TME240 – Composite Mechanics, 7.5 credits, Q3, 2019/20

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Course aim

The course provides an introduction to the mechanics of composite materials and, in particular, high performance continuous fibre-reinforced composites. The course will give comprehensive knowledge and understanding of composites and their mechanical behaviour with applications to composite structures common in industrial applications. This will include handbook assessment as well as more modern design evaluation methods such as the Finite Element Method (FEM). Different scales, from a single fibre and its interaction with the surrounding matrix via the concept of laminate theory up to an entire structure, will be treated; from micromechanics through levels of homogenisation up to macro-mechanics. Special emphasis is put on explaining failure mechanisms and modes, i.e. fibre breakage, matrix cracking, elastic buckling and progressive laminate failure.

Learning outcome (after completion of this course, the student should be able to)

- List and explain the basics of several different manufacturing procedures, their applicability and limitations.
- Explain elastic anisotropy and the special cases relevant for composites: orthotropy and transversal isotropy.
- Explain basic steps in homogenisation of heterogeneous materials including the Voigt and Reuss assumptions. This includes derivation and calculation of engineering constants for a composite ply based on homogenisation of a fibre-matrix unit cell.
- Derive the coupling between membrane and bending/torsion deformation and related generalised stress resultants (normal force and moment per unit length)
- Apply classical laminate theory to calculate the stress distribution in a composite laminate subjected to mechanical as well as thermal loads.
- Assess a composite structure with respect to various failure modes based on handbook calculations and FEM.
- Derive a finite element formulation for a composite plate and use that as basis for implementing code in MATLAB to solve plate problems by FEM.
- Be able to perform basic FE-analyses of composite structures, using both self-developed MATLAB code and commercial software (ANSYS).
- Be able to conceptualize design requirements for general load-cases with limited specification of material choice, manufacturing method, etc.

Contents

Elastic anisotropy; Homogenisation of lamina properties; Laminate theory; Plate theory (Kirchhoff-Love and Mindlin-Reissner); Finite element formulation of composite plates; Manufacturing of fibre composites; Failure of composite structures; Structural assessment of fibre composites using commercial software (ANSYS).

Prerequisites

- Basic course in Solid mechanics
- Basics of MATLAB including e.g.:
  - loops
  - matrix and vector operations and multiplications
  - visualisation
- A basic course in the finite element method (FEM) or corresponding knowledge in:
  - Weak formulation of governing equations
  - FE formulation of governing equations
  - Displacement approximations through (element) shape functions
  - Concepts of stiffness matrix and force vector
  - Numerical integration
  - Assembly of stiffness matrix and force vector
- Basic concepts of Kirchhoff plate theory (e.g. from Mechanics of solids TME235 or a similar course)

If the student is not already familiar with these topics before the course starts, the student is expected to be so (preferably before the course starts but) at the latest during the first weeks (MATLAB – first week; plate theory and FEM – first two weeks) of the course by means of reading additional material and performing tutorials recommended by the teachers. Please note that a significant part of the examination (more than one computer assignment) will require the use of MATLAB (or another programming language but then with less support from the teachers).

Regarding plate theory and the finite element method, some repetition of the basic concepts will be included in the course before specialising to laminated composite plates. However, in order to understand the full contents of the course, any student without a basic course in FEM will have to take own responsibility for learning the basics as stated above.

Organisation

The course is organised into **lectures, tutorials**, **computer classes** and a **seminar**. The main theory is presented in the lectures and exemplified during the tutorials. During the tutorials, also a significant amount of student 'self-activity' is planned. In addition, three graded computer assignments, which should be solved in *groups of two students (no more, no less)*, will be given in the course as part of the examination.

The currently planned schedule for the lectures, tutorials and computer classes is shown at the end of this memo. During the course, in case of changes, the updated schedule will be available on the course webpage.

Course literature

- *Analysis and Performance of Fiber Composites* (4^{th} ed), B.D. Agarwal, L.J. Broutman and K. Chandrashekhara, John Wiley & sons, New York, 2006. (Available at Cremona) – Recommended and permissible aid at the exam.

- Lecture notes (to be made available at the course homepage), also permissible aid at the exam.

