Implementation of Integrated Computational Materials Engineering or ICME to Manage the Fatigue Life of Components / Assemblies

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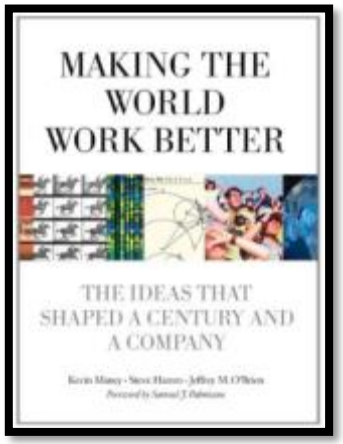
Who is VEXTEC?

- **Founded in 2000: Over $25 million from the United States Department of Defense Innovative Research programs for Technology Development**
- **Proprietary Software and Seven Patents: Virtual Life Management® (VLM®) generates VIRTUAL TWIN®**
- **Customers: Federal Government and Industries (Aerospace, Automotive, Electronics, Energy, MEDICAL DEVICES)**
- **Value Proposition: Help companies improve products and reduce cost**
  - **New products to market quickly**
  - **Improve reliability of existing products**
  - **Reduce physical and prototype testing requirements**
  - **Forecast product durability and manage product life cycle risk**
- **Business Model: Hybrid – Consulting Services, Software Licensing and Training**



VEXTEC accepted into FDA's Medical Device Development Tool (MDDT) pilot Program

Introduction

Software-enabled provider of solutions which test, assess and predict product fatigue/corrosion life

Software Enabled Solution

- Patented materials science algorithms based software to analyze and predict failure timelines and rates – applicable from simple levers to complex machines
- Software is a sophisticated computer simulation with inputs that can easily be varied to replace extensive and expensive physical testing programs

Value-Added Knowledge to Clients

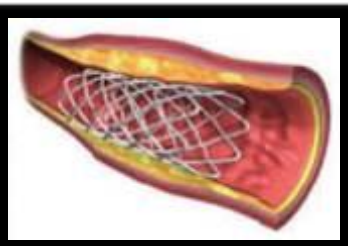
- Enables VEXTEC's clients to forecast product durability and manage product life cycle risk
- Knowing the life cycle of any given part or machine, the client can better manage utilization and replacement rates – a significant economic benefit

Applicable Across Multiple Industries

Aerospace & Defense

Automotive & Transportation

Industrial Equipment



Medical Implants

Virtual Life Management® (VLM®)

The capability of providing VLM provides relevant and important data to clients with an end result of improved cost containment and operating efficiency

Value Proposition

Replace or supplement physical testing for increased confidence

Forecast product durability and manage product life cycle risk

Bring new products to market quickly

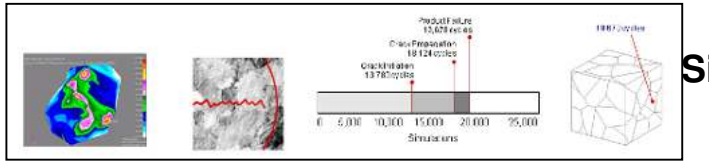
Assure product reliability and reduce cost

How It Works

- Generate predictive fatigue and corrosion durability models by combining client's available data with VEXTEC probabilistic models of material, geometry and loading
- Durability models simulate physics-based relationships of material, design, and application directly affecting fleet performance
- Provide client quick "What If" analysis to enable material and/or design changes and define maintenance and warranty cost programs

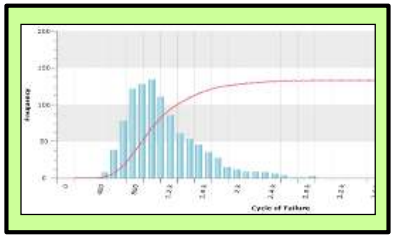
Product

Analysis



Simulate Damage in the Material

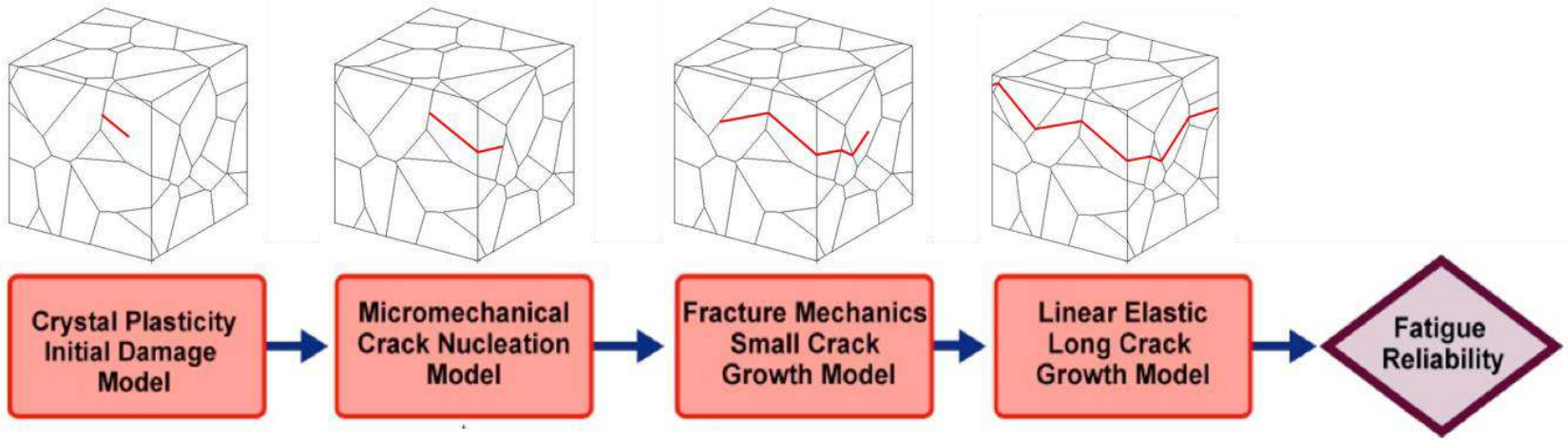
Results



Predict Risk of Failure

Technology

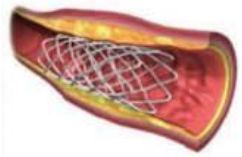
Damage is a process – VLM predicts failure by simulating the damage accumulation process



- The physics that drives the damage process changes as the damage accumulates
- Mathematical models exist to describe the physics at each stage
- ***VLM contains a library of damage models and stage transition rules that are applied as appropriate to the materials being simulated***

Demonstrated Success

VEXTEC has engaged its solutions for a variety of government and commercial applications for multiple industries in more than 100 successful implementations

	Industry	Client Type	Project Description
	**Aerospace**	**Airline (American)**	➢ Simulated lubrication changes & identified fix ➢ FAA approved ➢ $4M/year saved on bearings
	**Automotive**	**Engine Maker (Cummins)**	➢ Simulated 150 designs & identified top 3 ➢ $5M saved on engine block development program
	**Industrial Equipment**	**Specialty Manufacturer**	➢ Forecast maintenance schedule based on current usage ➢ $3M saved in reducing manufacturing line downtime
	**Healthcare**	**Medical Devices (Boston Scientific)**	➢ Evaluated material suppliers for different markets ➢ Avoided expensive developmental test program

Software: VPS-MICRO®

Simulated Fatigue Tests

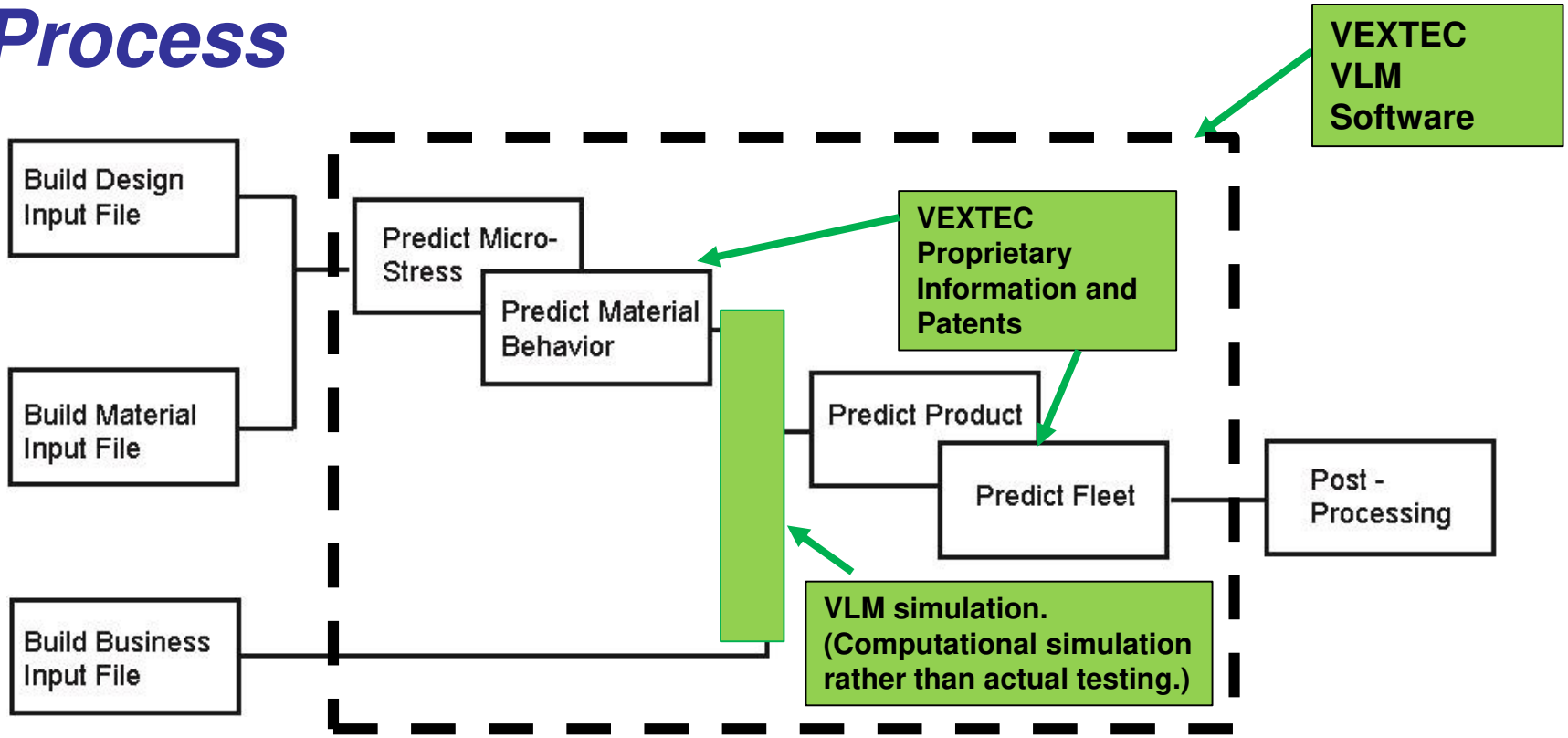
- Windows desktop tool
- Wide range of applications
  - Stand-alone tool for simple specimen geometry models
  - Integrate FEA models for complex geometry of full-scale components
- Output
  - Simulated S-N Curve
  - Virtual fracture surface
  - Detailed statistical analysis
- Customizable Software Product
  - Interface with Standard FEA software
  - Predict risk of failure from complex in-service loading spectrums

Simulated S-N Curve

Software Partners

ANSYS® SIMULIA MSC Software

VEXTEC VLM Analysis Simulation Process

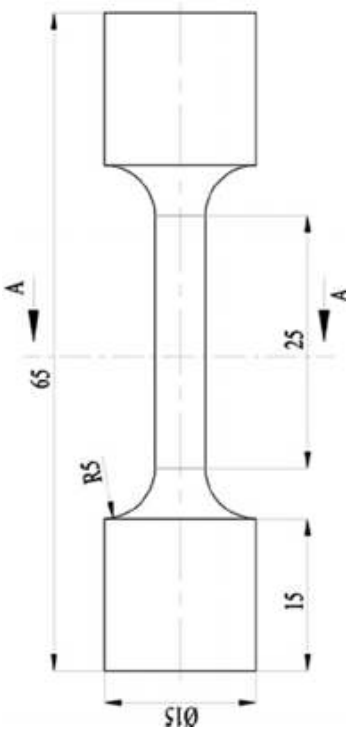


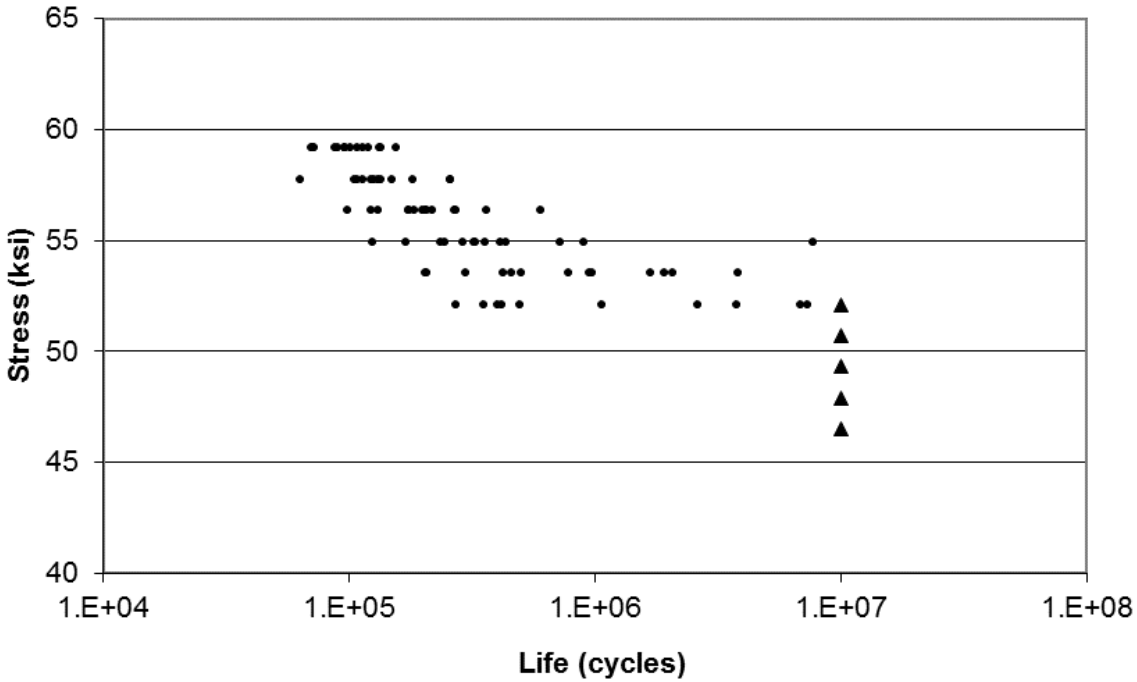
VLM reduces the amount of testing needed by computational simulation

