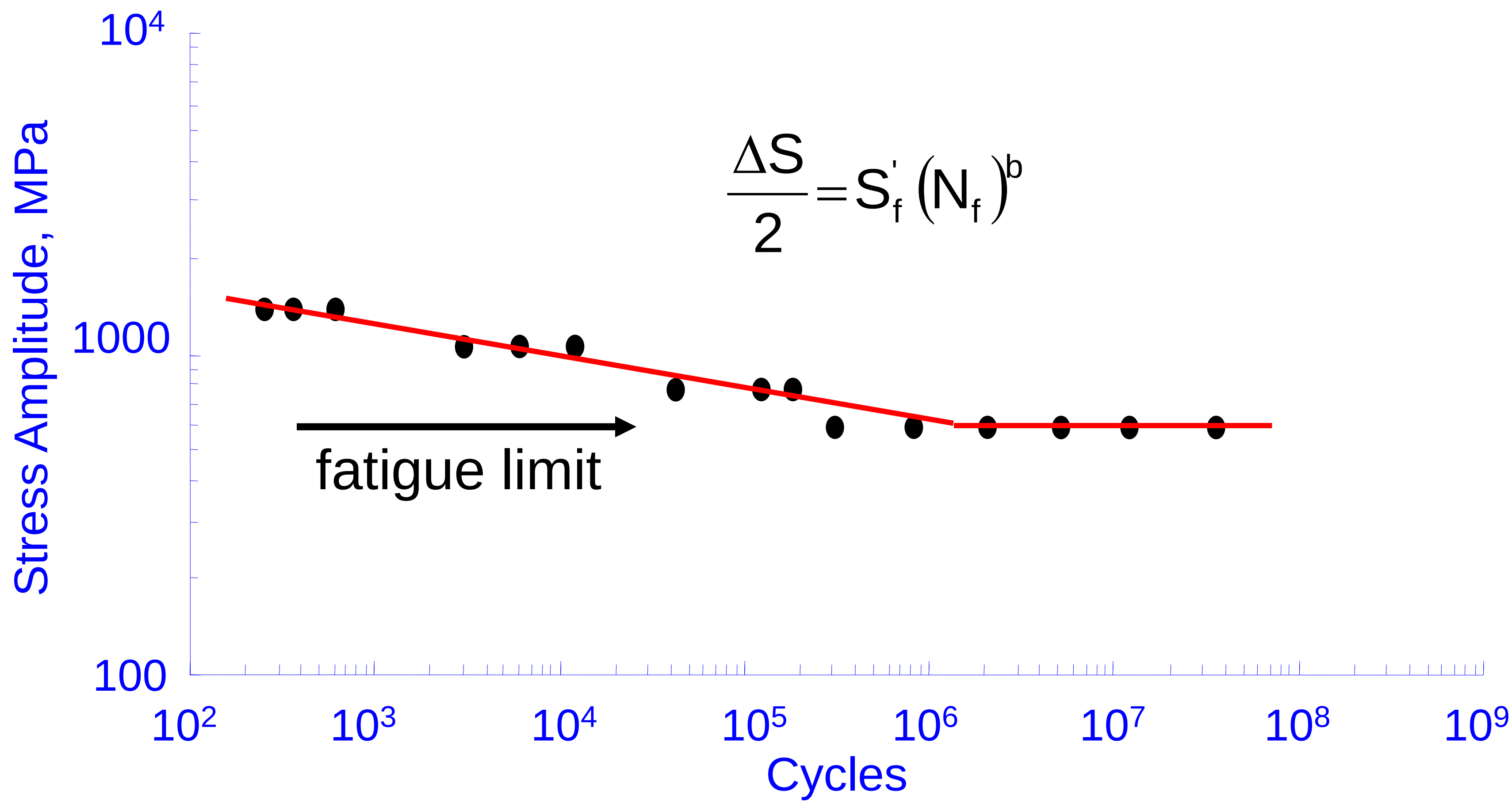
Alloy	Fatigue Life 10^5	10^6	10^7	10^8	10^9
2014-T4	290	235	186	152	138
2024-T4	297	214	166	145	138
6061-T6	186	152	117	104	90
7075-T6	276	200	166	152	145

6061-T6 Aluminum Test Data



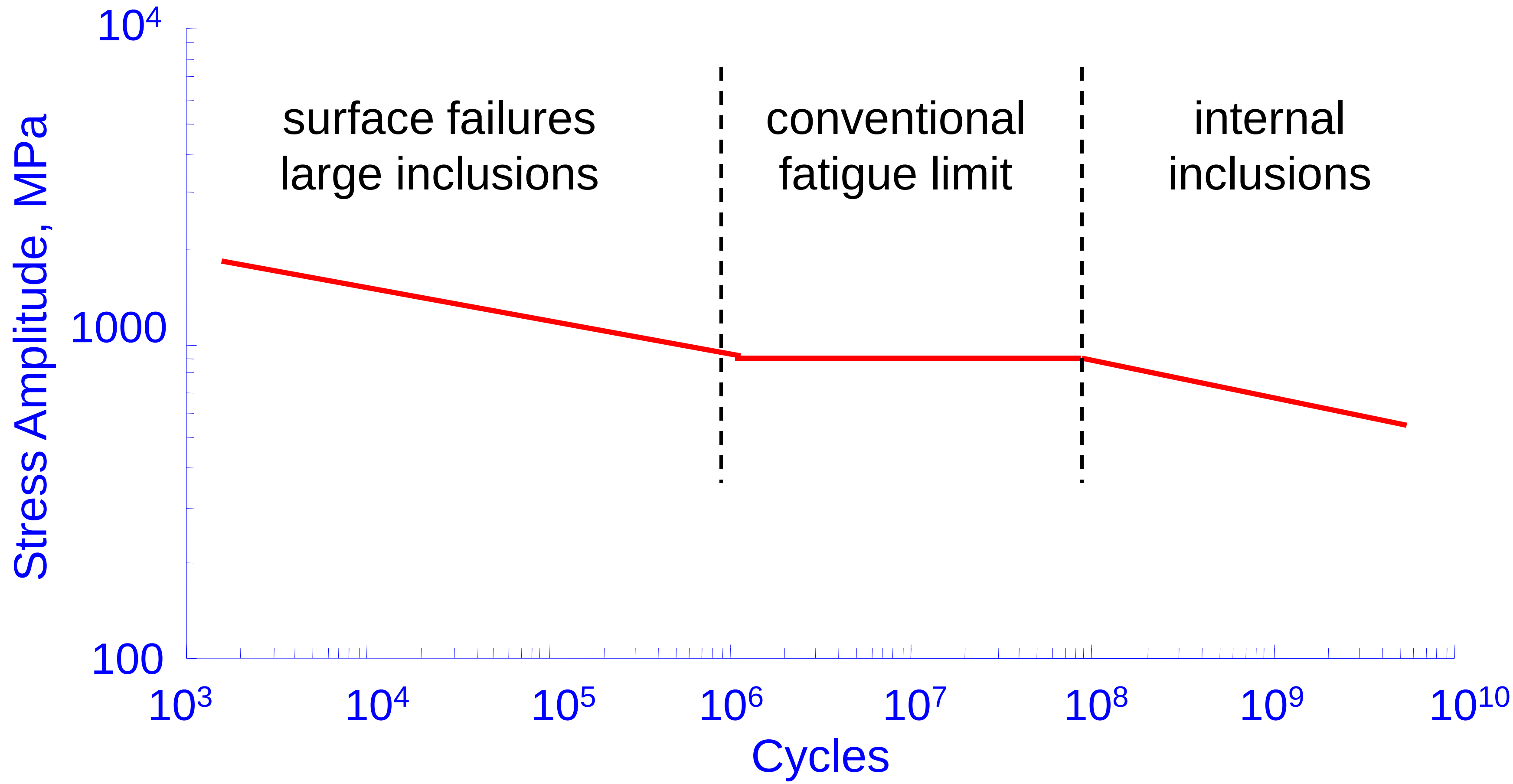
Sharpe et. al. Fatigue Design of Aluminum Components and Structures , 1996

