fe-safe™

fe-safe/Composites™

Powered by HELIUS:FATIGUE

Composite Durability Analysis Software for Finite Element Models

Overview

Safe Technology is the technical leader in the design and development of durability analysis software and is dedicated to meeting its customers' most demanding applications. It develops and sells fe-safe™, the leading fatigue analysis software suite for finite element models.

As a privately owned company, its independence and focus enables Safe Technology to continually bring the most advanced analysis technology to address real-world, industrial applications.

Firehole Composites is a global leader in advanced composite analysis and in transferring technology into commercial software. Since its founding in 2000, Firehole's mission has been to enable wide-spread use of composite materials leading to lighter, stronger and more fuel efficient designs. It offers a suite of products designed to significantly improve the composite design process.

Safe Technology has partnered with Firehole Composites to bring to market fe-safe/Composites™, a unique and advanced solution enabling the fatigue analysis of composite materials.

Introduction

Composites are an attractive material option for designers and manufacturers because of their high strength and stiffness to weight ratio, as well as the ability to tune the material properties for specific applications. As their use becomes more widespread, there is an increasing need to understand their behaviour and design life. Until now, an accurate and robust fatigue life prediction tool for composites has not been available.

Predicting fatigue life in composites is challenging because even simple load states lead to complex behaviour in the individual composite constituents. Furthermore, the effects of frequency and load history can only be dealt with adequately by using physics-based theories.

fe-safe/Composites™ meets these challenges head-on by combining Multicontinuum Theory with kinetic theory to introduce a game-changing technology for fatigue life prediction in composite structures.

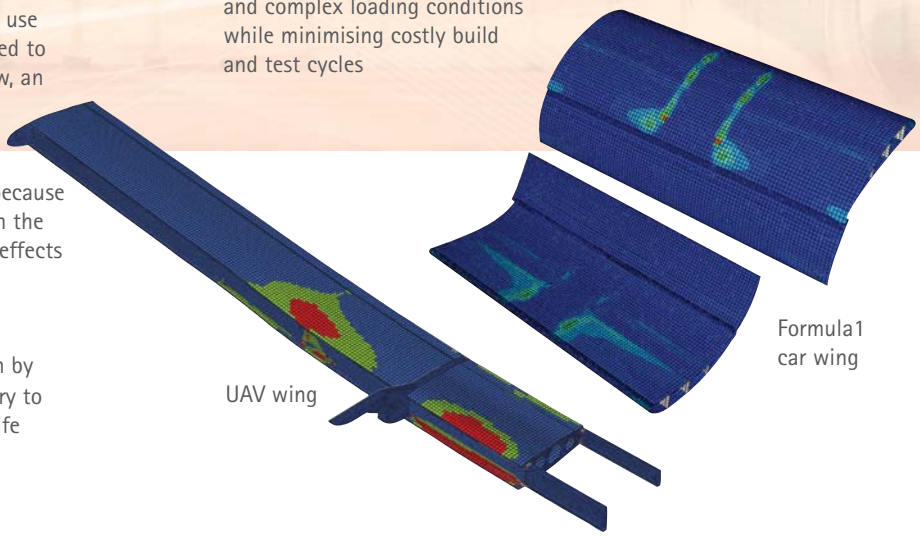
Summary

fe-safe/Composites™

- is a robust and computationally efficient tool for predicting fatigue life in composite structures consisting of unidirectional laminae
- predicts lamina-level fatigue life at every integration point in a Finite Element model
- predicts fatigue failure by applying kinetic theory to constituent-level stresses
- applies realistic physics to naturally account for the effects of frequency, mean stress, and combined loading
- requires only standard, static material properties and minimal fatigue characterisation
- can handle arbitrarily complex load histories

Key benefits

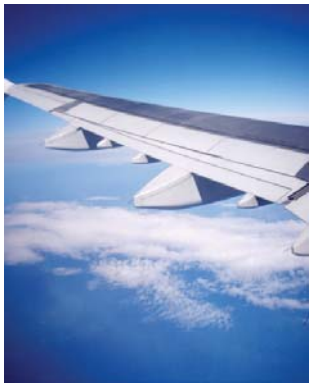
- Efficient, multiscale analysis for unidirectional composite structures
- Superior insight into composite fatigue behaviour
- Optimised designs with accurate simulation capability, minimising the need for over-design
- Reduced composite FEA simulation time due to computational efficiency
- Reduced cost and time-to-market with accurate simulation and reduced need for physical testing
- Easy implementation with intuitive GUI and seamless integration with leading FEA packages
- Offers a practical tool for investigating multiple designs and complex loading conditions while minimising costly build and test cycles



UAV wing

Formula1 car wing

Combining Multicontinuum Theory with kinetic theory to introduce game changing technology



Why use fe-safe/Composites™?