Traditional vs. Computational Fatigue Analysis

Traditional Fatigue Analysis

Empirical Methods





$$N_f = A\sigma_a^b$$

Fatigue Life

Fatigue Modifying Factors

"Fatigue Strength" is not a material property

$$S_e = k_a k_b k_c k_d k_e k_f k_g k_h k_i k_j k_k S'_e$$

$$S_e = \text{fatigue strength of component}$$

$$S'_e = \text{fatigue strength of test coupon}$$

k_a = surface factor

k_b = size factor

k_c = mean stress factor

k_d = reliability factor

k_e = temperature factor

k_f = notch factor

k_g = residual stress factor

k_h = texture factor

k_i = corrosion factor

k_j = plating factor

k_k = multi-axial stress factor

J. E. Shigley, Mechanical Engineering Design, McGraw-Hill, 1977, pp. 188

Advice from Prof. Shigley

"It is a relatively simple matter to design against a static failure because our knowledge is quite complete. But fatigue is a much more complicated phenomenon, only partially understood, and the engineer seeking to rise to the top of the profession must acquire as much knowledge of the subject as possible. Anyone can double or triple factors of safety, because of a lack of knowledge of fatigue , and get a design the will not fail. But such designs will not compete in today's market, and neither will the engineers who produce them." J. E. Shigley, Mechanical Engineering Design, McGraw-Hill, 1977, pp. 178

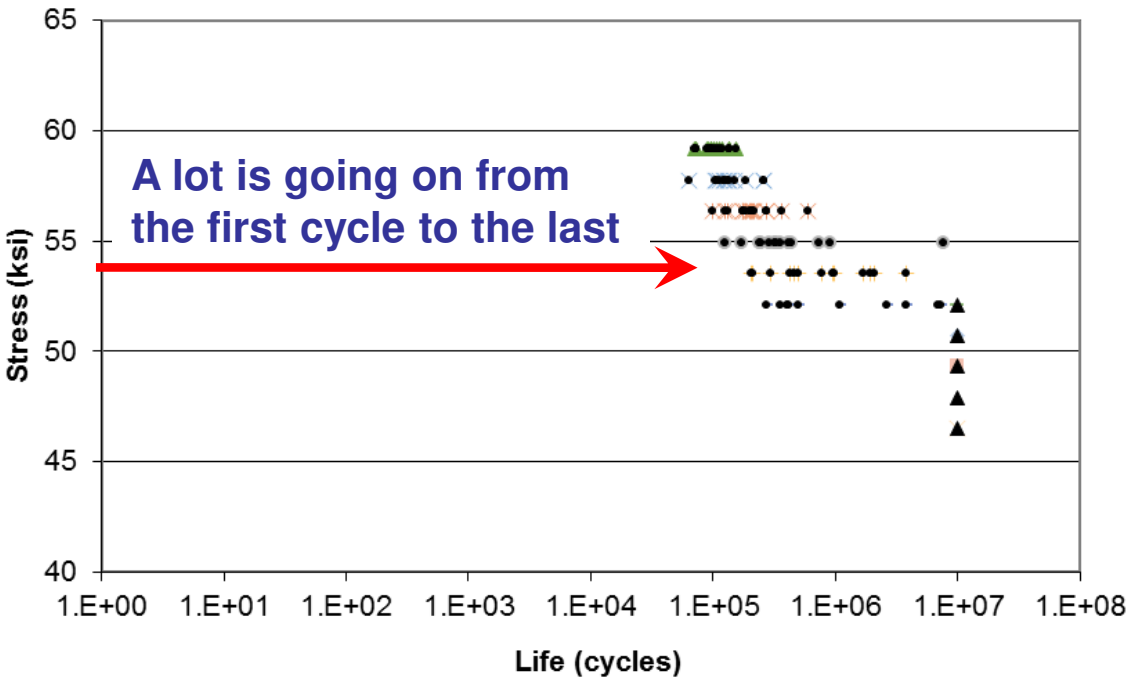
Fatigue Analysis

Why are there so many modifying factors?

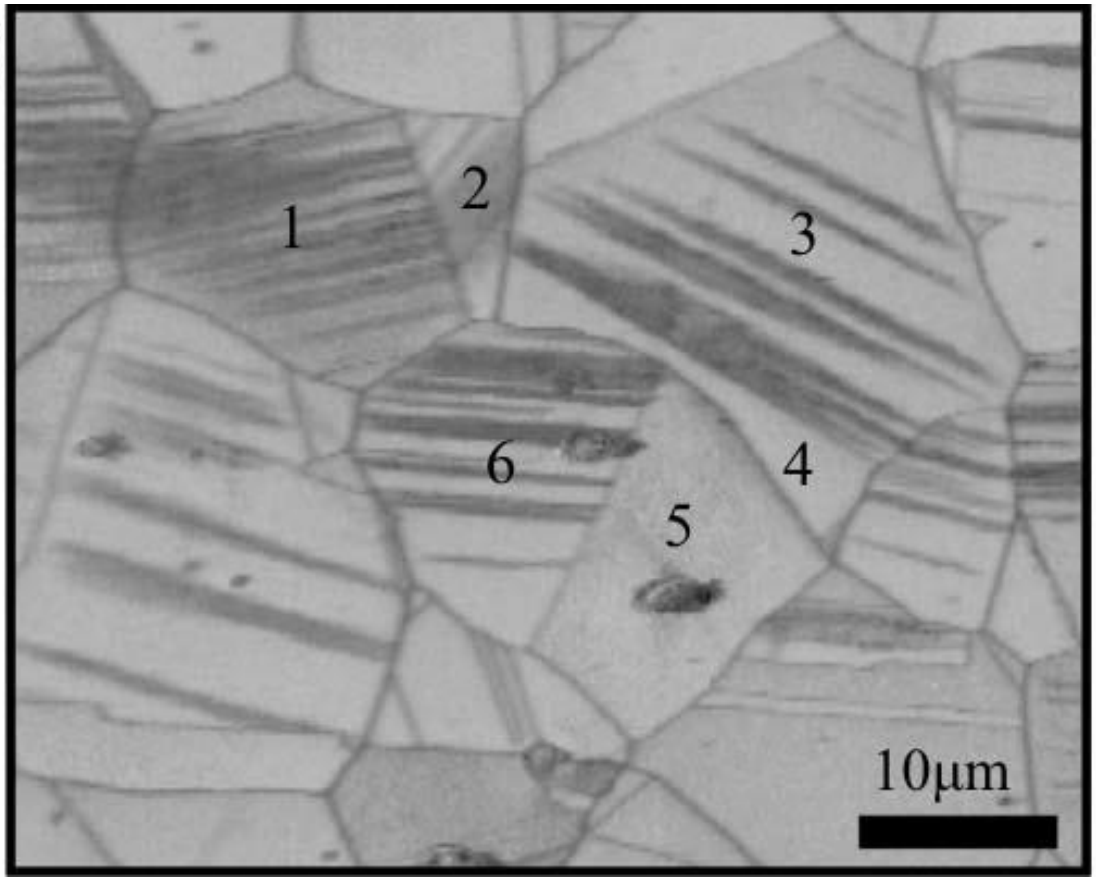
Fatigue response is much more complex than