Examination

The main course work consists of three **optional** computer assignments. A written report for each assignment must be submitted by the deadline (see course schedule). The assignments are graded and will then give maximum 3 credit points each. Altogether, **9 credit points** can thus be obtained towards the final grade, see below. These points will remain valid until the course is given next time.

The final written exam takes place in the morning on **Wednesday, 20 March, 8:30 in computer rooms**. Permissible aids during the exam are: course literature, tables of mathematics and physics (such as Standard Mathematical Tables), Chalmers-approved pocket calculator (Casio FX82..., Texas TI30... and Sharp ELW531/ELW531...) and MATLAB via the computers in the rooms were the exam is to be held. The exam comprises questions/problems which altogether can give **9 credit points**.

The final course grade is given as a combination of the credit points obtained at the exam and from the computer assignments according to the table below:

Grades are awarded as follows:

Required credit points	Chalmers grade
<10	U
10 (minimum 3 from the final exam)	3
13	4
16	5

NOTE: To obtain passing grade it is necessary to **obtain at least 3 points in the final exam** as well as (partial) completion of at least one computer assignment.

Since the projects are a significant part of the examination, it is essential that each group solves the tasks separately. To clarify better, *it is OK to***:**

- <u>collaborate and discuss around derivations</u> asked for in different subtasks. HOWEVER, <u>each group should in the end do the derivations themselves</u> and hand-in their own written solutions
- <u>discuss around implementation strategies in MATLAB</u> for different subtasks. HOWEVER, limit the discussions to <u>pen and paper discussions</u> otherwise you will know that you are on the border of what is not OK.

It is NOT OK to:

- Directly copy other groups derivations and hand them in as your own
- Share any amount of MATLAB-code or ANSYS files between groups.
- Copy and hand-in code which is partly written by another group. This is true for code written by other students this year as well as from previous years.

Any suspected cheating (including things like copying MATLAB code or parts of someone else's report) will be directly reported to the Disciplinary Committee, please refer to the collection of rules:
https://student.portal.chalmers.se/en/chalmersstudies/joint-rules-and-directives/Documents/20090920_Academic_Honesty.pdf Please note that failure to comply with the rules may lead to warnings or in worst case time limited suspension form Chalmers.
Regarding the ambition level and quality of the project reports, imagine the current situation: The person correcting and grading the report is your manager at the consultancy company where you work. You have been given an FE assignment and when you hand in the results your manager should be able to send the report directly to the client without further modification.

Industrial seminar

During the last week of the course all students are invited to attend a seminar on composite materials applications in collaboration with the Swedish Innovation Programme on Lightweight technology LIGHTer. This year LIGHTer workshop at Chalmers University of Technology has the theme "Pushing the boundaries in transportation with composites". The seminar usually attracts approximately 100 attendees and offers a good opportunity for the students to learn about state of the art in industry and academia in the area. The workshop will be organised by Brina Blinzler, Johanna Xu and Leif Asp.

Course evaluation

A continuous evaluation will be held during and after the course consisting of three meetings: one introductory meeting in the end of the first week (or the beginning of the second week), a mid-course meeting in the fourth week and a final evaluation after the course. A group of approximately three students are chosen at the first lecture to represent the class at the meetings. The goal of the mid-course meeting is to assess the current status of the course while the final meeting aims at developing the course for next year. **We greatly need and appreciate your feedback!**

Scheduled consultation

To increase our availability for you to ask questions, we have scheduled two consultations times each week where we will make sure to always be in the office:

Leif Asp:	Fridays 13-14
Brina Blinzler:	Mondays 13-14
David Carlstedt:	Tuesday 13-14
Shanghong Duan:	Wednesdays 13-14
Johanna Xu:	Thursdays 13-14

We will try to adapt after your needs and our schedules. If you want/need to ask a question at another time you are of course welcome to do so, but please be aware of that we might be out of office or occupied with other duties. Therefore, it is better if you can first make an appointment.

