FATIGUE PROPERTY MAPPING

KNOW YOUR MATERIAL

Fatigue Property Mapping™ characterization protocols systematically measure the factors that govern durability. The resulting engineering parameters are ready to use with durability simulation codes including Endurica CL™, Endurica DT™, Endurica EIE™, and fe-safe/Rubber™. These powerful and efficient tests show how your rubber part endures under realistic operating conditions. Begin with the Core Fatigue and Hyperelastic modules, then add on the items you need to get the physics just right in your analysis.

Hyperelastic Module
PAGE 3 — FPM H

Simple, planar, and equibiaxial tension, Mullins effect

Core Fatigue Module
PAGE 4 — FPM C

Fully relaxing behavior from both nucleation and fracture mechanical perspectives

Intrinsic Strength Module
PAGE 5 — FPM IS

Quantify endurance limits

Non Relaxing Module
PAGE 6 — FPM NR

Quantify strain crystallization, minimum and mean strain effects

Ageing Module
FPM AB BASIC — PAGE 11

FPM AM MASTER CURVE — PAGE 12

Quantify endurance limit, estimate ageing rate of stiffness, intrinsic and ultimate strength

Creep Module
PAGE 13 — FPM CR

Creep crack growth rate effects

Thermal Modules
Quantify dissipative properties, thermal properties

- PAGE 8 — FPM TB BASIC — BASIC
- PAGE 9 — FPM TA ADV — ADVANCED
- PAGE 10 — FPM TM K/WLF — WILLIAMS-LANDEL-FERRY

Cyclic Softening Module
PAGE 14 — FPM S

Quantify cyclic softening effects

Reliability Module
PAGE 7 — FPM R

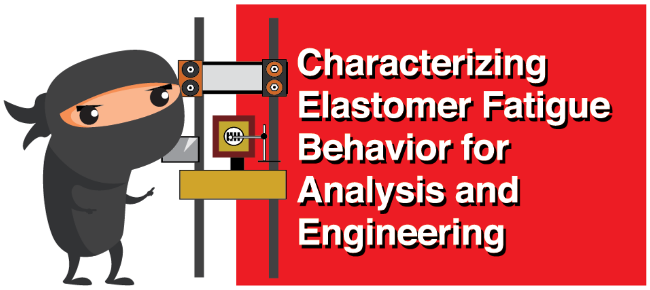
Weibull statistics for strength and crack precursor size populations

Ozone Module
PAGE 15 — FPM O

Quantify ozone attack critical energy and rate

www.endurica.com

GET DURABILTY RIGHT WITH ENDURICA TRAINING

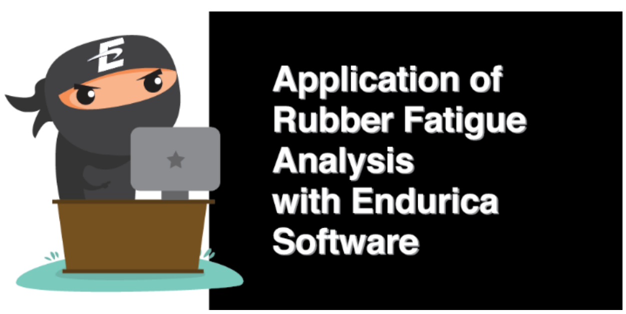


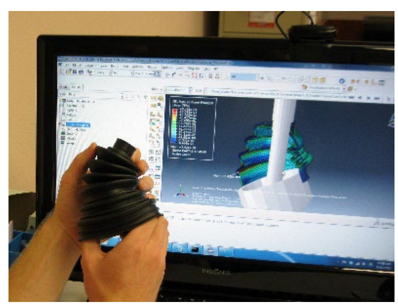
Learn the essential principles and practices of material characterization for fatigue life prediction, and strategies and procedures for planning effective fatigue test programs as well as making effective use of crack nucleation and fracture mechanics tools. The Characterizing Elastomer Fatigue Behavior for Analysis and Engineering workshop includes lectures to thoroughly understand the science behind Endurica's workflow and software solutions PLUS demos from Axel Physical Testing Services lab to fully illustrate the complete material characterization process.

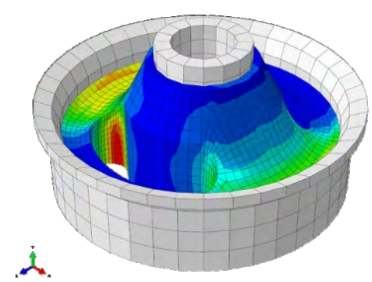
Course Objectives

- Know the physics and factors that govern the fatigue behavior of rubber
- Use accurate models and efficient procedures to characterize fatigue behavior
- Take advantage of test strategies that minimize risk and maximize productivity
- Use crack nucleation and fracture mechanics approaches effectively
- Use characterization to inform accurate fatigue calculations
- Use characterization to diagnose and solve development issues

More details at: https://endurica.com/characterizing/







Learn the Endurica software workflows to virtually evaluate fatigue performance and solve design issues at the concept stage. Attendees have returned to their firms and revolutionized their design processes by using the software to diagnose and solve fatigue issues.

Course Objectives

- Understand key principles governing fatigue in elastomers.
- Select and specify material models that accurately describe elastomer behavior.
- Apply fatigue analysis workflows for:
  - Infinite life analyses
  - Safe life analyses
  - Damage tolerant analyses
- Successfully solve durability issues using Endurica Software (CL, DT and EIE)

More details at: https://endurica.com/rubber-analysis/

HYPERELASTIC MODULE – REQUIRED TEST

Stress-Strain Behavior

The Hyperelastic Module produces the basic information about nonlinear stress-strain behavior that is needed to run a finite element model and to represent initial transient softening (Mullins effect) in the model.