$$N_f = A\sigma_a^b$$

Fatigue is a process, not an event

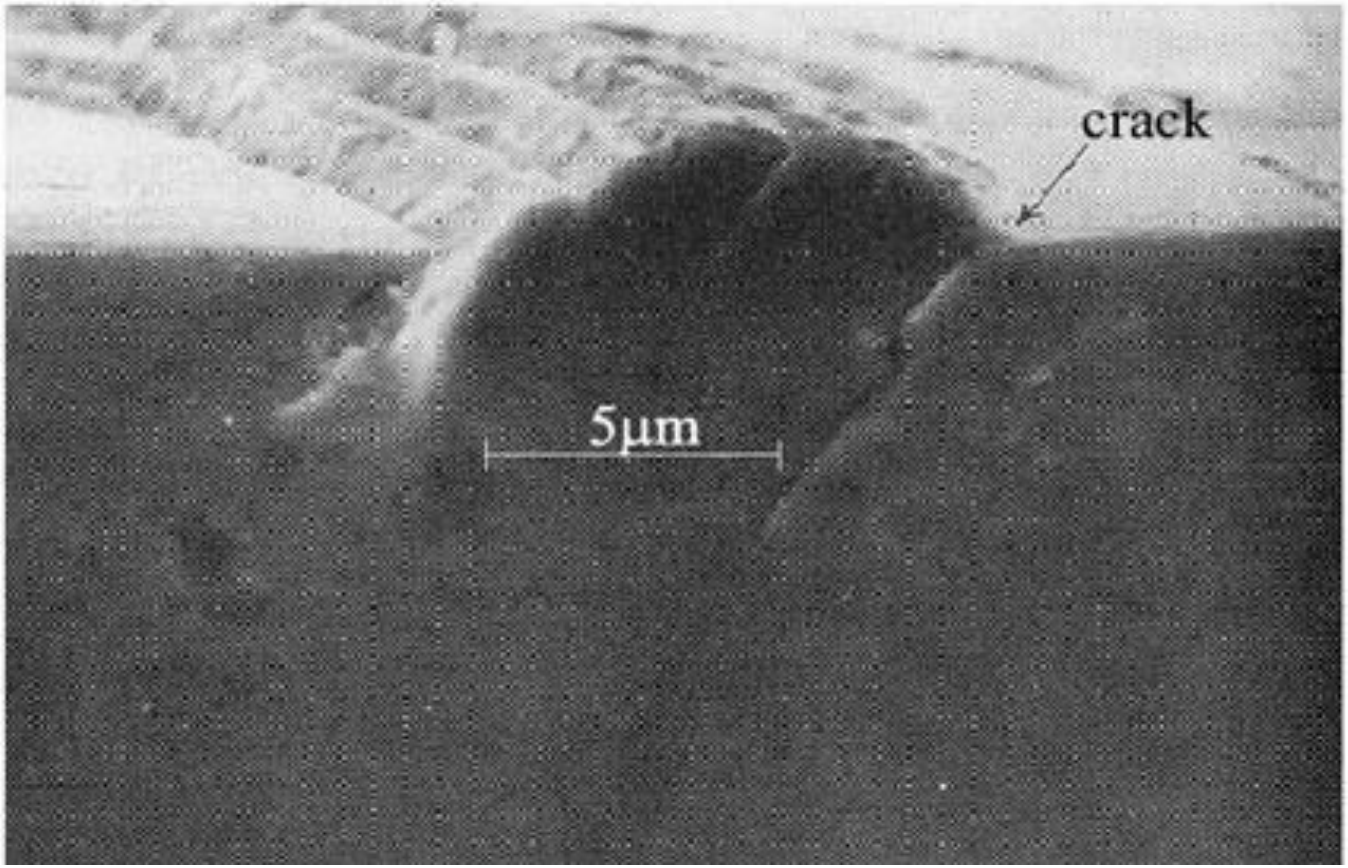


Intense slip bands of plastic deformation



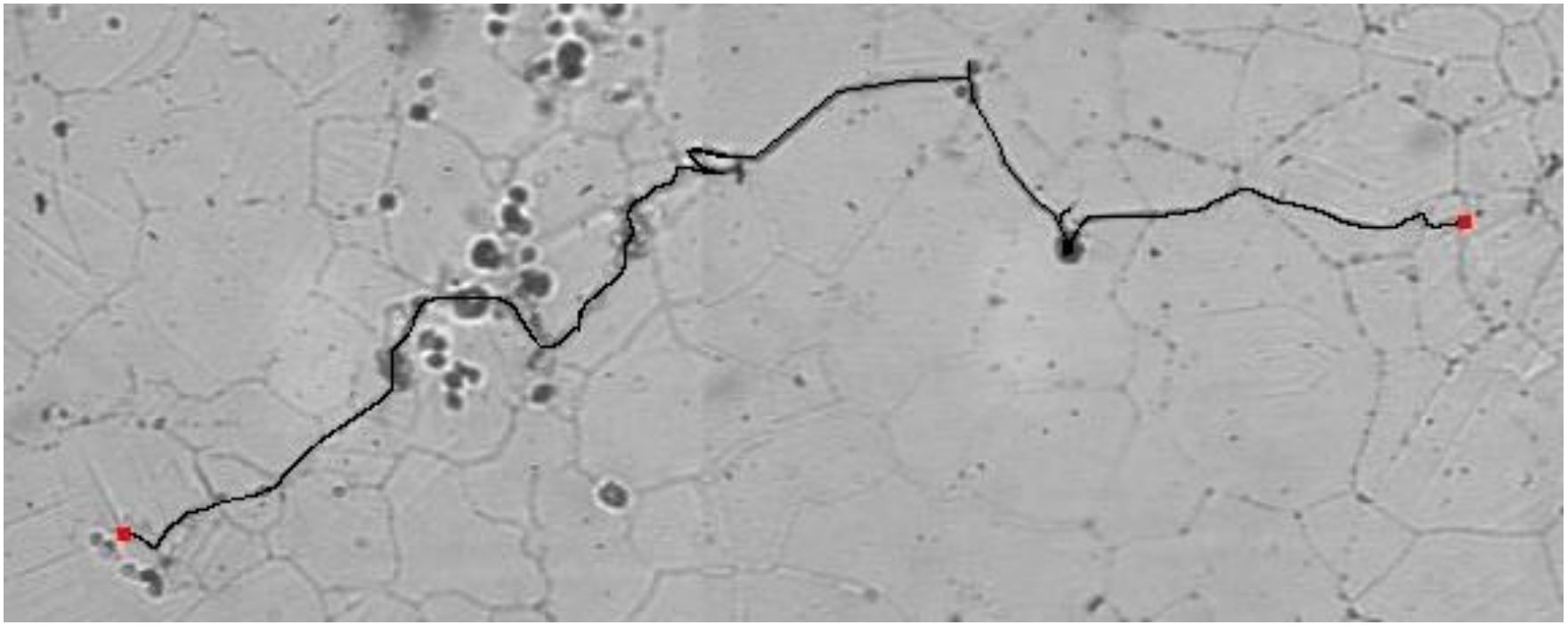
Prof. Christ and co-workers, 2013

Intense slip bands crack



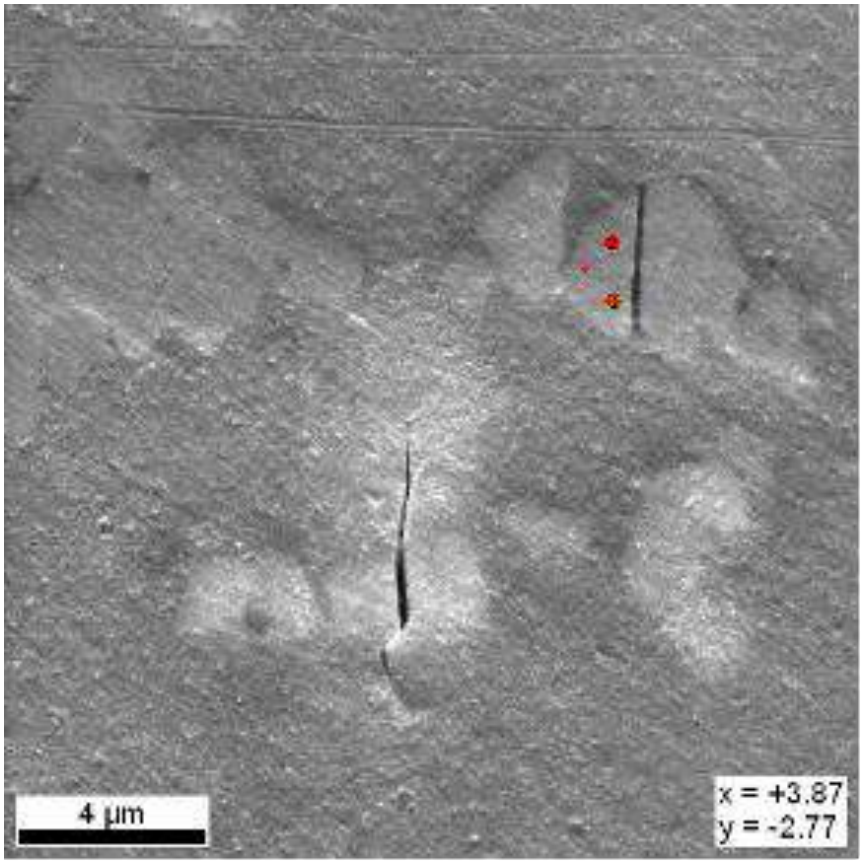
Prof. Suresh and co-workers ,1991

Fatigue Damage



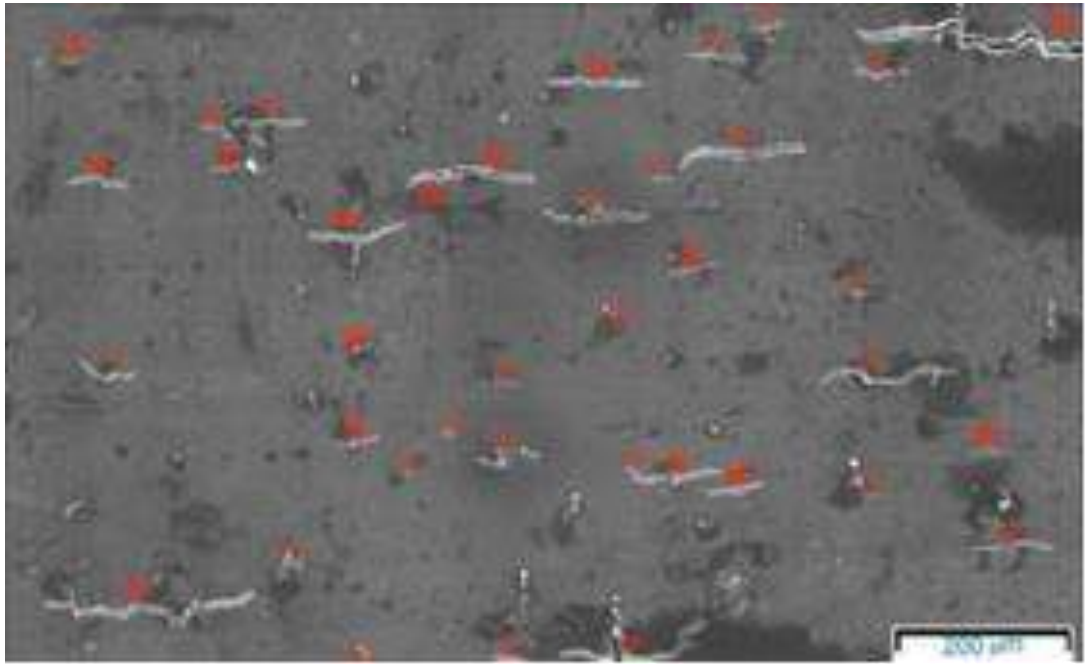
Micro crack dominated fatigue

- Some materials (high strength aluminum) crack during the manufacturing process.



Micro crack dominated fatigue

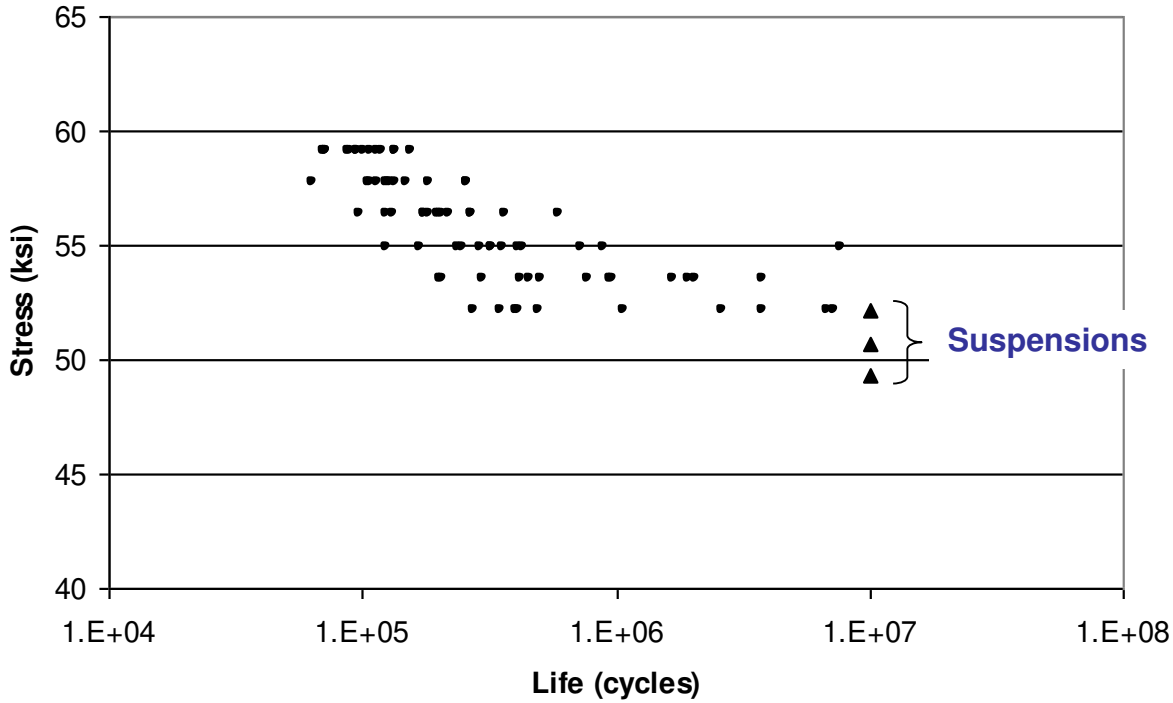
- Fatigue is dominated by the growth and coalesce of very small cracks.
- Fatigue is always governed by very localized damage



Complex Behavior: Infinite Strength

JIS Steel Data

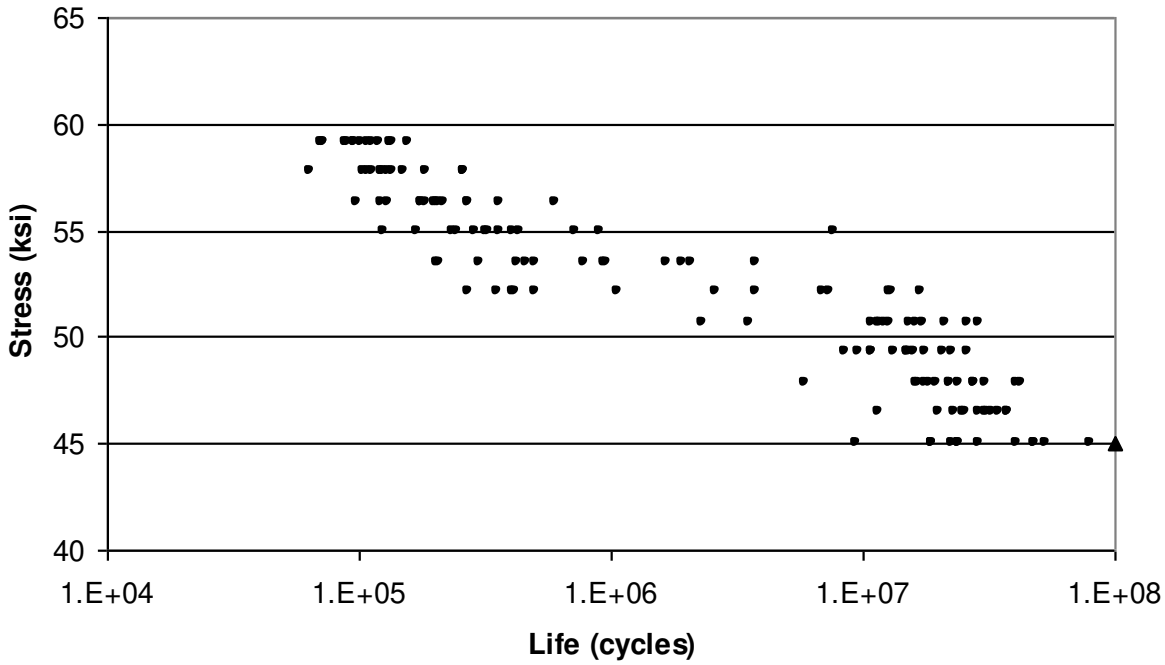
- S-N curve from typical 10^7 cycles laboratory tests of fatigue specimens
  - Test results indicate infinite (fatigue) strength of 52 ksi
  - Multiple tests suspensions at 10^7 cycles



Complex Behavior: Infinite Strength

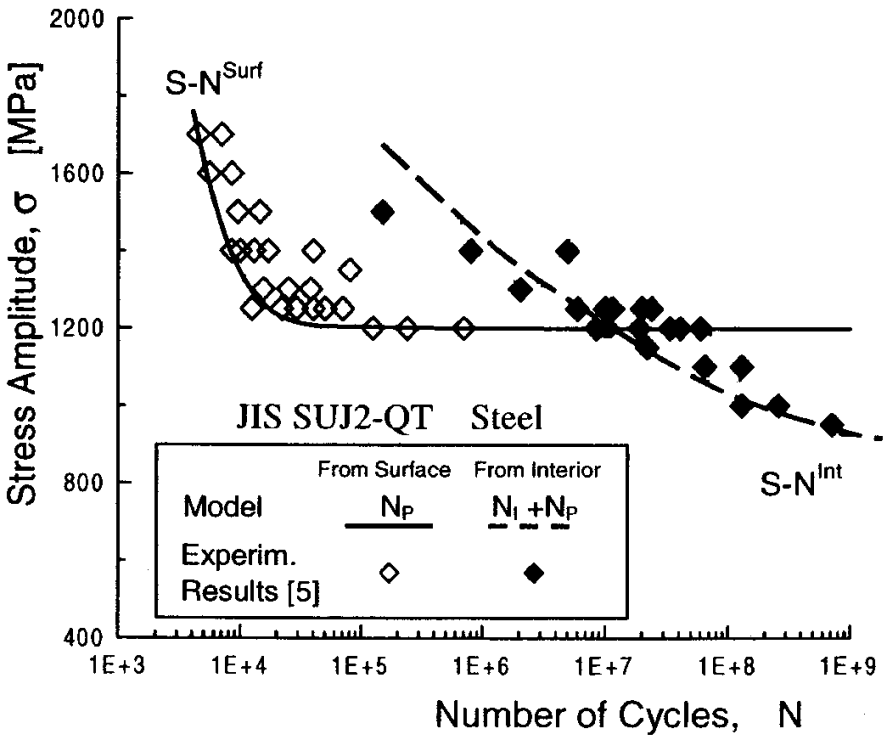
JIS Steel Data

- Testing beyond 10^7 cycles shows infinite strength well below 52 ksi
- Testing provided false assurance
- Test must be supplemented with modeling to reduce risk



Dual Mechanism Long Life SN Curve

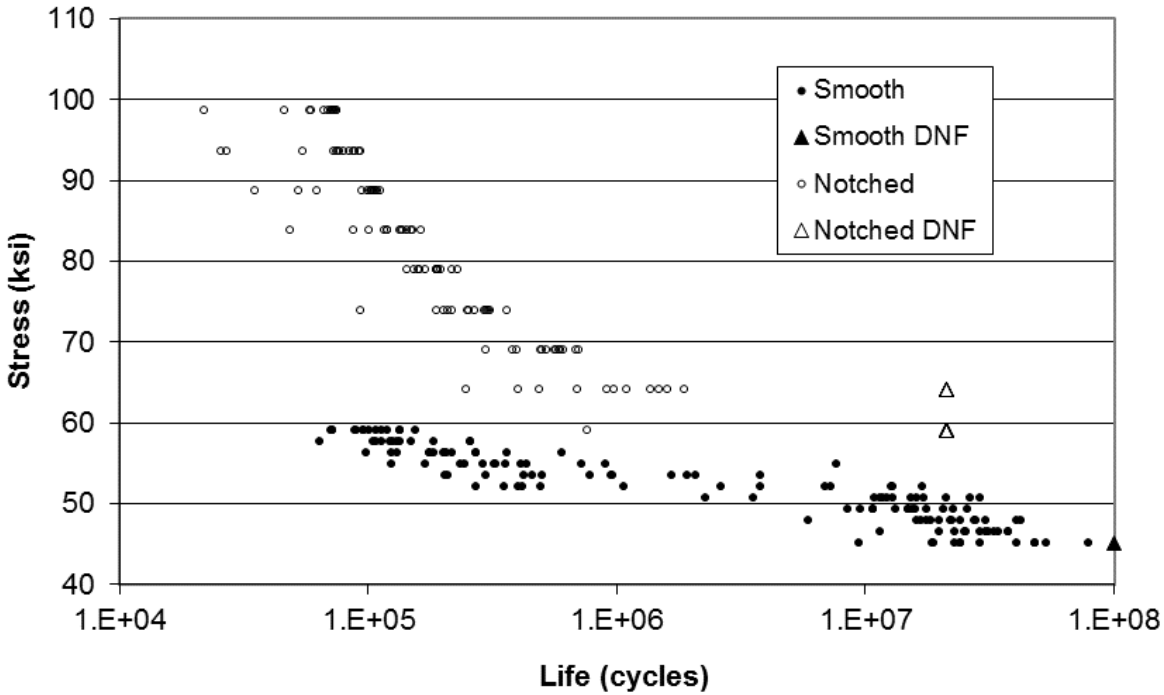
- Testing to determine risk is prohibitively expensive
  - Testing to full life is very expensive
  - Testing production hardware is very expensive
  - Testing many samples is very expensive
- Computational models allow simulation of required test protocols for risk assessment
- Mechanics understanding of fatigue allows computational prediction.