SN Curve for Steel

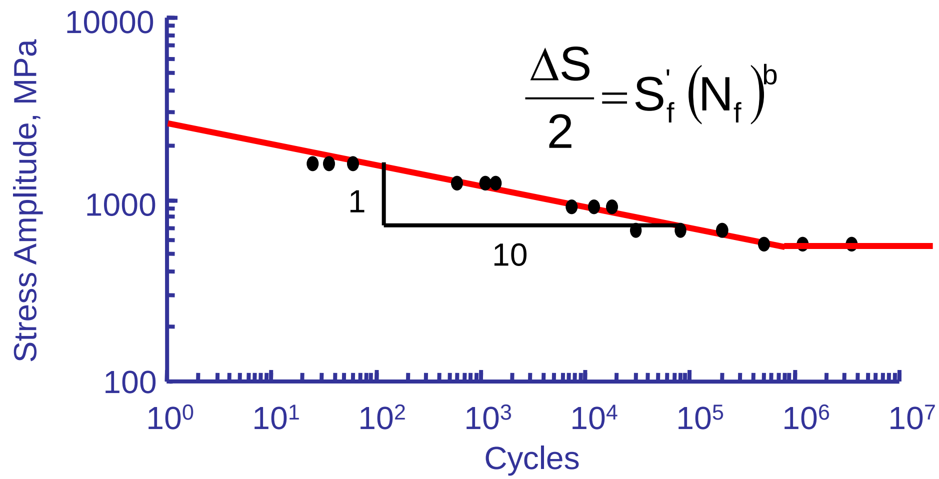


The fatigue limit is usually only found in steel laboratory specimens

Very High Cycle Fatigue of Steel



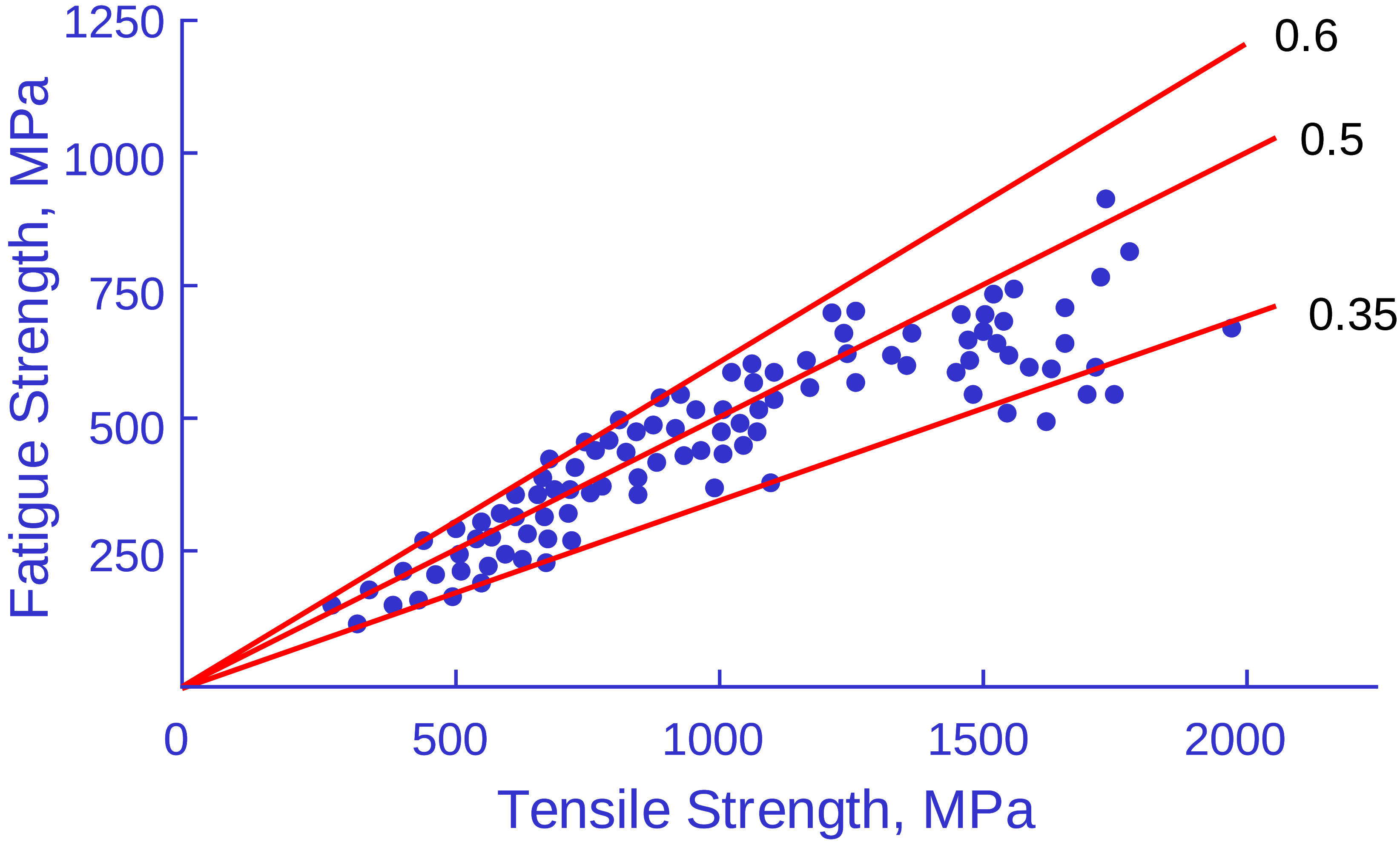
Fatigue Damage



$$N_f = \left(\frac{\Delta S}{2 S_f^{'}} \right)^{\frac{1}{b}}$$

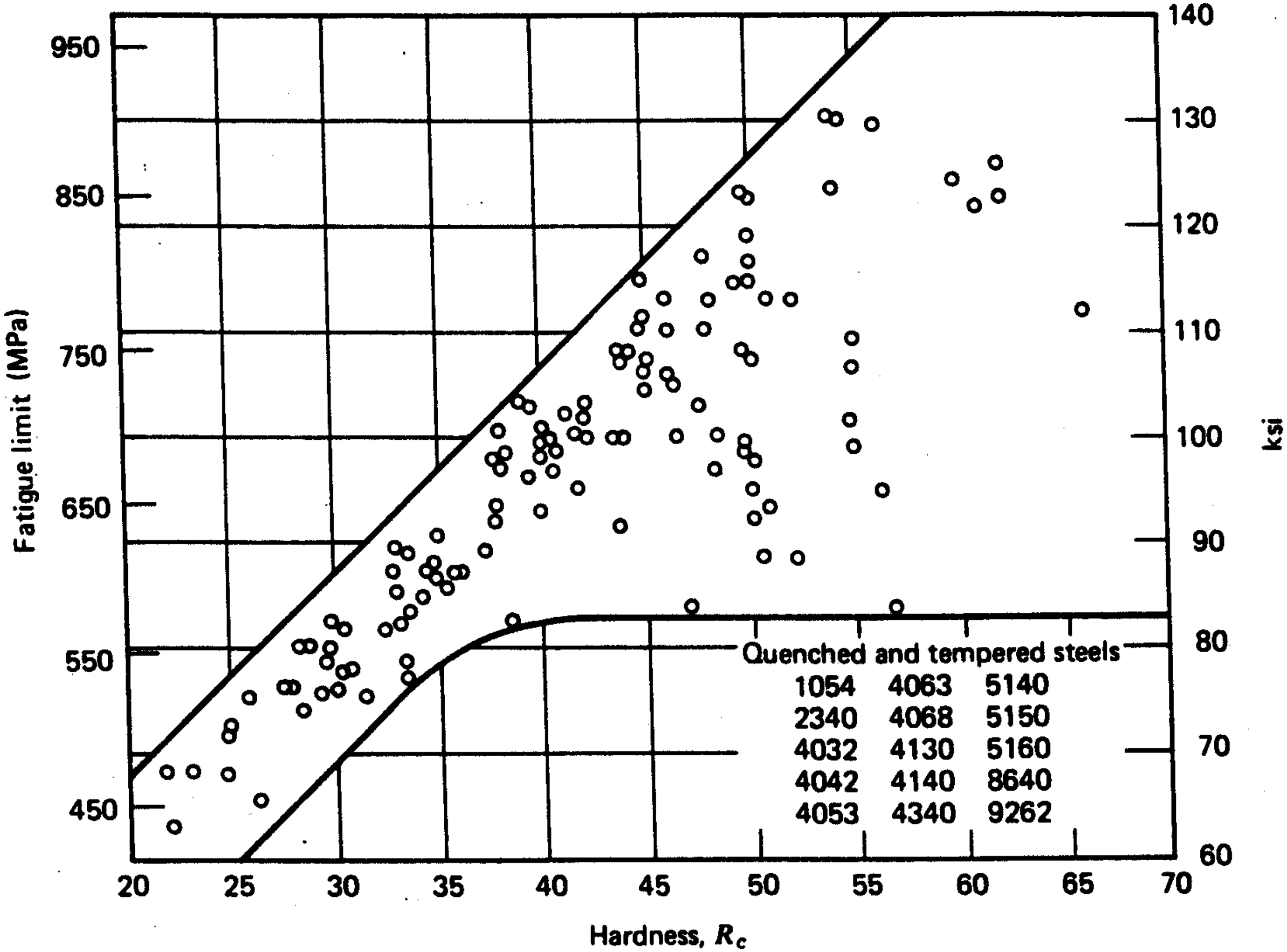
$$\text{Damage} \propto \Delta S^{10}$$

Fatigue Limit Strength Correlation

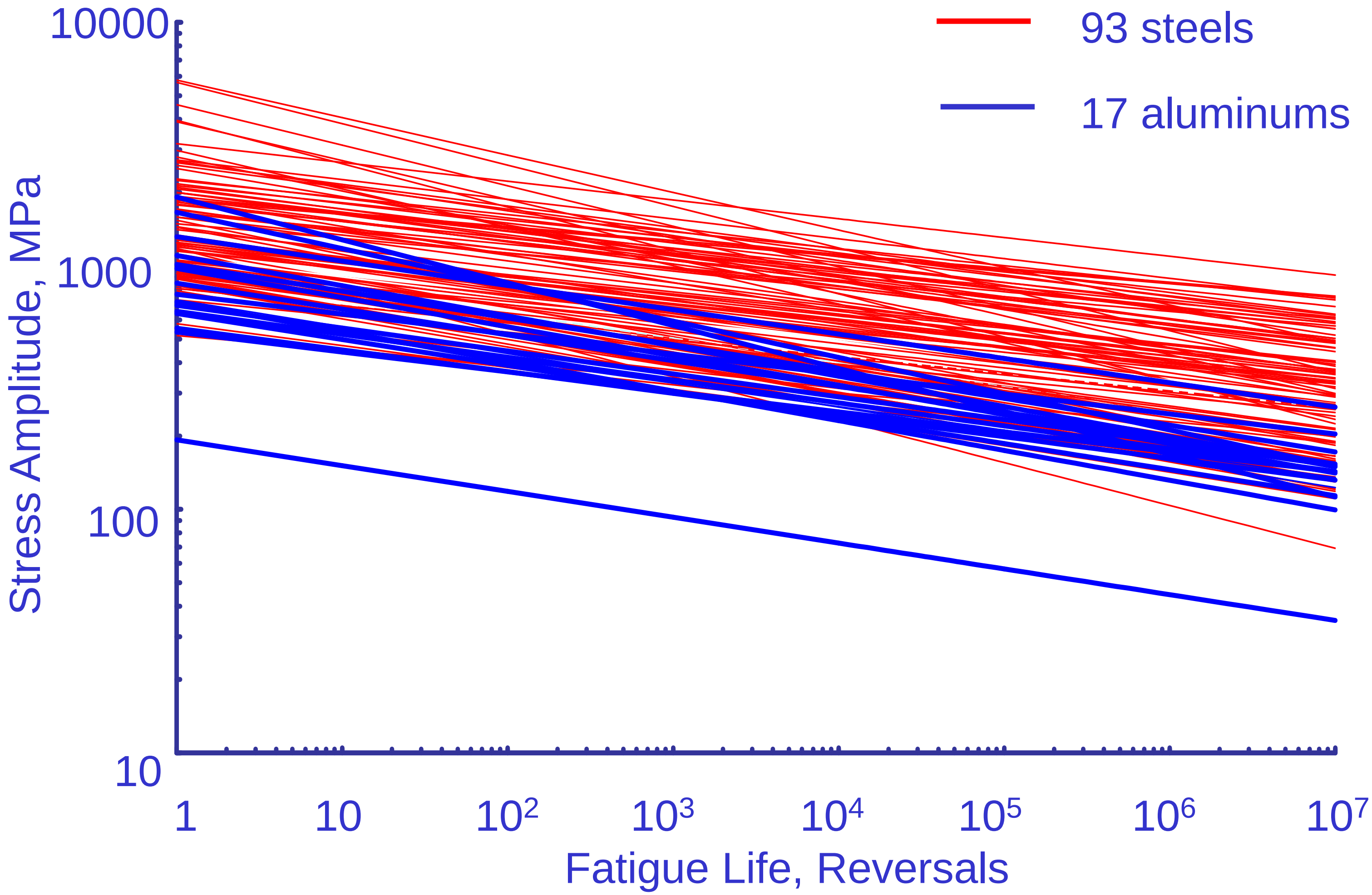


From Forrest, *Fatigue of Metals*, Pergamon Press, London, 1962

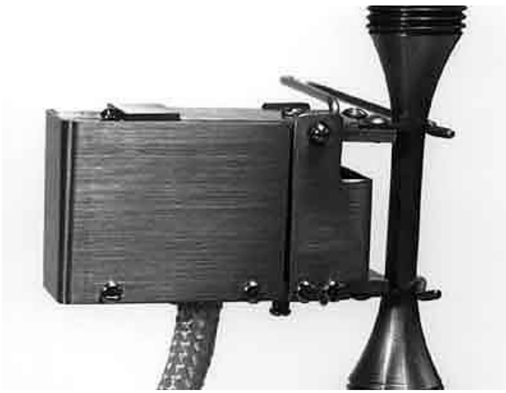
Fatigue Limit Strength Correlation

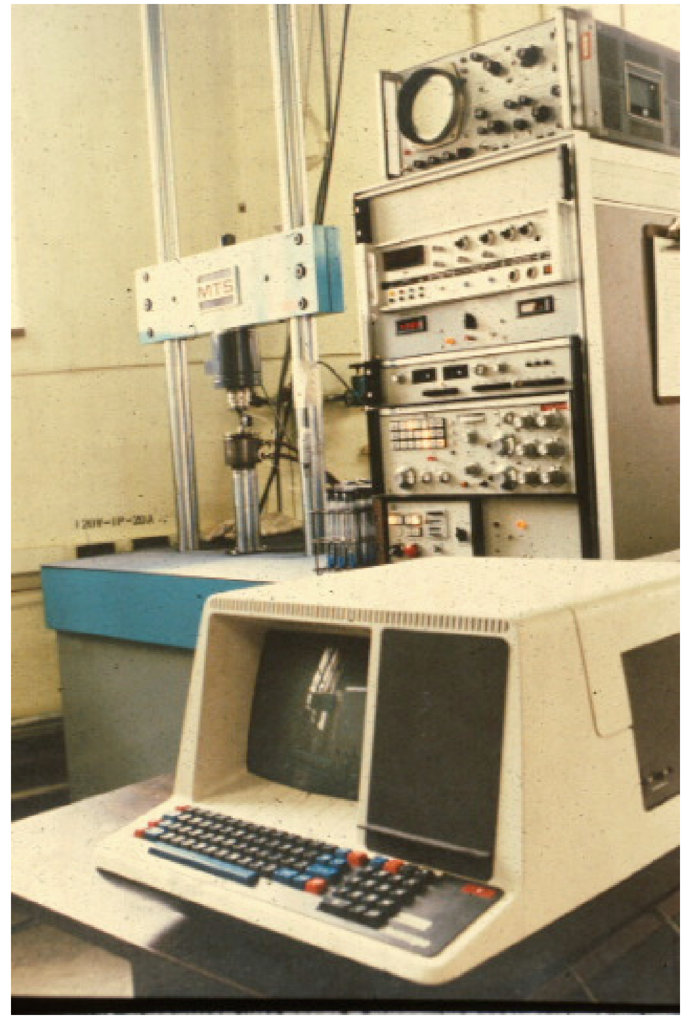


SN Materials Data

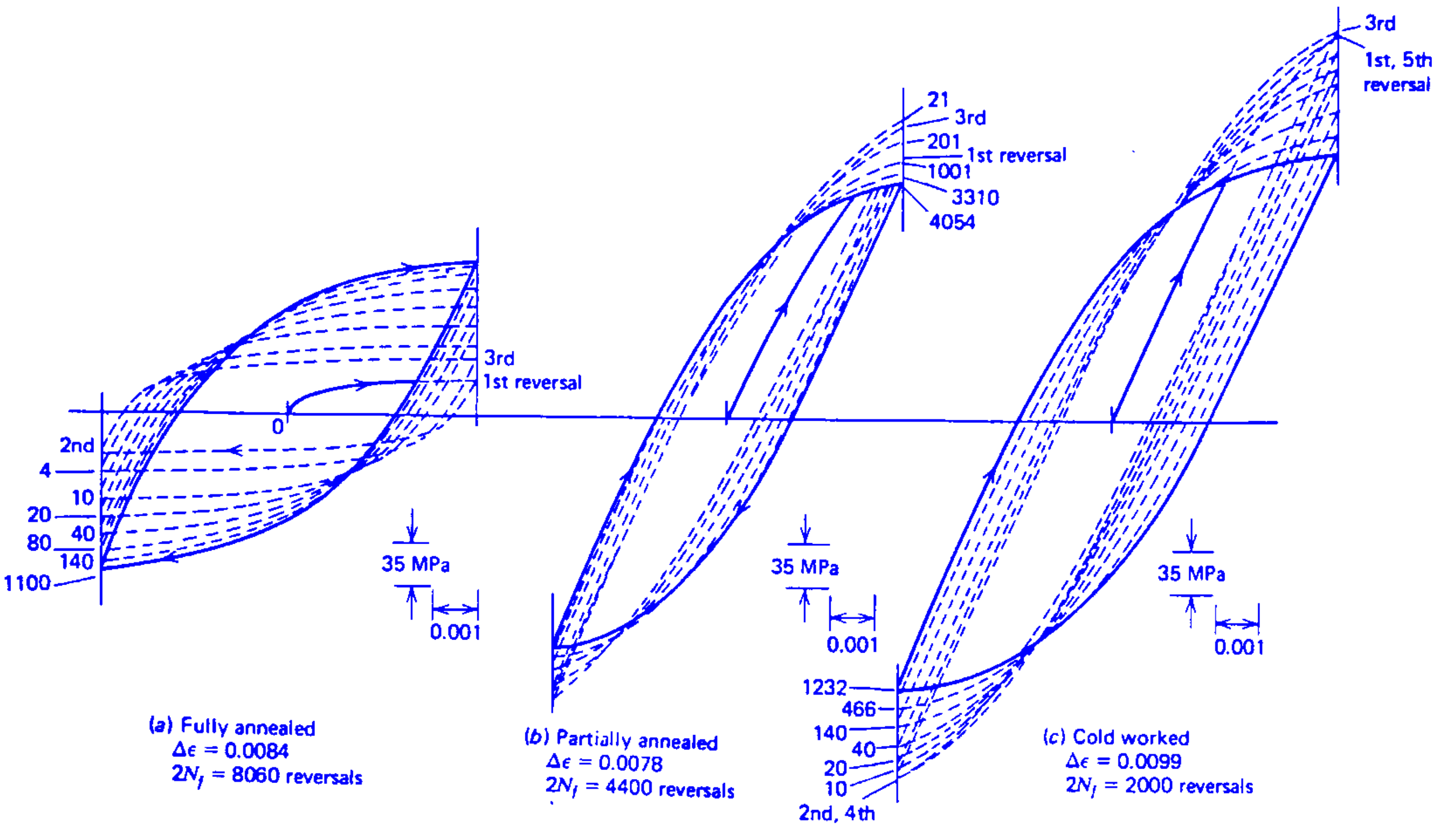


Strain Controlled Testing



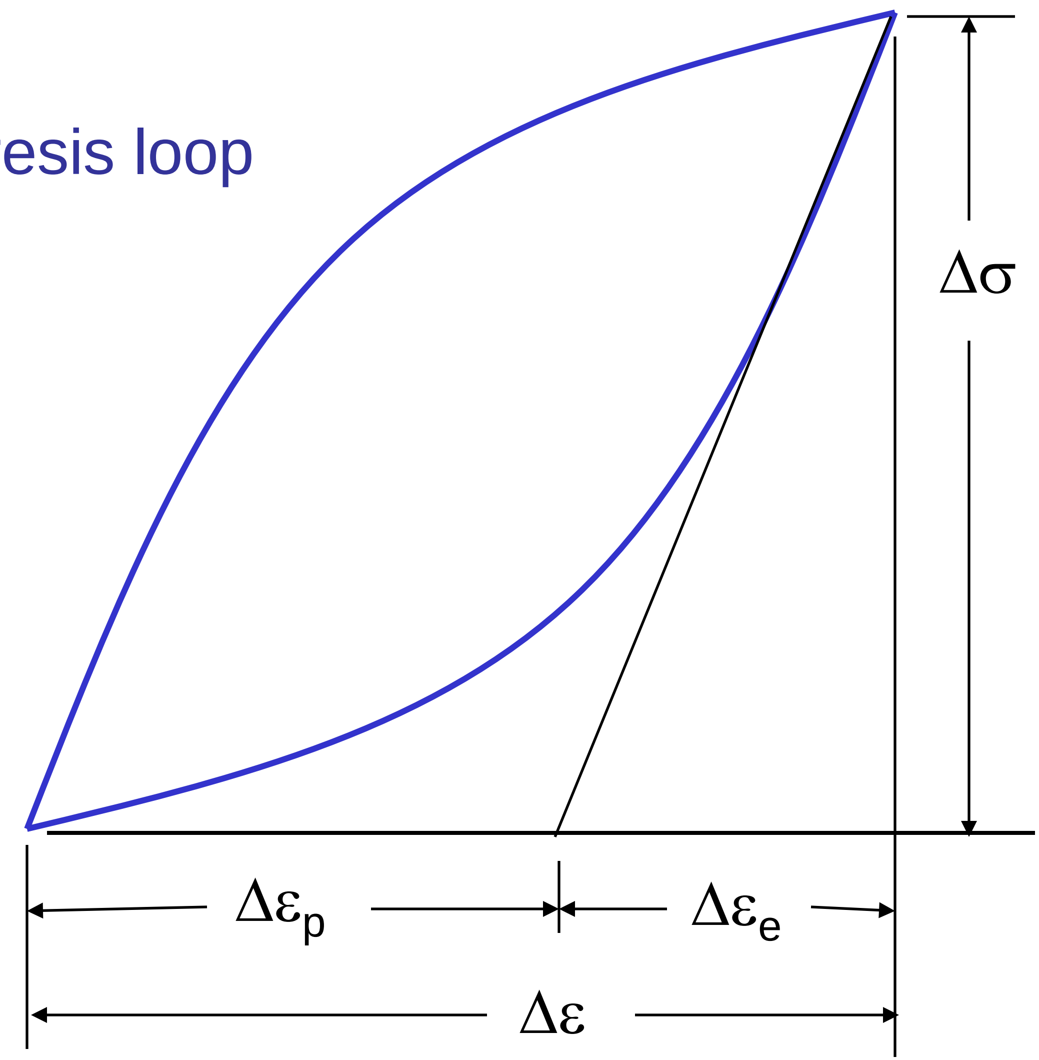


Cyclic Hardening / Softening

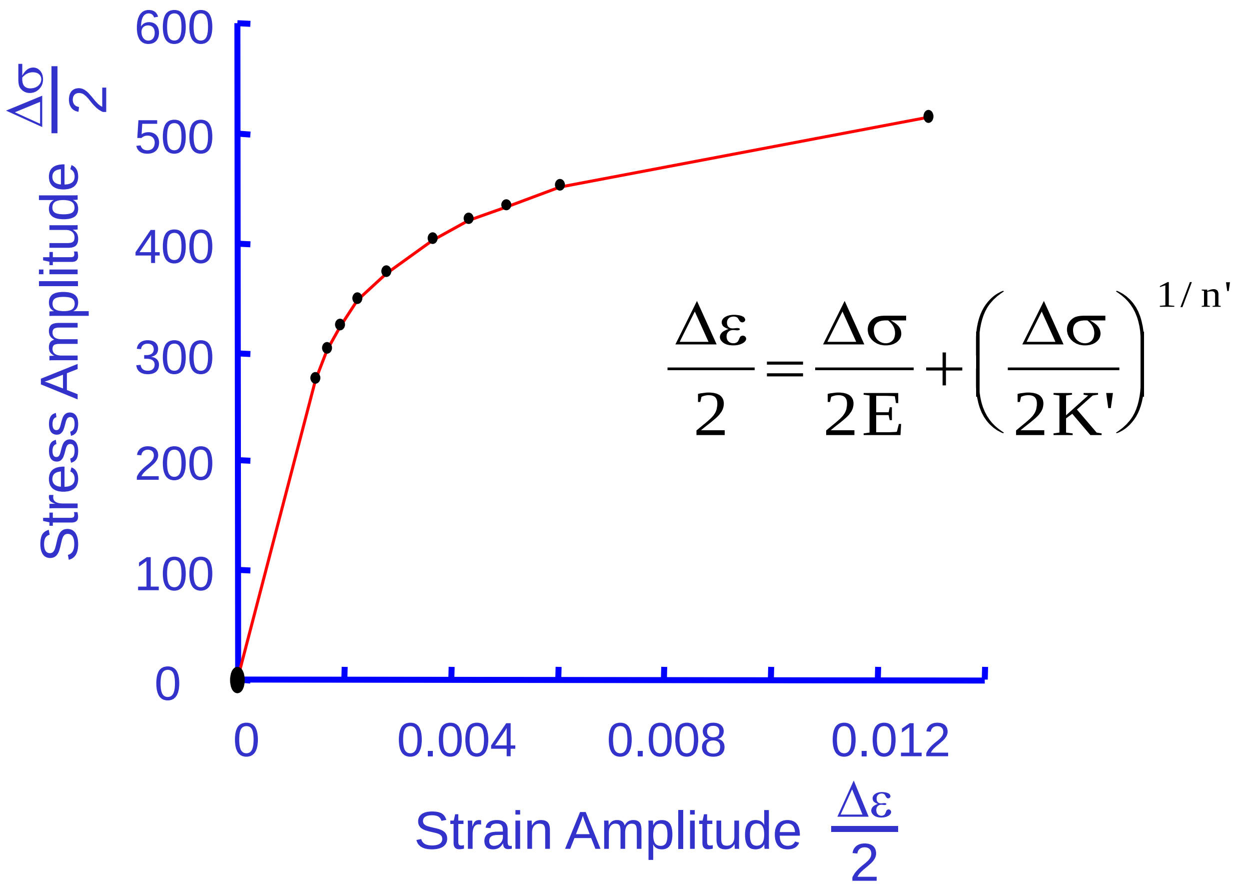


Stable Hysteresis Loop

Hysteresis loop

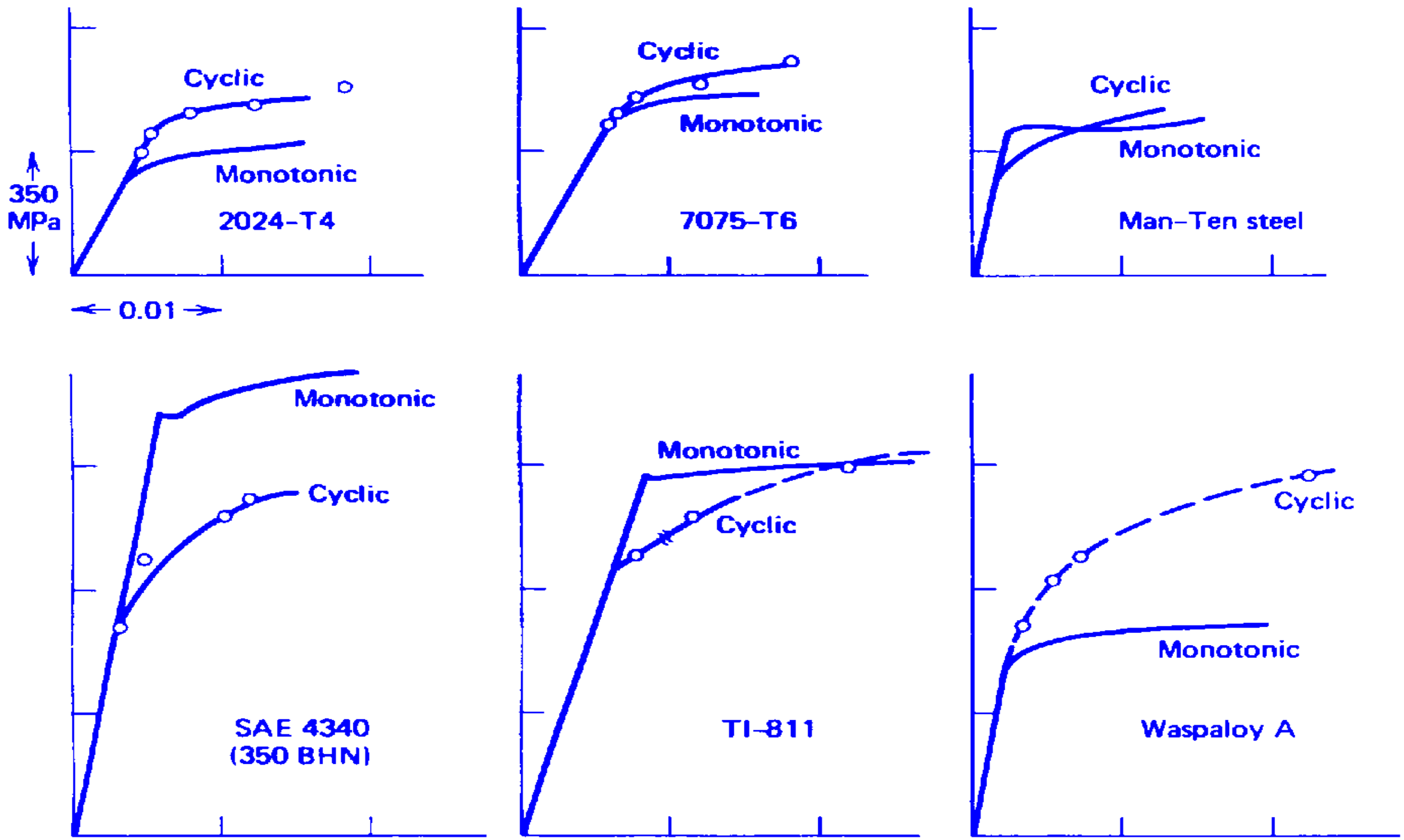


Strain-Life Data $\sigma - \varepsilon$

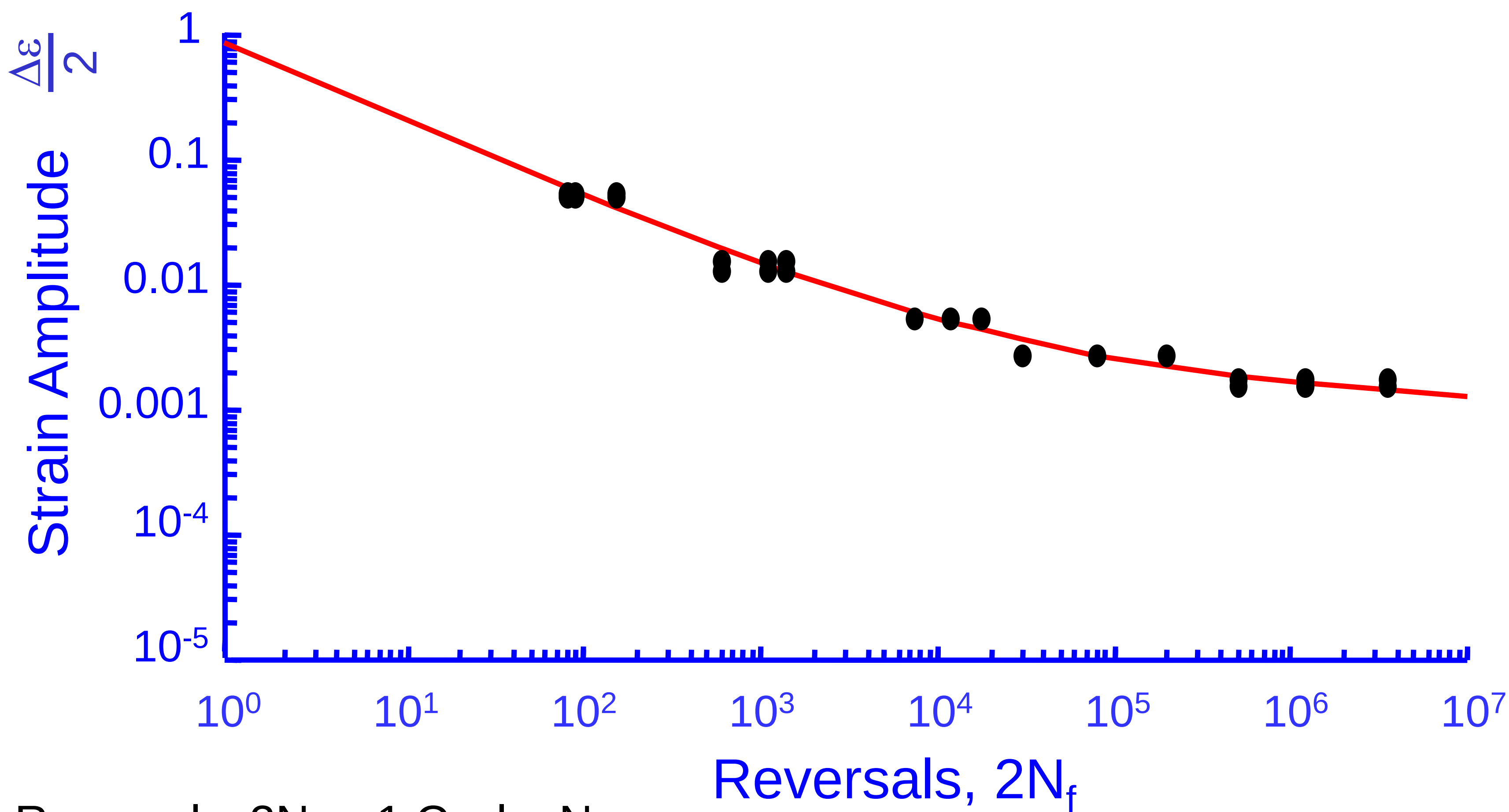


During cyclic deformation, the material deforms on a path described by the cyclic stress strain curve