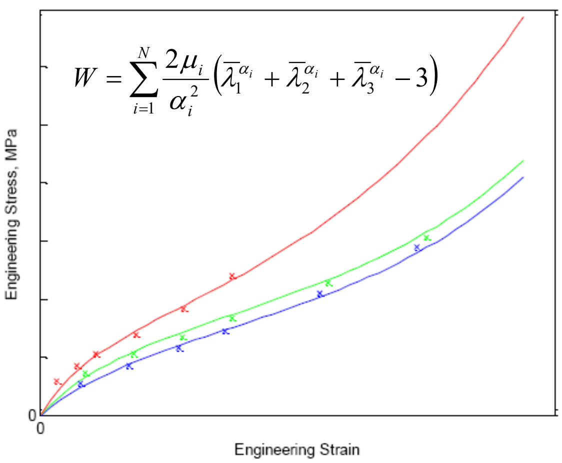
- simple tension, slow cyclic loading, raw data
- planar tension, slow cyclic loading, raw data
- biaxial tension, slow cyclic loading, raw data
- 5 strain levels
- number of slabs needed for test: 4

Use with

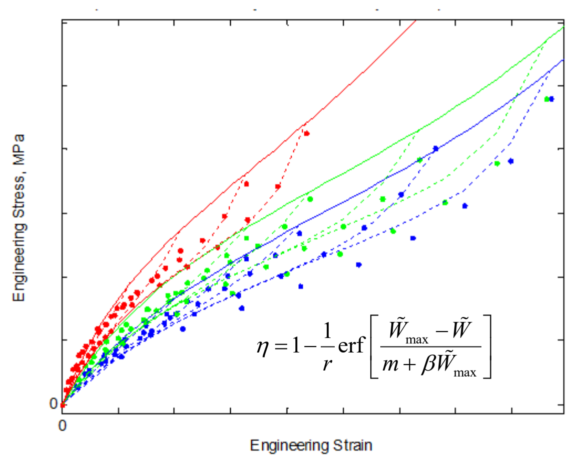
- Ogden hyperelastic law
- Mullins/Ogden Roxburgh
- and other hyperelastic laws on request

Analysis and Reporting / Deliverables

- identification of a suitable hyperelastic function and parameters for FEA
- identification of parameters for specifying Mullins effect in ABAQUS, ANSYS or MARC
- unit cube validation and stability check



Typical hyperelastic law fit to stress-strain curves measured in simple (blue), planar (green) and equibiaxial (red) tension.



Typical Mullins law fit to cyclic stabilized stress-strain curves.

FPM-H **Hyperelastic Module** completed at lab ambient temperature (23°C) **$2,100**

Additional Options

FPM-HV **Volumetric Compression Add-on to Hyperelastic Module** **$475**
Useful for specifying dilatational behavior of elastomers in highly confined deformation states. Requires 1 additional slab.
Recommended when p / K > 5%

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FPM-H-TEMP **Temperature Upcharge for non 23°C Hyperelastic Module** **$925**
Indicate temperature with range of -40°C to 150°C

FULLY RELAXING MODULE – REQUIRED TEST

Fatigue Behavior

This module is a pre-requisite for any fatigue analysis.

The Core Module gives the basic fatigue crack growth rate curve as well as the strain-life curve and crack precursor size.

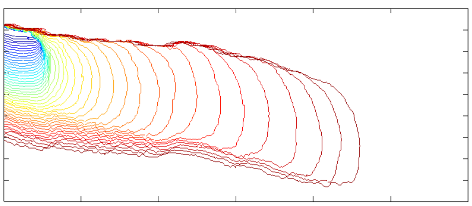
Use with
- Thomas Law
- Lake-Lindley
- Table Lookup

Experiment Overview

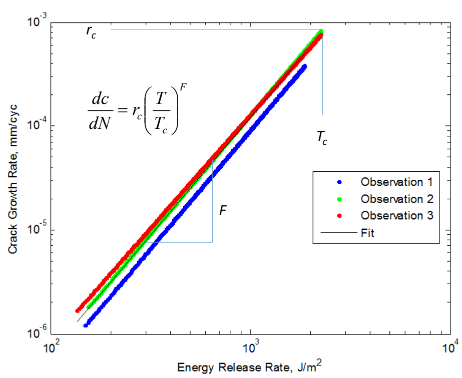
- static tearing
- fatigue crack growth (20 hour procedure)
- cyclic simple tension to rupture, 2 strain levels
- number of slabs needed for test: 5

Analysis and Reporting / Deliverables

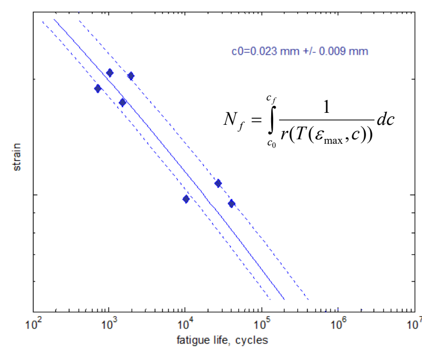
- critical tearing energy T_c
- tensile strain, stress, energy at break
- Thomas Law fatigue crack growth rate curve and its parameters r_c and F
- crack precursor size c_0 calculation and sensitivity analysis
- computed strain-life, stress-life, and energy-life fatigue curves



Typical crack tip images collected during fatigue testing. Each contour shows the crack tip shape at a given number of cycles. Colors indicate time/cycles, with blue at the beginning of the test, and deep red at the end.



Fatigue crack growth rate observations and model fit parameters.



Crack nucleation experiments overlaid with computed strain-life curve corresponding to crack precursor size c_0. Dotted lines show the effect of crack precursor size variation on the strain-life curve.

FPM-C	**Fully Relaxing Fatigue - Core Module** completed at lab ambient temperature (23°C) fully relaxing (R = 0) conditions for all fatigue tests	**$7,750**
Additional Option		
FPM-CORE-TEMP	**Temperature Upcharge for non 23°C Hyperelastic Module** Indicate temperature with range of -40°C to 150°C	**$1,400**

INTRINSIC STRENGTH MODULE

Required for safety factor/infinite life/fatigue limit analysis

Recommended for cases with fatigue life longer than 10^6 cycles

This module measures the material's intrinsic strength – the minimum energy release rate required to produce crack growth. Operation below this limit does not supply sufficient energy to grow a crack so the intrinsic strength is also called the endurance limit. Use this module when the material is expected to serve for a very large number of cycles.