Composites are intrinsically different from metals and require a different approach to fatigue analysis.

Key differences between metals and fibre-reinforced composites drive physically different load responses:

- Composites have multiple constituents with unique material properties contributing separately to the load response, so the composite stress and the constituent stress are not the same
- Composite behaviour is directionally dependant because it is influenced by the orientation of the fibres and surrounding laminae
- Most of the fatigue damage in composites is accumulated as microcracks in the matrix material

This results in characteristically different responses to fatigue loading. Fatigue failure in composites is different from that in metals.

Metal fatigue failure is characterised by slow crack propagation; cracks initiate and propagate in a series of notch blunting and crack propagation events. By contrast, composite fatigue failure is a diffuse accumulation of damage, including multiple damage modes and complex failure mechanisms.

This fundamental difference in material response requires a different approach to be used for the analysis of composite fatigue. Traditional metal analysis methods are not applicable to composites.

Technology overview

Powered by HELIUS:FATIGUE from Firehole Composites, fe-safe/Composites™ provides the only commercial solution available that can extract constituent stresses for use with physics-based fatigue theories without substantial computational cost or the need for exotic material data.

Fatigue failure in fibre-reinforced polymer composites (FRPs) is generally driven by failure in the matrix constituent [1, 2, 3]. As such, polymer kinetics provides an effective means for predicting fatigue life in composites. This approach requires the behaviour of individual constituent materials of the composite to be handled separately. fe-safe/Composites™ has the solution.

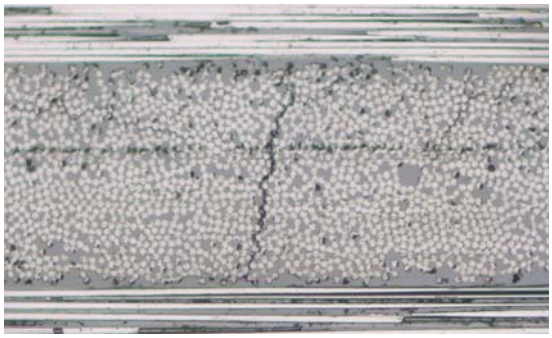
HELIUS:FATIGUE uses Multicontinuum Theory (MCT) to calculate the stress and strain of the fibre and matrix, allowing fatigue damage to be modelled at the constituent level rather than for the homogenised composite.

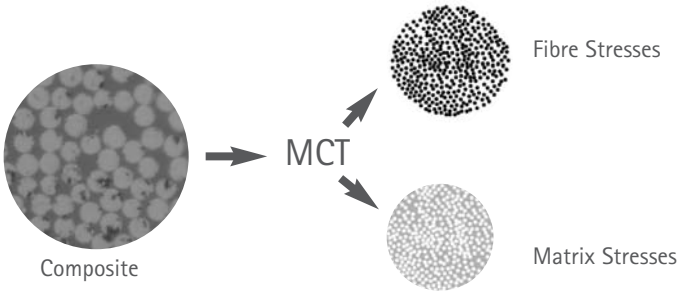
HELIUS:FATIGUE employs the kinetic theory of fracture as a physics-based method for predicting fatigue using the calculated matrix stress.

HELIUS:FATIGUE uses an efficient, multi-scale decomposition which enables constituent-based analysis of large-scale structural models with negligible computational burden.

Proven technology

The MCT technology used in HELIUS:FATIGUE is well documented and has undergone numerous validation exercises in government and industry[4,5]. The physics-based fatigue methodology is based on the well established kinetic theory of fracture.





Enabling composite fatigue analysis at the constituent level

Traditional metal fatigue analysis methods are not applicable to composites

Process overview

Two distinct operations are used by fe-safe/Composites™ to predict the fatigue life in a composite structure:

- Material characterisation
  - Static properties of the composite lamina and its constituents are used with Multicontinuum Theory to characterise the material
  - Two S-N curves for the lamina are used to characterise two different failure modes: off-axis and on-axis
- Fatigue life prediction
  - Constituent stresses are accurately calculated from the average lamina-level stress at each integration point in an FEA model using Multicontinuum Theory
  - Constituent stresses are converted to an equivalent fatigue stress
  - The equivalent fatigue stress is used in the kinetic theory equations to predict composite fatigue life

The result is a determination of cycles to failure at every integration point, presented as a contour plot for the structure.