Cyclic Stress Strain Curve

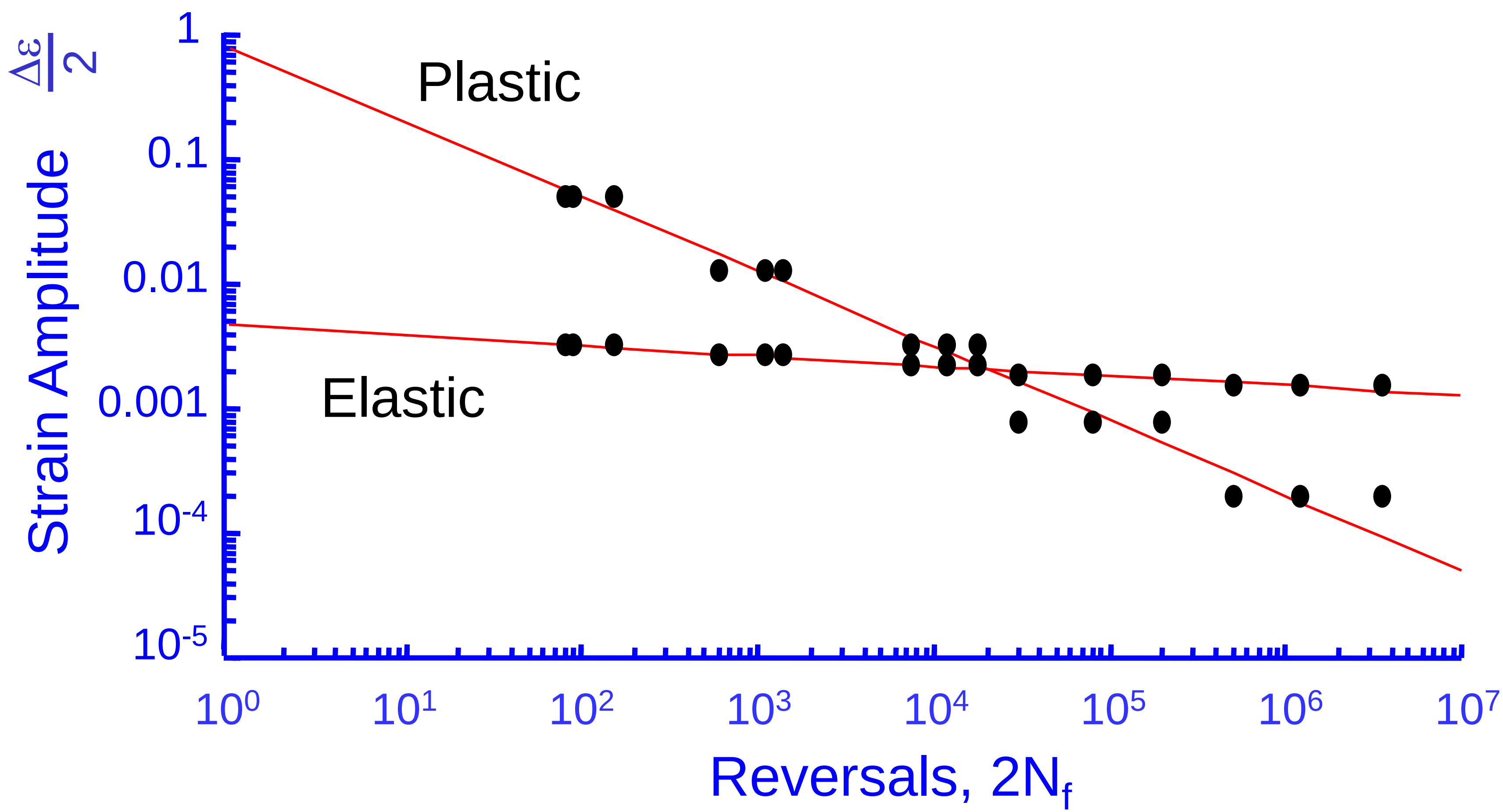


Strain-Life Data $\Delta\varepsilon$ - $2N_f$

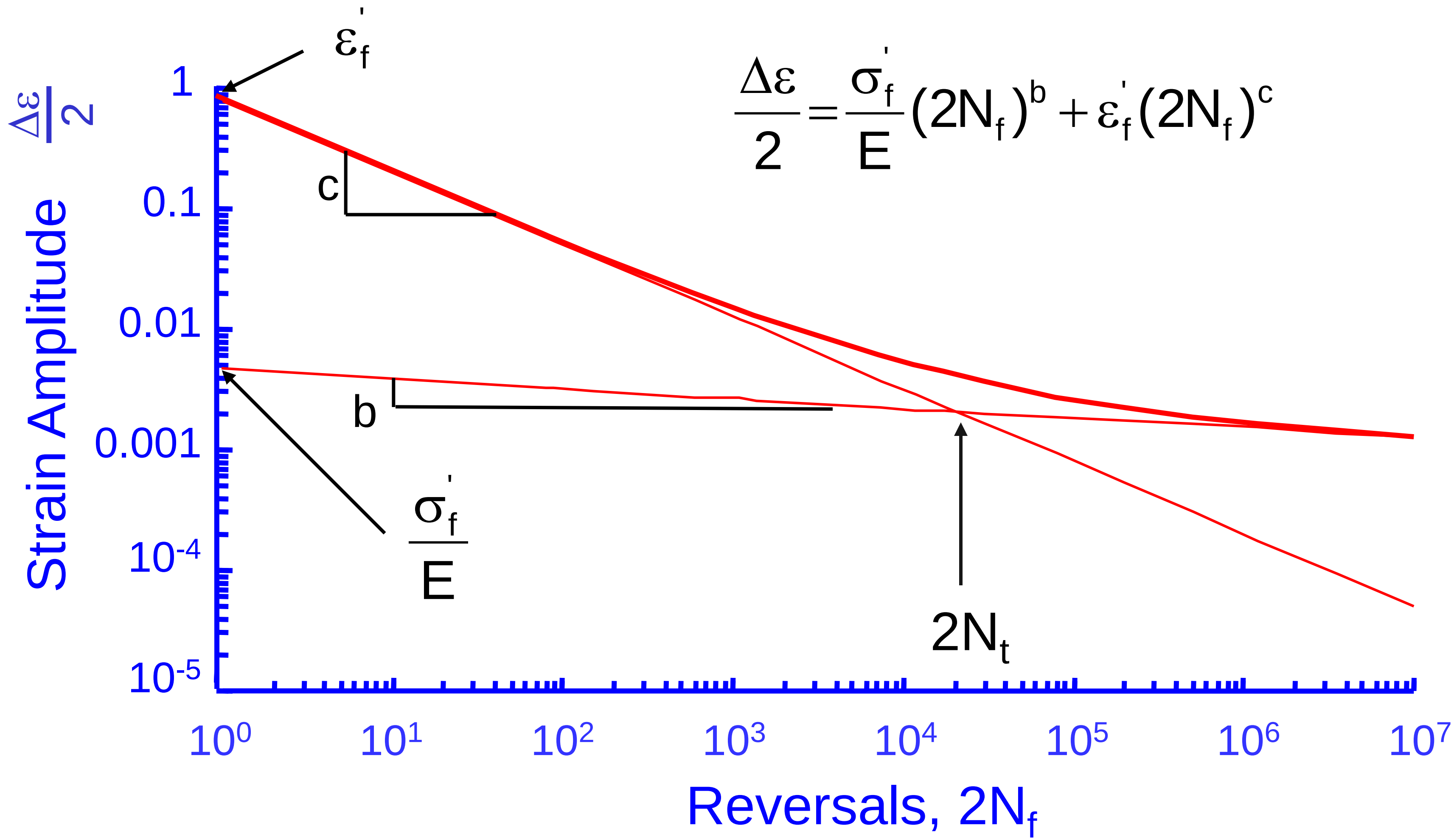


2 Reversals, $2N_f$ = 1 Cycle, N_f

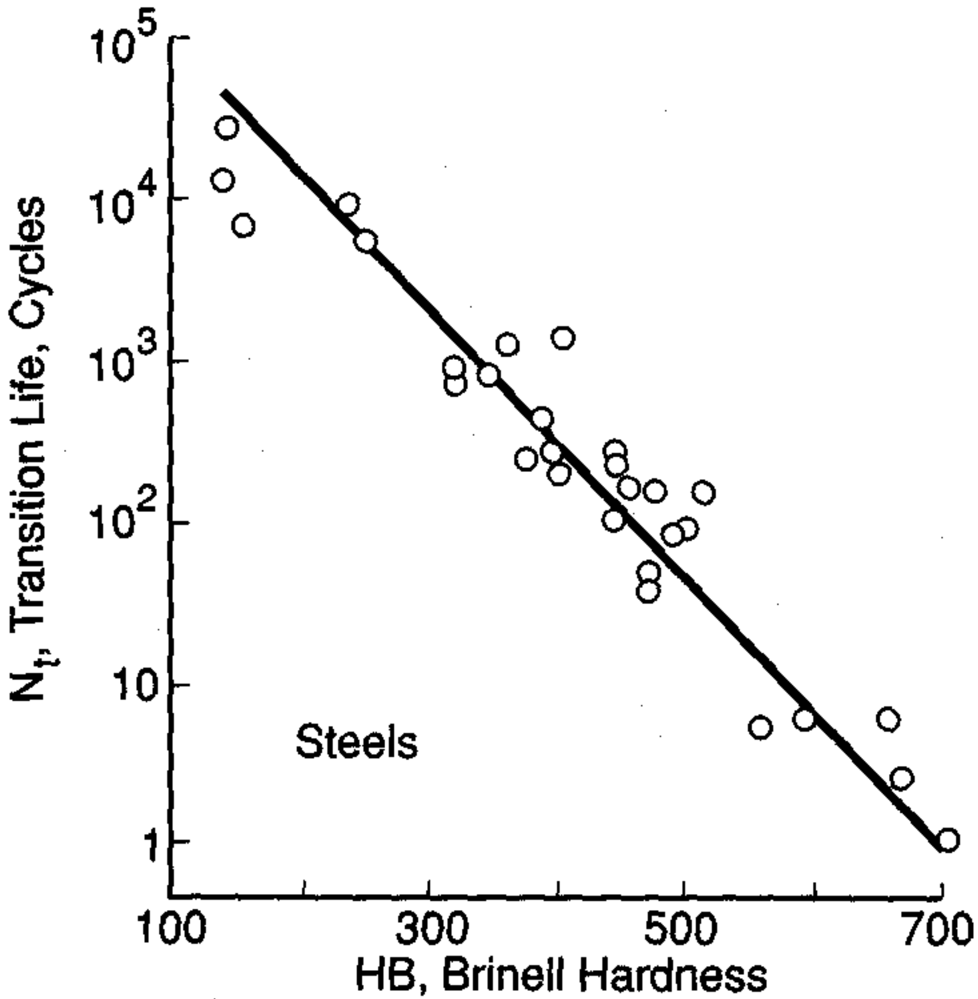
Elastic and Plastic Strain-Life Data



Strain-Life Curve

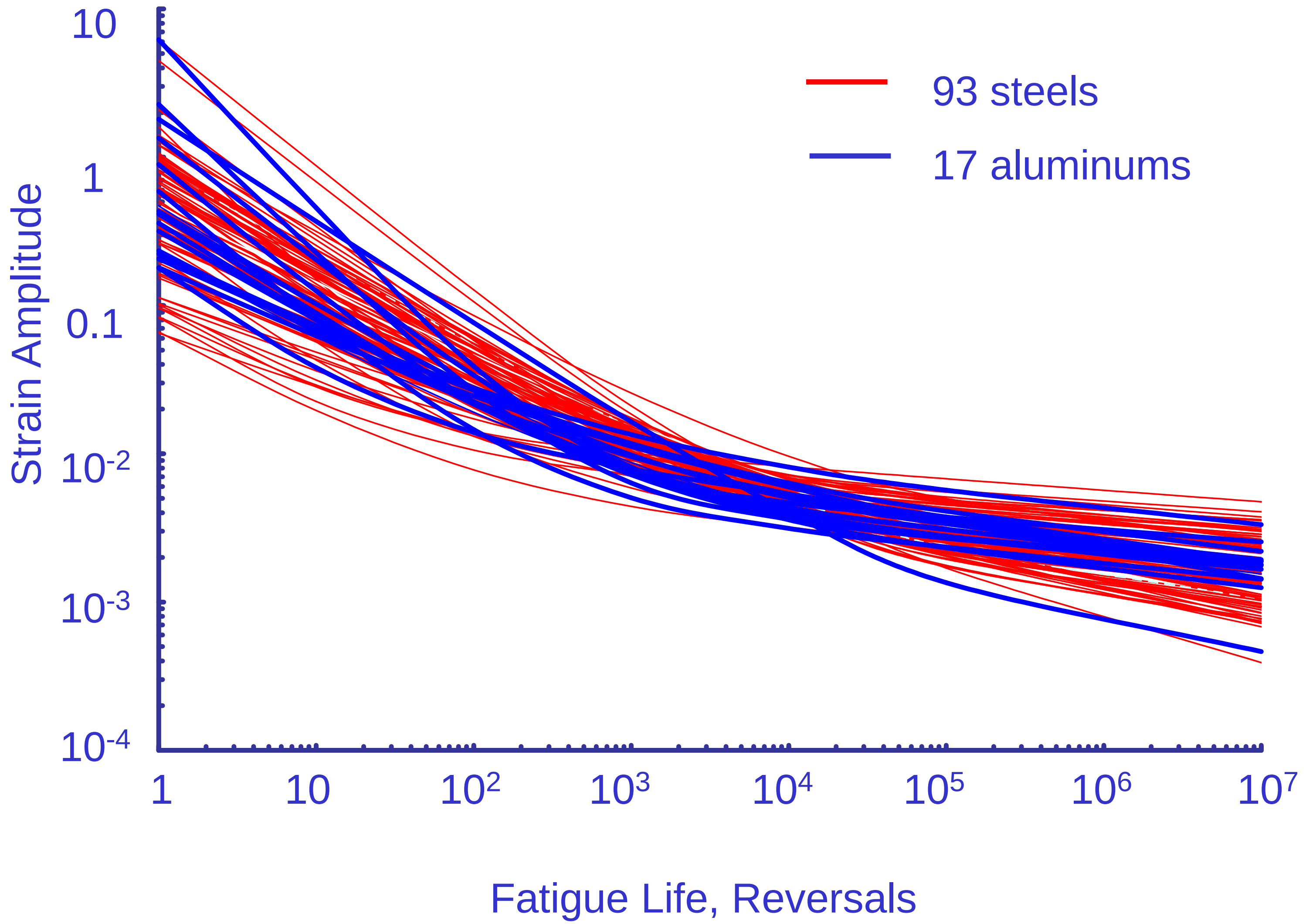


Transition Fatigue Life



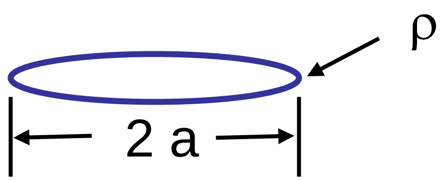
From Dowling, Mechanical Behavior of Materials, 1999

εN Materials Data



Crack Growth Testing

Stress Concentration of a Crack



$$K_T = 1 + 2\sqrt{\frac{a}{\rho}}$$

$$K_T \sim 2000$$

for a crack

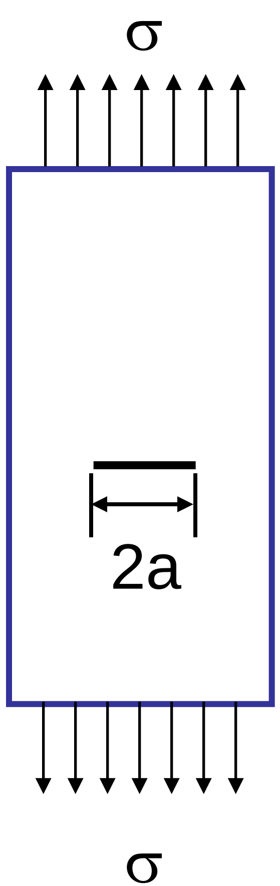
$a \sim 10^{-3}$

$\rho \sim 10^{-9}$

$$\sigma_{local} = 2000\,\sigma_{applied}$$

Traditional material properties like tensile strength are not very useful for cracked structures

Stress Intensity Factor

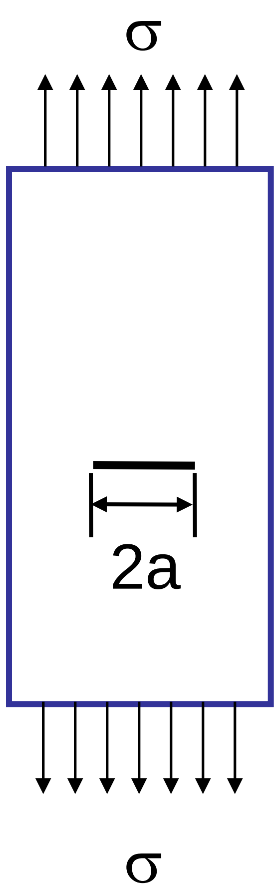


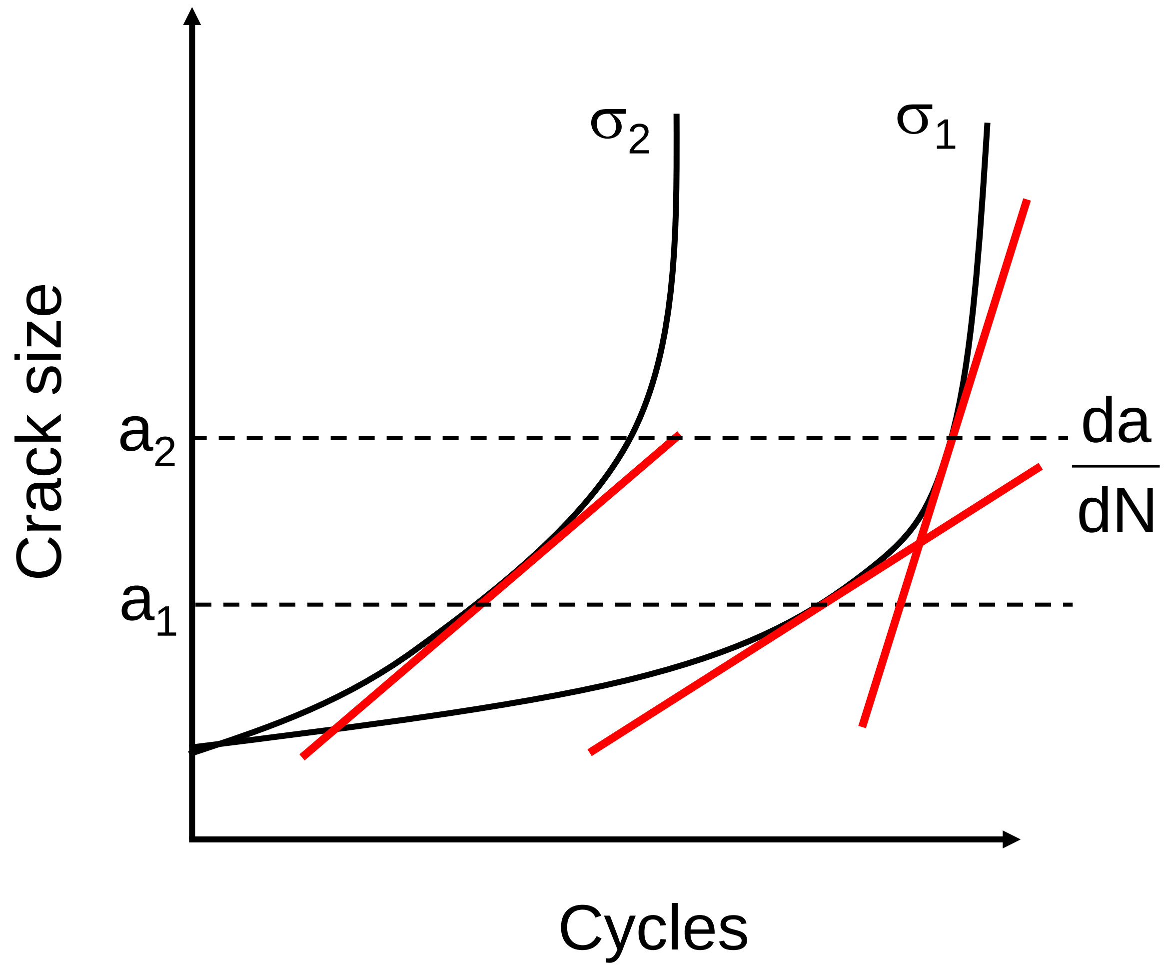
$$K = \sigma \sqrt{\pi a}$$

K characterizes the magnitude of the stresses, strains, and displacements in the neighborhood of a crack tip

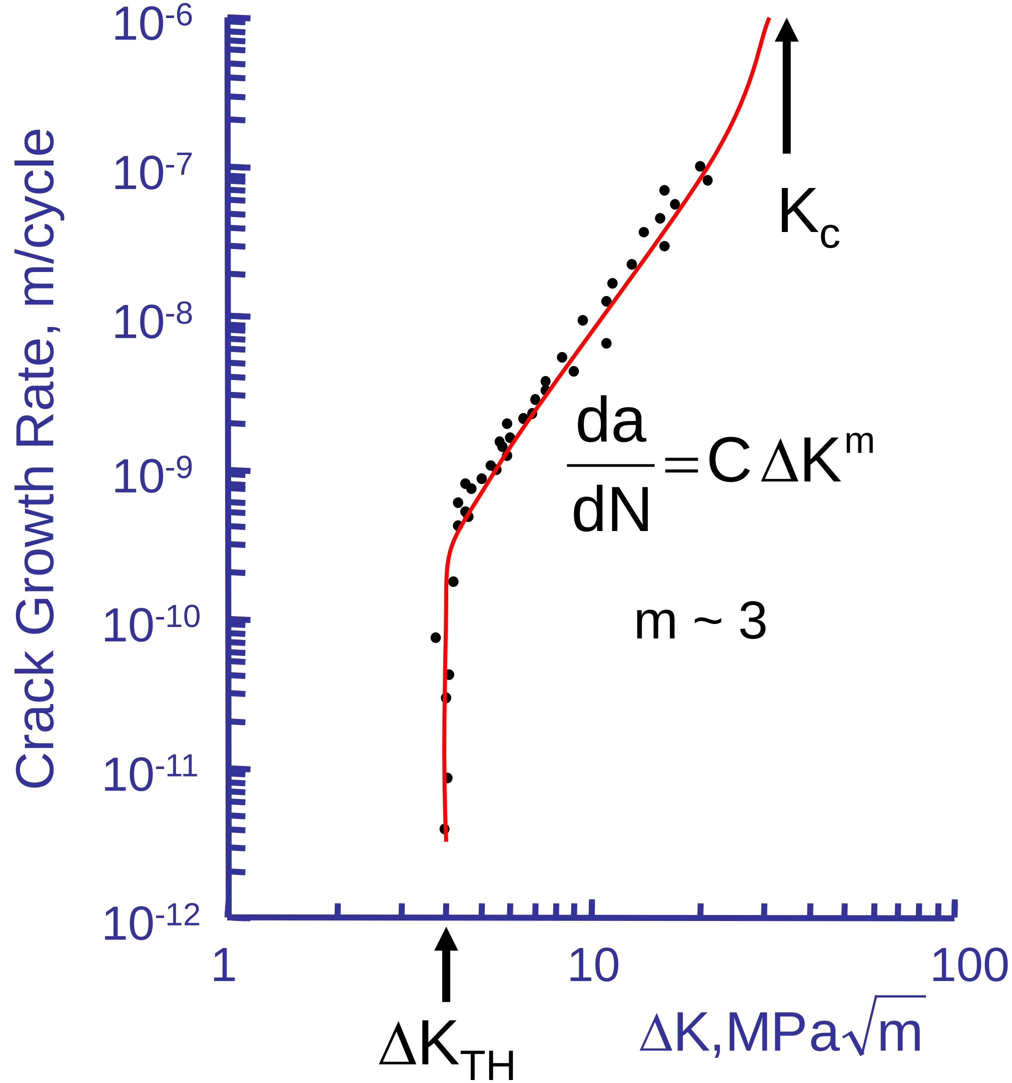
Two cracks with the same K will have the same behavior

