Fatigue and Fracture
( Basic Course )

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

Model the physics on this scale

Use the models on this scale
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
Cyclic deformation leads to the development of slip bands and fatigue cracks.

Crack Nucleation
Slip Band in Copper

Slip Band Formation

Loading

Unloading

Extrusion

Undeformed material

Intrusion
Ma, B-T and Laird C. “Overview of fatigue behavior in copper single 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

N = 240

N = 300

N = 1200

N = 2000
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.

2219-T851 Cracked Particle

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.

7075-T6 Cracking at Inclusion
Crack Initiation at Inclusions

Subsurface Crack Initiation

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

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

Stage II

loading direction

free surface
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

Inconel 718

$\Delta \varepsilon = 0.02$

$N_f = 936$

$N = 900$

$N = 160$

$N = 240$

$N = 520$
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
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

\[ \sigma \]

\[ \varepsilon \]

monotonic plastic zone
Stresses Around a Crack (continued)

Minimum Load

σ

σ

cyclic plastic zone

σ

ε

σ

ε

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Crack Closure

a. S = 0

b. S = 175

c. S = 250
Crack Opening Load

- Damaging portion of loading history
- Nondamaging portion of loading history
- 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

shear stress  

slip bands

10 μm

crack growth direction
Fatigue Life, $2N_f$

- **1045 Steel - Tension**

Graph showing:
- **Fatigue Life, $2N_f$** on the x-axis.
- **Damage Fraction $N/N_f$** on the y-axis.

- **Shear** and **Tension** modes.
- **Nucleation** with a 100 μm crack.

Images of microstructures are also present.
1045 Steel - Torsion

Fatigue Life, $2N_f$

Damage Fraction $N/N_f$

- Tension
- Shear
- Nucleation

Fatigue Life, $2N_f$ vs. Damage Fraction $N/N_f$
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

Stress Amplitude, MPa

Cycles to Failure

Testing time @ 30 Hz

1 hour  1 day  1 month  1 year
### Fatigue Strength

<table>
<thead>
<tr>
<th>Alloy</th>
<th>$10^5$</th>
<th>$10^6$</th>
<th>$10^7$</th>
<th>$10^8$</th>
<th>$10^9$</th>
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</thead>
<tbody>
<tr>
<td>2014-T4</td>
<td>290</td>
<td>235</td>
<td>186</td>
<td>152</td>
<td>138</td>
</tr>
<tr>
<td>2024-T4</td>
<td>297</td>
<td>214</td>
<td>166</td>
<td>145</td>
<td>138</td>
</tr>
<tr>
<td>6061-T6</td>
<td>186</td>
<td>152</td>
<td>117</td>
<td>104</td>
<td>90</td>
</tr>
<tr>
<td>7075-T6</td>
<td>276</td>
<td>200</td>
<td>166</td>
<td>152</td>
<td>145</td>
</tr>
</tbody>
</table>
6061-T6 Aluminum Test Data

Sharpe et. al. Fatigue Design of Aluminum Components and Structures, 1996
The fatigue limit is usually only found in steel laboratory specimens.

\[
\frac{\Delta S}{2} = S_f (N_f)^b
\]
Very High Cycle Fatigue of Steel

- **Surface Failures**
  - Large inclusions
- **Conventional Fatigue Limit**
- **Internal Inclusions**

**Graph Details:**
- **X-axis:** Cycles
- **Y-axis:** Stress Amplitude (MPa)
- **Data Range:**
  - Cycles: $10^3$ to $10^{10}$
  - Stress Amplitude: $100$ to $10^4$
Fatigue Damage

\[ \frac{\Delta S}{2} = S'_f \left( N_f \right)^b \]

\[ N_f = \left( \frac{\Delta S}{2S'_f} \right)^{\frac{1}{b}} \]

Damage \ \propto \ \Delta S^{10}
Fatigue Limit Strength Correlation

Fatigue Limit Strength Correlation

The graph shows the correlation between fatigue limit strength and hardness, denoted as $R_c$. The data points represent quenched and tempered steels, with hardness values ranging from 20 to 70 and fatigue limit strength ranging from 450 to 950 MPa.