Complex Behavior: Notch effect

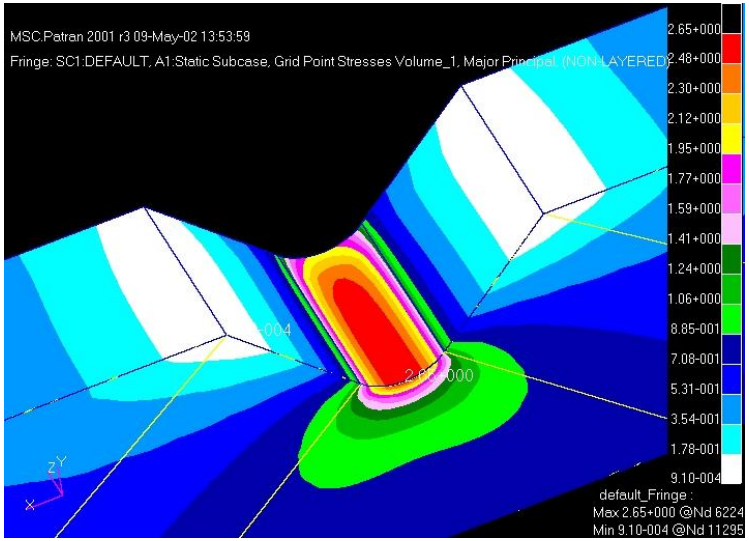
JIS Steel Data

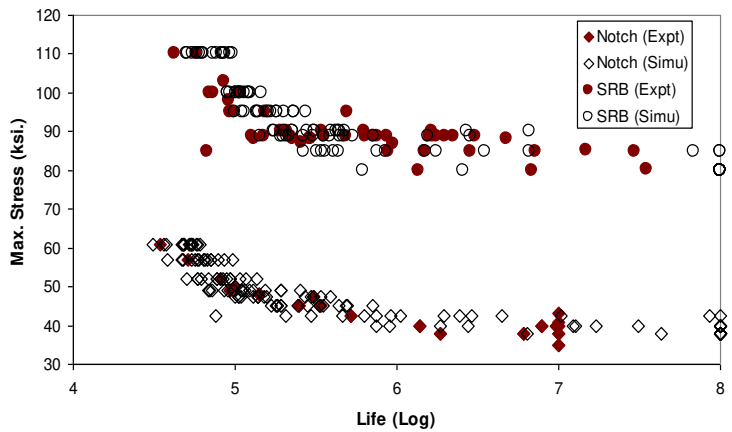
- S-N curve for notched specimen (Kt = 3) plotted with local notch root stress
  - Fatigue notch factors (Neuber and Glinka) are available but they require experimentally determine notch sensitive factors.



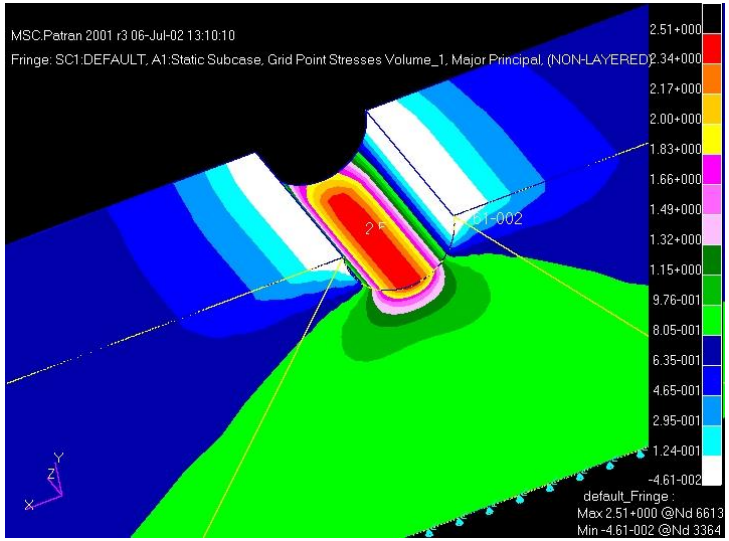
Notch Fatigue Predictions

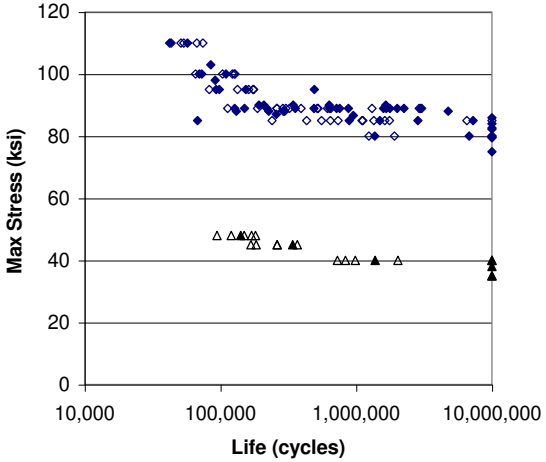
Kt = 3





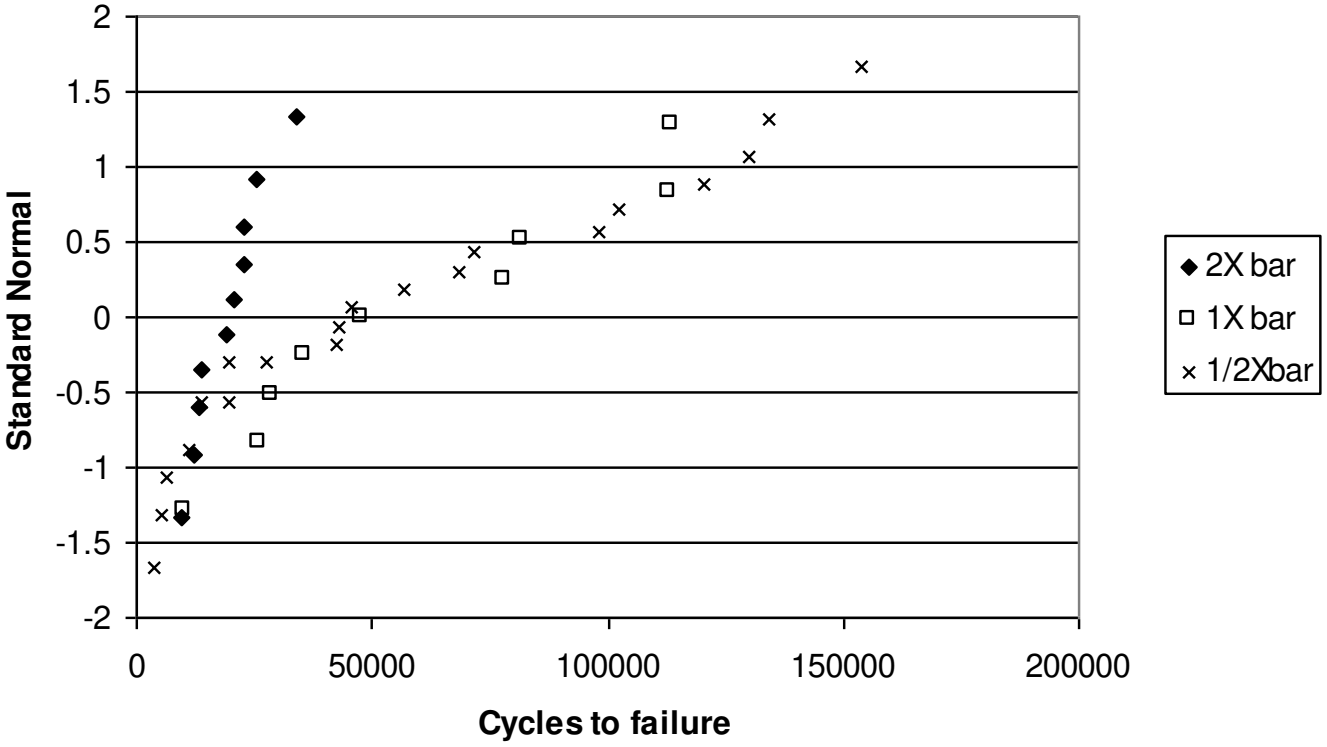
Kt = 2.5





Size Effect

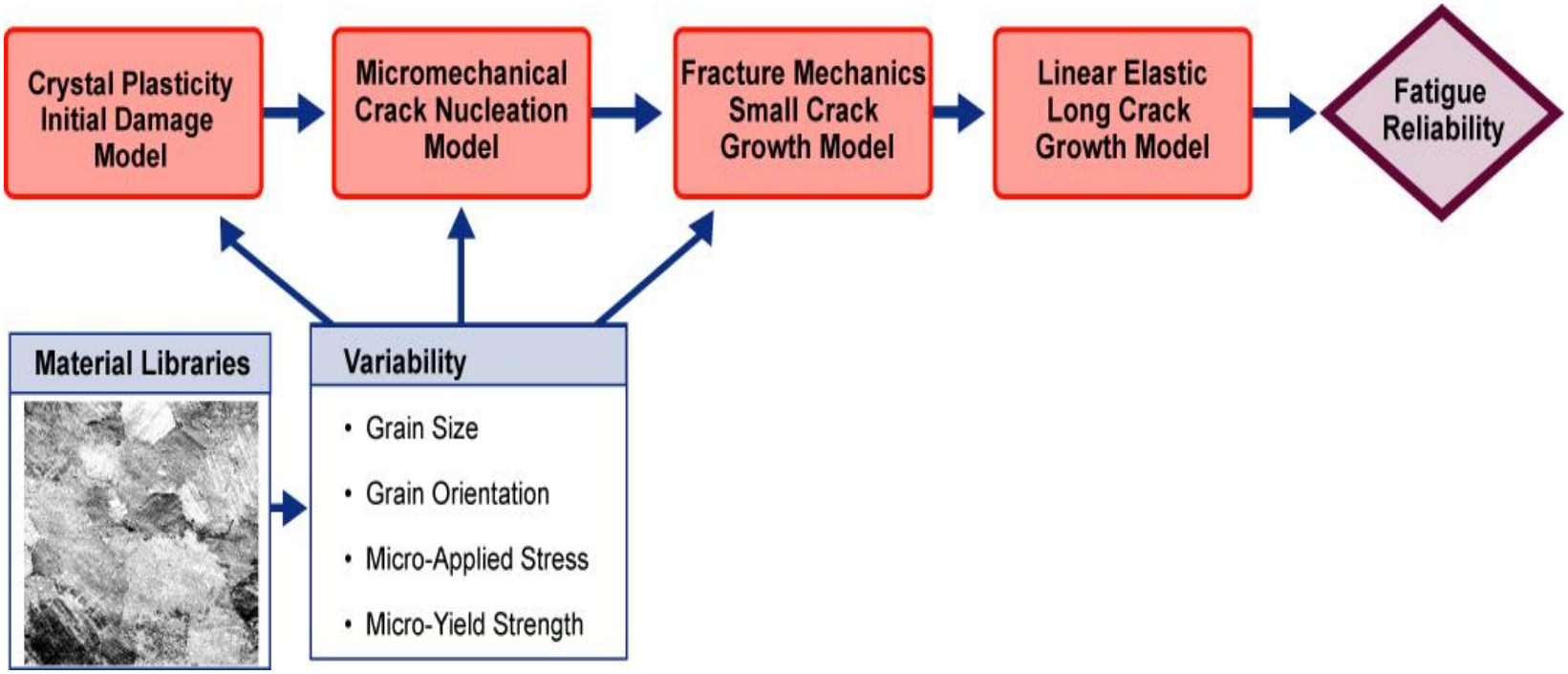
- IN 100 laboratory test data
- Smooth round bars cut from the same block with the same microstructure



Empirical Fatigue Models

- Simple empirical models relating the number of cycles to "crack initiation" vs. applied load
- Do not account for the local process of crack formation
- Do not account for multiple phases of fatigue
- Cannot accurately represent damage processes that are not explicitly a part of the database test program
- How to handle extrinsic uncertainties within the fleet?
  - Random stress among components
  - Random geometry among components
  - Random stress amplitude for a single component

Computational Fatigue Models



Computational Material Model

- Model the material at a fundamental level.
- Loading and environment become extrinsic factors to the material model.
- This allows simple test coupon data to be used directly in fatigue analysis of complex components.

VLM Predicts How, When, Where, and Why Damage Occurs

Standard Industry Analysis

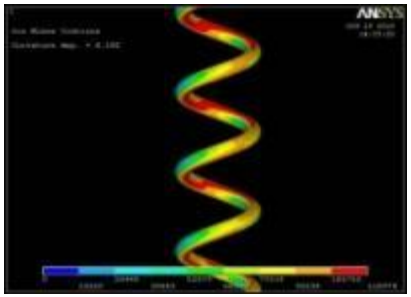
MSC Software
Simulating Reality, Delivering Certainty™

