ES98F-15 Predictive Modelling of Advanced Engineering Materials

24/25

Department
School of Engineering
Level
Taught Postgraduate Level
Module leader
Lukasz Figiel
Credit value
15
Module duration
10 weeks
Assessment
60% coursework, 40% exam
Study location
University of Warwick main campus, Coventry

Description

Introductory description

This module will provide students with fundamental principles and practical aspects of predictive modelling of advanced engineering materials through the presentation of the the state-of-the-art micromechanics approaches (both mechanistic and data-driven) in combination with their numerical implementation (with the Finite Element Method) to enable design and optimisation of advanced engineering materials (e.g. composite materials, metamaterials) across the scales, i.e. from their microscale right up to their infrastructural (component) scale.
This will be achieved through lectures (including guest lectures), research case studies and workshop activities.

Module aims

The principal aim is to provide students with state-of-the art predictive modelling approaches to analyse, design and optimise advanced engineering materials (such as composites) and their structural components that combine concepts from micromechanics, multi-scale analysis, finite element method and data-driven approaches.

Outline syllabus

This is an indicative module outline only to give an indication of the sort of topics that may be covered. Actual sessions held may differ.

1. Introduction (Week 1) - overview of the main concepts and challenges related to predictive modelling of advanced engineering materials
2. Revision of the main concepts from continuum solid mechanics (Week 1 and 2) - concept of strain and stress; governing equations incl. PDEs and constitutive laws
3. General formulation of Finite Element Method equations (Week 3) - weak form; Galerkin approximation; shape functions; 1D elements; stiffness matrix assembly; reduced system of equations
4. Isoparametric formulation of the Finite element method (Week 4-5) - isoparametric concept, 2D elements, numerical integration, stress and strain calculation; discretisation error
5. Overview of micromechanics and multi-scale methods (Week 5-6): separation of scales; representative volume element; Hill-Mandel condition; effective elastic response; upper and lower bounds
6. Theory of homogenization for linear elastic periodic systems (Week 7): two-scale analysis; asymptotic expansion; effective properties; periodic boundary conditions
7. Computational homogenisation of composite materials (Weeks 8-9): heterogeneous multiscale methods, non-linear mechanics problems; transport problems; first-order computational homogenisation; higher-order computational homogenization approaches
8. Data-driven approaches to computational homogenisation (Week 10): computational cost of mechanistic-based heterogeneous multi-scale approaches; accelerating multi-scale predictions using data-driven approaches; neural network approaches to multi-scale analysis; Gaussian Process regression in computational homogenisation

Learning outcomes

By the end of the module, students should be able to:

- Appreciate the need for predicting the response of modern engineering materials and structures
- Understand the role of micromechanics and multi-scale methods for the analysis of advanced engineering materials
- Implement and solve numerically (with the FEM) linear elastictity problems in 2D
- Recognise elements of a data-driven multi-scale simulation framework
- Integrate the computational homogenization procedure into the finite element method-based solution procedure

Indicative reading list

J. Fish & T. Belytschko. A First Course in Finite Elements, Wiley, 2007 (available from the Library).

R. de Borst; M. A. Crisfield, Nonlinear finite element analysis of solids and structures, 2012 (available from the Library)

J. Fish, Practical multiscaling, Wiley, 2013 (available from the Library).

S. Torquato, Random heterogeneous materials, Springer, 2002 (available online from the Library)

[View reading list on Talis Aspire]

Research element

Guest lecturers are invited to provide an overview of their state-of-the-art research advances in the field of predictive modelling for advanced engineering materials

Subject specific skills

1. Ability to predict and analyse the behaviour of advanced engineering materials using predictive modelling
2. Develop skills related to model formulation and computer implementation within the finite-element solution framework
3. Perform a multi-scale analysis for a simple composite material

Transferable skills

1. Soft skills - develop an ability to discuss a range of topics related to the application of advanced modelling methods to the field of engineering materials
2. Technical writing skills - develop an ability to write concise and scientifically rigorous reports.

Study

Study time

Type	Required
Lectures	10 sessions of 2 hours (13%)
Practical classes	10 sessions of 2 hours (13%)
Private study	110 hours (73%)
Total	150 hours

Private study description

Private study and independent learning towards the viva voce and the coursework report.

Costs

No further costs have been identified for this module.

Assessment

You must pass all assessment components to pass the module.

Assessment group D1

	Weighting	Study time
Report	60%	
For a given composite material implement a computational procedure to calculate its effective elastic properties		
Viva Voce	40%	
It will examine knowledge in fundamental aspects of the module as well as some practical aspects. The range of material will be clearly indicated.		

Feedback on assessment

1. Written group feedback on the Viva Voce.
2. Written individual feedback on the report.

Past exam papers for ES98F

Availability

Courses

This module is Core optional for:

- Year 1 of TESA-H1B1 Postgraduate Taught Predictive Modelling and Scientific Computing

This module is Option list B for:

- Year 1 of TPXA-F345 Postgraduate Taught Modelling of Heterogeneous Systems (PGDip)