- Quenched and tempered steels:
  - 1054: 4063 5140
  - 2340: 4068 5150
  - 4032: 4130 5160
  - 4042: 4140 8640
  - 4053: 4340 9262

The graph includes a trend line that illustrates the general correlation between these two properties.
SN Materials Data

Fatigue Life, Reversals

Stress Amplitude, MPa

- 93 steels
- 17 aluminums
Strain Controlled Testing
Cyclic Hardening / Softening

(a) Fully annealed
\[ \Delta e = 0.0084 \]
\[ 2N_f = 8060 \text{ reversals} \]

(b) Partially annealed
\[ \Delta e = 0.0078 \]
\[ 2N_f = 4400 \text{ reversals} \]

(c) Cold worked
\[ \Delta e = 0.0099 \]
\[ 2N_f = 2000 \text{ reversals} \]
Stable Hysteresis Loop

Hysteresis loop

\[ \Delta \sigma \]

\[ \Delta \varepsilon_p \quad \Delta \varepsilon_e \]

\[ \Delta \varepsilon \]
During cyclic deformation, the material deforms on a path described by the cyclic stress strain curve
Cyclic Stress Strain Curve

- **2024-T4**
  - Cyclic
  - Monotonic

- **7075-T6**
  - Cyclic
  - Monotonic

- **Man-Ten steel**
  - Cyclic
  - Monotonic

- **SAE 4340 (350 BHN)**
  - Monotonic
  - Cyclic

- **TI-811**
  - Monotonic
  - Cyclic

- **Waspaloy A**
  - Cyclic
  - Monotonic
Strain-Life Data  \( \Delta \varepsilon - 2N_f \)

2 Reversals, \( 2N_f = 1 \) Cycle, \( N_f \)
Elastic and Plastic Strain-Life Data

Strain Amplitude $\Delta \varepsilon$

Reversals, $2N_f$

Plastic

Elastic
\begin{equation}
\frac{\Delta \varepsilon}{2} = \frac{\sigma'_f}{E}(2N_f)^b + \varepsilon'_f(2N_f)^c
\end{equation}
Transition Fatigue Life

From Dowling, Mechanical Behavior of Materials, 1999
Crack Growth Testing
Stress Concentration of a Crack

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

for a crack

\[ a \sim 10^{-3} \]
\[ \rho \sim 10^{-9} \]

\[ K_T \sim 2000 \]

\[ \sigma_{\text{local}} = 2000 \sigma_{\text{applied}} \]

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

\[ \sigma \]

\[ \sigma_1 \quad \sigma_2 \]

\[ a_1 \quad a_2 \]

\[ \frac{da}{dN} \]

Cycles

Crack size

2a
Crack Growth Data

\[ \frac{da}{dN} = C \Delta K^m \]

\( m \sim 3 \)
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 \( \approx \frac{\sigma_u}{2} \)

\[ a_c = 2.52 \left( \frac{\Delta K_{TH}}{\sigma_u} \right)^2 \]
Non-propagating Crack Sizes

\[ \Delta K_{TH} = 5 \text{MPa}\sqrt{m} \]
Stable Crack Growth

\[
\frac{da}{dN} = C \Delta K^m
\]

Stable growth region
Crack Growth Data

Ferritic-Pearlitic Steel:
\[
\frac{da}{dN} = 6.9 \times 10^{-12} (\Delta K \text{ MPa} \sqrt{m})^{3.0}
\]

Martensitic Steel:
\[
\frac{da}{dN} = 1.4 \times 10^{-10} (\Delta K \text{ MPa} \sqrt{m})^{2.25}
\]

Austenitic Stainless Steel:
\[
\frac{da}{dN} = 5.6 \times 10^{-12} (\Delta K \text{ MPa} \sqrt{m})^{3.25}
\]

Barsom, “Fatigue Crack Propagation in Steels of Various Yield Strengths”
Aluminum Crack Growth Rate Data

Crack Growth Data

### Things Worth Remembering

<table>
<thead>
<tr>
<th>Method</th>
<th>Physics</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stress-Life</td>
<td>Crack Nucleation</td>
<td>0.01 mm</td>
</tr>
<tr>
<td>Strain-Life</td>
<td>Microcrack Growth</td>
<td>0.1 - 1 mm</td>
</tr>
<tr>
<td>Crack Growth</td>
<td>Macrocrack Growth</td>
<td>&gt; 1 mm</td>
</tr>
</tbody>
</table>

- **Method**
  - Stress-Life
  - Strain-Life
  - Crack Growth

- **Physics**
  - Crack Nucleation
  - Microcrack Growth
  - Macrocrack Growth

- **Size**
  - 0.01 mm
  - 0.1 - 1 mm
  - > 1 mm
Fatigue, How and Why

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

Material Data

Component Geometry

Service Loading

Analysis

Fatigue Life Estimate
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

<table>
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<th>Physics</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Stress-Life</td>
<td>Crack Nucleation</td>
<td>0.01 mm</td>
</tr>
<tr>
<td>BS 7608</td>
<td>Crack Growth</td>
<td>1 - 10 mm</td>
</tr>
<tr>
<td>Strain-Life</td>
<td>Microcrack Growth</td>
<td>0.1 - 1 mm</td>
</tr>
<tr>
<td>Crack Growth</td>
<td>Macrocrack Growth</td>
<td>&gt; 1 mm</td>
</tr>
</tbody>
</table>
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

Material Data
SN curve
Ka, Ks, ...