ANSYS

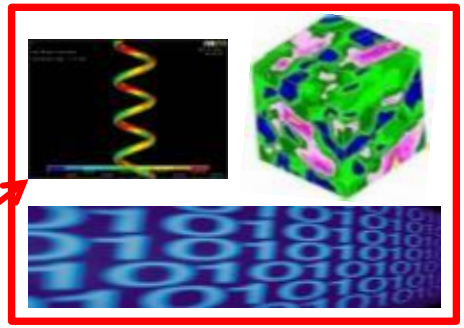
SIMULIA

PTC

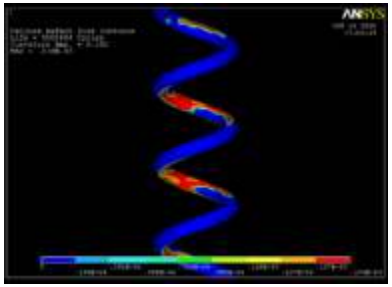
Design & Stress



VLM Analysis

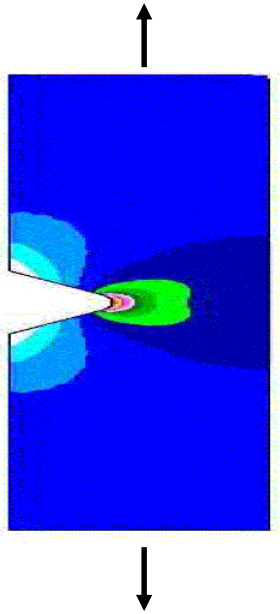


Life & Where & Why



Computational Structural Models

Example: Finite element analysis



+

Hooke's Law

Plasticity

Plate Theory

=

Displacement

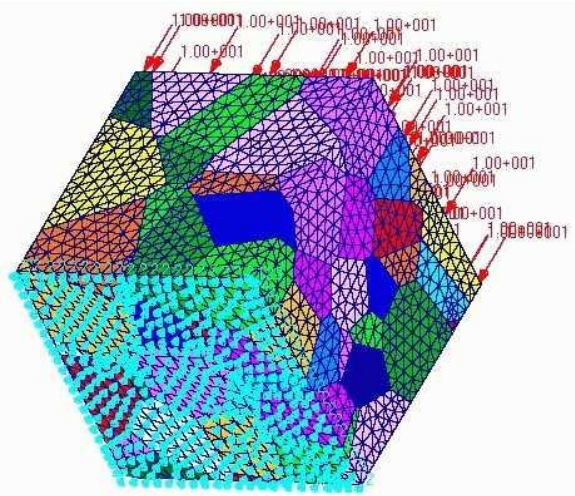
Strain

Stress

Mode Shapes

Computational Material Models

Example: VPS™ MICRO fatigue analysis

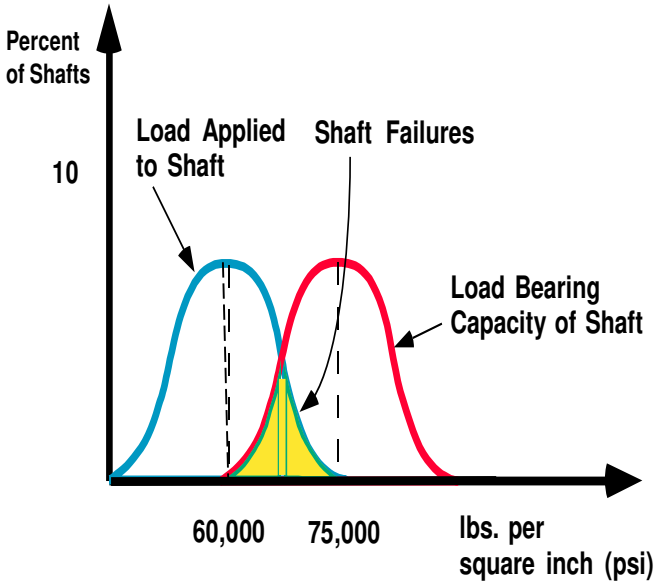


+ Dislocation Theory
Crystal Plasticity
Fracture Mechanics

= Crack Nucleation
Small Crack Growth
Long Crack Growth

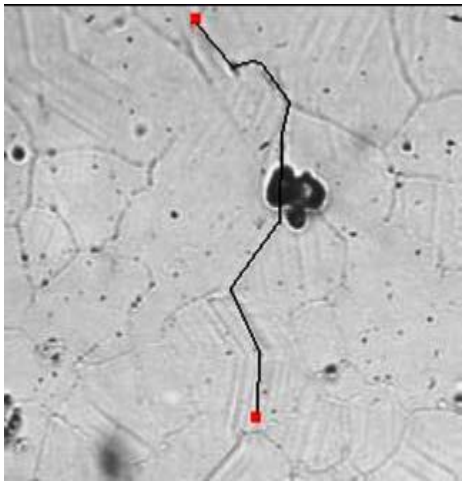
Uncertainty Management

VLM approach predicts failures



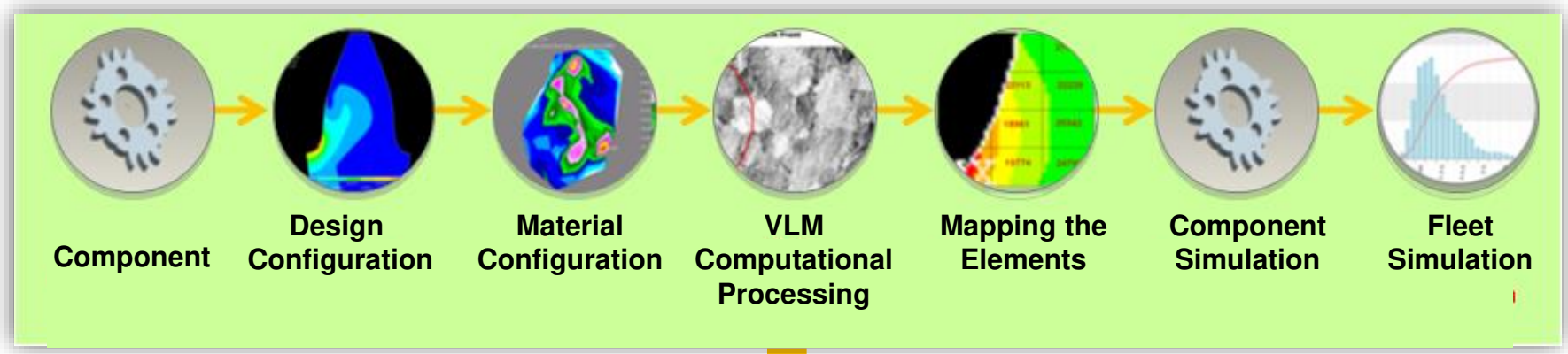
Fatigue strength is traditionally determined by testing

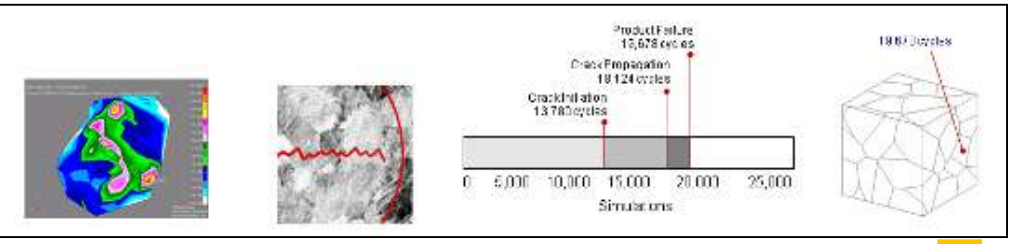
Conventional view of component

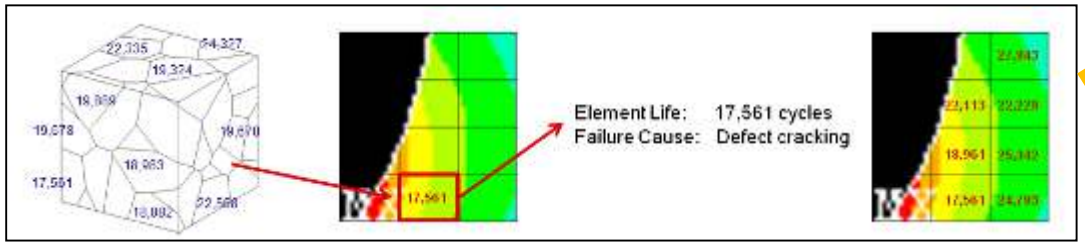


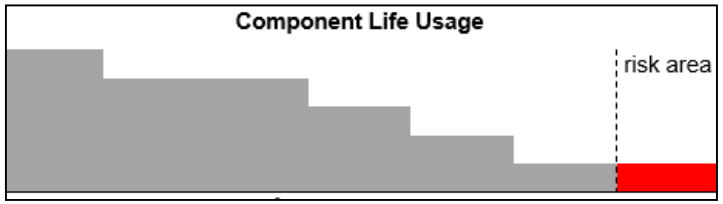
VEXTEC's view of component, grains & damage

VLM: Grain – FEA – Component – Fleet

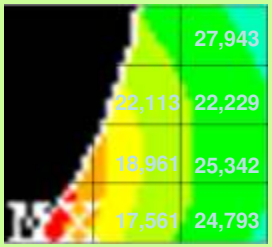






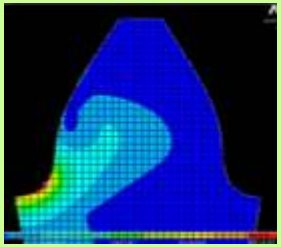


VLM: Grain – FEA – Component – Fleet

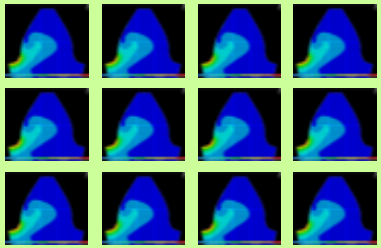


Integrate VLM Results with FEA

Tooth Life: 15,932 cycles
Failure Cause: Defects



VLM Integration for Entire Component

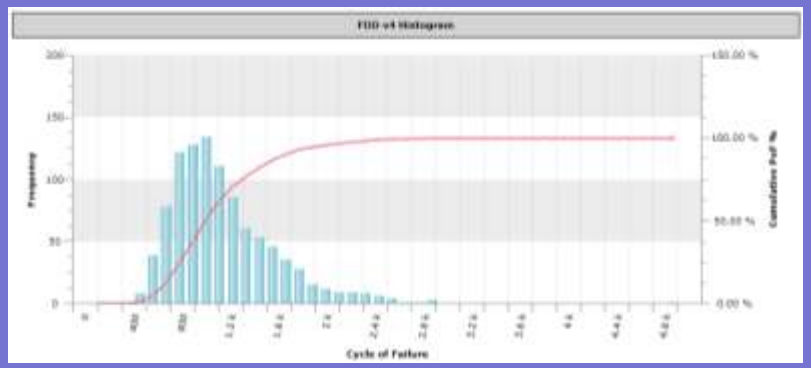


Repeat Sequence for Each Tooth

Component Life:
14,334 cycles

1st Virtual Twin Gear Simulated

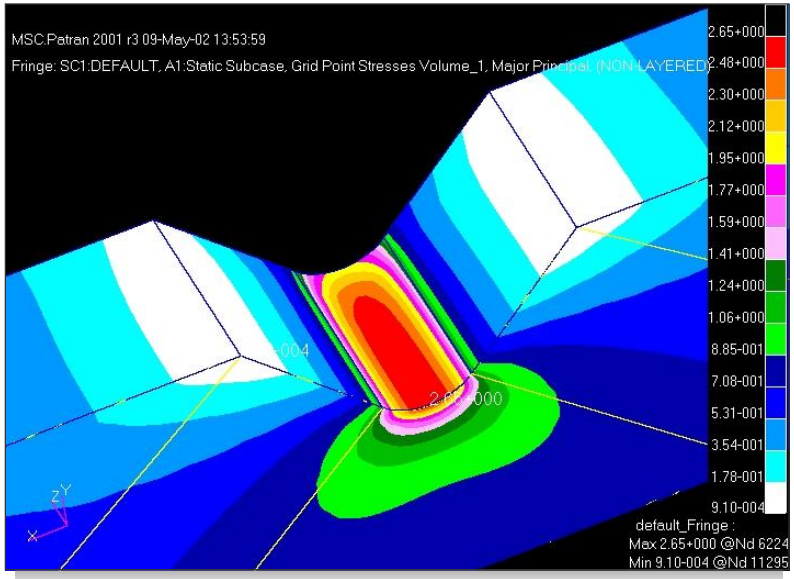
VT_1, VT_2, VT_3 … $VT_{1,000}$



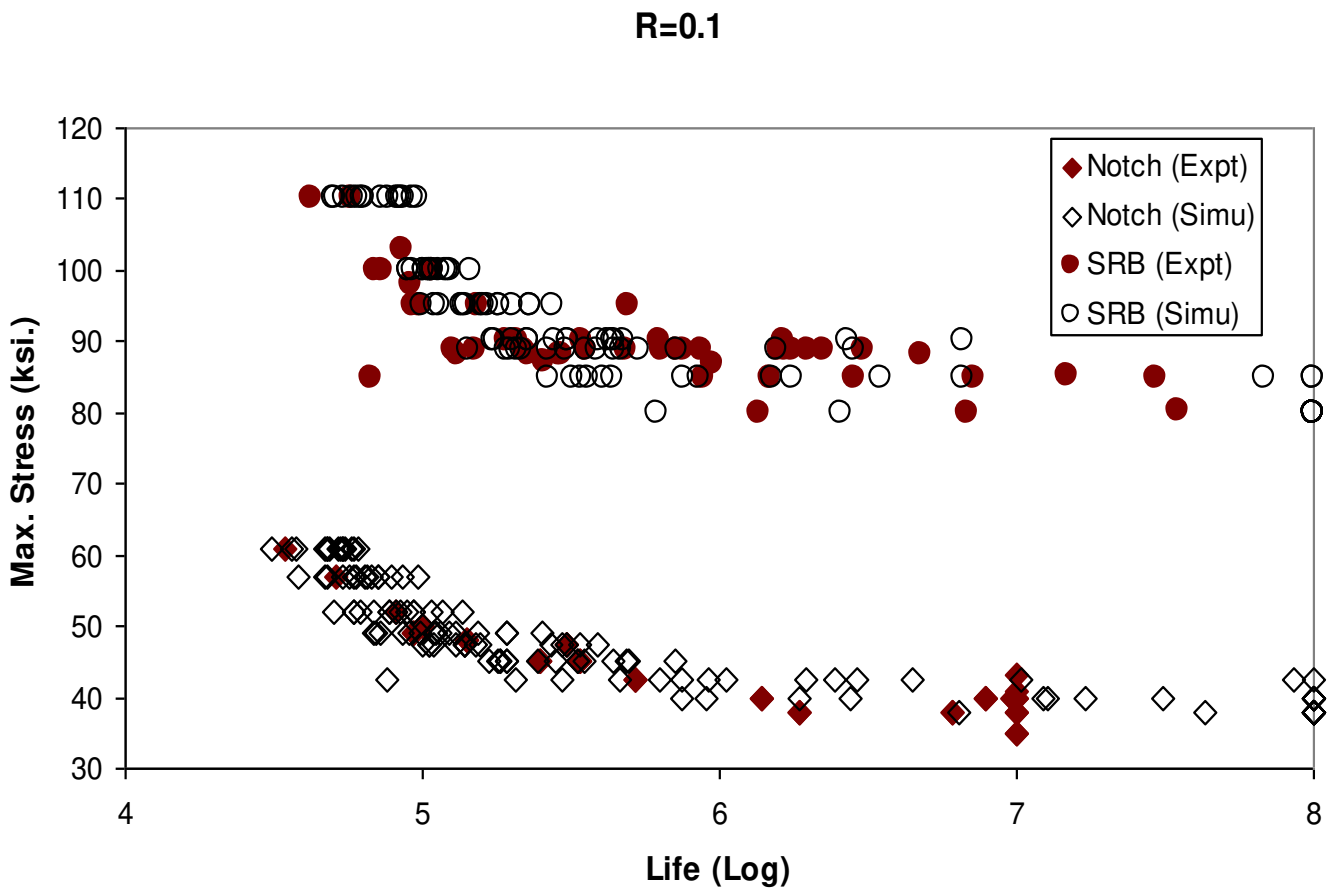
Run 1,000 Simulations

VLM Notch FEM Model Simulation

1. Determine nodal stress
2. Determine nodal area.
3. Perform microstructural fatigue analysis at each node.
4. Set component life to minimum life of all nodes.