Experiment Overview

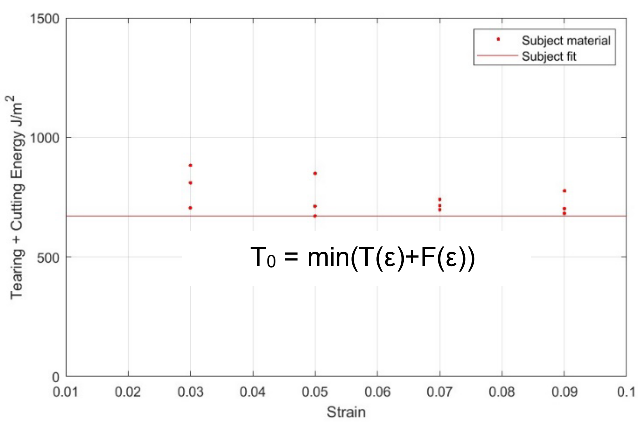
- cutting force vs. strain, minimum 3 strain levels
- number of slabs needed for test: 3

Use with

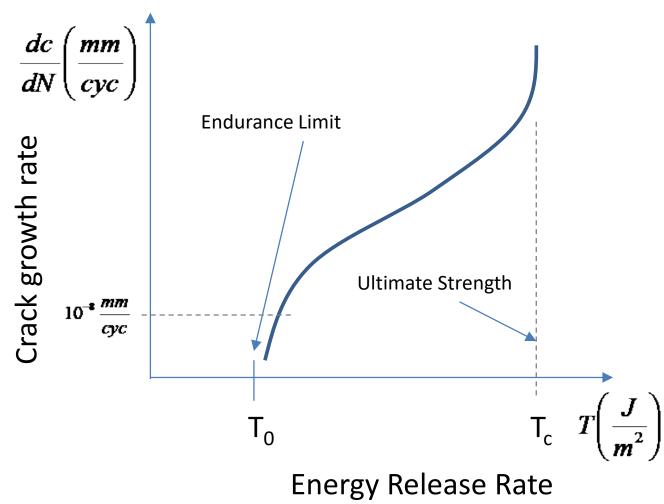
- Safe-life safety factor analysis
- Lake Lindley Law

Analysis and Reporting / Deliverables

- cutting vs. tearing curve
- cutting energy vs. strain curve
- intrinsic strength T_0



The intrinsic strength minimizes the sum of the tearing and cutting energies.



The intrinsic strength is the lower bound of the fatigue crack growth rate curve.

FPM-IS	**Intrinsic Strength Module** completed at lab ambient temperature (23°C)	**$2,445**

NON-RELAXING FATIGUE MODULE

Recommended for cases where cyclic minimum loading is greater than zero and material may strain crystallize

Test is run under a range of nonrelaxing (R > 0) conditions

Note: It is required to run FPM-C in order to run this Module.

Under nonrelaxing loads, some elastomers exhibit enhanced fatigue life / slowed crack growth due to strain crystallization effects. The effect is measured using crack arrest experiments in which a crack growing initially under fully relaxing loads is gradually operated under increasingly nonrelaxing loads. This information is required when constructing rubber's Haigh diagram for a crystallizing material.

Experiment Overview

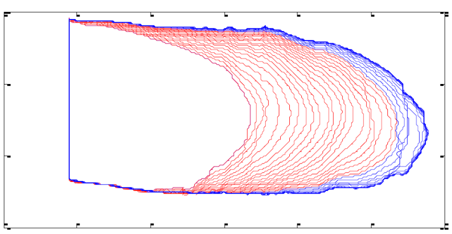
- fatigue crack growth arrest procedure with minimum strain sweep
- number of slabs needed for test: 1

Use with

- Mars-Fatemi Strain Crystallization Law
- X(R) Strain Crystallization Law

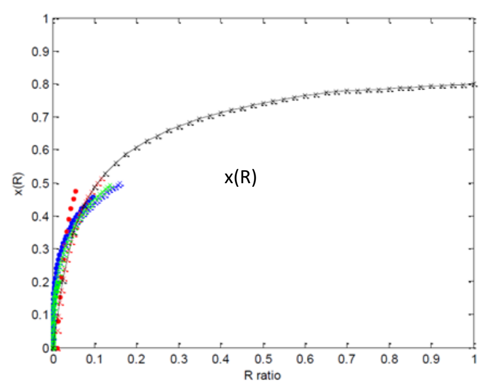
Analysis and Reporting / Deliverables

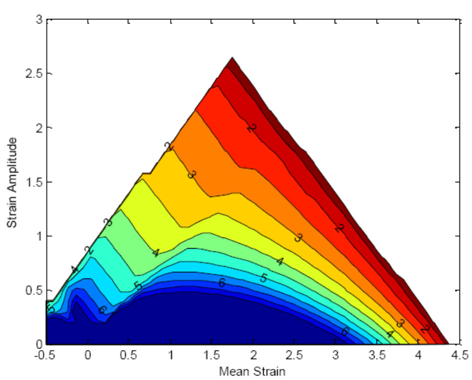
- crack arrest history c(N) for nonrelaxing cycles
- strain crystallization functions *F*(*R*) and *x*(*R*)
- Haigh diagram showing sensitivity to minimum strain of crack nucleation life



At left, Crack tip images obtained during crack arrest experiments. Red images show the crack tip while growing under fully relaxing conditions. Blue images show the crack tip while growing under nonrelaxing conditions.

At right, Typical strain-crystallization function *x*(*R*), showing dependence on the degree of nonrelaxation ratio *R* = Tmin / Tmax (where Tmin and Tmax are the energy release rate cycle extremes).





At left, Typical Haigh diagram for simple tension / compression loading, computed based on crack growth measurements and crack precursor size inferred from nucleation experiments. Contours are colored and labeled according to the base 10 logarithm of the fatigue crack nucleation life.

FPM-NR	**Non-Relaxing Fatigue Module at 23°C**	**$3,000**

Additional Option

FPM-NR-TEMP	**Temperature Upcharge for non 23°C Non-Relaxing Module** Indicate temperature with range of -40°C to 150°C	**$850**

RELIABILITY MODULE

Recommended when probability of failure needs to be estimated.

If ordered with FPM-C, includes analysis of strain life curve dependence on probability of occurrence.

The Reliability Module characterizes the rate of occurrence of crack precursors of a given size. This information is useful for estimating likely strength or fatigue failure rates for quality/warranty applications.