Component Geometry
$K_f$

Service Loading
$\Delta S$, $S_m$

Analysis

Fatigue Life Estimate
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
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

Material Data

Component Geometry

Service Loading

Weld SN curve

Class

Analysis

Fatigue Life Estimate

\[ \Delta S \]
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
Advantages:

- Manufacturing effects are directly included
- Large empirical database exists
Limitations:
- Difficult to determine weld class for complex shapes
- No benefit for improving manufacturing process
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

Material Data

Component Geometry

Service Loading

ε - N curve
σ - ε curve
K_f
ΔS, S_m

Analysis

Fatigue Life Estimate
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

Material Data
- da/dN curve

Component Geometry
- $K$ (K)

Service Loading
- $\Delta S$, $S_m$

Analysis

Fatigue Life Estimate
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
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
Choose an appropriate risk and replace critical parts after some specified interval.
Damage Tolerant

Inspect for cracks larger than $a_1$ and repair

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
- Fatigue Calculator
Fatigue Calculator® is a useful set of web-based fatigue analysis software tools for computing fatigue lives of metallic components and structures. No single method is best for all situations, so several methods have been included: stress-life, strain-life, fracture mechanics crack growth and welds. Each of the methods have their own strengths and weaknesses. Therefore, if you are not familiar with the constant amplitude fatigue analysis before using the other types of analysis.

Note: This site is best viewed using Internet Explorer with javascript enabled. We are currently working to improve compatibility with other browsers.
Constant Amplitude Calculators

Fatigue Technology
- Constant Amplitude
  - Fatigue Calculators
    - Stress Life
    - Strain Life
    - Crack Growth
    - Welds
  - Finders
  - Technical Background
  - Other
- Probabilistic
  - Fatigue Calculators
    - Stress Life
    - Strain Life
    - Crack Growth
    - Welds
  - Finders
  - Technical Background
  - Other

Constant Amplitude 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.
- Welds
  - Complex weld shapes and residual stresses require special fatigue considerations.

Note: This site is best viewed using Internet Explorer with Javascript enabled. We are currently working to improve compatibility with other browsers.
Deterministic Analysis

Constant Amplitude Stress-Life Analysis

Loading

You may choose to specify either the stresses or the desired life/safety factors and compute the other. If you choose to calculate the stresses, leave this section blank.

- Maximum
  - S_{max} = \sigma_{max} = \text{25} \text{ MPa}
- Minimum
  - S_{min} = \sigma_{min} = \text{-25} \text{ MPa}
- Alternating
  - S_a = \sigma_a = \text{MPa}
- Mean
  - S_m = \sigma_m = \text{MPa}

Material
Deterministic Analysis (continued)

Material

You may use the Material Finder by clicking on the Material Property Finder Icon to look up the proper values for your material or specify values directly. If you do not enter a value for the Fatigue Limit, a default value of 127 MPa will be assumed.

<table>
<thead>
<tr>
<th>Type</th>
<th>Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate</td>
<td>800</td>
</tr>
<tr>
<td>Fatigue Limit</td>
<td>0</td>
</tr>
</tbody>
</table>

If this section is left blank, they will be estimated from the ultimate strength.

<table>
<thead>
<tr>
<th>Intercept</th>
<th></th>
<th></th>
<th>Slope</th>
<th></th>
</tr>
</thead>
</table>

Modifying Factors

Either specify the modifying factors directly or choose a finish from the drop-down box. If you don’t know, a default value of 1 will be used.

| Surface Factor |  | | Loading Factor |  | | Size Factor |  | | Diameter |  |
|----------------|---|---|----------------|---|---|--------------|---|---|-----|
|                |   |   |                |   |   |               |   |   |     |   |
|                |   |   |                |   |   |               |   |   |     |   |
|                |   |   |                |   |   |               |   |   |     |   |
|                |   |   |                |   |   |               |   |   |     |   |
|                |   |   |                |   |   |               |   |   |     |   |
Deterministic Analysis (continued)
Deterministic Analysis Results

Stress-Life Calculations Complete.