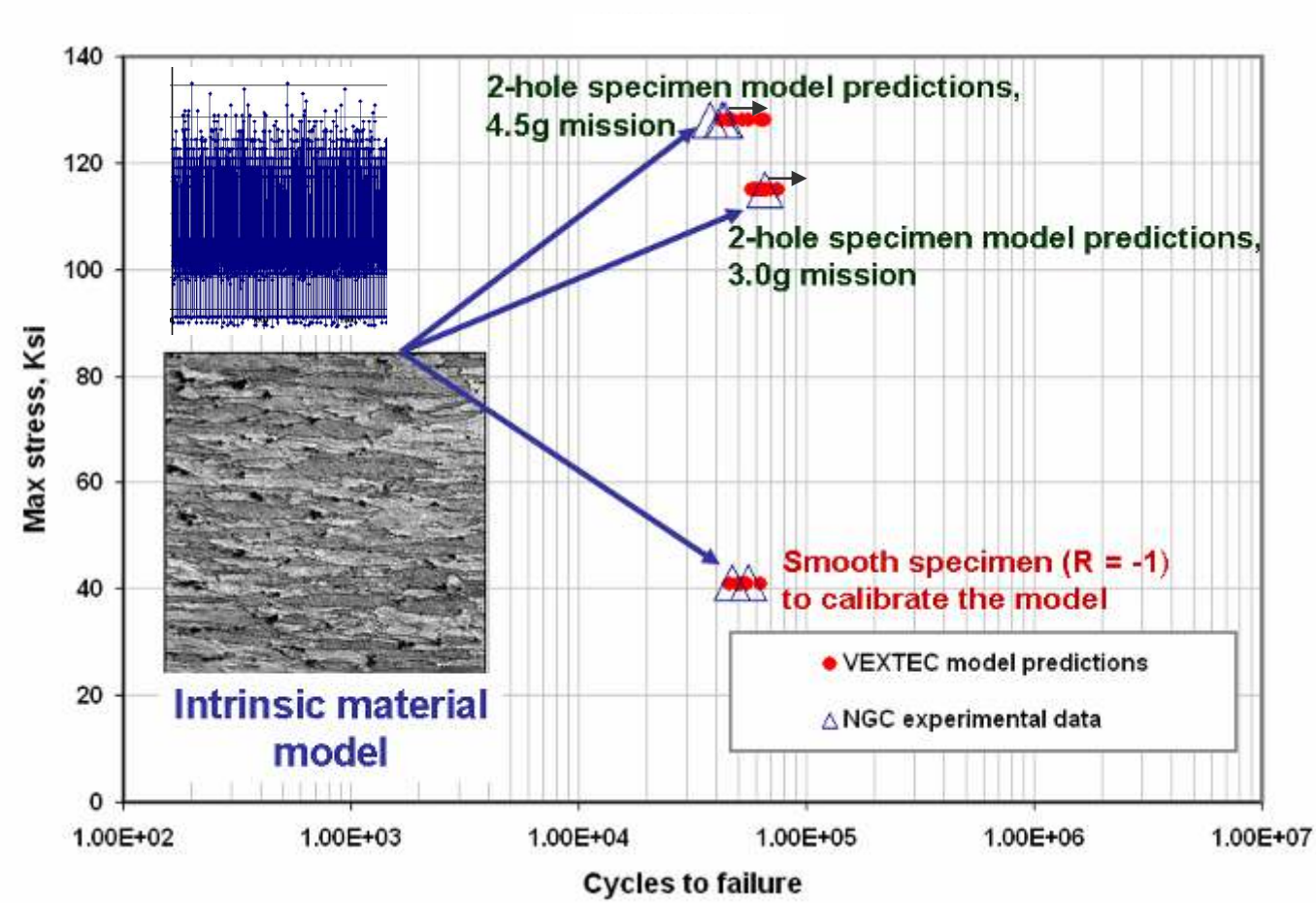


VLM Notch Effects R = 0.1



VLM predicted the notch effect from a single smooth bar data point.

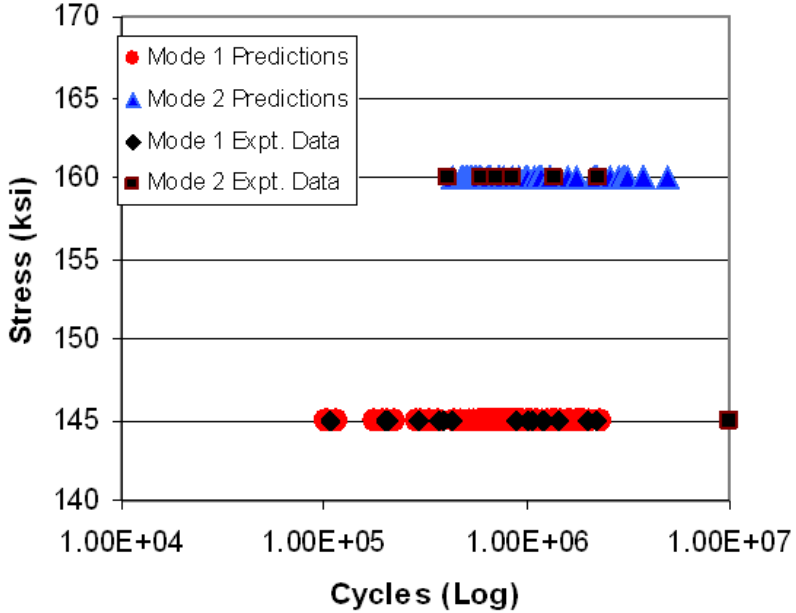
Spectrum Loading Fatigue



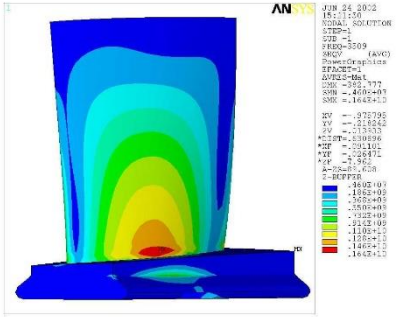
Same material model used for various geometry/loads

Vibration Mode Dependent Fatigue

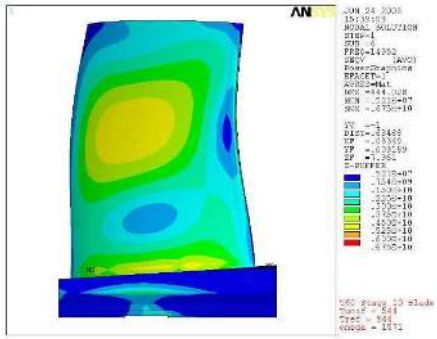
VEXTEC predictions validated with test



1st Bending Mode (Mode 1)



1st Torsion Mode Mode 2



Cardiac Leads: Summary and Outcomes

Summary

- Simulated fatigue buckling test under 2 load conditions
- Virtual DOE consisted of 9600 individual coil simulations

Outcomes / Next Steps

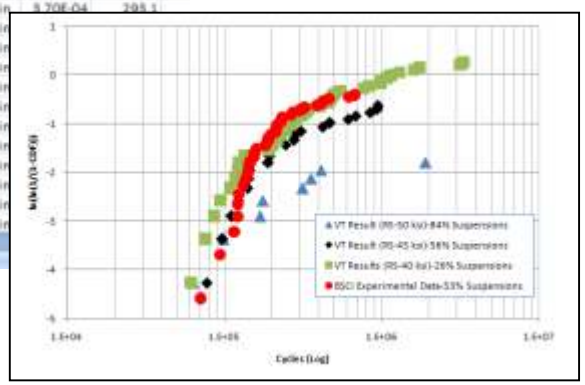
- Sensitivity study around particle size, density and residual stress
- Determined residual stress to be a calibrated value - new knowledge
- Developed Insights - Design alternatives, Material substitution, Vendor management
- Potential - Sensitivity analysis, Design trade studies, Supplier controls, Design optimization
- Add Realism – Coiling Simulation for Residual Stresses

Statistics							
Total Life			Nucleation Life			Short Crack Life	
mean	-3 sigma	+3 sigma	mean	-3 sigma	+3 sigma	mean	-3 si
17400.0767	7.76E+03	3.93E+04	12008.719	4.39E+03	3.33E+04	82.11268	4.8

Results Summary			Crack Nucleation Summary			
Specimen #	Total Life	Units	Life	Initiation 7	Initiation 5	Critical Shc Crit
1	28170	cycles	15740	grain	3.85E-04	265.5
2	17170	cycles	12970	grain	3.70E-04	295.1
3	17830	cycles	14470	grain		
4	22450	cycles	17420	grain		
5	14110	cycles	8766	grain		
6	12630	cycles	11210	grain		
7	9189	cycles	6216	grain		
8	24960	cycles	16320	grain		
9	15920	cycles	8468	grain		
10	18360	cycles	12360	grain		
11	13920	cycles	10600	grain		
12	10720	cycles	8359	grain		
13	17020	cycles	15400	grain		

MICRO_output | Probability Plot

Ready



VDOE Results for Residual Stress

VLM Implementation

Software: VPS-MICRO®

Simulated Fatigue Tests

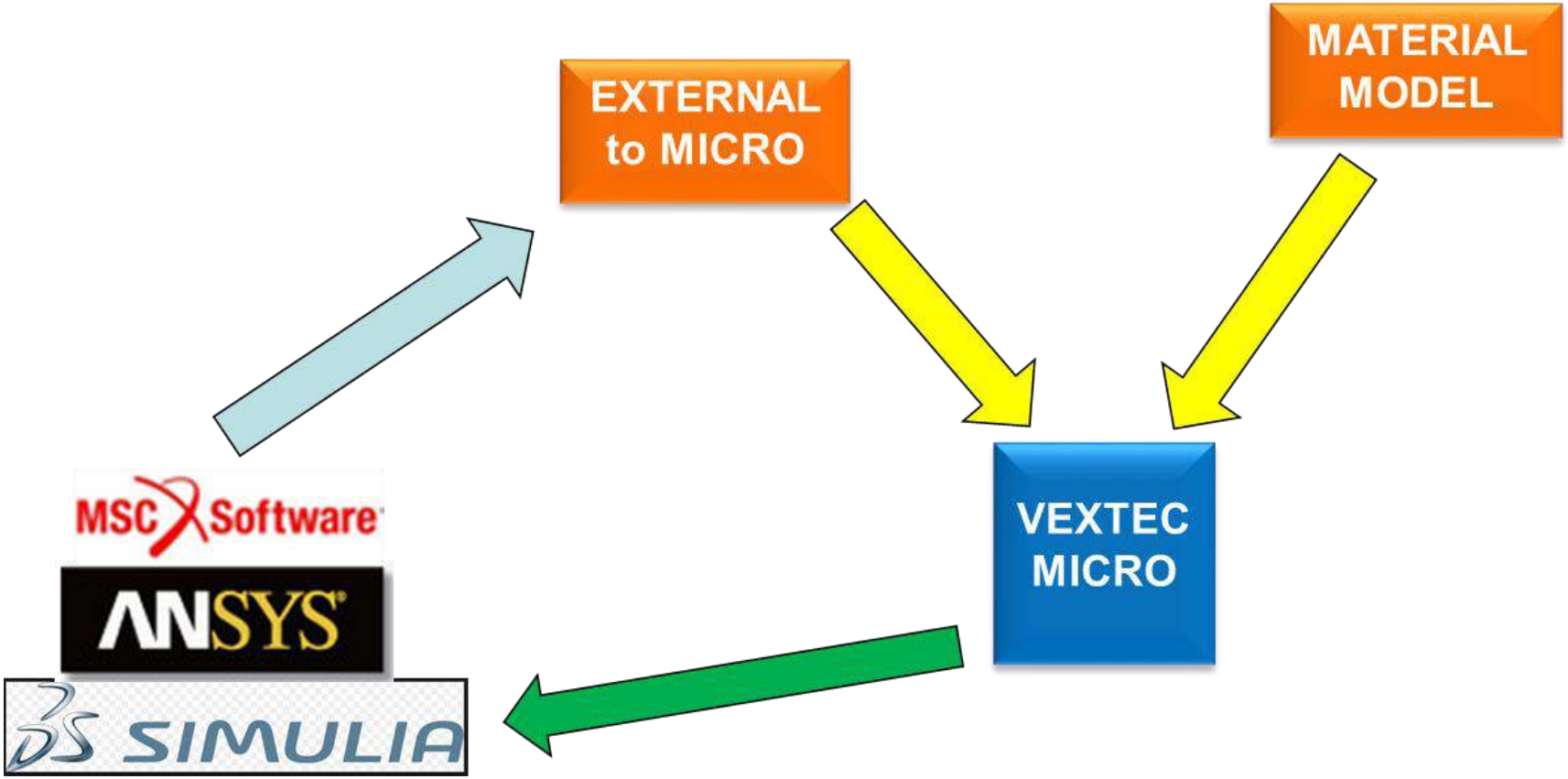
- Windows desktop tool
- Wide range of applications
  - Stand-alone tool for simple specimen geometry models
  - Integrate FEA models for complex geometry of full-scale components
- Output
  - Simulated S-N Curve
  - Virtual fracture surface
  - Detailed statistical analysis
- Customizable Software Product
  - Interface with Standard FEA software
  - Predict risk of failure from complex in-service loading spectrums