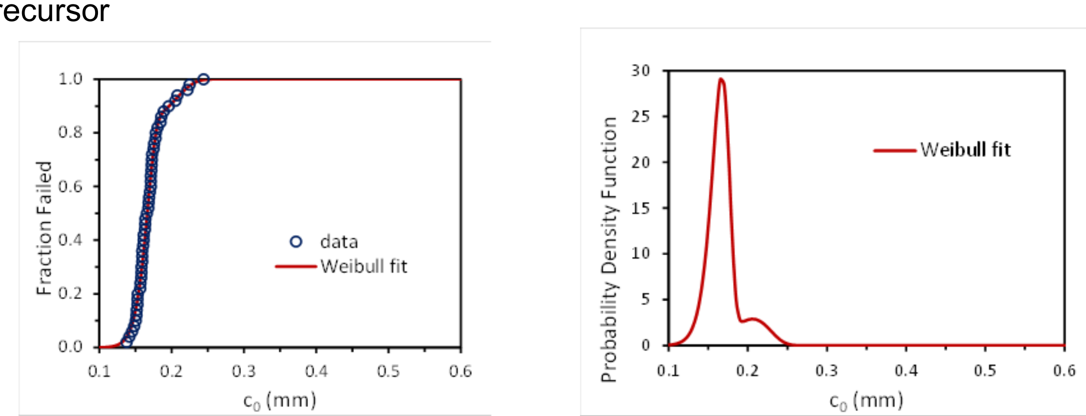
Use with
- Reliability estimates
- Weibull distribution

Experiment Overview

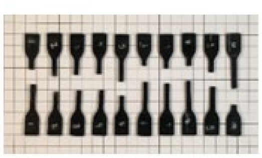
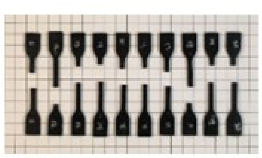
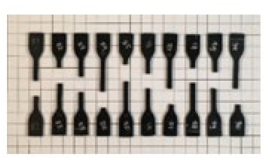
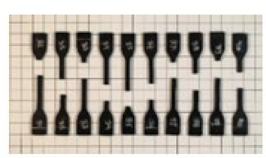
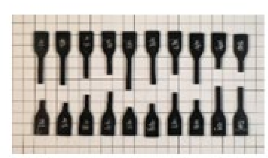
- 50 simple tension pull-to-failure experiments
- static tearing, 3 replicates
- number of slabs needed for test: 10

Analysis and Reporting / Deliverables

- summary statistics for pull to failure (strain, stress, energy at break)
- calculation of crack precursor size distribution c_0
- Weibull distribution parameters relating frequency of occurrence to size of crack precursor



Typical Weibull analysis results showing cumulative and probability density distributions for crack precursor size.

FPM-RL	**Reliability Module (23°C)**	**$3,450**

THERMAL EFFECTS MODULE - BASIC

Recommended for cases with self-heating or thermal gradients.

User gives 2 (additional to FPM-C) temperatures between -40°C & 150°C.

It is required to run FPM-C in order to run this Module.

FPM TB BASIC

The basic thermal module produces information useful for computing heat generation rate and crack growth rate law sensitivity to temperature. Use for cases involving significant self-heating and/or thermal gradients (ie Δθ > 25°*C*).

Use with

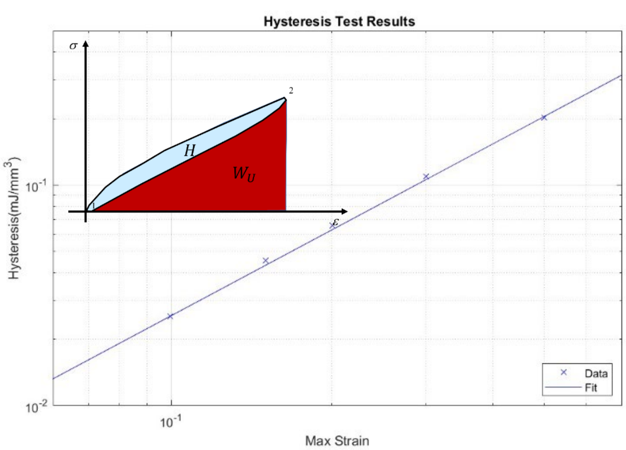
- Power law strain amplitude hysteresis model
- Terziyski-Kennedy temperature law
- Exponential fatigue crack growth temperature sensitivity

Experiment Overview

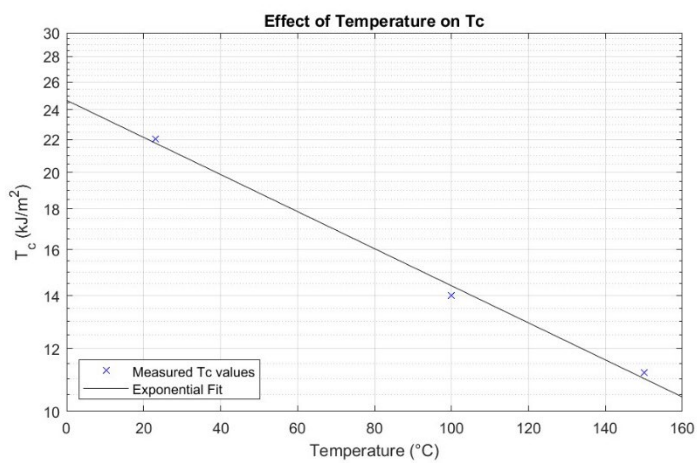
- static tearing raw data at 2 temperatures (in addition to the temperature run in FPM-C)
- cyclic stress strain raw data at 1 temp., 1 frequency, 5 strain levels
- number of slabs needed for test: 3

Analysis and Reporting / Deliverables

- heat generation law parameters describing dependence of hysteresis on strain
- tear strength vs. temperature
- crack growth rate law temperature sensitivity coefficient C



Dependence of hysteresis *H* on max strain.



Dependence of tearing energy T_c on specimen temperature.

FPM-TB **Thermal Effects Module - Basic** **$4,995**

Additional Options

FPM-TB-THRM **Thermal Conductivity, Specific Heat, and Density** **$1,050**

THERMAL EFFECTS MODULE - ADVANCED

For improved accuracy in structural and heat transfer analyses of self-heating and thermal gradient effects.

Note: FPM-TB is required as a prerequisite

The advanced thermal module is an add-on to the basic module. It enables greater accuracy and completeness in the representation of temperature and frequency effects in structural and thermal models.