The calculated safety factor is:

\[ n = 2.2 \]

We used the following data that you entered:

\[
\begin{align*}
S_u &= 500 \text{ MPa} \\
X_0 &= 3 \\
S_{\text{max}} &= 40 \text{ MPa} \\
S_{\text{min}} &= -30 \text{ MPa}
\end{align*}
\]

We calculated the following parameters based on default values and values that you entered:

\[
\begin{align*}
k_\text{ij} &= 1 \\
k_\text{log} &= 1 \\
S_{\text{FL}} &= 250 \text{ MPa} \\
k_\text{eff} &= 0.62 \\
S_y &= 20 \text{ MPa} \\
S_{\text{m}} &= 0 \text{ MPa}
\end{align*}
\]
Probabilistic Analysis

Probabilistic Stress-Life Analysis

Since as much data as you know, estimation is not enough, you will be asked for more. Bolded fields represent absolutely required data to begin calculations. Other data may become necessary as calculation proceeds. This is the probabilistic method, so select a distribution and scale parameter for each variable. The scale parameter has a different meaning for each distribution type, see Description of Distribution Types for more information. You may choose None if you wish to keep this variable constant throughout the probabilistic analysis.

Description of Distribution Types

Loading

Loading typically follows a normal distribution. The coefficient of variation, COV, is typically around 0.2.

You may choose to specify either the stresses or the desired life / safety factor and compute the other. If you choose to calculate the stresses, leave this section blank.

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>Units</th>
<th>Distribution Type</th>
<th>Scale Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nd</td>
<td></td>
<td></td>
<td>Normal</td>
<td>0.2</td>
</tr>
<tr>
<td>Min</td>
<td></td>
<td></td>
<td>Normal</td>
<td>0.2</td>
</tr>
<tr>
<td>Max</td>
<td></td>
<td></td>
<td>Normal</td>
<td>0.2</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td>Normal</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Material
### Probabilistic Analysis (continued)

#### Material

You may use the Material Wizard by clicking on the Material Property Wizard icon to look up the proper values for your material or specify values directly. If you do not enter a value for the Fatigue Limit, a default value of 0.5 $S_u$ will be assumed.

![Material Property Wizard](http://www.dev.fatiguecalculator.com/probabilistic/stresslifeexp.htm)

**Material**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
<th>Units</th>
<th>Distribution Type</th>
<th>Coefficient of Variation</th>
<th>Coefficient of Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate Strength</td>
<td>$S_u$</td>
<td>MPa</td>
<td>Normal</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Fatigue Limit</td>
<td>$S_{FL}$</td>
<td>MPa</td>
<td>None</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

If this section is left blank, values will be estimated.

#### Elastic Moduli

- **Intercept**: $b$
- **Slope**: $a$

#### Modifying Factors

Either specify the modifying factor directly or choose a finish from the drop-down box. If you don't know, a default value of 1 will be used.
Probabilistic Analysis (continued)

Modifying Factors

Either specify the modifying factor directly or choose a finish from the drop-down box. If you don't know, a default value of 1 will be used.

<table>
<thead>
<tr>
<th>Surface Factor</th>
<th>Leading Factor</th>
<th>Size Factor</th>
<th>Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k_{mp}$</td>
<td>$k_{1}$</td>
<td>$k_{2}$</td>
<td>$d$</td>
</tr>
</tbody>
</table>

Value or Finish | Distribution Type | Coefficient of Variation
--- | --- | ---
Machined | Normal | 1.1

Stress Concentration

Either specify $K_f$ directly or enter $K_f$ and the radius.

<table>
<thead>
<tr>
<th>Stress Concentration Factor (Factor)</th>
<th>$K_f$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>Distribution Type</td>
</tr>
<tr>
<td>3</td>
<td>Normal</td>
</tr>
</tbody>
</table>

Use $K_f$ in analysis? No

Radius

Calculate $K_f$
Probabilistic Analysis Results

Calculating...

It may take several minutes to complete the calculations. Please be patient.

Probabilistic Stress-Life Calculations Complete.

The calculated answers:

% probability of failure

Proportional Sensitivity

Material Properties

Loading

Surface Finish

Stress Concentrations

See the data for each chart

Warning:

S_0 > 230 MPa so S_0 is set to 1.
Fatigue and Fracture
( Basic Course )