Crack Growth Measurements





Crack Growth Data



Threshold Region

$$\Delta K_{TH} > \Delta\sigma \sqrt{\pi a}\; f\left(\frac{a}{w}\right)$$

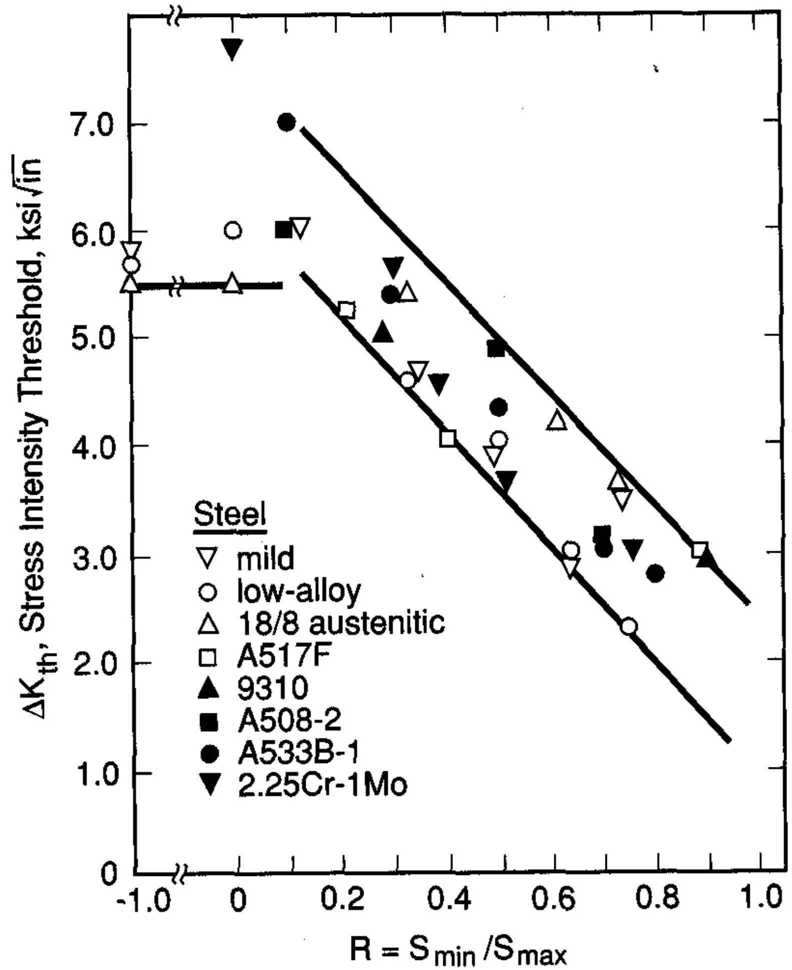
threshold stress intensity

flaw shape

flaw size

operating stresses

Threshold Stress Intensity



From Dowling, Mechanical Behavior of Materials, 1999

Non-propagating Crack Sizes

Small cracks are frequently semielliptical surface cracks

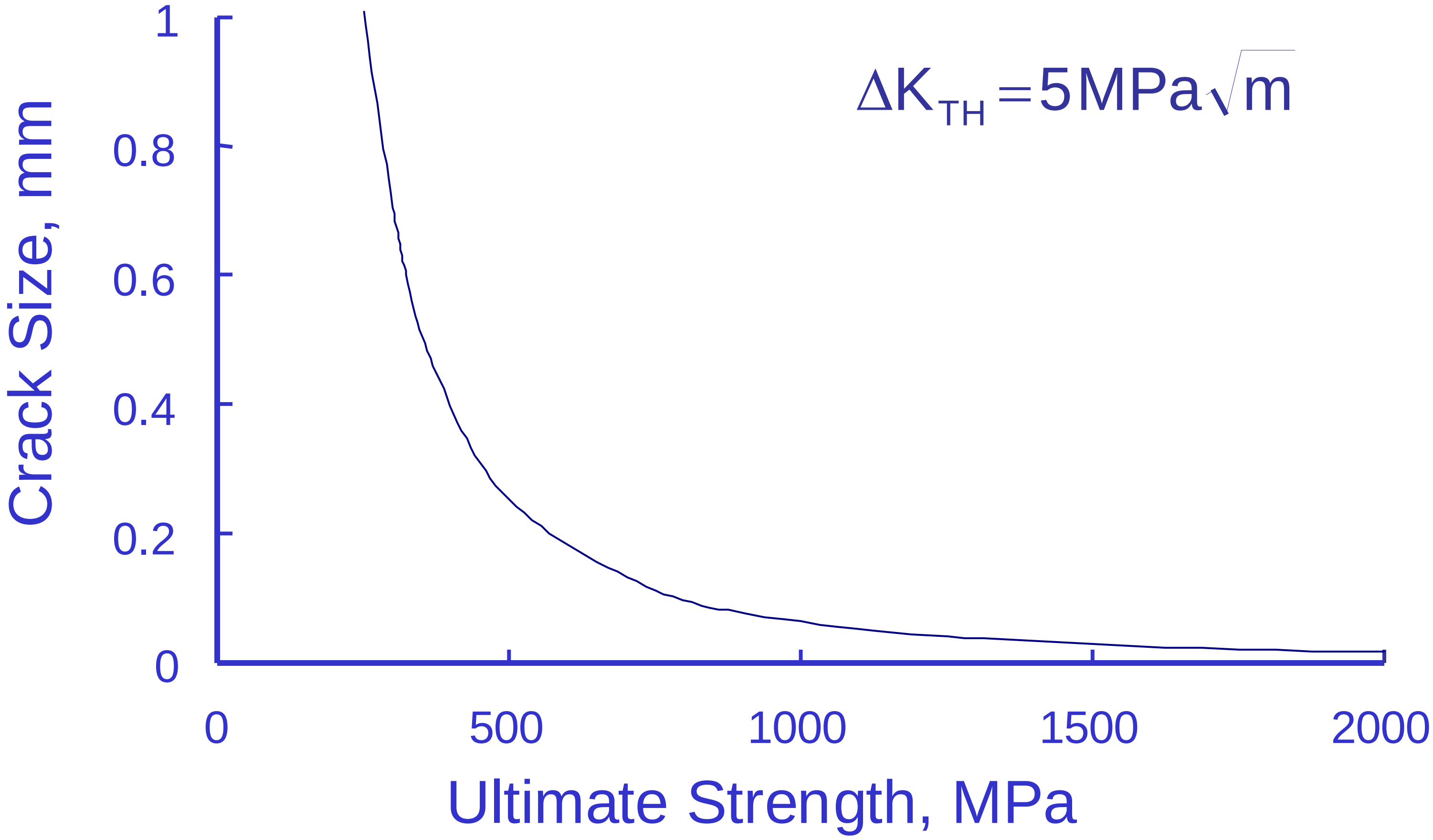
$$\Delta K_{TH} > \Delta\sigma 1.12 \frac{2}{\pi}\sqrt{\pi a}$$

$$a_c = 0.63\left(\frac{\Delta K_{TH}}{\Delta\sigma}\right)^2$$

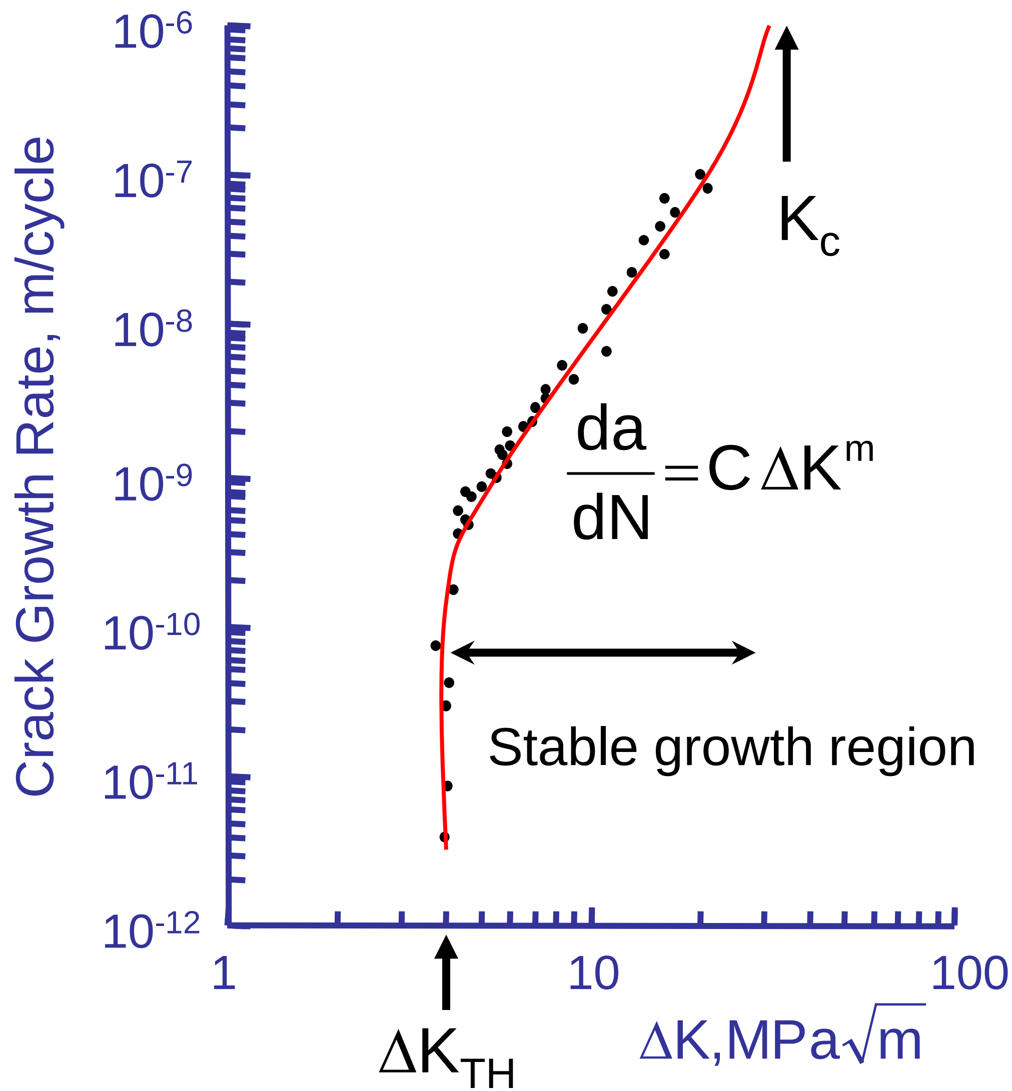
Smooth specimen fatigue limit $\approx \dfrac{\sigma_u}{2}$

$$a_c = 2.52\left(\frac{\Delta K_{TH}}{\sigma_u}\right)^2$$

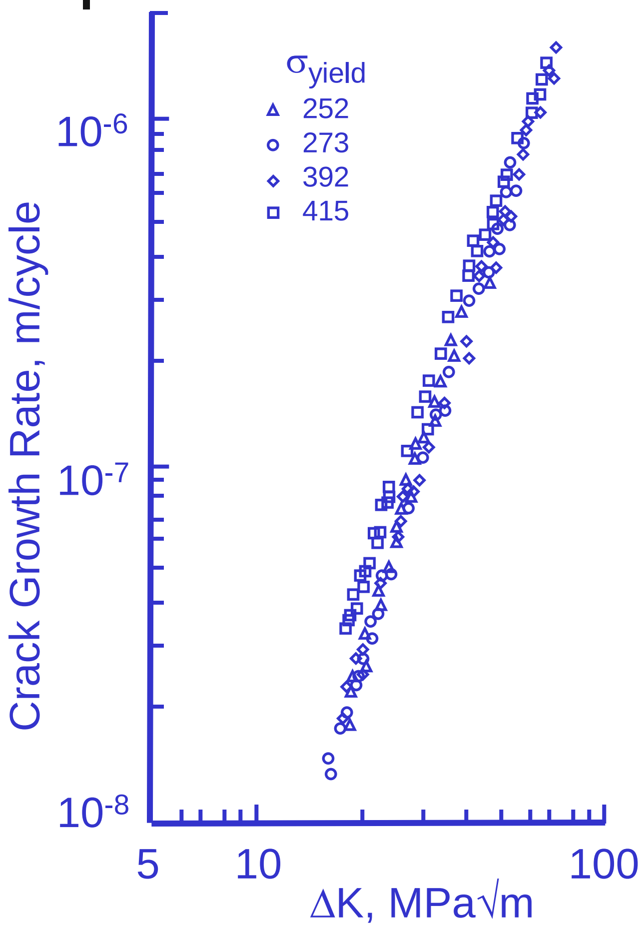
Non-propagating Crack Sizes



Stable Crack Growth



Crack Growth Data



Ferritic-Pearlitic Steel:

$$\frac{da}{dN} = 6.9 \times 10^{-12} \left(\Delta K \, MPa\sqrt{m}\right)^{3.0}$$

Martensitic Steel:

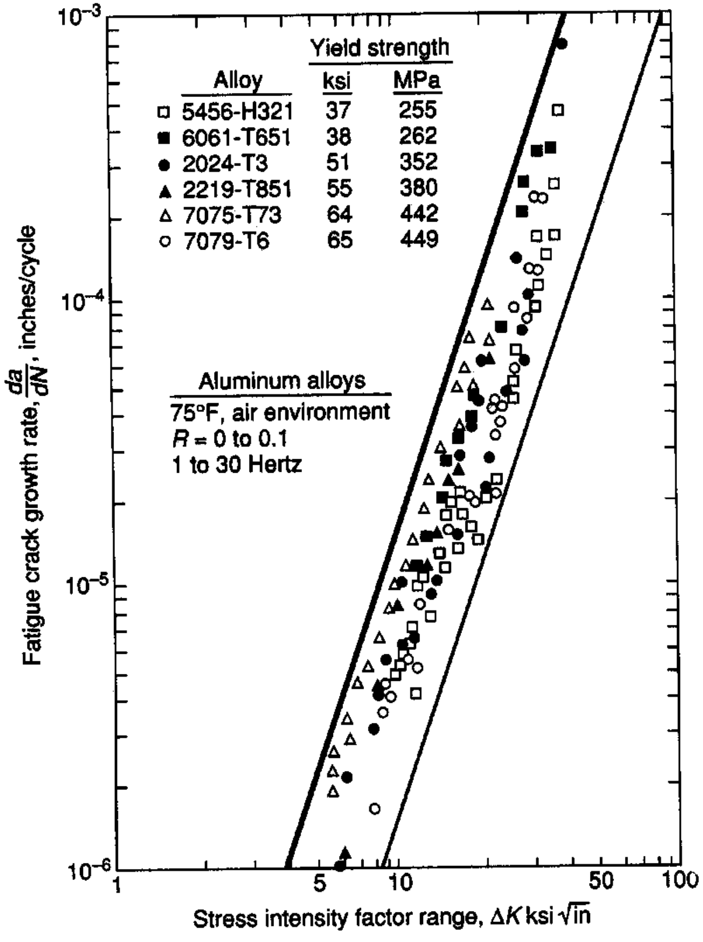
$$\frac{da}{dN} = 1.4 \times 10^{-10} \left(\Delta K \, MPa\sqrt{m}\right)^{2.25}$$

Austenitic Stainless Steel:

$$\frac{da}{dN} = 5.6 \times 10^{-12} \left(\Delta K \, MPa\sqrt{m}\right)^{3.25}$$

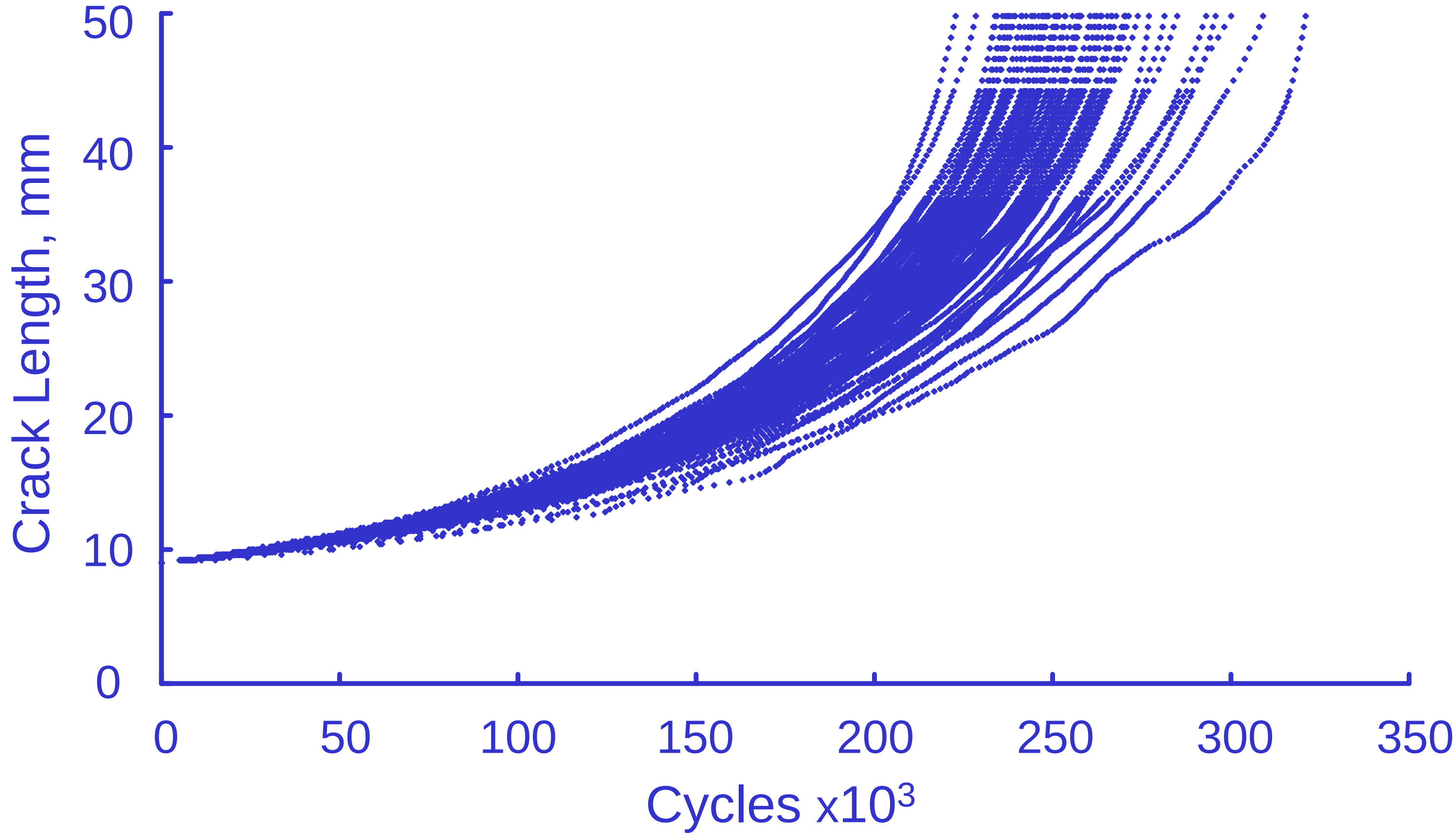
Barsom, "Fatigue Crack Propagation in Steels of Various Yield Strengths"
Journal of Engineering for Industry, Trans. ASME, Series B, Vol. 93, No. 4, 1971, 1190-1196

Aluminum Crack Growth Rate Data



Sharp, Nordmark and Menzemer, *Fatigue Design of Aluminum Components and Structures*, 1996

Crack Growth Data



Virkler, Hillberry and Goel, "The Statistical Nature of Fatigue Crack Propagation", Journal of Engineering Materials and Technology, Vol. 101, 1979, 148-153

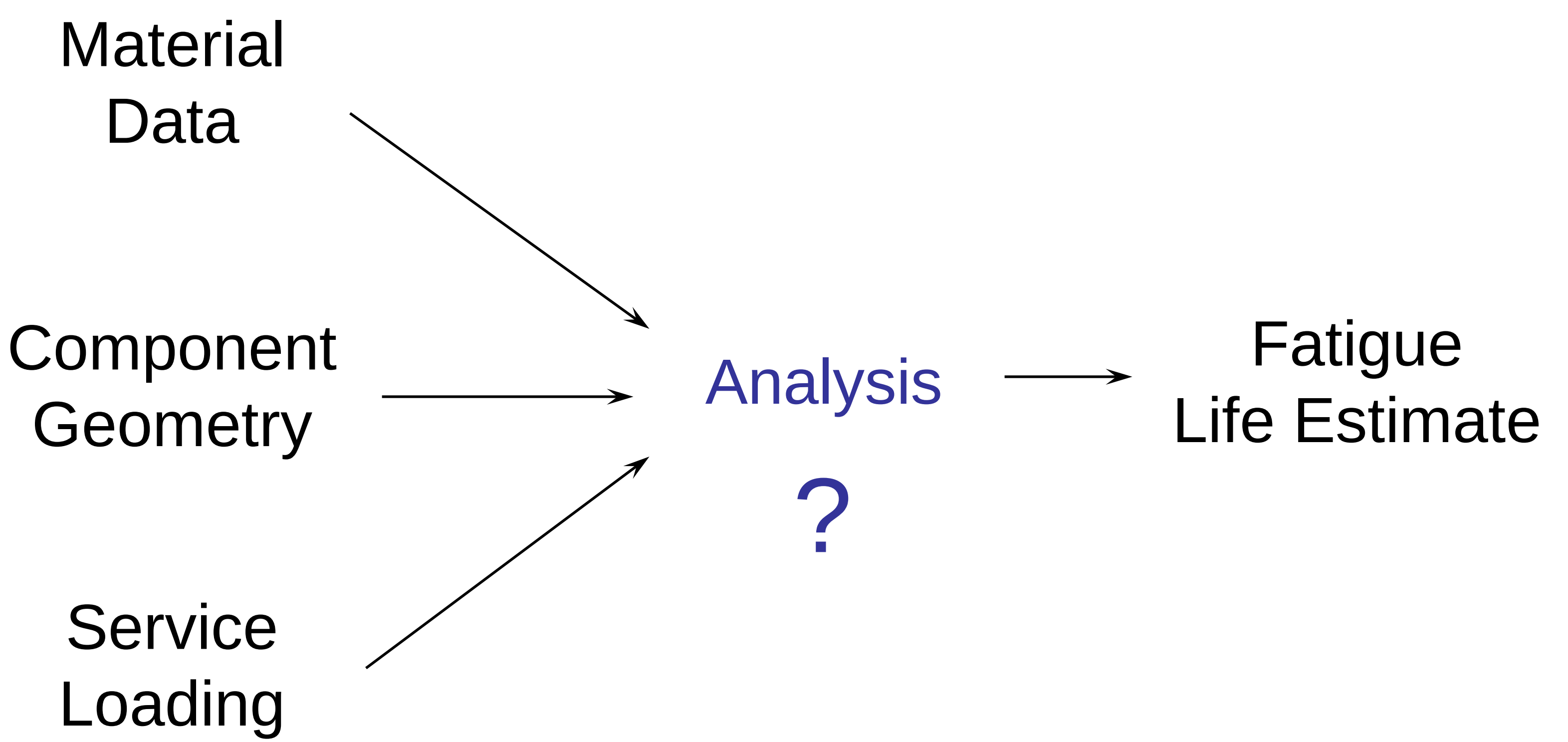
Things Worth Remembering

Method	Physics	Size
Stress-Life	Crack Nucleation	0.01 mm
Strain-Life	Microcrack Growth	0.1 - 1 mm
Crack Growth	Macrocrack Growth	> 1mm

Fatigue, How and Why

- Physics of Fatigue
- Material Properties
- **Similitude**
- Fatigue Calculator

Fatigue Analysis



The Similitude Concept

Why Fatigue Modeling Works !