Key features

Computationally efficient

Designed specifically for the analysis of composite materials, Multicontinuum Theory has been shown to add only 3% to the computational time required for a large-scale structural analysis. Thus, fe-safe/Composites™ offers a practical tool for investigating multiple design and loading conditions while keeping costly test cycles to a minimum.

Requires only industry-standard material data

The fe-safe/Composites™ approach uses standard material data and S-N curve data that can be readily determined from coupon testing or handbook values of unidirectional lamina.

Helius Material Manager

In order to properly characterise a composite material for fatigue analysis, composite and constituent properties must be determined.

Helius Material Manager is a user-friendly tool designed to help complete this characterisation. Helius Material Manager:

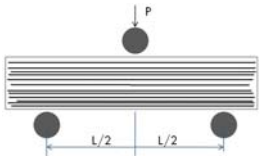
- utilises a high-speed micromechanics model to assess the consistency of constituent properties
- has a robust nonlinear solver to "back out" constituent properties from composite properties
- contains default values for constituent properties if they are not known

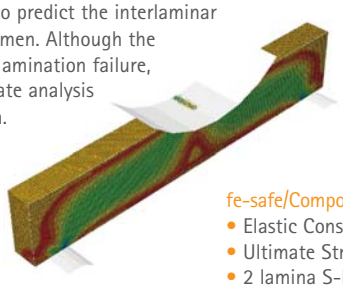
Combines key fe-safe™ features with Helius:Fatigue technology

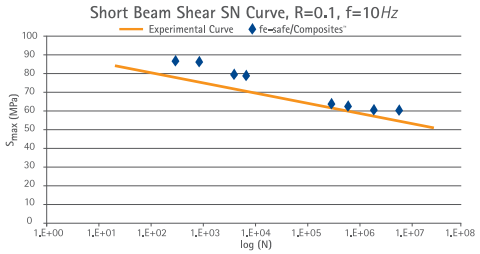
The fatigue analysis can be applied to named element groups on the model. This enables the user to combine the analysis of composites and the analysis of metals using fe-safe™ on the same component and in one analysis.

Analysis Example

In this example, fe-safe/Composites™ is used to predict the interlaminar fatigue response of a short beam shear specimen. Although the loading results in a complex, shear-based delamination failure, fe-safe/Composites™ demonstrates that accurate analysis is achievable using standard tensile S-N data.







fe-safe/Composites™ requires only standard material inputs:

- Elastic Constants (E_{11}, E_{22}, ν_{12}, ν_{23}, G_{12})
- Ultimate Strengths ($\pm S_{22}$, S_{12})
- 2 lamina S-N curves: 1 longitudinal and 1 transverse

Accurate fatigue analysis of composites with the comprehensive capabilities of fe-safe™ to analyse complex loading conditions

Capabilities overview

FEA models

- Inputs are elastic stresses so that the results can be scaled and superimposed to produce service stress time histories
- Analysis of solid and shell elements, which can be mixed in the same model. No effective in-built limit to the number of elements in the model or the file size. 64-bit file readers allow large files to be analysed
- FEA results from several files can be concatenated
- Interfaces to ABAQUS (.fil & .odb), ANSYS (.rst), MSC.Nastran (.op2 & .f06), NX Nastran (.op2 & .f06), NEiNastran (.op2 & .f06), Pro/Mechanica (ASCII & binary), I-deas (.unv), ADAMS, .dac, MTS RPCIII (.rsp), BEASY, FEMSYS, CADFIX, MSC.Patran, Altair HyperMesh & Optistruct. All interfaces included as standard
- The whole model file need not be read into fe-safe™. Intelligent pre-scanning and load case selection.

Inputs

- Standard material properties for the composite lamina
- Elastic constants (E_{11}, E_{22}, ν_{12}, ν_{23}, G_{12})
- Strengths ($\pm S_{22}$, S_{12})
- Fibre volume fraction
- Two lamina S-N curves: one off-axis, one on-axis

Component loading

fe-safe™ can analyse very complex load conditions.