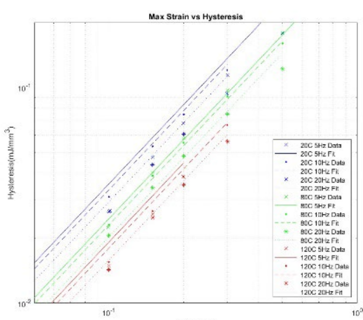
Use with
- Powerlaw strain amplitude hysteresis model
- Terziyski-Kennedy temperature and frequency model
- Exponential fatigue crack growth temperature sensitivity
- Table lookup temperature model

Experiment Overview

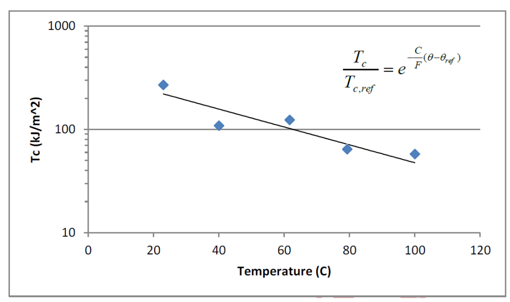
- static tearing raw data at 2 more temperatures (in addition to the 3 temperatures already collected in FPM-C and FPM-TB)
- cyclic stress strain raw data at 3 temperatures and 3 frequencies
- thermal conductivity, specific heat & density measurements
- thermal expansion measurement
- number of slabs needed for test: 3

Analysis and Reporting / Deliverables

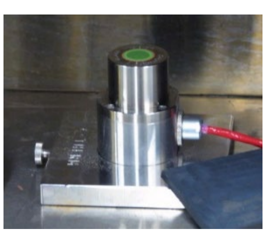
- heat generation law parameters describing dependence of hysteresis on strain, rate, and temperature
- tear strength vs. temperature
- fatigue crack growth rate law temperature look up table
- coefficient of thermal expansion



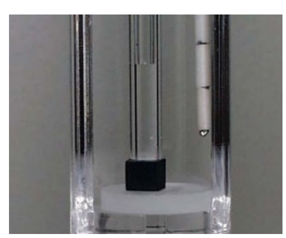
Dependence of hysteresis H on max strain, temperature and frequency.



Dependence of tearing energy T_c on specimen temperature.



Thermal transport properties are measured using transient plane source method.



Thermal expansion is measured using thermomechanical analysis (TMA).

FPM-TA Thermal Effects Module - Advanced $9,975

THERMAL EFFECTS MODULE – K/WLF

This module is used to determine the strain, temperature and frequency dependence of the viscoelastic storage and loss modulus for use in thermal-mechanical analysis with temperature effects and energy dissipation, or self-heating considerations.

FPM
TM
K/WLF

The K/WLF module is named for Kraus and for Williams-Landel-and-Ferry, two representations used to describe viscoelastic DMA (Dynamic Mechanical Analysis) measurements. Supports thermal-mechanical workflows for product temperature and energy dissipation analysis.

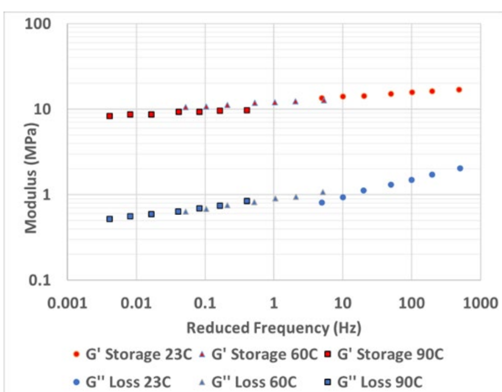
Use with
- Kraus hysteresis law
- WLF temperature / rate law
- Lookup table hysteresis law

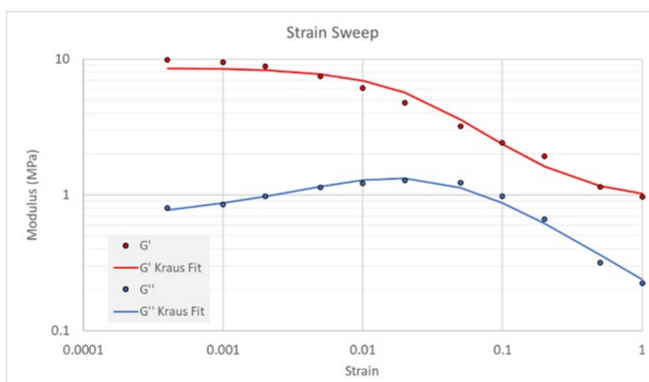
Experiment Overview

- low Strain Frequency Sweeps at 3 temperatures
- low Strain Temperature Sweep
- strain Sweep – initial and repeat – at specified temperature and frequency
- optional thermal conductivity, specific heat and density
- three replicates of each test
- number of slabs needed for test: 4

Analysis and Reporting / Deliverables

- Kraus fit for strain amplitude dependence of storage and loss modulus.
- WLF shift and master curve for storage and loss modulus to describe response over a wide range of temperatures and frequencies.
- look-up tables for master curve representation and Kraus parameter fits for input to simulation codes.
- formatted input for analysis codes and final report





FPM-TM-KWLF	**Thermal Effects Module – K/WLF**	**$3,650**

Additional Options

FPM-TM-THRM	**Thermal Conductivity, Specific Heat, and Density** Requires 1 additional slab.	**$1,050**
FPM-TM-TEMP	**Temperature Upcharge for +2 Temperatures** For frequency sweeps	**$600**

AGEING MODULE - BASIC

Recommended for cases with fatigue life longer than 10^6 cycles, and when ageing must be taken into account for a specific aged condition.