Simulated S-N Curve

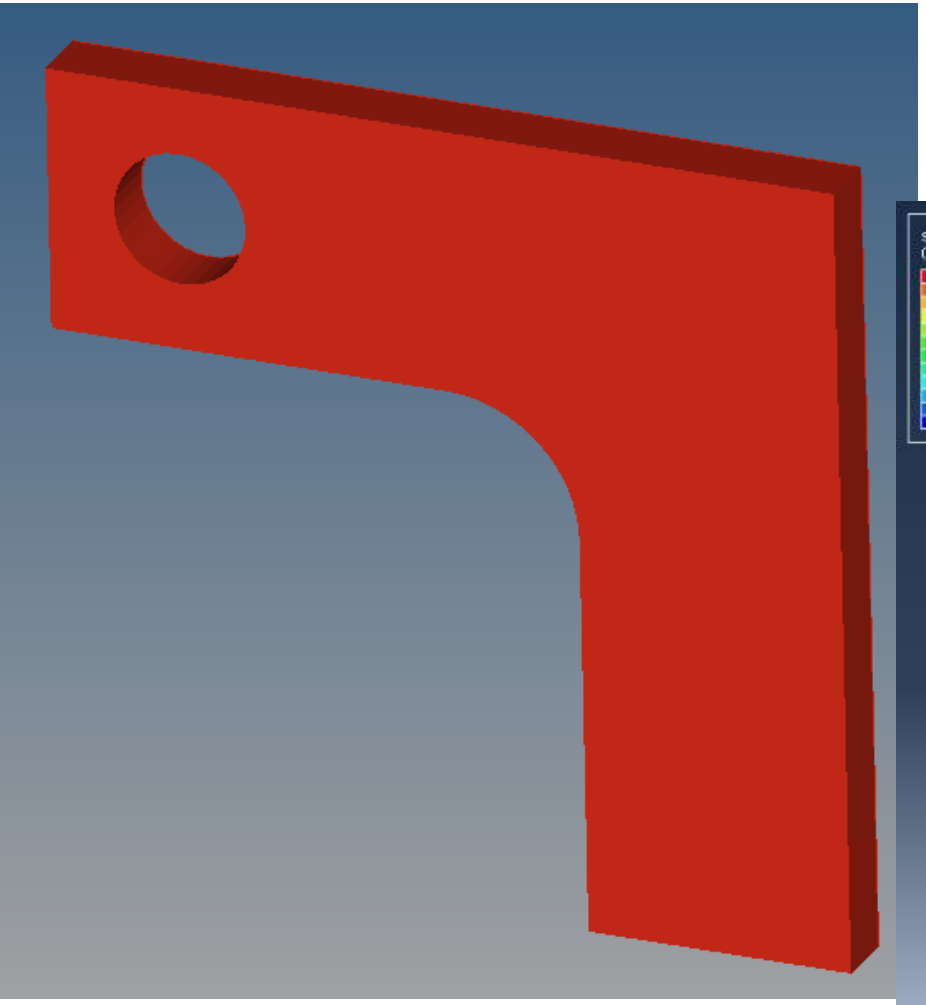
Software Partners

ANSYS® SIMULIA MSC Software®

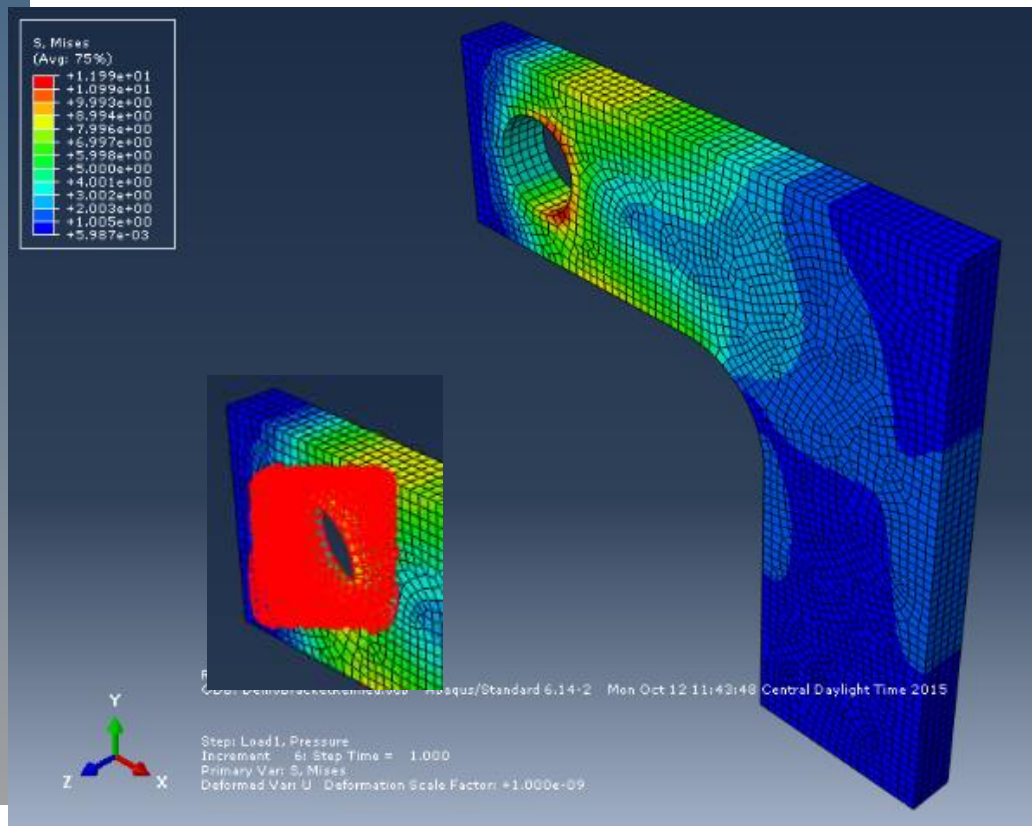
VEXTEC - VPS-MICRO® Software Flow Chart



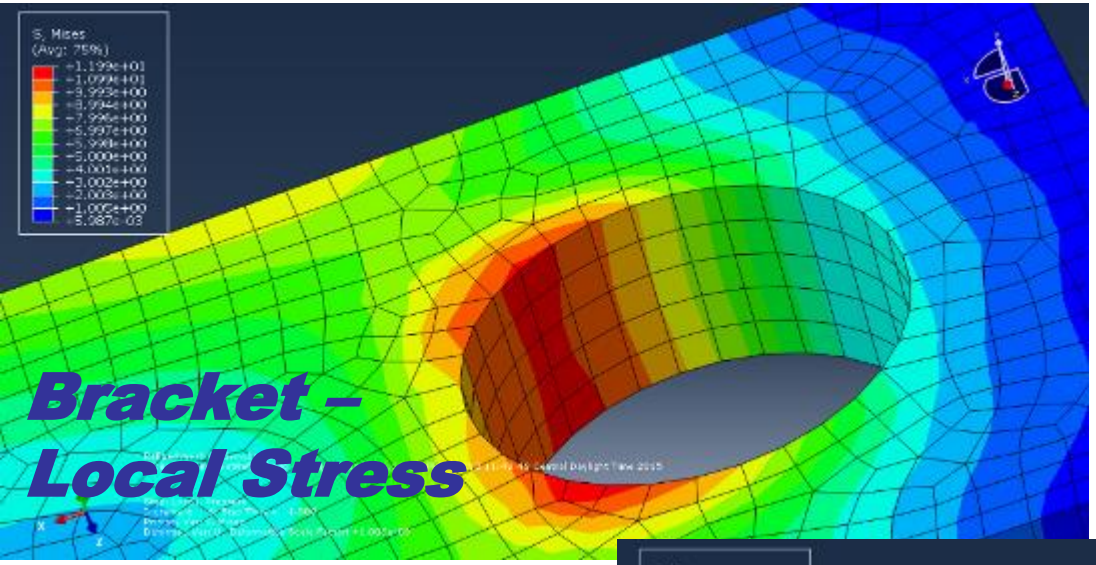
VEXTEC - VPS-MICRO® FEA Example



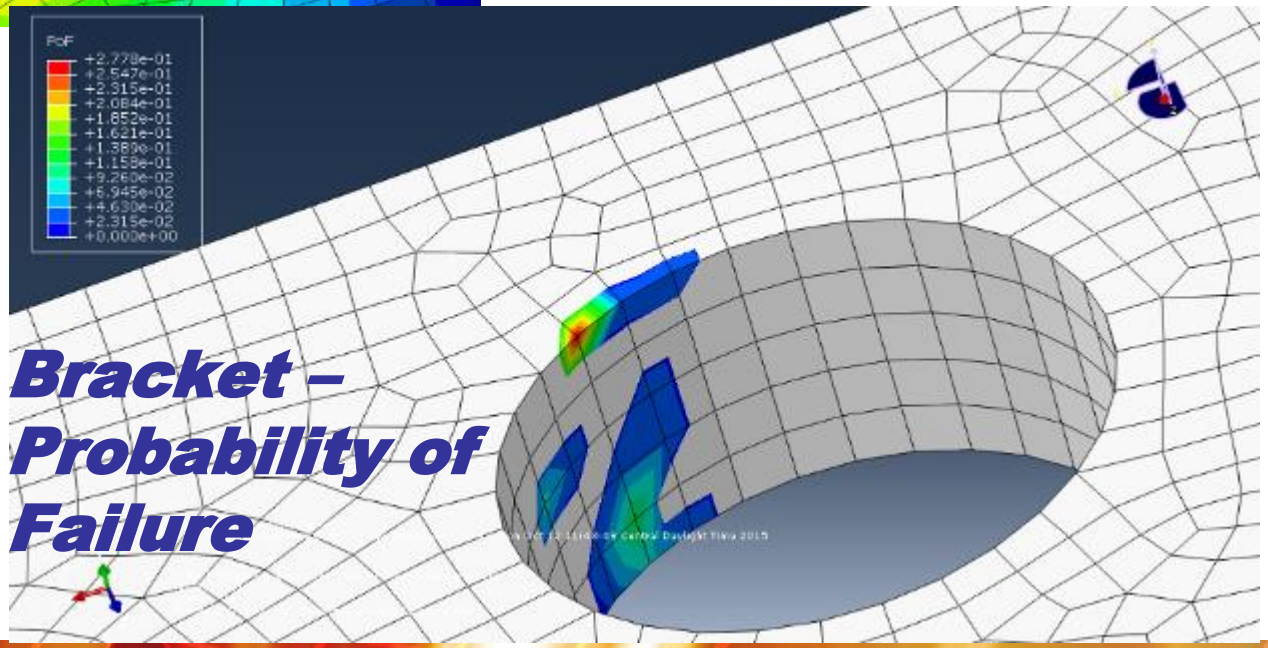
Bracket



VEXTEC - VPS-MICRO® FEA Example



Bracket – Local Stress



Bracket – Probability of Failure

VEXTEC's VPS-MICRO Software

VEXTEC VPS-MICRO

File Help

- Global Geometry
  - Select Model Type
- Loading
  - Select Mission Type
- Material
  - Select Material
  - Microstructural Properties
  - Microstructural Phases
  - Crack Growth Parameters
  - Defects
  - Mechanisms
- Run Simulation
  - Setup Simulation

Select between simple component with uniform stress or a complex finite elment model.

All inputs should be either in SI units or English units.

Simple Model

FEA Model

Enter Surface Area 1.9806412e-5

For a simple specimen (smooth round bar), provide surface areas

Back Next

Model Type: SSA Current Material: No selection

Loading Inputs

VEXTEC VPS-MICRO

File Help

- Global Geometry
  - Select Model Type
- Loading
  - Select Mission Type
- Material
  - Select Material
  - Microstructural Properties
  - Microstructural Phases
  - Crack Growth Parameters
  - Defects
  - Mechanisms
- Run Simulation
  - Setup Simulation

This screen allows for simulation of laboratory stress vs. life curve or complex mission analysis.

All inputs should be either in SI units or English units.

Constant Amplitude Variable Amplitude

Number of Sets 4

Max Stress	861.845	Min Stress	-861.845
Max Stress	779.108	Min Stress	-779.108
Max Stress	696.371	Min Stress	-696.671
Max Stress	655.002	Min Stress	-655.002

For a simple specimen enter max and min stress

Back Next

Model Type: SSA Current Material: No selection

Material Selection

VEXTEC VPS-MICRO

File Help

- Global Geometry
  - Select Model Type
- Loading
  - Select Mission Type
- Material
  - Select Material
  - Microstructural Properties
  - Microstructural Phases
  - Crack Growth Parameters
  - Defects
  - Mechanisms
- Run Simulation
  - Setup Simulation

Select a material within VPS-MICRO database or create a new material.

All inputs should be either in SI units or English units.

- STEEL
  - HSLA
    - Bosch-HSLS37HRC
    - SI-HSLS37HRC

Add -->

<-- Remove

SI-HSLS37HRC

Shear Modulus 90454.76

Poissons Ratio 3e-1

Back Next

Model Type: SSA Current Material: SI-HSLS37HRC

Select the appropriate material in the library and click "Add"

Current VLM Material Library

Steels
AISI 1010
AISI 304 Stainless
AISI 4340
AISI 9310
AM 355 Stainless
Pryowear 53
Pryowear 675
17-4PH 1025 Martensitic Steel
17-4PH 1150 Martensitic Steel

Nickel Super Alloys
Bimodal Waspaloy at 1000F
Bimodal Waspaloy at Room temperature
Coarse grain Waspaloy at 1000F
IN 100
IN 713 - Directionally Solidified
IN 713 – Equiaxed
IN 713 - Radially Solidified
IN 713 - Single Crystal
Medium Grain Waspaloy
Rene 88

Aluminum Alloys
AA 2024
AA 7075-T651
AA 7050-T3

Titanium Alloys
Cast Ti64
Cold Rolled Bimodal Ti64
Cold Rolled Equiaxed Ti64
Fine Bimodal Ti64
Forged Bimodal Ti64
Forged Equiaxed Ti64
Forged Ti64
HCF Ti64

Cast Iron
Ductile (Nodular)
Grey (Graphite Flake)

Iron Super Alloys
Hastaloy-X

Electronic Materials
SnPb (eutectic) solder
SnAgCu (lead-free) solder
OFHC-Oxygen free high conductivity copper

Medical Materials
MP-35N
MP-35LT
Nitinol

Cobalt Super Alloys
Alloy 188 (Inconel 188/Haynes 188)

Intermetallics
Gamma – TiAl

Magnesium
ZE-41A

Cold Spray Coatings
CP-Al
He6061-Al

VEXTEC is continuously expanding the library of standard materials. In the future users will be able to add their own material models.

VEXTEC's VPS-MICRO Software

Microstructural Phases

File Help

Global Geometry
Select Model Type
Loading
Select Mission Type
Material
Select Material
Microstructural Properties
Microstructural Phases
Crack Growth Parameters
Defects
Mechanisms
Run Simulation
Setup Simulation

For a multi-phase material, select the number of phases and then input the microstructural properties for each phase.

All inputs should be either in SI units or English units.

Number of Phases 1

Phase-1

Volume Fraction (%) 1
Specific Fracture Energy 2.1e-1
Grain Orientation martensite

Grain Size
Distribution Lognormal
Mean 1.19888e-5
COV 4e-1

Frictional Strength
Distribution Weibull
Char. Value 930.8
Slope 4.5

Back

Model Type: SSA Current Material: SI-HSLS37HRC

Crack Growth Properties

VEXTEC VPS-MICR

File Help

Global Geometry
Select Model Type
Loading
Select Mission Type
Material
Select Material
Microstructural Properties
Microstructural Phases
Crack Growth Parameters
Defects
Mechanisms
Run Simulation
Setup Simulation

Select an appropriate Long Crack Growth model from the list below.

All inputs should be either in SI units or English units.

Long Crack Growth Law Paris Law

Paris Law Parameters
Paris Law Exponent 3.9

Paris Law Coefficient
Distribution Lognormal
Mean 3.16e-12
COV 3e-1

Back Next

Model Type: SSA Current Material: SI-HSLS37HRC

In General, the "Microstructural Phases" & "Crack Growth Property" inputs are "locked" and the user cannot change them. Super-users can modifying these input parameters.

Defect Inputs

VEXTEC VPS-MICRO

File Help

- Global Geometry
  - Select Model Type
- Loading
  - Select Mission Type
- Material
  - Select Material
  - Microstructural Properties
  - Microstructural Phases
  - Crack Growth Parameters
  - Defects
  - Mechanisms
- Run Simulation
  - Setup Simulation
- Simulation Results
- SN Curve For All Sets
- Set 3 (696.371)
- Set 4 (655.002)

For a material known to contain defects, enter the defect statistics.

All inputs should be either in SI units or English units.

Defect Size

Distribution: Lognormal — Mean: 3.25e-6 — COV: 4.13e-1

Defect Density

Distribution: Lognormal — Mean: 52679744 — COV: 3e-1

Back Next

Model Type: SSA Current Material: SI-HSLS37HRC

If appropriate, input defect (or inclusion) size & defect density parameters as statistical variables

Damage Mechanisms

VEXTEC VPS-MICRO

File Help

- Global Geometry
  - Select Model Type
- Loading
  - Select Mission Type
- Material
  - Select Material
  - Microstructural Properties
  - Microstructural Phases
  - Crack Growth Parameters
  - Defects
  - Mechanisms
- Run Simulation
  - Setup Simulation
- **Simulation Results**
- SN Curve For All Sets
- Set 2 (779.108)
- Set 3 (696.371)
- Set 4 (655.002)

Fatigue is a multi-stage process. Select the stages of crack growth to be simulated.

All inputs should be either in SI units or English units.

Fatigue Type Fatigue

Fatigue Stages

- [x] Crack Nucleation
- [x] Small Crack Growth
- [x] Long Crack Growth

Crack Initiation Mechanism

- (•) Transgranural
- ( ) Intergranular

Back Next

Model Type: SSA Current Material: SI-HSLS37HRC

At present none of the settings in this screen can be modified

Number of Simulations

VEXTEC VPS-MICRO

File Help

- Global Geometry
  - Select Model Type
- Loading
  - Select Mission Type
- Material
  - Select Material
  - Microstructural Properties
  - Microstructural Phases
  - Crack Growth Parameters
  - Defects
  - Mechanisms
- Run Simulation
  - Setup Simulation
- **Simulation Results**
- SN Curve For All Sets
- Set 1 (861.845)
- Set 2 (779.108)
- Set 3 (696.371)
- Set 4 (655.002)

Having built the model, run the desired number of simulations.

All inputs should be either in SI units or English units.