What is the Similitude Concept

The “Similitude Concept” allows engineers to relate the behavior of small-scale cyclic material test specimens, defined under carefully controlled conditions, to the likely performance of real structures subjected to variable amplitude fatigue loads under either simulated or actual service conditions.

Fatigue Analysis Techniques

Stress - Life

BS 7608, Eurocode 3

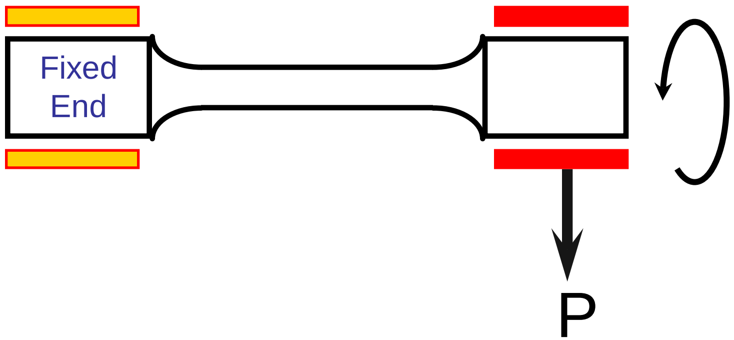
Strain - Life

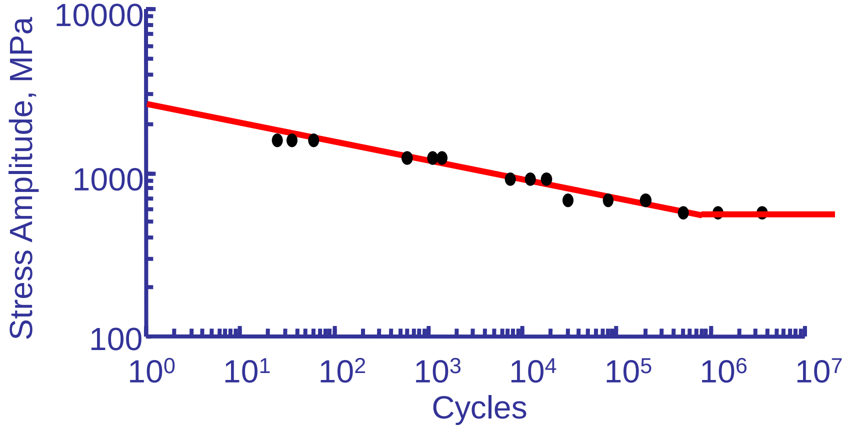
Crack Growth

Life Estimation

Method	Physics	Size
Stress-Life	Crack Nucleation	0.01 mm
BS 7608	Crack Growth	1 - 10 mm
Strain-Life	Microcrack Growth	0.1 - 1 mm
Crack Growth	Macrocrack Growth	> 1mm

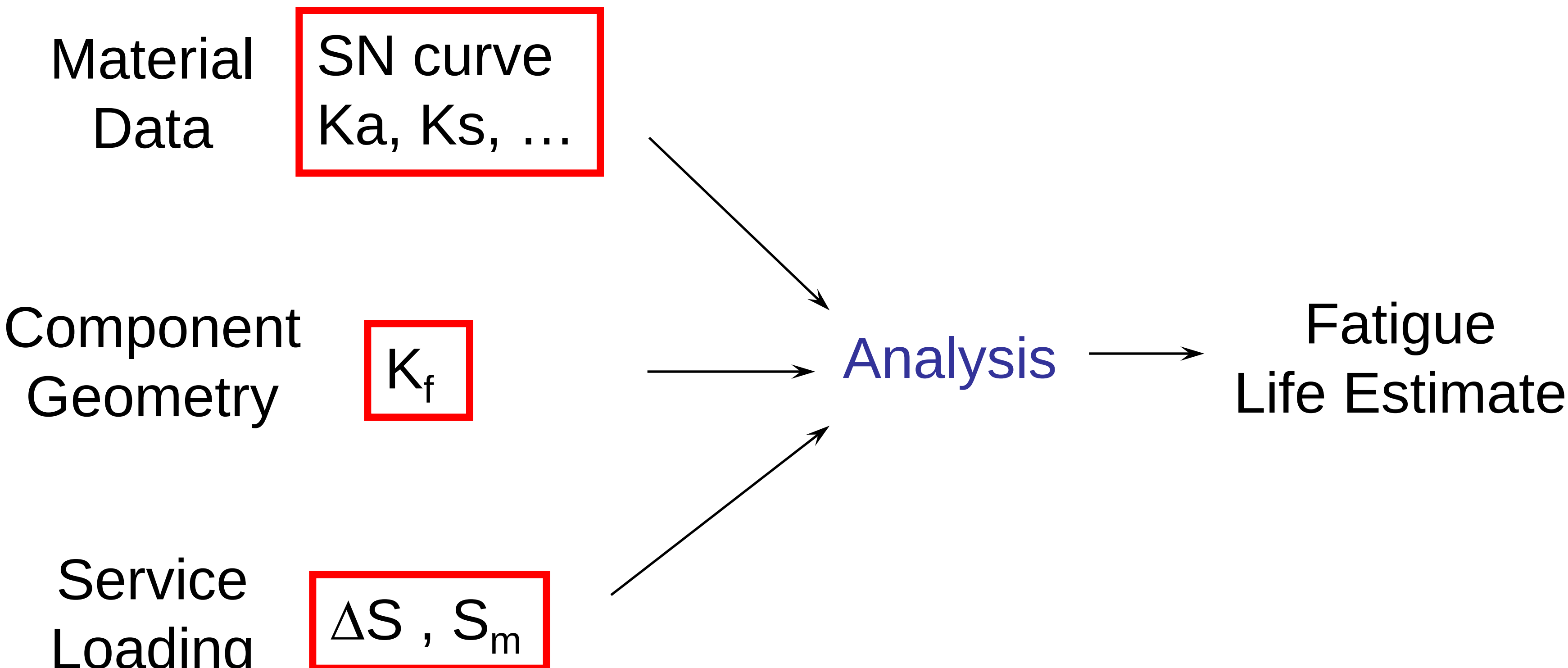
Stress-Life Fatigue Modeling





The Similitude Concept states that if the instantaneous loads applied to the 'test' structure (wing spar, say) and the test specimen are the same, then the response in each case will also be the same and can be described by the material's S-N curve.

Fatigue Analysis: Stress-Life



Stress-Life

- Major Assumptions:
  - Most of the life is consumed nucleating cracks
  - Elastic deformation
  - Nominal stresses and material strength control fatigue life
  - Accurate determination of K_f for each geometry and material

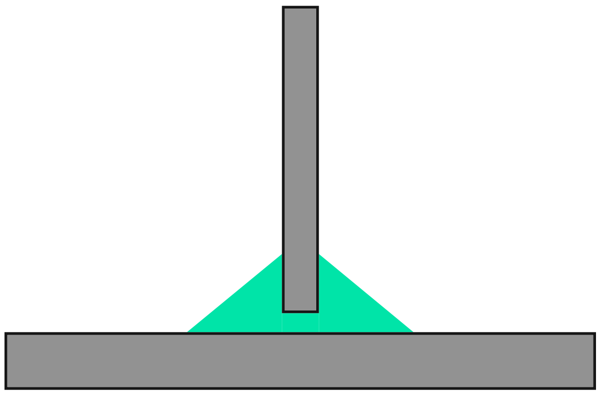
Stress-Life

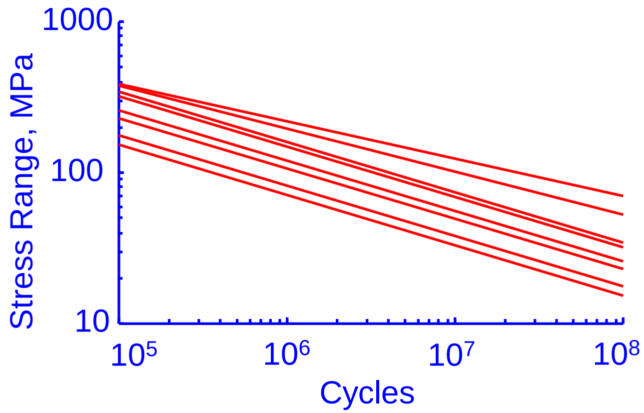
- Advantages:
  - Changes in material and geometry can easily be evaluated
  - Large empirical database for steel with standard notch shapes

Stress-Life

- Limitations:
  - Does not account for notch root plasticity
  - Mean stress effects are often in error
  - Requires empirical K_f for good results

BS 7608 Fatigue Modeling

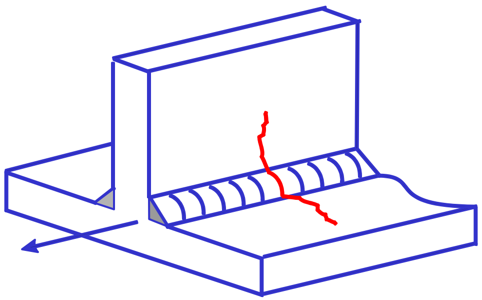




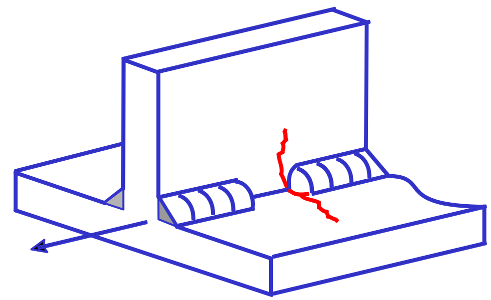
The Similitude Concept states that if the instantaneous loads applied to the 'test' structure (welded beam on a bulldozer, say) and the test specimen (standard fillet weld) are the same, then the response in each case will also be the same and can be described by one of the standard BS 7608 Weld Classification S-N curves.

Weld Classifications

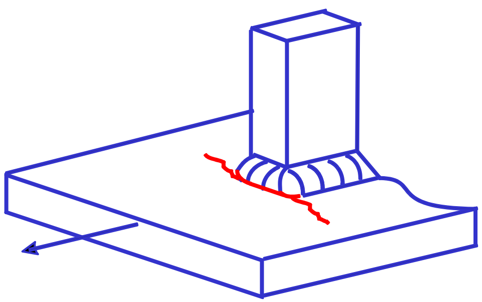
D



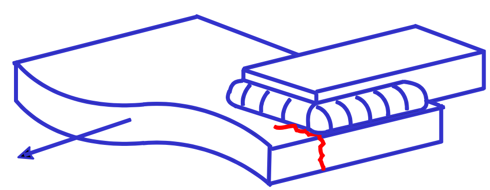
E



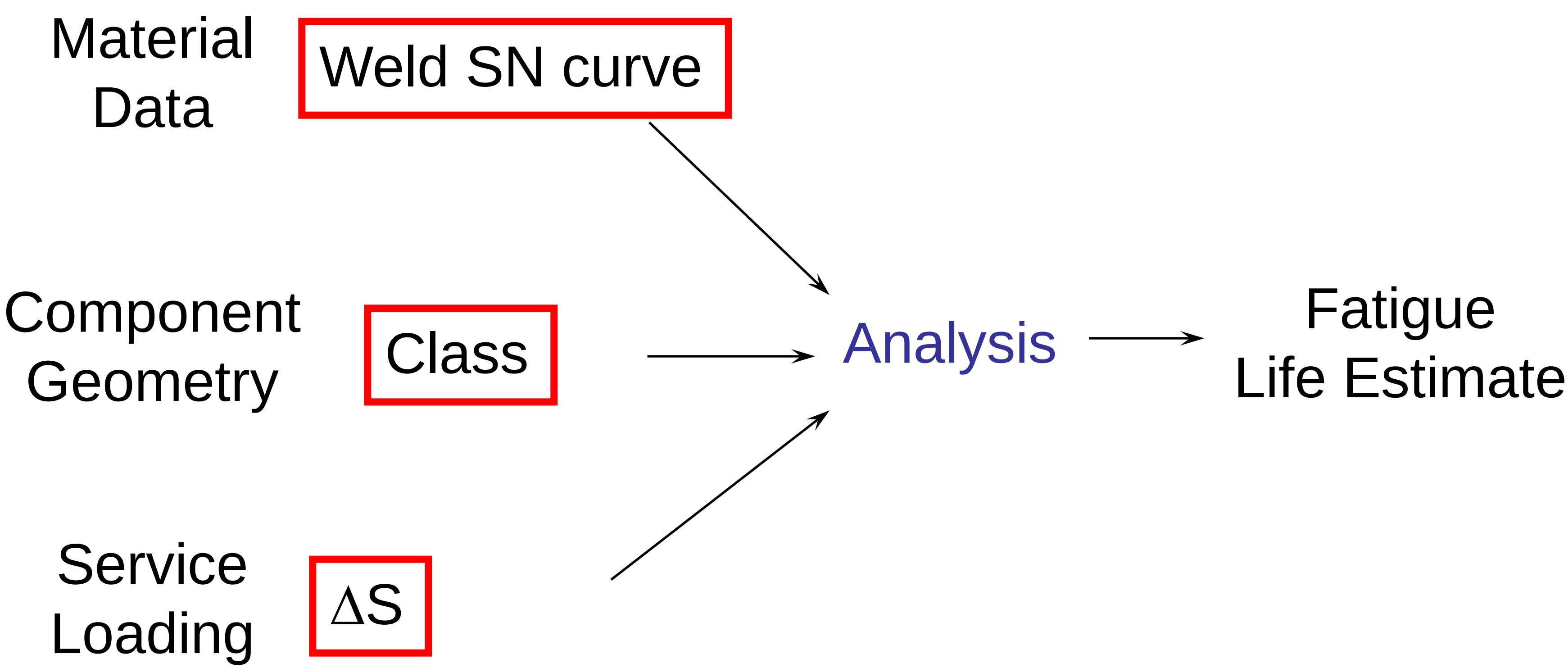
F2



G



Fatigue Analysis: BS 7608



BS 7608

- Major Assumptions:
  - Crack growth dominates fatigue life
  - Complex weld geometries can be described by a standard classification
  - Results independent of material and mean stress for structural steels

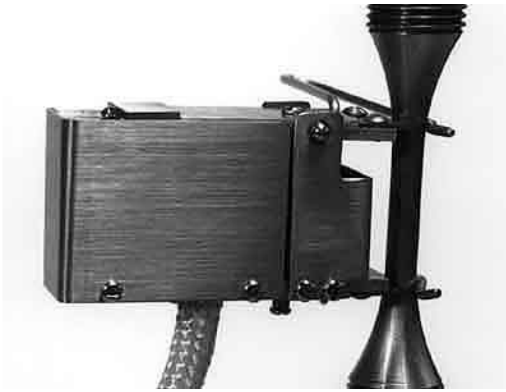
BS 7608

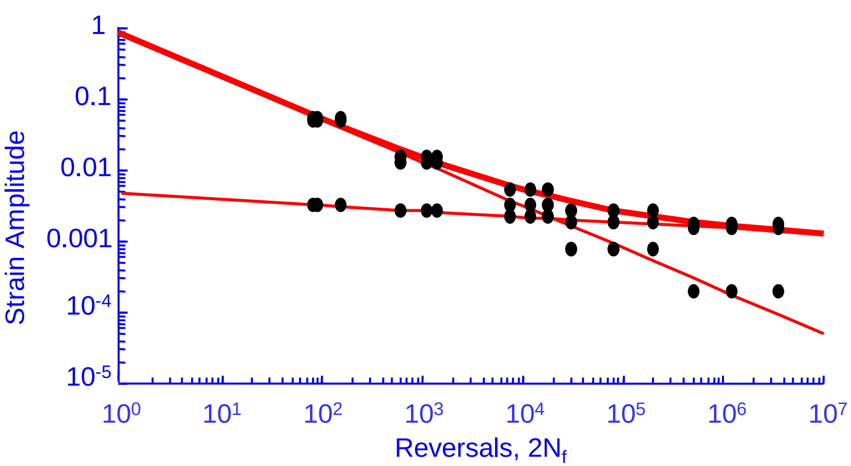
- Advantages:
  - Manufacturing effects are directly included
  - Large empirical database exists

BS 7608

- Limitations:
  - Difficult to determine weld class for complex shapes
  - No benefit for improving manufacturing process

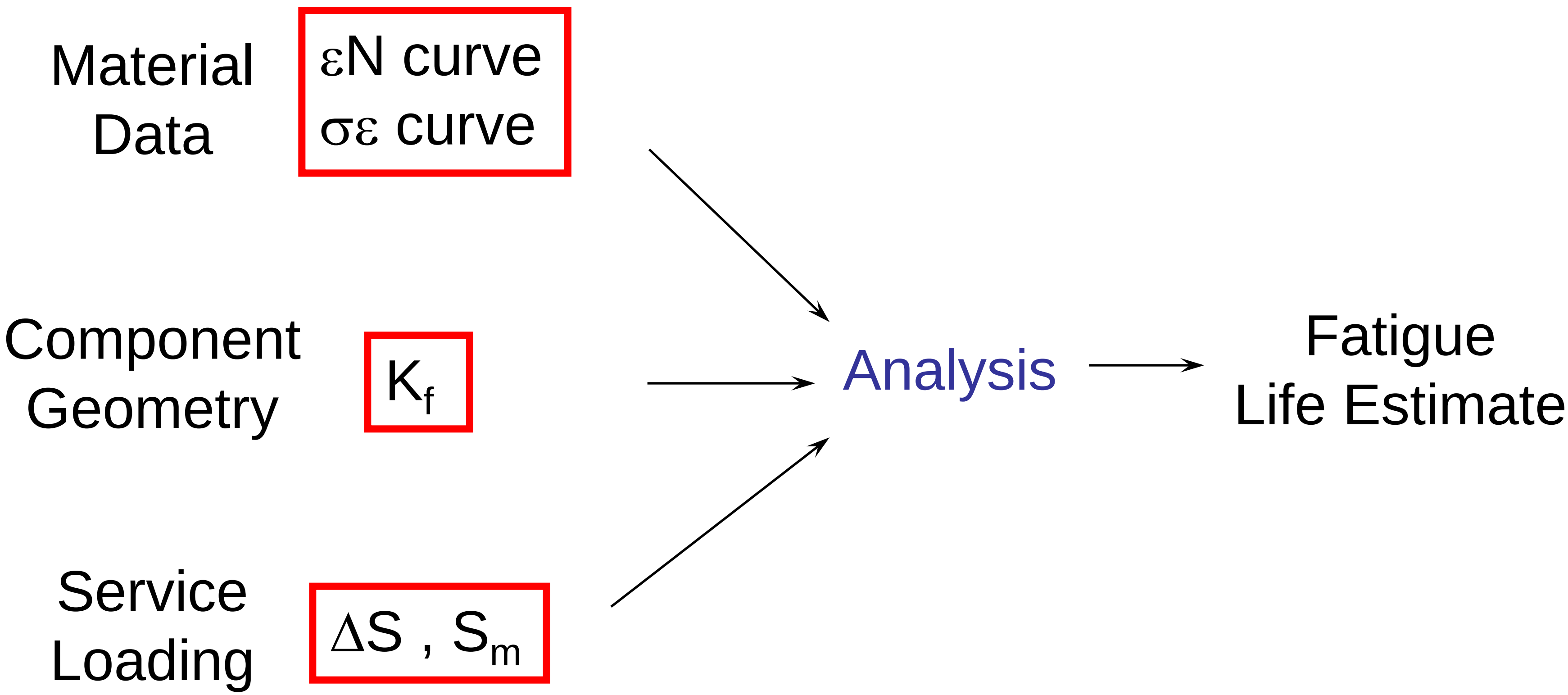
Strain-Life Fatigue Modeling





The Similitude Concept states that if the instantaneous strains applied to the 'test' structure (vehicle suspension, say) and the test specimen are the same, then the response in each case will also be the same and can be described by the material's e-N curve. Due account can also be made for stress concentrations, variable amplitude loading etc.