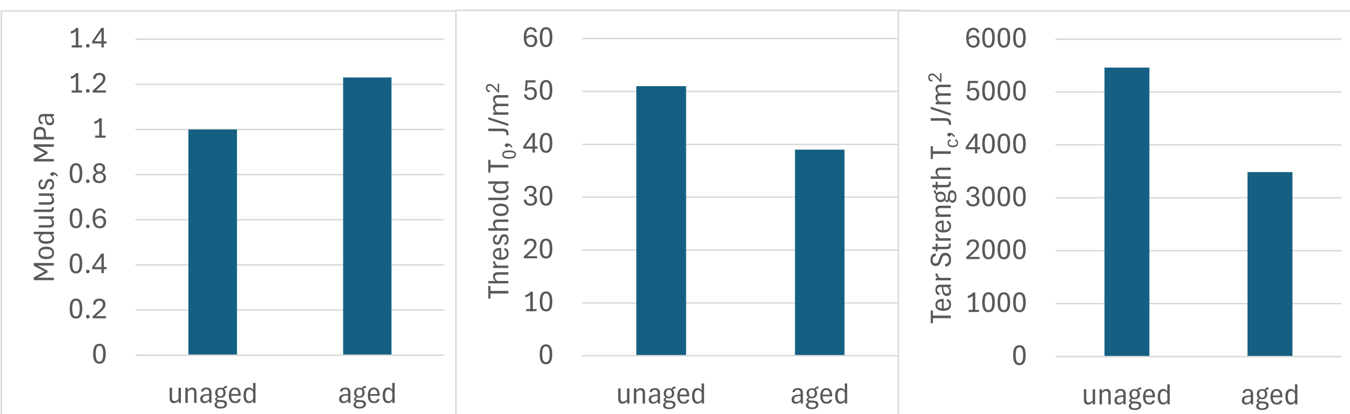
Note: It is required to run FPM-IS in order to run this Module.

The ageing module is recommended when the material operates below the endurance limit. Although cracks may not grow due to mechanical fatigue, the material properties may still evolve with exposure to heat history. The results of this module enable the user to compute fatigue performance considering both unaged and aged material properties.

Use with
- Simple comparison of unaged and specified aged behavior

Experiment Overview
- ageing in oven at 1 client-specified time and temperature
- static tearing raw data, unaged vs. aged
- cutting force raw data, unaged vs. aged
- number of slabs needed for test: 5

Analysis and Reporting / Deliverables
- stiffness, unaged vs. aged
- cutting vs. tearing curve, unaged vs aged
- intrinsic strength T_0, unaged vs aged
- tearing energy T_c, unaged vs aged
- fatigue threshold strain, stress, energy, unaged vs aged (when ordered with FPM-C)



Comparison of unaged and aged stiffness and crack growth rate law parameters.

FPM-AB	**Ageing Module - Basic**	**$4,975**

AGEING MODULE – MASTER CURVE

Recommended for cases with fatigue life longer than 10^6 cycles, and when ageing must be taken into account.

Note: It is required to run FPM-IS in order to run this Module.

The extended life module is recommended when the material operates below the endurance limit. Although cracks may not grow due to mechanical fatigue, the material properties may still evolve with exposure to heat history. A series of oven ageing experiments is used to develop master curves showing the evolution of stiffness, intrinsic strength, and fracture strength with time. The protocol also produces an estimate of the activation energy of the Arrhenius rate law describing the time-temperature dependence of ageing in the material.

Experiment Overview

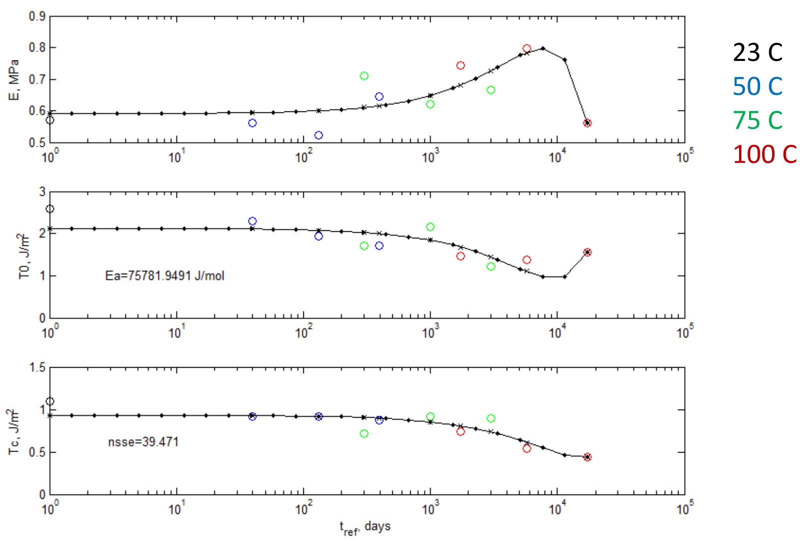
- ageing in oven at 3 temperatures for 3 time periods: 3 days, 10 days, 30 days
- static tearing raw data, 3 ageing periods x 3 ageing temperatures
- cutting force raw data, 3 strain levels x 3 ageing periods x 3 ageing temperatures
- number of slabs needed for test: 30

Analysis and Reporting / Deliverables

- cutting vs. tearing curve at each aged condition
- intrinsic strength T_0 vs. ageing master curve
- tearing energy T_c vs. ageing master curve
- Arrhenius activation energy, E_a
- fatigue threshold strain, stress, energy vs. ageing curves (when ordered with FPM-C)
- parameters specifying ageing time and temperature dependence of T_0 and T_c
- extrapolation of ageing effects to longer timescales for an application-specific temperature

Use with

- Arrhenius ageing law



Ageing experiments over a 3x3 matrix of oven temperature and time settings are used to develop accelerated degradation curves. Based on the Arrhenius rate law, the accelerated degradation curves are compiled into a master curve for a specific reference temperature (here, the reference temperature is 23° C).

FPM-AM Ageing Module – Master Curve $14,850

CREEP CRACK GROWTH MODULE

FPM CR

Recommended for cases involving long periods under static load

Lab ambient temperature (23°C)

The creep crack growth rate module produces information useful for cases involving long-term static loads under which time-dependent crack growth (rather than cycle-dependent crack growth) may occur.