- Composite fatigue life for any mechanical load history with load-time data can be predicted
- A time history of component loading can be applied to the results of a 'unit load', linear elastic FEA analysis
- Time histories of multiaxial loading can be superimposed to produce a time history of the stress tensor at each location on the model (fe-safe™ supports over 4000 load histories of unlimited length)
- A sequence of FEA stresses can be analysed
- Complex test programmes and 'proving ground' sequences can be produced easily
- High and low frequency loading can be superimposed with automatic sample rate matching by interpolation
- Supported file formats include .DAC, single and multi-channel ASCII, Safe Technology .amc file, RPCIII, Servotest, Snap-Master and other files. All file formats are read directly, without file converters

These load conditions can be combined and superimposed with great flexibility. PSDs, dynamics, rainflow matrices and other capabilities are included.

Calculated cycles to failure

- Calculated for each individual cycle
- Calculated using the kinetic theory of fracture to determine failure in the matrix constituent
- Predicted for two failure modes:
  - Matrix damage parallel to fibres (transverse)
  - Matrix damage perpendicular to fibres that leads to fibre failure (longitudinal)

Material data

- Helius Material Manager is a stand alone tool that is included with fe-safe/Composites™
- Helius Material Manager can be used to calculate a set of composite and constituent material properties for use in fe-safe/Composites™
- A comprehensive database of material properties is provided
- The material properties in fe-safe™ can be extended and modified by the user
- Isothermal data for any temperature can be used

Advanced features

- High temperature fatigue included as standard - the user can define a material characterised at a selected temperature
- Comprehensive management of element and node groups is supported
- The fatigue analysis can be applied to the complete model, or to named element groups - this means the user can combine the analysis of composites in fe-safe/Composites™ and the analysis of metals using the algorithms in fe-safe™ standard, in one single analysis
- Different properties can be used for each element or node group
- The user can easily change any of the inputs and re-run the analysis, ideal for parametric studies
- Standard analyses can be set up and re-run easily, ideal for parametric studies
- Powerful batch processing, with parameter modification for sensitivity studies

Output

All contour plots can be generated in a single analysis run.

- Cycles to failure and failure mode at each node or element, shown as a contour plot of the structure in the FEA viewer
- Fatigue lives at each node or element (3D contour plot) in user-defined units, e.g. miles, flights, hours
- A text file of user inputs, analysis type and a results summary is produced for QA trace-back
- Additional groups of elements can be defined in fe-safe™ as the hot-spots are identified

Signal processing and analysis

fe-safe/Composites™ includes all the safe4fatigue™ features for processing and fatigue analysis from measured data

- Digital filters, spike removal and noise shaping
- Interactive multi-channel editing with immediate graphics display
- Single and multi-channel peak/valley time-slicing with cycle omission
- Manipulation and powerful re-scale/combine functions for signals, cycle matrices and load spectra
- Full suite of amplitude and frequency analysis, including rainflow cycle counting, PSDs, transfer functions
- Comprehensive fatigue analysis from strain gauges, including a full multiaxial fatigue analysis suite
- Fully featured graphics display and hard copy
- Print graphics to disk, copy and paste graphics to other MS Windows programs

Additional features

- Comprehensive online help
- Common user interface across all supported platforms

Licensing

- fe-safe™ is supported on Windows, Linux and UNIX
- fe-safe/Composites™ is currently supported on Windows only
- Networked licence manager/controller
- Distributed processing - rapid analysis using multiple licences for distributed processing across a network

This is not a complete list of the features in fe-safe™ and fe-safe/Composites™. To discuss your particular requirements please contact your local distributor or Safe Technology.

References
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3. J. Petermann and A. Plumtree, "A unified fatigue failure criterion for unidirectional laminates," Composites: Part A, vol. 32, 2001, pp. 107-118
4. E. Nelson, A. Hansen, J. Welsh, and J. Mayes. "Recent Advances in Failure Predictions of Composite Laminates Using Multicontinuum Technology," Proceedings of the 49th AIAA SDM Conference, Schaumburg, Illinois: 2008
5. Mayes, J.S. and Hansen A.C. (2004) "A Comparison Of Multicontinuum Theory Based Failure Simulation With Experimental Results" Part B of the World-Wide Failure Exercise sponsored by DERA, Great Britain. Composites Science and Technology, 64(3-4), 517-527

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