Fatigue Analysis: Strain-Life



Strain-Life

- Major Assumptions:
  - Local stresses and strains control fatigue behavior
  - Plasticity around stress concentrations
  - Accurate determination of K_f

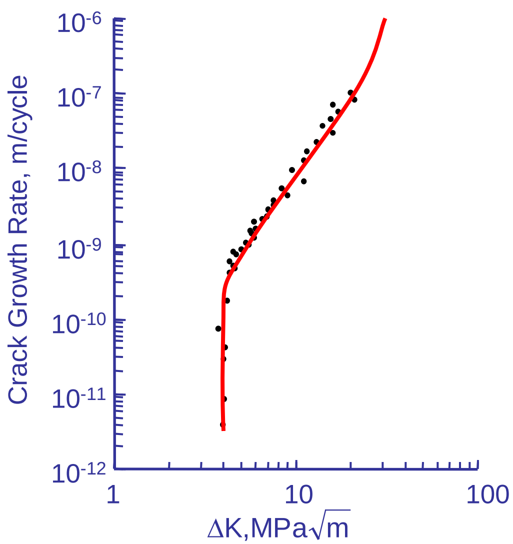
Strain-Life

- Advantages:
  - Plasticity effects
  - Mean stress effects

Strain-Life

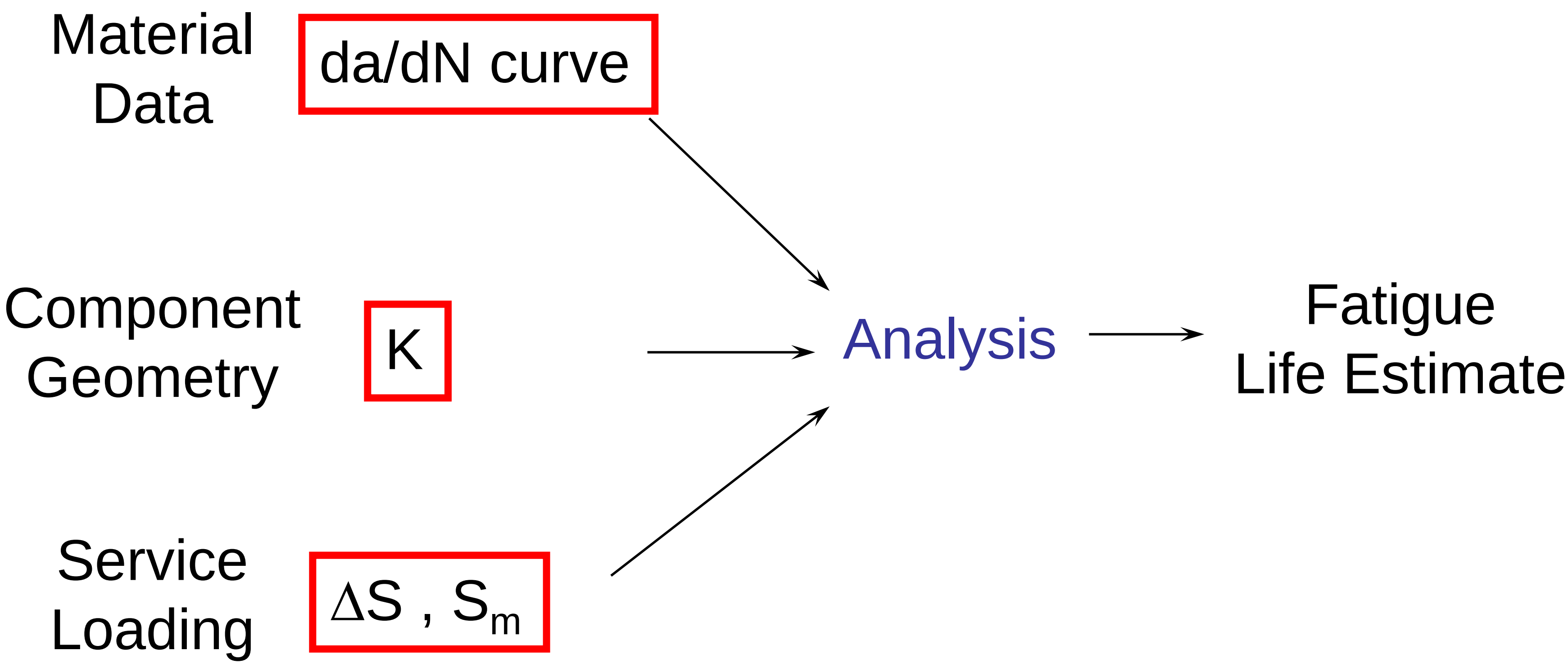
- Limitations:
  - Requires empirical K_f
  - Long life situations where surface finish and processing variables are important

Crack Growth Fatigue Modeling



The Similitude Concept states that if the stress intensity (K) at the tip of a crack in the 'test' structure (welded connection on an oil platform leg, say) and the test specimen are the same, then the crack growth response in each case will also be the same and can be described by the Paris relationship. Account can also be made for local chemical environment, if necessary.

Fatigue Analysis: Crack Growth



Crack Growth

- Major Assumptions:
  - Nominal stress and crack size control fatigue life
  - Accurate determination of initial crack size

Crack Growth

- Advantage:
  - Only method to directly deal with cracks

Crack Growth

- Limitations:
  - Complex sequence effects
  - Accurate determination of initial crack size

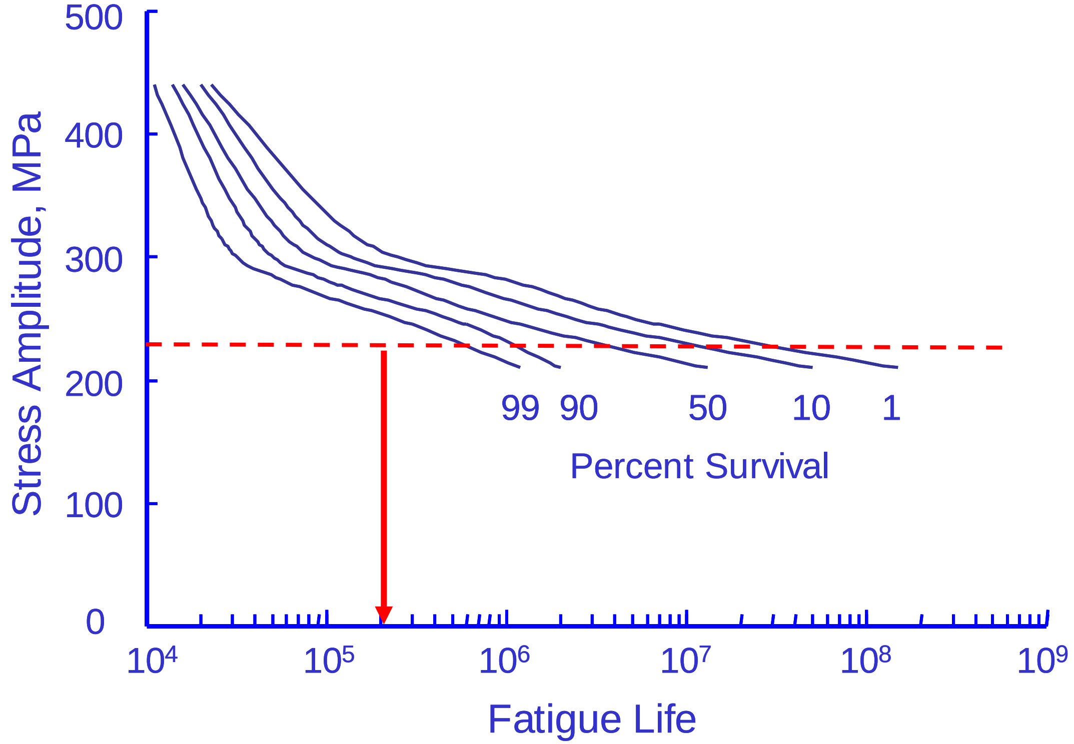
Choose the Right Model

- Similitude
  - Failure mechanism
  - Size scale

Design Philosophy

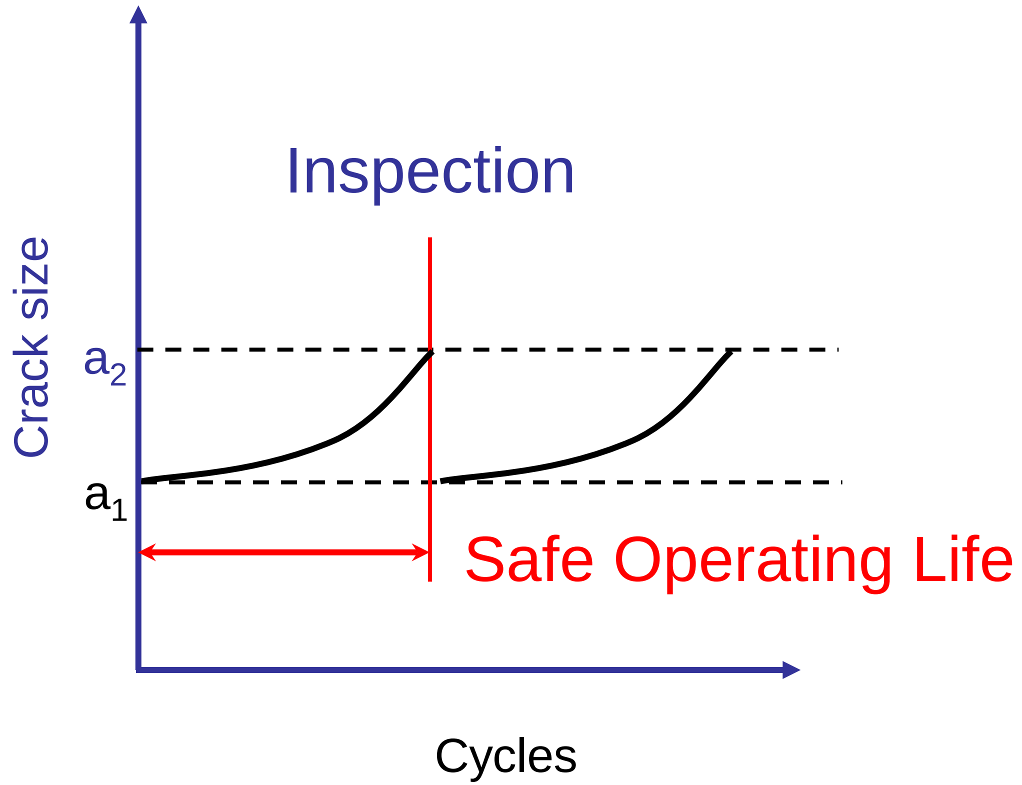
- Safe Life
- Damage Tolerant

Safe Life



Choose an appropriate risk and replace critical parts after some specified interval

Damage Tolerant



Inspect for cracks larger than a_1 and repair

Inspection

A Boeing 777 costs \$250,000,000

A new car costs \$25,000

For every \$1 spent inspecting and maintaining a B 777 you can spend only 0.01¢ on a car

Things Worth Remembering

- Questions to ask
  - Will a crack nucleate ?
  - Will a crack grow ?
  - How fast will it grow ?
- Similitude
  - Failure mechanism
  - Size Scale

Fatigue, How and Why

- Physics of Fatigue
- Material Properties
- Similitude
- **eFatigue**

eFatigue

Some Observations

Most fatigue failures are not the result of an expert using the wrong analysis etc.

Most fatigue failures are a result of a non-expert not considering fatigue because it is too complicated, not enough data etc.

Fatigue will no longer be taught in the major research universities as they focus on new science.

Prof Yukitaka Murakami

Science in the Sunlight

Science in the Shade

Science in the Sunlight

Science in the Shade

A Common Viewpoint (controversial)

Fatigue is reasonably well understood, major problems are solved and current research is applications driven towards investigating special cases and improving the accuracy of our evaluations.

Fatigue is assessment is just like finite element analysis, buy some software and make a color plot.

Fatigue Calculators

There is a need for some fatigue analysis tools that take only a few minutes to learn so non-experts can reliably conduct a fatigue assessment.

www.eFatigue.com

eFatigue - Fatigue Calculator

eFatigue
a trusted source for fatigue analysis

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Stress-Life
Strain-Life
Materials
Stress-Life Materials
Strain-Life Materials
Technical Background
Stress-Life Background
Strain-Life Background

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Fatigue Calculator

Fatigue Calculator

Fatigue failures are always a consideration for any structure that is dynamically or cyclically loaded. The effective use of the appropriate fatigue technology and analysis is an essential part of assuring the fatigue resistance and durability of all mechanical components.

Most fatigue technologies and fatigue analysis software have only been used by experts with costs to match. No longer. Designed and supported by the fatigue group at the University of Illinois, the Fatigue Calculator portion of the eFatigue website contains all of the technologies and tools needed for accurate fatigue assessments with an interface that is easy for the non-expert to navigate. With a Fatigue Calculator any engineer can quickly and easily conduct a fatigue or durability analysis. There are no logins or charges needed to use the Fatigue Calculator portion of the eFatigue website.

Databases for material properties, stress concentration factors, and stress intensity factors are included with the various Fatigue Calculators. Learn by Example and a description of the methods and input parameters are provided.

Fatigue analysis methods are based on stress-life, strain-life or crack growth. Fatigue technologies are applications of the methods for specific kinds of problems or materials.

New fatigue technologies and databases are continuously being developed and added to the Fatigue Calculator and eFatigue.

What is eFatigue?

eFatigue is the full featured version of the FatigueCalculator with the ability to store personal and corporate databases for materials and loadings. Results from any analysis, including both plots and tables,are be stored for later retrieval. In addition, Fatigue Analyzers for more computationally intensive problems such as directly processing finite element models and variable amplitude loadings from large data files are included in eFatigue. With an appropriate login, users also have access to proprietary analysis procedures and databases. eFatigue will be available to the general public in a few months.

eFatigue - Constant Amplitude Home

eFatigue
a trusted source for fatigue analysis

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Fatigue Technologies
- Constant Amplitude
- Variable Amplitude
- Finite Element Model
- Multiaxial
- Probabilistic
- High Temperature

Constant Amplitude
- Fatigue Calculators
  - **Stress-Life**
  - **Strain-Life**
  - **Crack Growth**
  - **BS 7608 Welds**
- Finders
  - Stress Concentration
  - Stress Intensity
  - BS 7608 Weld Classification
- Materials
  - Stress-Life Materials
  - Strain-Life Materials
  - Crack Growth Materials
- Technical Background
  - Stress-Life Background
  - Strain-Life Background
  - Crack Growth Background
  - BS 7608 Welds Background

Constant Amplitude Home

There are three primary methods for estimating the fatigue resistance of components and structures. Stress-Life analysis assumes that the stresses always remain elastic even at the stress concentrators. Most of the live is consumed nucleating small microcracks. This is typical for long life situations (millions of cycles) where the fatigue resistance is controlled by nominal stresses and material strength. Strain-Life is used for situations where plastic deformation occurs around the stress concentrations. An example would be in a structure that has one major load cycle every day. Both stress-life and strain-life provide an estimate of how long it will take to form a crack about 1mm long. Crack growth analysis is then used to estimate how long it will take to grow a crack to final fracture. Fatigue of welds requires special considerations because of their complex shape and loading.

This section provides analysis for simple constant amplitude loading for all of the methods. It is typically found in power transmission applications such as shafts, gears etc. It is frequently used in the early stages of design to set the overall stress levels and to select appropriate materials. Many design and testing specifications are written in terms of constant amplitude loading.

Finders are provided to obtain the necessary input information for material properties and stress concentration or stress intensity factors.

Fatigue Calculators

Stress-Life
Use this method for long life situations where the strength of the material and the nominal stress control the fatigue life.

Strain-Life
This method is used for finite fatigue lives where plasticity around stress concentrations is important.

Crack Growth
Use this method to determine how long it will take a crack to grow to a critical size.

BS 7608 Welds
Complex weld shapes and residual stresses require special fatigue considerations.

eFatigue - Stress Concentration Fact...

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Constant Amplitude
- Fatigue Calculators
  - **Stress-Life**
  - **Strain-Life**
  - **Crack Growth**
  - **BS 7608 Welds**
- Finders
  - Stress Concentration
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  - Crack Growth Background
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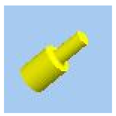
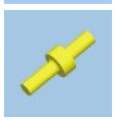
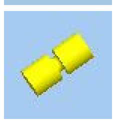
Stress Concentration Factor Finder

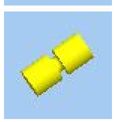
▶Rectangular Bars

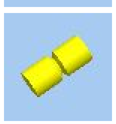
▼Rounds and Shafts


Round Shaft with a Single Fillet


Round Shaft with Double Fillets


Round Shaft with Groove


Round Bar with U-shaped Groove


Round Bar with V-shaped Groove


Round Shaft with Semi-Circular Keyway


Round Shaft with a Transverse Hole

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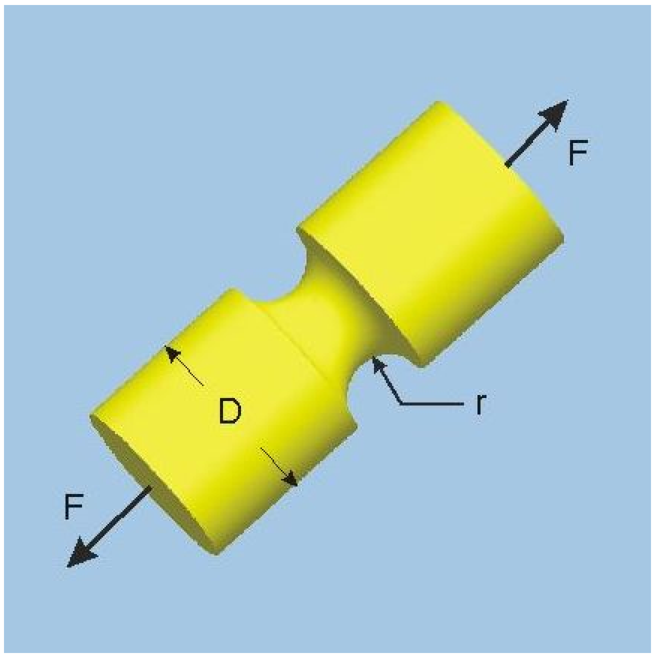
Stress Concentration Factor Finder

Round Shaft with Groove

Tension | Bending | Torsion



Select Different Geometry

Variables

Net Section Stress

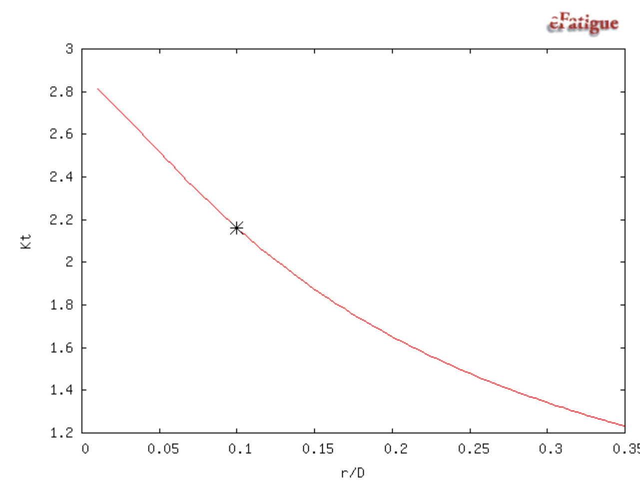
D 10 mm

r 1 mm

Calculate Kt

Results

$K_t = 2.16$



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Constant Amplitude Material Property Finder

- [ ] Stress-Life
- [x] Strain-Life
- [ ] Crack Growth

Filter by owner: Show All [Update Filter]

Constant Amplitude

- Aluminum 1100, Su=110.0
- Aluminum 2014-T6, Hand Forged, Su=483.0
- Aluminum 2014-T6, Su=510.0
- Aluminum 2024-T3, Su=490.0
- Aluminum 2024-T4, Su=476.0
- Aluminum 5083-0, BHN=93
- Aluminum 5083-H12, Su=385.0
- Aluminum 5183-0, Weld metal, BHN=92
- Aluminum 5454, Forged, Su=334.0
- Aluminum 5456-H311, Su=400.0

[Add Strain-Life Material]

Aluminum 5454, Forged, Su=334.0

Technology	Constant Amplitude Strain-Life
Owner	public
Material Type	aluminum
Material Alloy	5454
Material Process	Forged
Elastic Modulus	$E =$ 69000 MPa
Ultimate Strength	$S_u =$ 334 MPa
Fatigue Strength Coefficient	$\sigma_f' =$ 554 MPa
Fatigue Strength Exponent	$b =$ -0.089
Fatigue Ductility Coefficient	$\varepsilon_f' =$ 0.31
Fatigue Ductility Exponent	$c =$ -0.62
Cyclic Strength Coefficient	$K' =$ 373 MPa
Cyclic Strain Hardening Exponent	$n' =$ 0.047
Material Reference	SAE Paper 840120 Wong

[Edit This Material] [Delete This Material] [Material Property Estimator] eFatigue - Constant Amplitude St... × | Microsoft PowerPoint: Apply differe... ×

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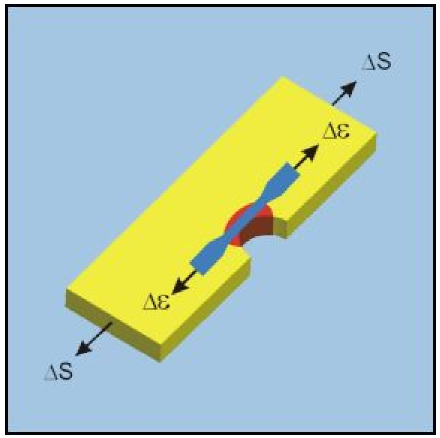
Constant Amplitude Strain-Life Analysis

Fatigue Calculator



Although most engineering structures and components are designed such that the nominal stresses remain elastic, local stress concentrations often cause plastic strains to develop in regions around them. The strain-life method assumes that the smooth specimens tested in strain control simulate fatigue damage in local region around the stress concentration.

Use of the strain-life analysis method is limited to situations where crack nucleation and the growth of small microcracks consumes the majority of the service life.

Enter as much data as you know. If it is not enough, you will be asked for more. Sections with a light blue background represent the minimum required data to begin calculations. Other data may become necessary as calculation proceeds. Pressing the ⓕ button provides help in the form of an equation or default information for a parameter.

Experienced user mode is off. Turn experienced user mode on for a more concise form.

Experienced User On

Click on the button below to learn by example:

Learn By Example

Loading

Loads can be entered as either the maximum and minimum values or as the stress range and mean stress.