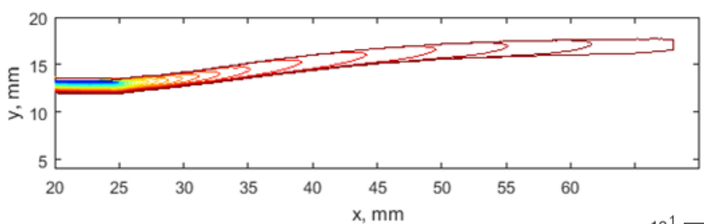
Use with
- Powerlaw creep crack growth model
- Table lookup creep crack growth rate law

Experiment Overview

- raw data from quasistatic creep crack growth procedure
- number of slabs needed for test: 1

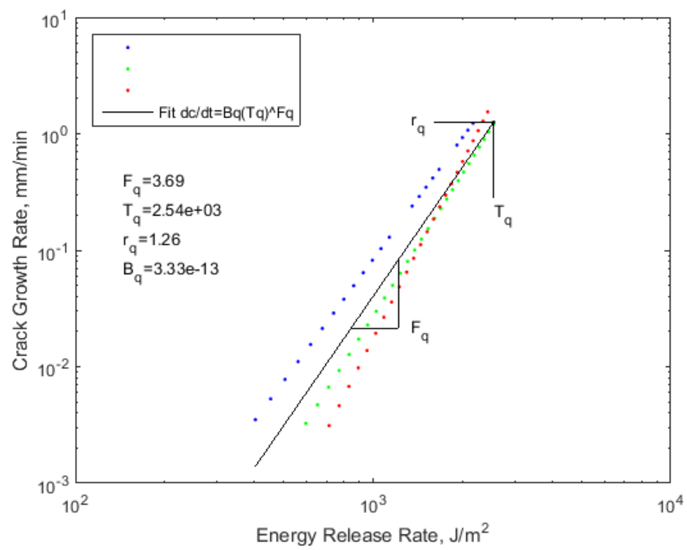
Analysis and Reporting / Deliverables

- creep crack growth rate curve and its parameters (T_q, r_q, and F_q)



Typical crack tip images collected during fatigue testing. Each contour represents the crack tip shape at a given number of cycles. Colors indicate time, with blue at the beginning of the test, and deep red at the end.

Fatigue crack growth rate observations and model fit parameters.



FPM-CR	**Elastomer Fatigue Property Map – Creep Crack Growth Module**	**$1,615**

Additional Option

FPM-CR-TEMP	**Elastomer Fatigue Property Map – Creep Crack Growth Module** Indicate temperature with range of -40°C to 175°C	**$850**

CYCLIC SOFTENING MODULE

Recommended for cases where stiffness degradation limits durability

The cyclic softening module produces information about the rate at which stiffness evolves under cyclic solicitations. This information is useful for modeling stiffness evolution under fatigue cycles using Endurica DT's stiffness loss cosimulation feature. The experiment is run in displacement control, and it records the evolution of the peak stress with cycles.

Experiment Overview

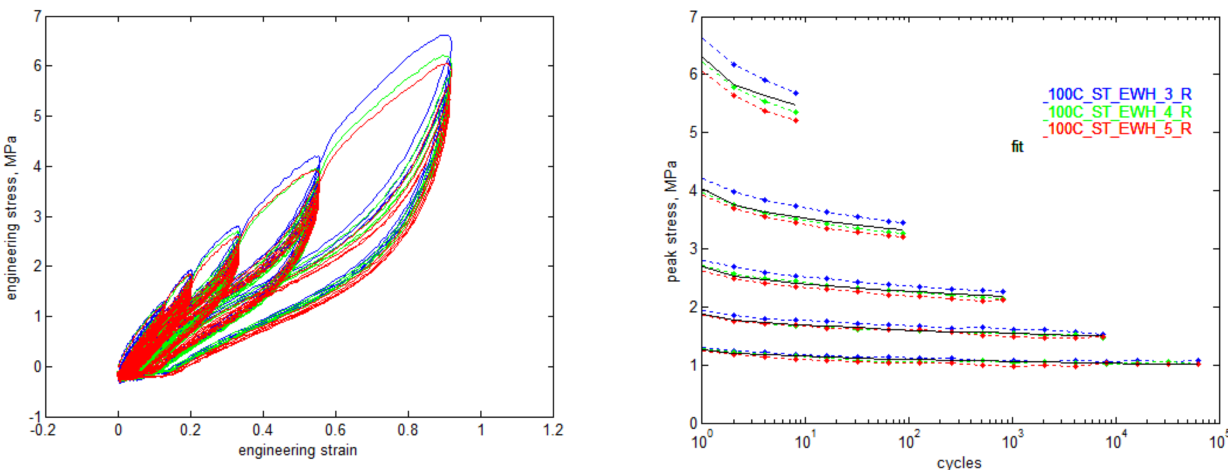
- raw data from cyclic softening procedure on simple tension strips at 5 strain levels
- number of slabs needed for test: 1

Analysis and Reporting / Deliverables

- family of cyclic softening curves showing stiffness degradation rate as a function of life consumed
- curve fit to cyclic softening model

Use with

- Cyclic softening model



Cyclic softening stress-strain response (left), and evolution of peak stress at 5 different strain levels.

FPM-S	**Elastomer Fatigue Property Map – Cyclic Softening 23°C**	**$2,845**

Additional Option

FPM-S-TEMP	**Temperature Upcharge for non 23°C Cyclic Softening Module** Indicate temperature with range of -40°C to 175°C	**$850**

OZONE EFFECT MODULE

Required when rubber that has a susceptibility to ozone attack is operating in an environment with ozone.

Ozone is a trace gas that strongly reacts with some rubbers to produce surface cracking following exposure. Ozone cracking can limit useful product life, even when mechanical cycles operate below the mechanical fatigue threshold. The Endurica ozone attack testing method determines: $\mathcal{E}_z$ the critical strain for ozone attack; T_z the critical tearing energy for ozone attack; and r_z the rate of crack growth due to ozone attack.