Simulations count 15

Run Simulations

Back Next

Model Type: SSA Current Material: SI-HSLS37HRC

VEXTEC's VPS-MICRO Software

Output- SN Curve

VEXTEC VPS-MICRO

File Help

- Global Geometry
  - Select Model Type
- Loading
  - Select Mission Type
- Material
  - Select Material
  - Microstructural Properties
  - Microstructural Phases
  - Crack Growth Parameters
  - Defects
  - Mechanisms
- Run Simulation
  - Setup Simulation
- Simulation Results
- SN Curve For All Sets
  - SN Curve
- Set 1 (861.845)
- Set 2 (779.108)
- Set 3 (696.371)
- Set 4 (655.002)

SN Curve

Mean ☐ Median ☐

Export

SI-HSLS37HRC
Analysis Type -- SSA -- Mon Oct 26 2015

— Stress Set# 1 — Stress Set# 2 — Stress Set# 3 — Stress Set# 4

Max. Stress: 880, 860, 840, 820, 800, 780, 760, 740, 720, 700, 680, 660, 640

Life (Log Cycles): 2.000e+4, 3.000e+4, 5.000e+4, 7.000e+4, 1.000e+5, 2.000e+5, 3.000e+5, 5.000e+5

7:48 PM

VEXTEC's VPS-MICRO Software

Output- PDF (Histogram) of Total Life

VEXTEC VPS-MICRO

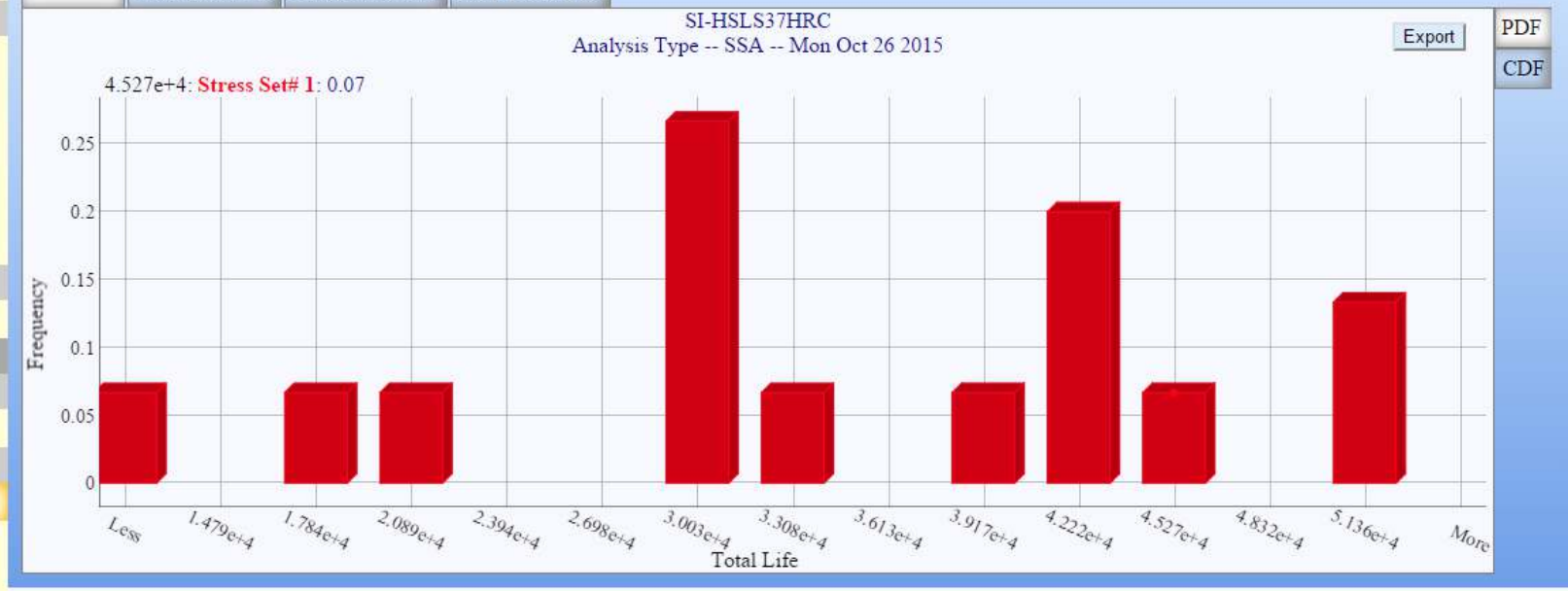
File Help

- Global Geometry
  - Select Model Type
- Loading
  - Select Mission Type
- Material
  - Select Material
  - Microstructural Properties
  - Microstructural Phases
  - Crack Growth Parameters
  - Defects
  - Mechanisms
- Run Simulation
  - Setup Simulation
- **Simulation Results**
- SN Curve For All Sets
  - SN Curve
- Set 1 (861.845)
  - Life Prediction
  - Failure Parameters
  - Individual Results View
  - Detailed Results View
- Set 2 (779.108)
- Set 3 (696.371)
- Set 4 (655.002)

Life Prediction

Compare to: Set 2 Set 3 Set 4

Total Life | Nucleation Life | Short Crack Life | Long Crack Life



Set Number	Mean	Median	Mode	COV
1	3.611e+4	3.229e+4	3.003e+4	3.182e-1

Histogram Parameters

# of Bins + - 15

Min. Value -1e+99

Max. Value 1e+99

Default

OK

Model Type: SSA Current Material: SI-HSLS37HRC

Output- Individual Simulation Results

VEXTEC VPS-MICRO

File Help

- Global Geometry
  - Select Model Type
- Loading
  - Select Mission Type
- Material
  - Select Material
  - Microstructural Properties
  - Microstructural Phases
  - Crack Growth Parameters
  - Defects
  - Mechanisms
- Run Simulation
  - Setup Simulation
- **Simulation Results**
- SN Curve For All Sets
  - SN Curve
- Set 1 (861.845)
  - Life Prediction
  - Failure Parameters
  - Individual Results View
  - Detailed Results View
- Set 2 (779.108)
- Set 3 (696.371)
- Set 4 (655.002)

Individual Results View

Component Number 1

Fatigue Life

Total Life	1.479e+4
Nucleation Life	8.004e+3
Short Crack Life	5.634e+3
Long Crack Life	1.156e+3

Critical Parameters

Initiation Site	Grain
Initiation Grain Size	4.189e-5
Initiation Phase	1
Frictional Strength	5.559e+2
Micro Stress	1.857e+3
Schmid Factor	2.322e+0
Non Failing Cracks	417

7:51 PM

Output- Detailed Results

VEXTEC VPS-MICRO

File Help

- Global Geometry
  - Select Model Type
- Loading
  - Select Mission Type
- Material
  - Select Material
  - Microstructural Properties
  - Microstructural Phases
  - Crack Growth Parameters
  - Defects
  - Mechanisms
- Run Simulation
  - Setup Simulation
- **Simulation Results**
- SN Curve For All Sets
  - SN Curve
- Set 1 (861.845)
  - Life Prediction
  - Failure Parameters
  - Individual Results View
  - Detailed Results View
- Set 2 (779.108)
- Set 3 (696.371)
- Set 4 (655.002)

Detailed Results View

Specimen	Microckracks	Total Life	Nucleation Life	Short Crack Life	Long Crack Life	Initiation Grain Size	Initiation Defect Size	Failure Phase	Schmid Factor
1	417	1.479e+4	8.004e+3	5.634e+3	1.156e+3	4.189e-5	0.000e+0	1	2.322e+0
2	1189	5.441e+4	1.742e+4	3.563e+4	1.365e+3	2.925e-5	0.000e+0	1	2.043e+0
3	911	3.605e+4	1.042e+4	2.438e+4	1.259e+3	3.883e-5	0.000e+0	1	2.826e+0
4	1068	4.301e+4	1.804e+4	2.325e+4	1.722e+3	1.931e-5	0.000e+0	1	2.044e+0
5	881	3.229e+4	2.221e+4	8.756e+3	1.319e+3	3.851e-5	0.000e+0	1	2.037e+0
6	1117	4.402e+4	1.264e+4	3.017e+4	1.210e+3	3.881e-5	0.000e+0	1	2.743e+0
7	656	2.218e+4	5.083e+3	1.601e+4	1.093e+3	4.166e-5	0.000e+0	1	2.077e+0
8	1069	4.318e+4	3.899e+3	3.774e+4	1.542e+3	3.182e-5	0.000e+0	1	2.042e+0
9	831	3.037e+4	6.910e+3	2.215e+4	1.307e+3	3.683e-5	0.000e+0	1	2.062e+0
10	629	2.047e+4	1.369e+4	5.848e+3	9.311e+2	4.151e-5	0.000e+0	1	2.039e+0
11	845	3.056e+4	3.809e+3	2.486e+4	1.896e+3	3.560e-5	0.000e+0	1	2.035e+0
12	865	3.133e+4	9.651e+3	2.080e+4	8.775e+2	3.858e-5	0.000e+0	1	2.074e+0
13	1110	5.152e+4	7.627e+3	4.274e+4	1.156e+3	3.687e-5	0.000e+0	1	2.152e+0
14	1082	4.528e+4	1.938e+4	2.482e+4	1.083e+3	2.832e-5	0.000e+0	1	2.043e+0
15	1066	4.219e+4	2.527e+4	1.509e+4	1.826e+3	4.230e-5	0.000e+0	1	3.035e+0

Export

7:52 PM

VEXTEC VLM – Test To Success

Reference

- FDA Guidance Document for Stents and Delivery Systems – April 2010
- DOE Paradigm – Four Corners (can add plus Center Point)
- 90% Reliability / 90% Confidence

Traditional Testing

- 90 / 90 Test to Success translates into 22 tests per data point and for 5 points gives 110 tests
- Estimated Cost for 400M cycles at 50 Hz and Time based on assumptions made by VEXTEC
  - Cost ~$1M
  - Time Depends on # of Test Machines – 9 months to X years
- Company should add own numbers

VEXTEC VLM

- Confirmatory Testing – Level1 (Test Sample) and Level 2 (Device / Component)
- Material Model Development
- Software License Cost
- Labor Cost
- Estimated Cost and Time
  - $80K
  - 4 months (Level 2 testing)
  - Expands to full matrix for 25% more

Summary

- Cost Advantage – 12.5 to 1
- Time Advantage – 2 to 1 and up
- Can Easily Scale for 95/95 or 99/99

VEXTEC VLM – Test To Failure

Reference

- Automotive Customer – Gears, Bearings, Springs, ….
- – Test to Failure to generate a S-N curve for Metal component subject to cyclic loading
- – Test Matrix - Includes 5 Sizes from smallest to the largest and subject to 5 different Displacement amplitudes from smallest to largest–10 samples at each

Traditional Testing

- 90 / 90 Test to Success translates into 22 tests per data point and for 5 points gives 110 tests
- Estimated Cost for 400M cycles at 50 Hz and Time based on assumptions made by VEXTEC
  - Cost ~$1M
  - Time Depends on # of Test Machines – 9 months to X years

VEXTEC VLM

- Confirmatory Testing – Level1 (Test Sample) and Level 2 (Device / Component)
- Material Model Development
- Software License Cost
- Labor Cost
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Summary

- Cost Advantage – 12.5 to 1
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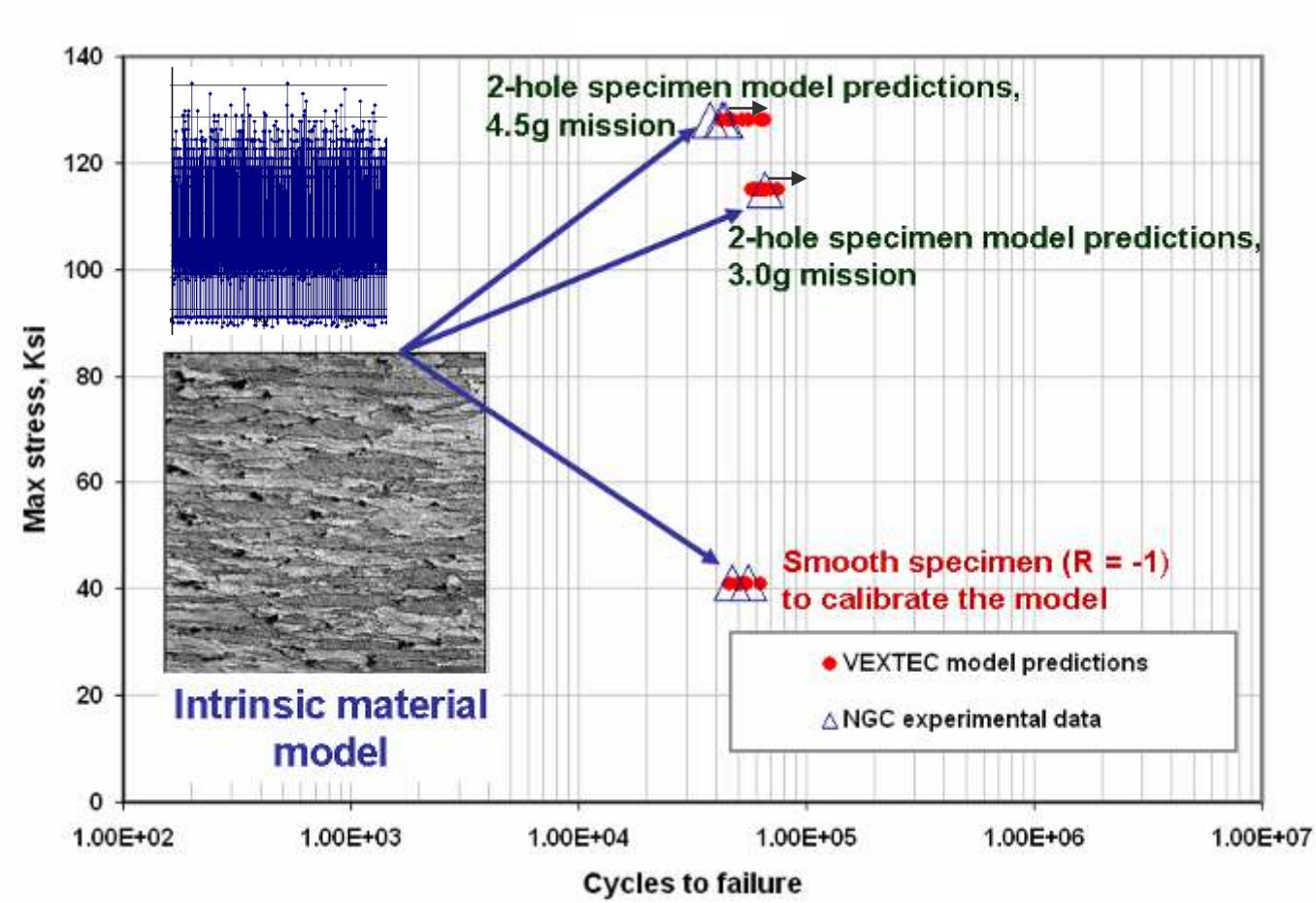
- Can Easily Scale for 95/95 or 99/99

VEXTEC

Thank You

www.vextec.com

Spectrum Loading Fatigue



Same material model used for various geometry/loads