Stresses or strains entered may be elastic-plastic. You can use elastic finite element or other elastic calculations as input by selecting (elastic) units for stress or strain. Examples include input from elastic finite element models and strength of materials calculations such as bending beams. In this case, a plasticity correction will be made to the input stresses or strains before computing the fatigue life using Neuber's Rule.

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Constant Amplitude Strain-Life Analysis

Experienced User Off

Load Template

Loading

Loading Units			mm/mm
Maximum	S_{max} or e_{max} =		mm/mm
Minimum	S_{min} or e_{min} =		mm/mm
OR			
Range	ΔS or Δe =		mm/mm
Mean	S_m or e_m =		mm/mm

Material

Material Property Finder | Material Property Estimator

Type		steel	
Fatigue Strength Coefficient	σ_f' =		MPa
Fatigue Strength Exponent	b =		
Fatigue Ductility Coefficient	ε_f' =		
Fatigue Ductility Exponent	c =		
Elastic Modulus	E =		MPa
Fatigue Limit	S_{FL} =		MPa
Fatigue Limit Reversals	$2N_{FL}$ =		Reversals
Cyclic Strength Coefficient	K' =		MPa
Cyclic Strain Hardening Exponent	n' =		

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Calculate

Calculate Life | Clear Form

Save these results in your home directory:

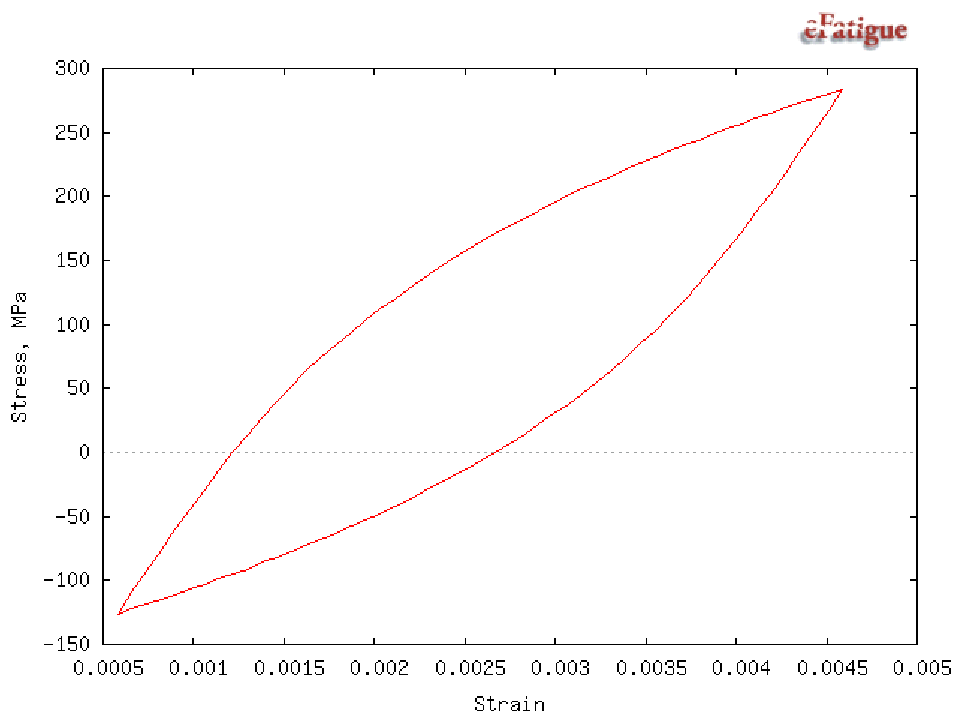
CAStrainLife 2010_01_25_124816 | Save

Name may only contain letters, numbers, underscores, dashes, periods and spaces.

Analysis Results

N_f = 58655 cycles

Hysteresis Loop



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Damage Summation
Stress-Life Background
Strain-Life Background
Crack Growth Background
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Variable Amplitude Strain-Life Analysis

Text Boxes | Clipboard | Files

Enter at least two points. You may paste tab and newline delimited text (such as would be copied from a spreadsheet) into a box, and it will be expanded out automatically.

1		drop 1
2		drop 2
3		drop 3
4		drop 4
5		drop 5
6		drop 6

Add Row | Add Column | Validate

Save data as ascii file in your home directory:

Save

Name may only contain letters, numbers, underscores, dashes, periods and spaces.

Load Scaling

Loading Units	mm/mm
Channel Select	1
Scale Factor	1
Zero Offset	0

Plot | Clear Loading

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  - Stress-Life Materials
  - Strain-Life Materials
- Technical Background
  - Stress-Life Background
  - Strain-Life Background

Files > dsocie

A	FEMStressLife 2009_03_07_113407	Sat Mar 7 2009 10:34:52
A	FEMStressLife 2009_03_07_113503 - results.rst	Sat Mar 7 2009 10:35:13
A	FEMStressLife 2009_03_07_144745	Sat Mar 7 2009 13:47:53
A	FEMStressLife 2009_03_07_144807 - results.rst	Sat Mar 7 2009 13:48:15
A	FEMStressLife 2009_03_28_112124 - shaft64_results.txt	Sat Mar 28 2009 10:21:35
A	FEMStressLifeExample_1	Fri Feb 20 2009 14:49:17
A	FEMStressLife_2009_02_03_111955	Tue Feb 3 2009 10:20:30
A	FEMStressLife_Example	Wed Feb 18 2009 06:51:20
	Project/	Wed Jan 6 2010 06:26:39
L	SAE_test.txt	Mon Dec 7 2009 10:44:56
A	VAStressLife 2009_09_18_080900	Fri Sep 18 2009 07:09:18
	efatigue.current.model	Sat Mar 28 2009 10:21:31
	efatigue.current.model.log	Sat Mar 28 2009 10:21:31

A Analysis Results
L Loading File

Working With Files

Upload a file here:

[Browse...] [Upload File]

File and directory names may only contain letters, numbers, underscores, dashes, periods and spaces.

Validate that checked file is a Finite Element Model and show summary:

[Validate Finite Element Model]

Validate that checked file is a readable Loading File:

[Validate Loading File]

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- Technical Background
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Variable Amplitude Strain-Life Analysis

Analysis

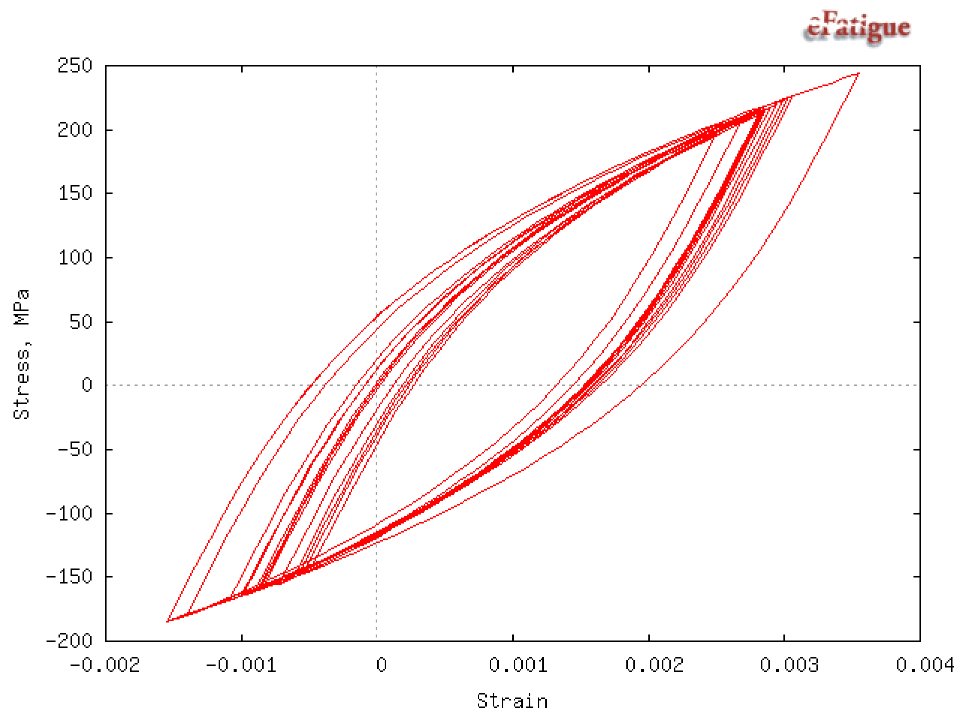
Analyze | Clear Form

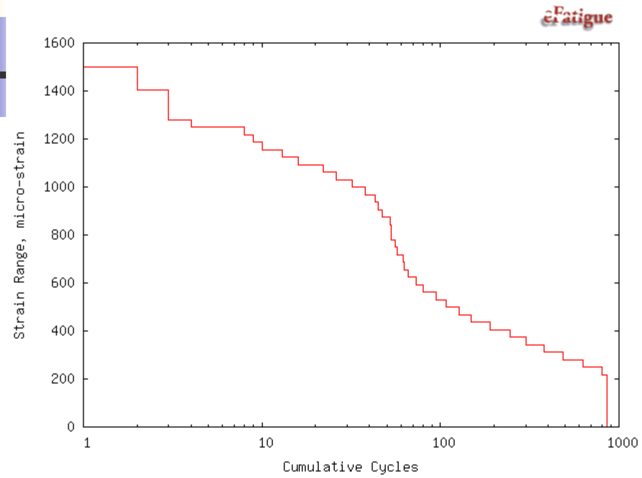
Viewing analysis **VAStrainLife Example_6** owned by **darrell**

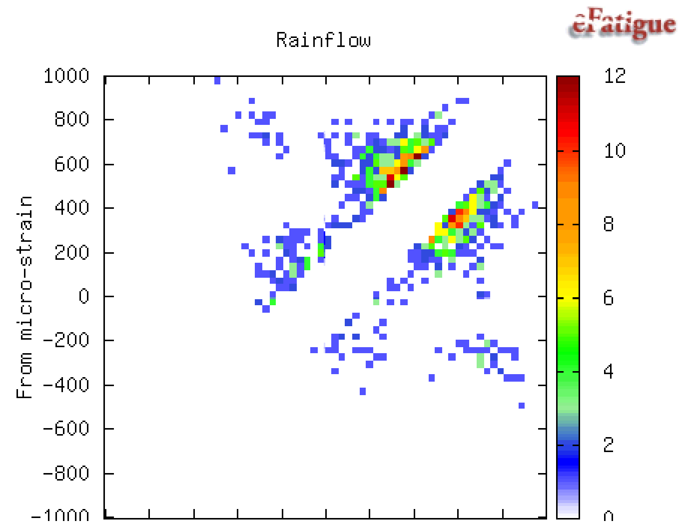
Analysis Results

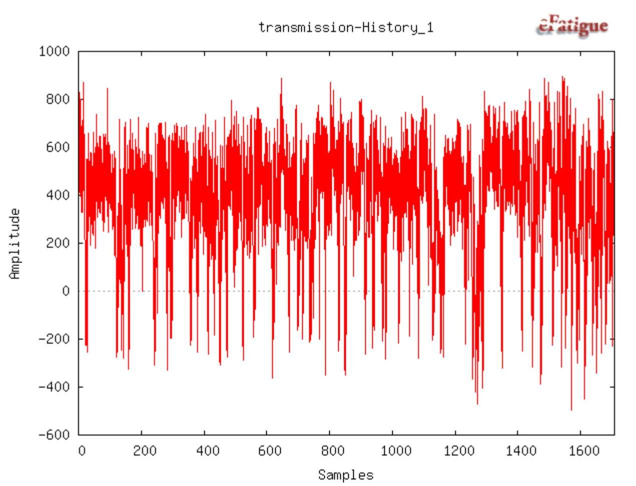
N_f= 1391

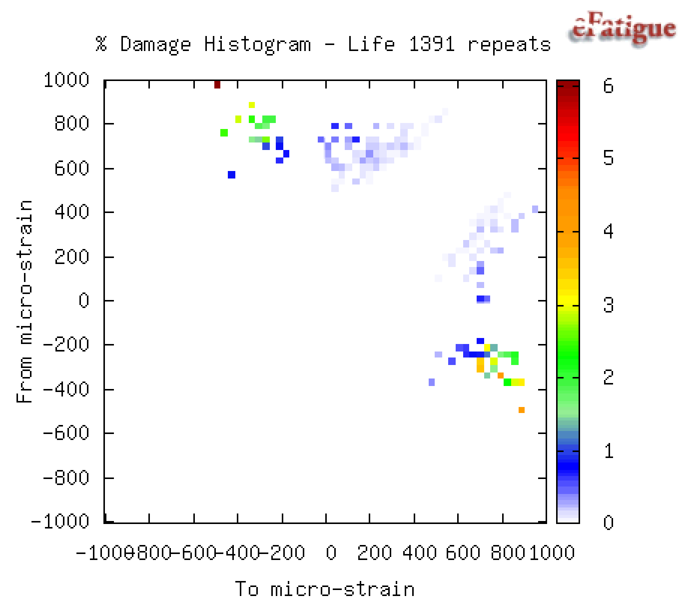
Hysteresis Loop




eFatigue
Strain Range, micro-strain
1600
1400
1200
1000
800
600
400
200
0
1
10
100
1000
Cumulative Cycles


eFatigue
Rainflow
From micro-strain
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
12
10
8
6
4
2
0


transmission-History_1
eFatigue
Amplitude
1000
800
600
400
200
0
-200
-400
-600
0
200
400
600
800
1000
1200
1400
1600
Samples


eFatigue
% Damage Histogram - Life 1391 repeats
From micro-strain
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
6
5
4
3
2
1
0
-1000-800-600-400-200 0 200 400 600 800 1000
To micro-strain

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  - Strain-Life Background
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Probabilistic Strain-Life Analysis

Experienced User Off

Load Template

Loading

Loading Units: MPa

				Distribution Type	*Scale Parameter*
Maximum	S_{max} or e_{max} =		MPa	None	
Minimum	S_{min} or e_{min} =		MPa	None	
OR					
Range	ΔS or Δe =		MPa	None	
Mean	S_m or e_m =		MPa	None	

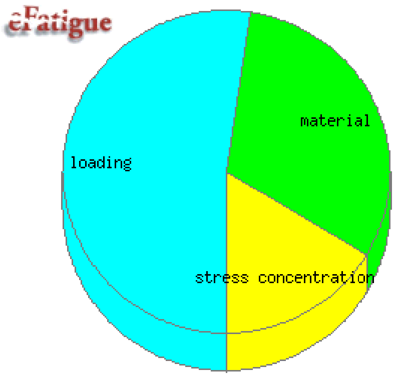
Material

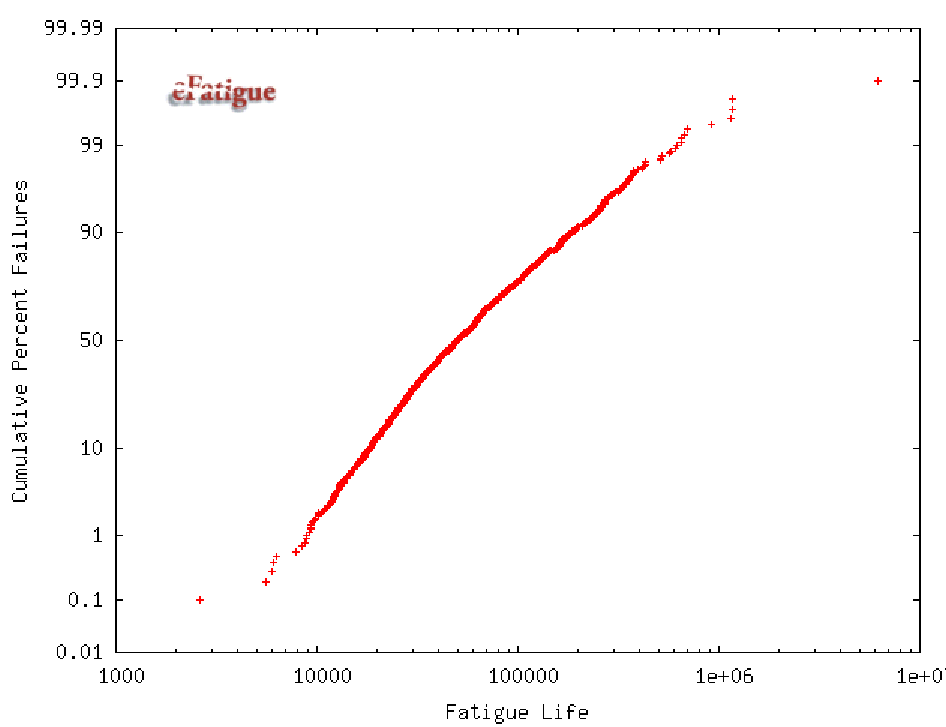
Material Property Finder | Material Property Estimator

Type: steel

				Distribution Type	*Scale Parameter*	*Correlation Coefficient*
Fatigue Strength Coefficient	σ_f' =		MPa	None		
Fatigue Strength Exponent	b =			None		
Fatigue Ductility Coefficient	ε_f' =			None		
Fatigue Ductility Exponent	c =			None		
Elastic Modulus	E =		MPa	None		
Fatigue Limit	S_{FL} =		MPa	None		

Probabilistic Sensitivity Analysis





Variable	Value	Deterministic Sensitivity	Probabilistic Sensitivity	Mean	COV
Loading			0.83		
ΔS or Δe	N(0.00100 mm/mm,0.200)	-3.55	0.82	0.00100	0.201
S_m or e_m	N(0.00050 mm/mm,0.200)	-0.52	0.12	0.00050	0.197
Material Properties			0.49		
K′	1441 MPa	0.79	0.00	1441	0.000
n′	0.283	-1.32	0.00	0.283	0.000
E	206800 MPa	-2.32	0.00	206800	0.000
b	-0.118	-2.05	0.00	-0.118	0.000
c	-0.412	-8.87	0.00	-0.412	0.000
σ_f'	L(883 MPa,0.100)	1.56	0.18	887	0.099
ε_f'	L(0.160,0.200)	1.99	0.46	0.163	0.200
Stress Concentrators			0.26		
K_f	N(3.00,0.05)	-4.65	0.26	3.00	0.049

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Multiaxial Strain-Life Analysis

Material

You may select a material by clicking on the Material Property Finder button or specify individual properties directly.

Material Property Estimator will show the default properties that are computed from the input values.

[Material Property Finder] [Material Property Estimator]

Estimated values are displayed in blue

Name		**Aluminum 7075-T651, Su=580.0**		
Type		aluminum		
Fatigue Strength Coefficient	σ_f' =	1231	MPa	
Fatigue Strength Exponent	b =	-0.122		
Fatigue Ductility Coefficient	ε_f' =	0.263		
Fatigue Ductility Exponent	c =	-0.806		
Elastic Modulus	E =	70000	MPa	
Fatigue Limit	S_{FL} =		MPa	158 MPa
Fatigue Limit Reversals	$2N_{FL}$ =		Reversals	20000000
Cyclic Strength Coefficient	K′ =	852	MPa	
Cyclic Strain Hardening Exponent	n′ =	0.074		

Shear

Shear Fatigue Strength Coefficient	τ_f' =		MPa	711 MPa
Shear Fatigue Strength Exponent	b_γ =			-0.122
Shear Fatigue Ductility Coefficient	γ_f' =		MPa	0.46
Shear Fatigue Ductility Exponent	c_γ =			-0.806
Nonproportional Hardening Coefficient	α_{NP} =			0
Poisson's Ratio	ν =			0.3
Shear Modulus	G =		MPa	2.69E+04 MPa