Experiment Overview

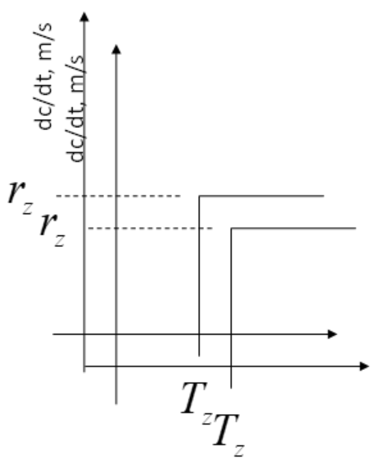
- images of crack development on specimen
- 3 replicates
- number of slabs needed for test: 1

Use with

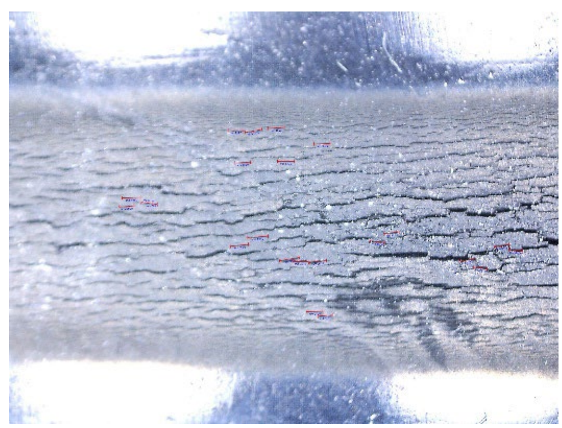
- Williams ozone attack model
- Gent-McGrath ozone attack model

Analysis and Reporting / Deliverables

- determine $\mathcal{E}_z$ - critical strain
- determine r_z - ozone crack growth rate
- determine T_z - critical energy for ozone attack



Typical crack growth rate behavior and parameters under ozone attack.



Typical surface cracking after ozone attack

FPM-O **Elastomer Fatigue Property Map – Ozone Effect Module** **$950**

Default exposure: 50 pphm O_3 concentration, 72 hrs @ room temperature 23°C

Ordering Instructions

1) Send **Purchase Order** specifying number of materials and tests to be run, and the email address to which results should be delivered, to:

   Endurica LLC
   jasuter@endurica.com
   1219 West Main Cross, Suite 201
   Findlay, OH 45840
   USA
   Phone: +1-419-957-0543

2) Test specimens are die-cut from customer-provided sheets of approximate dimensions 150 mm x 150 mm x 1-2 mm. Please see the **Fatigue Property Map Order Form** on the following page for the number of material slabs required.

   a. Label each slab with the material identifier you want us to use in reporting.

   b. Complete the **Fatigue Property Map Material Shipment Form** for each material and include it with your material samples.

3) Test execution times may vary, depending on lab backlog and Modules requested. Once testing, analysis and reporting are complete, you will receive an email from Endurica containing the analysis and summary report, and all raw data files.

Notes:

All results delivered via email. The raw data is delivered in an ASCII format.
The analysis and summary report is delivered in PDF format.

Customer data and materials will be retained for 1 year after initial data delivery.

Purchase Order, VISA, MasterCard, AMEX, and Discover Card are accepted methods of payment.

Terms: NET 30 Days after Delivery of Final Report and Data.

Fatigue Property Map Testing Order Form *Include one form for each material in shipment*

☐	Item	Module	Customer Specifications	Slabs*	Price
	FPM-H	Hyperelastic	Peak strain levels: Temperature:	4	$2,100
	FPM-HV	Volumetric Compression	Temperature:	1	$475
	FPM-H-TEMP	Temp Upcharge	Temperature:		$925
	FPM-C	Core Fatigue Testing	Test Temp: Test Freq:	5	$7,750
	FPM-CORE-TEMP	Temp Upcharge	Temperature:		$1,400
	FPM-IS	Intrinsic Strength		3	$2,445
	FPM-NR	Nonrelaxing	Test Temp: Test Freq:	1	$3,000
	FPM-NR-TEMP	Temp Upcharge	Temperature:		$850
	FPM-R	Reliability		10	$3,450
	FPM-TB	Thermal – Basic	Test Temps (2):	3	$4,995
	FPM-TA	Thermal - Advanced	Test Temps (3): Frequencies (3):	3	$9,975
	FPM-TM-K/WLF	Thermal - WLF	Test Temps (3-5):	4	$3,650
	FPM-TM-THRM	Thermal Conductivity, Specific Heat and Density	Temperature:	1	$1,050
	FPM-TM-TEMP	Temp Upcharge	Temperature 1: Temperature 2:		$600
	FPM-AB	Ageing - Basic	Aged / Unaged	5	$4,975
	FPM-AM	Ageing – Master Curve	Ageing Oven Temps (3):	30	$14,850
	FPM-CR	Creep Crack Growth	Test Temp:	1	$1,615
	FPM-CR TEMP	Temp Upcharge	Temperature:		$850
	FPM-S	Cyclic Softening	Test Temp:	1	$2,845
	FPM-S-TEMP	Temp Upcharge	Temperature		$850
	FPM-O	Ozone Effect	O_3 Concentration: Test Temp: Time:	1	$950
			Totals		

* Nominal slab dimensions are 150 mm x 150 mm x 2 mm.

Customer Notes:		
Company Name:	Contact:	Email:
Address:	Title:	Phone:

Ship to: Endurica LLC - Attn. Joe Suter - 1219 West Main Cross, Suite 201 - Findlay, OH 45840 - USA

About Our Fatigue Property Mapping Service

The service enables engineers to obtain, from a commercial source, reliable, affordable measurements suitable for use in fatigue analysis.

Training on the experimental procedures and analysis for fatigue life prediction is available. For complete information and our schedule of upcoming classes please visit www.endurica.com/training2/

About Endurica

Endurica LLC develops the world's most versatile and best-validated fatigue life simulation system for elastomers. Through our technology and services, Endurica empowers our clients' analysis of the real-world fatigue performance of elastomers at the design stage, when the greatest opportunity exists to influence performance, and before investment in costly fatigue testing of prototypes. Endurica was founded in 2008 and received the 2020 Tibbetts Award for outstanding cutting-edge technology by the United States Small Business Administration. www.endurica.com

About ACE Laboratories

The talented team of professionals at ACE Laboratories provides independent analytical and physical testing services. ACE's 200,000 square-foot, state-of-the-art, ISO/IEC 17025 accredited polymer testing laboratory is staffed by experienced technicians boasting over 200 years of combined industry experience in their professional journey to set new standards in the testing industry. https://www.ace-laboratories.com/

About Axel Products

Founded in 1994, Axel Products provides testing services for engineers and analysts with a focus on the characterization of nonlinear materials such as elastomers and plastics. Data from the Axel laboratory is often used to develop material models in finite element analysis codes such as ABAQUS, Ansys, fe-safe/Rubber, Hexagon (MSC/Marc), and LS-Dyna. Testing services are also provided to examine sealing and fatigue problems, long-term thermal mechanical testing, and high strain rate testing. www.axelproducts.com