Calculate

Calculate Life | Clear Form

Analysis Results

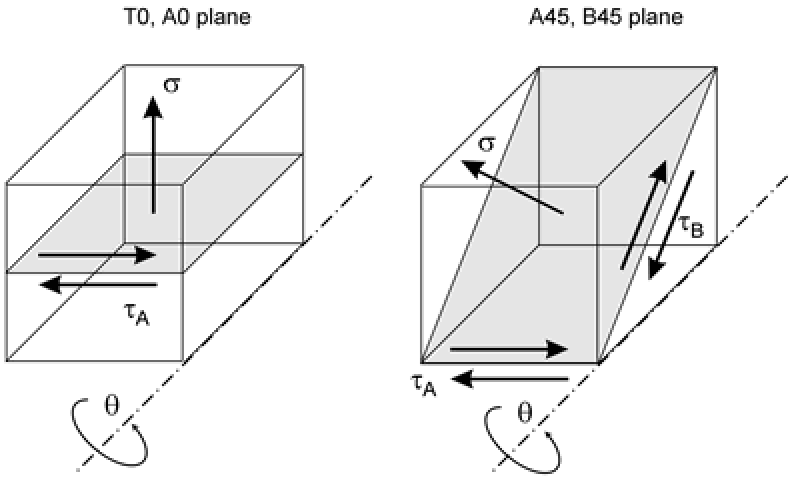
N_f (Fatemi-Socie) = 1.858e+03

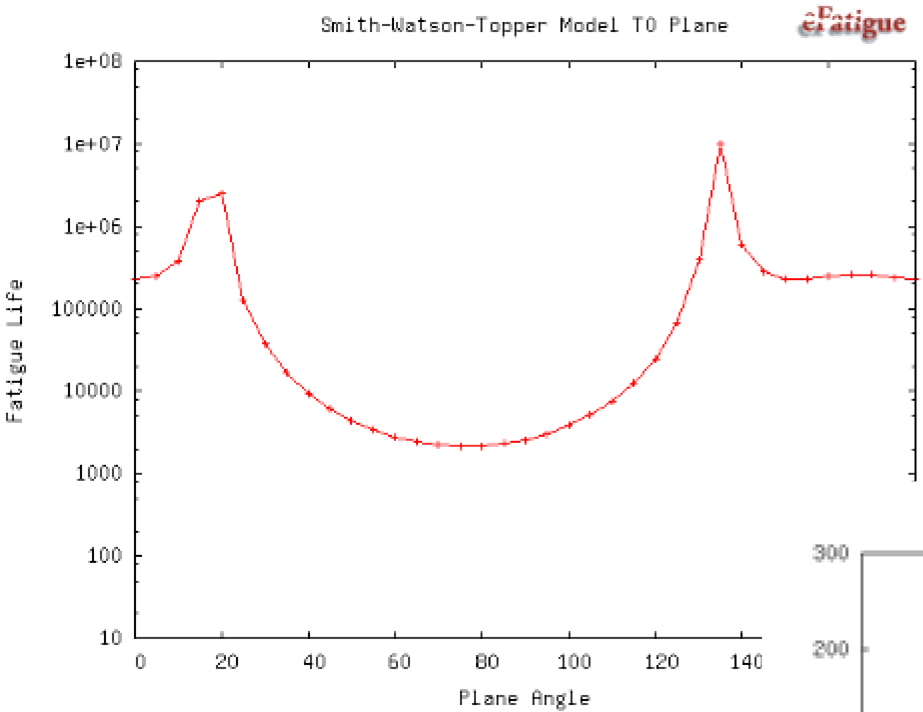
N_f (SWT) = 2.127e+03

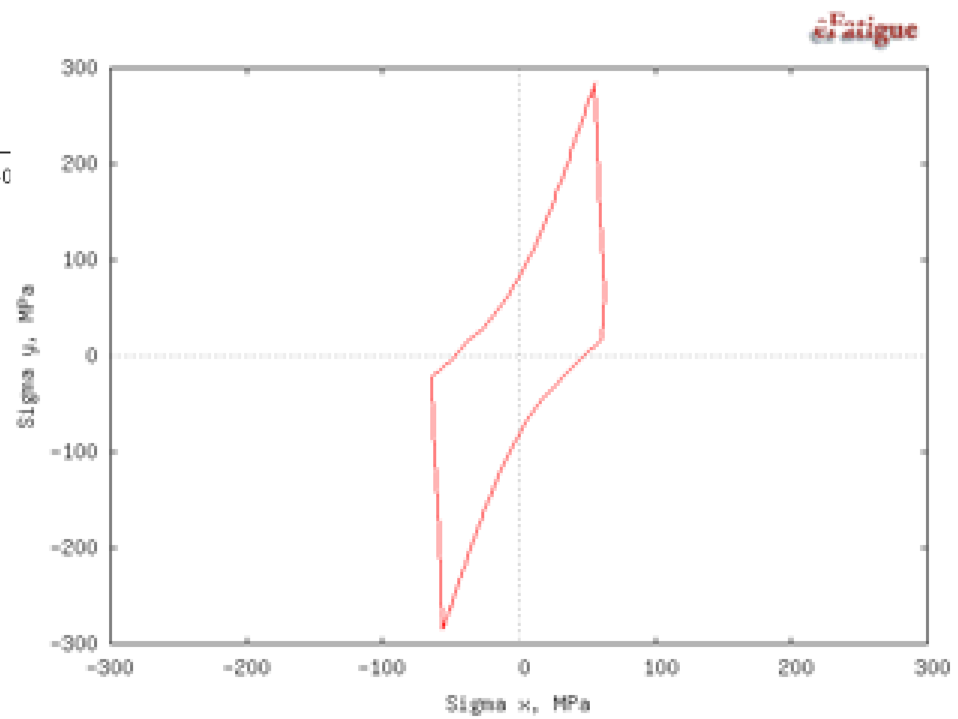
N_f (Brown-Miller) = 1.459e+03

N_f (Liu Mode I) = 2.109e+03

N_f (Liu Mode II) = 2.454e+03




Smith-Watson-Topper Model T0 Plane
eFatigue
Fatigue Life
1e+08
1e+07
1e+06
100000
10000
1000
100
10
0
20
40
60
80
100
120
140
Plane Angle


eFatigue
Sigma y, MPa
300
200
100
0
-100
-200
-300
Sigma x, MPa

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Finite Element Models Home

There are two primary methods for estimating the fatigue resistance of components and structures from Finite Element Model results. Stress-Life analysis assumes that the stresses always remain elastic even at the stress concentrators. Most of the life is consumed nucleating small microcracks. This is typical for long life situations (millions of cycles) where the fatigue resistance is controlled by nominal stresses and material strength. Strain-Life is used for situations where plastic deformation occurs around the stress concentrations. An example would be in a structure that has one major load cycle every day. Both stress-life and strain-life provide an estimate of how long it will take to form a crack about 1mm long. We suggest that you first review the constant amplitude section if you are unfamiliar with the basic methods and terminology.

This section provides analytical tools for processing FEM data for both of the methods. Fatigue analysis from a finite element model is essentially the same as constant or variable amplitude fatigue analysis with one major difference. Multiaxial stresses must be considered in the fatigue assessment. In ductile materials, multiaxial stresses considerations are particularly important because shear stresses, not principle stresses, are responsible for the nucleation and initial growth of fatigue cracks.

Both ANSYS *.rst file format and ABAQUS *.fil formats are currently supported. Results from the fatigue analysis are summarized in a series of bar charts and also returned in a *.rst or *.fil file for plotting.

Finders are provided to obtain the necessary input information for material properties.

Fatigue Analyzers

Stress-Life
Use this method for long life situations where the strength of the material and the nominal stress control the fatigue life.

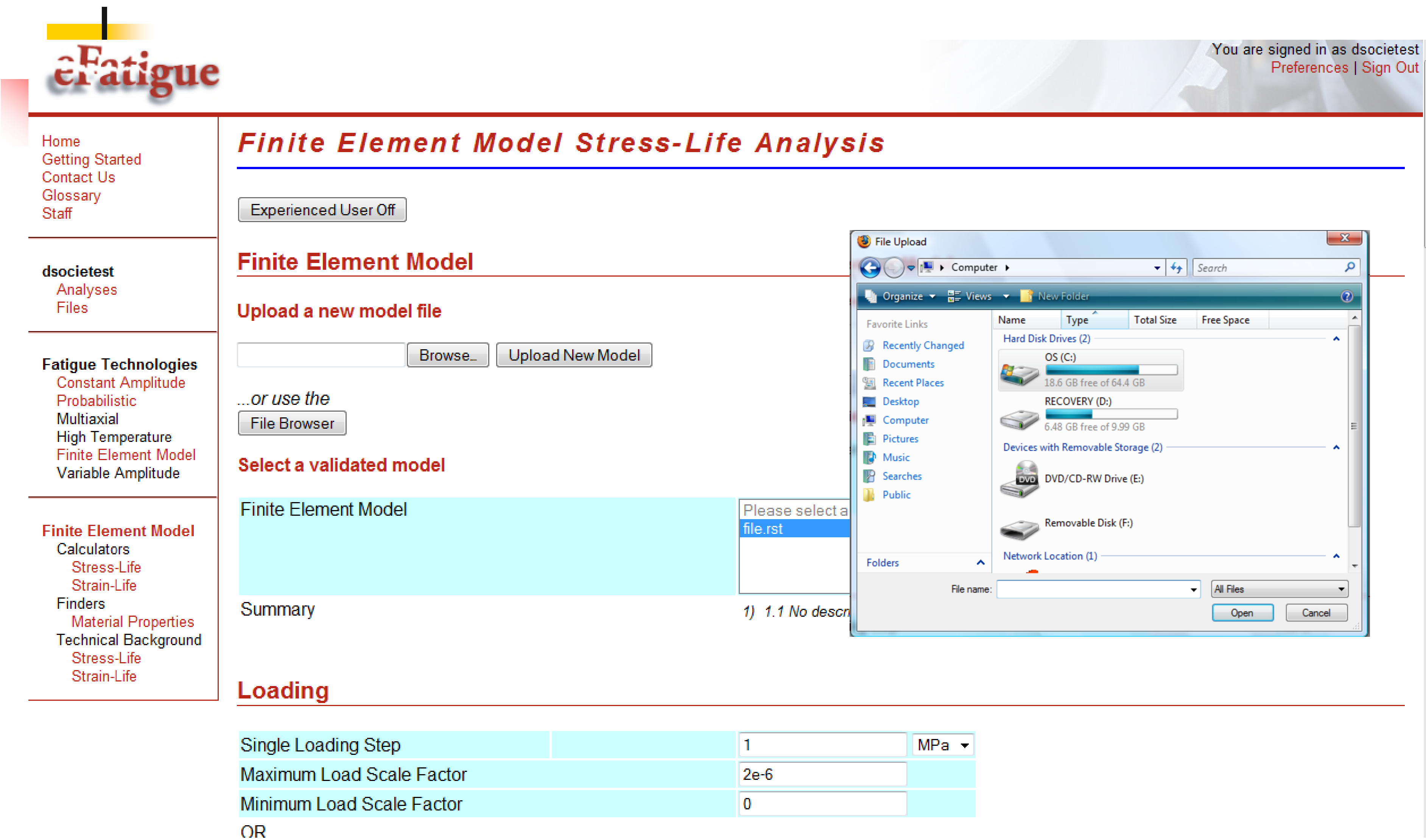
Strain-Life
This method is used for finite fatigue lives where plasticity around stress concentrations is important.

Finders

Material Properties
Find material properties for fatigue analysis.

Technical Background

Supported File Types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Experienced User Off
Finite Element Model
Upload a new model file
Browse...
Upload New Model
...or use the
File Browser
Select a validated model
Finite Element Model
Please select a
file.rst
Summary
1) 1.1 No descri
Loading
Single Loading Step
1
MPa
Maximum Load Scale Factor
2e-6
Minimum Load Scale Factor
0
OR
File Upload
Computer
Search
Organize
Views
New Folder
Favorite Links
Recently Changed
Documents
Recent Places
Desktop
Computer
Pictures
Music
Searches
Public
Folders
Name
Type
Total Size
Free Space
Hard Disk Drives (2)
OS (C:)
18.6 GB free of 64.4 GB
RECOVERY (D:)
6.48 GB free of 9.99 GB
Devices with Removable Storage (2)
DVD/CD-RW Drive (E:)
Removable Disk (F:)
Network Location (1)
File name:
All Files
Open
Cancel

Calculate

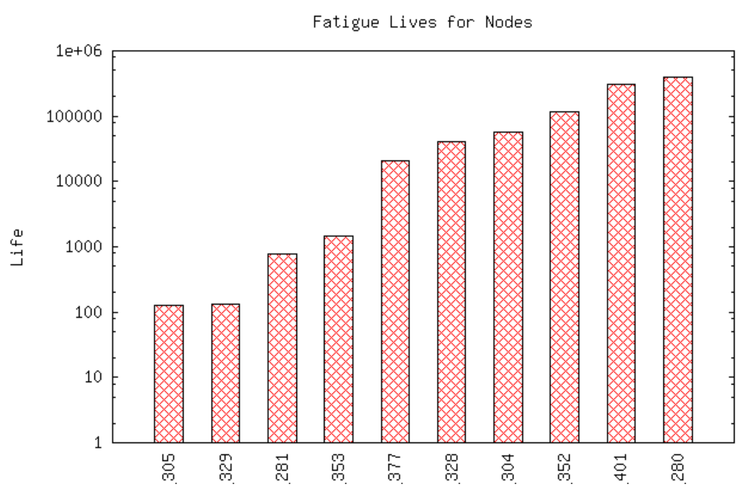
Clear Results (Keep Input) Clear Form

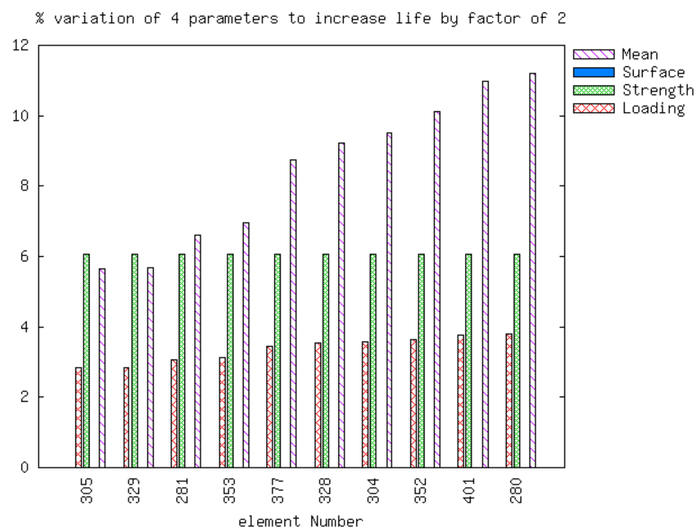
Viewing analysis FEMStressLife_2008_11_13_032850

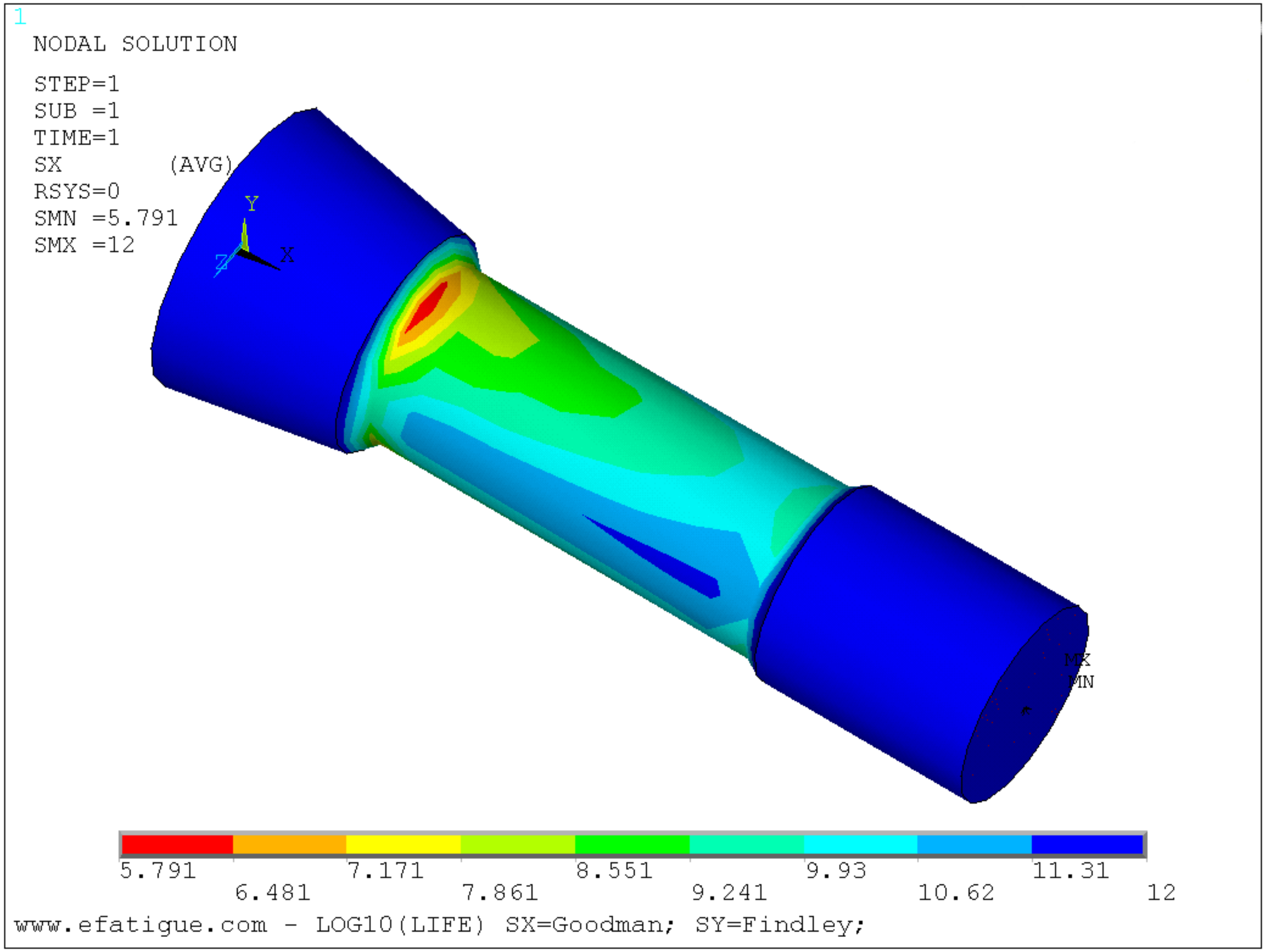
Analysis Results

N_f = 1.248e+02 repeats
Failure Location = element 305
Output Log

Plots






1
NODAL SOLUTION
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TIME=1
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RSYS=0
SMN =5.791
SMX =12
Y
Z
X
MX
MN
5.791
6.481
7.171
7.861
8.551
9.241
9.93
10.62
11.31
12
www.efatigue.com - LOG10(LIFE) SX=Goodman; SY=Findley;

eFatigue
a trusted source for fatigue analysis

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Loading

You may enter the loading in a series of text boxes, paste from the clipboard or as a triangle wave.

Units for ε_x	mm/mm
Units for T	C
Units for Δt	min

Text Boxes | Clipboard | Triangle

Enter up to ten points. You may paste tab and newline delimited text (such as would be copied from a spreadsheet) into a box, and it will be expanded out automatically. The cycle begins at ε_x=0 and T=20°C

Initial Monotonic Loading

Point	ε_x	T	Δt	Control Mode	
1	0.005	550	120	Mechanical Strain	remove

Add A Datapoint

Cyclic Loading

Point	ε_x	T	Δt	Control Mode	
1	-0.005	100	120	Mechanical Strain	remove
2	0.005	550	120	Mechanical Strain	remove

Add A Datapoint

Use the Plot button below to verify that the correct loading information was entered.

Plot | Clear Loading

Material

SI units (mm/mm , MPa , sec and °C) are expected for all material parameters.

You may select a material by clicking on the Material Property Finder button or specify individual properties directly.

Material Property Finder

Type	steel

Stress Strain Properties

$$\dot{\varepsilon}^{in} = \left\{ \begin{array}{ll} A_o\left(\frac{\bar{\sigma}}{K_o}\right)^{n_1} \exp\left(\frac{-\Delta H^{in}}{RT}\right) & \left(\frac{\bar{\sigma}}{K_o}\right) \leq 1 \\ \hline A_o \exp\left[\left(\frac{\bar{\sigma}}{K_o}\right)^{n_2} - 1\right] \exp\left(\frac{-\Delta H^{in}}{RT}\right) & \left(\frac{\bar{\sigma}}{K_o}\right) \geq 1 \end{array} \right\}$$

α =	0.0000118						
E =	210000	+	-35	T +	0	T^2 MPA for T <	435
	318000	+	-283	T +	0	T^2 MPA	
n_1 =	5.4						
n_2 =	8.3						
K_o =	256	+	0	T +	0.0014	T^2 MPA for T <	304
	568	+	-0.6	T +	0	T^2 MPA	
A_o =	4.0e9						
ΔH^{in} =	210600						

Creep Damage

$$\frac{1}{N_f^{creep}} = \int_0^{t_c} A_{cr}\Phi^{cr} \exp\left(\frac{-\Delta H^{cr}}{RT}\right)\left(\frac{\alpha_1\bar{\sigma} + \alpha_2\sigma_h}{K}\right)^m \qquad \phi_{cr} = \exp\left[-\frac{1}{2}\left(\frac{\dot{\varepsilon}_{th}/\dot{\varepsilon}_{mech} - 1}{\xi^{cr}}\right)^2\right]$$

ξ^{cr} =	0.4
ΔH^{cr} =	2.481e5
A_{cr} =	1.562e14
m =	11.34
α_1 =	0.333
α_2 =	1.0

Calculate

Calculate Life | Clear Form

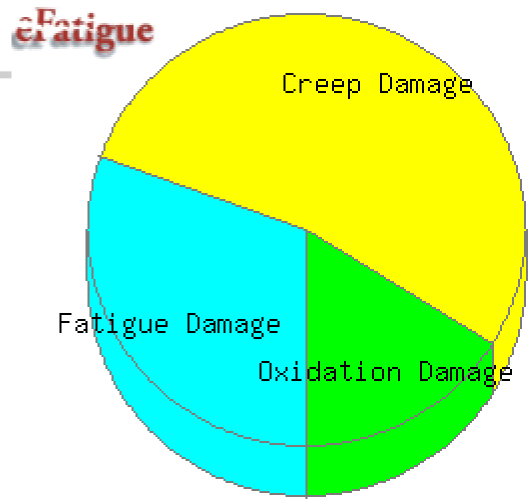
Analysis Results

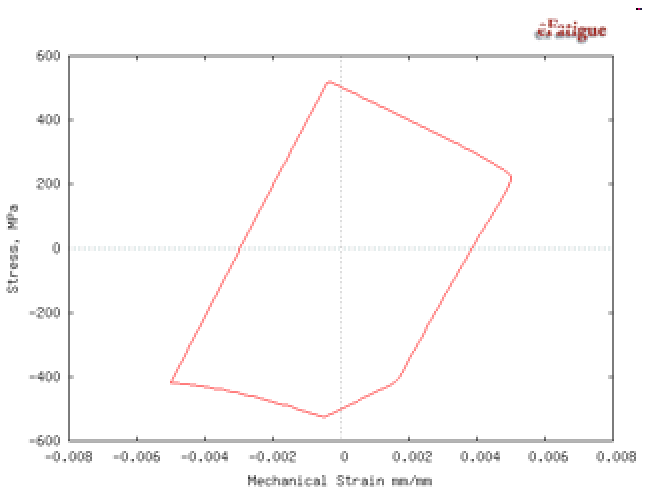
N_f = 368

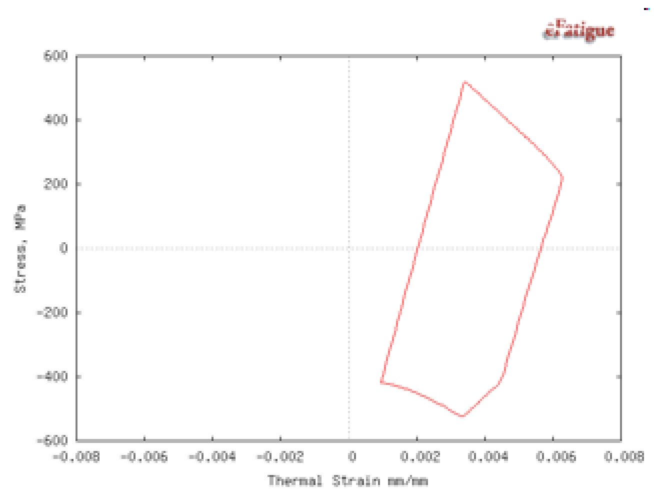
$N_f^{fatigue}$ = 1203

$N_f^{oxidation}$ = 2276

N_f^{creep} = 692







Summary

eFatigue – Bring fatigue assessment out of the shade into the sunlight where many people can have access fatigue technology on demand.

Fatigue and Fracture