Course schedule:

(Please refer to the course homepage for updates)

Date	Day	Contents	Book chapters (Home)	Exercises (Home)
21/1	**Tue 8-10**	**Lecture 1 (BB) in HA2** Course introduction	1;2.1-2.2	
21/1	**Tue 10-12**	**Lecture 2 (BB) in HA2** Elastic anisotropy, stress-strain relationship for a single lamina	5.1-5.2.1; (5.2.2-5.2.3); 5.3.1-5.3.7; (5.3.8); 5.3.9; 5.4	
22/1	**Wed 8-10**	**Tutorial 1 (JX) in HA2** Elastic anisotropy, lamina stress-strain relationship		5.3, 5.17a, 5.19ab, A4[2] (5.5, 5.6, 5.10, 5.16, 5.18a, 5.20ab, A1[2], A3[2])
24/1	**Fri 8-10**	**Lecture 3 (BB) in HA2** homogenisation, lamina properties	3.1-3.3; (3.4-3.5); 3.7; (3.8) + LN[1]	
24/1	**Fri 10-12**	**Tutorial 2 (JX) in HA2** Lamina properties		3.7 (1 comb.), 3.8, 3.18, 3.21 (3.1, 3.2, 3.4, 3.6, 3.9, 3.10, 3.11, 3.23)
28/1	**Tue 8-10**	**Lecture 4 (LA) in HA2** Laminate theory 1, Intro to Assignment 1	6.1-6.7; 6.9 + LN[1]	
28/1	**Tue 10-12**	**Tutorial 3 (DC) in HA2** Laminate theory 1		6.12, 6.17, P2 – 20130313 (6.1, 6.3, 6.5, 6.10)
29/1	**Wed 8-10**	**Lecture 5 (LA) in HA2** Laminate theory 2	6.1-6.7; 6.9 + LN[1]	
31/1	**Fri 8-10**	**Computer class (DC/SD) in MT11, MT12** Assignment 1: Laminate theory		
31/1	**Fri 10-12**	**Lecture 6 (BB) in HA2** Anisotropic plate theory (Kirchhoff)	7.1-7.3 + LN[1]	
4/2	**Tue 8-10**	**Lecture 7 (BB) in HA2** Anisotropic plate theory (Mindlin)	7.4 + LN[1]	
4/2	**Tue 10-12**	**Tutorial 4 (DC) in HA2** Laminate theory 2		P1 – 20120309, 6.13 (6.15; 6.18, P1 – 20130830)
5/2	**Wed 8-10**	**Lecture 8 (BB) in HA2** Weak form of Mindlin + FEM	LN[1]	
7/2	**Fri 8-10**	**Computer class (DC/SD) in MT11, MT12** Assignment 1: Laminate theory		
7/2	**Fri 10-12**	**Tutorial 5 (DC) in HA2** Plate theory		P3a – 20130118, P1 – 20130118 (P3a – 20130313, 7.1, 7.9)

10/2	**Mon 17:00**	**DEADLINE: Assignment 1 (lead TA: SD)**		
11/2	**Tue 8-10**	**Lecture 9 (BB) in HA2** FEM, Intro. Assignment 2	LN[1]	
11/2	**Tue 10-12**	**Tutorial 6 (DC) in HA2** Plate theory and FEM		P3 – 20140115, P2a - 20120309 (7.6, 7.7, 7.8, P1 – 20120906
12/2	**Wed 8-10**	**Lecture 10 (BB) in HA2** Damage initiation	3.6; 5.4 + LN[1]	
14/2	**Fri 8-10**	**Computer class (DC/SD) in MT11, MT12** Assignment 2: FE implementation		
14/2	**Fri 10-12**	**Tutorial 7 (SD) in HA2** Damage initiation		P2 – 20140115, P2 – 20130118, 3.16 (5.19, 5.20cd, C1[2], C3[2], C4[2])
18/2	**Tue 8-10**	**Lecture 11 (LA) in HA2** Damage progression, notch effects	6.8; 8.2.1-8.2.1.2; 8.2.4 + LN[1]	
18/2	**Tue 10-12**	**Tutorial 8 (SD) in HA2** Damage progression & notch effects		P3 – 20120906; P2b - 20130830, 8.1, 8.4 (6.14, 8.2, 8.3, 8.5)
19/2	**Wed 8-10**	**Computer class (DC/SD) in MT11, MT12** Assignment 2: FE implementation		
21/2	**Fri 8-10**	**Computer class (DC/SD) in MT11, MT12** Assignment 2: FE implementation		
21/2	**Fri 10-12**	**Lecture 12 (LA) in HA2** Interlaminar stresses, delamination	8.1 + LN[1]	
24/2	**Mon 17:00**	**DEADLINE: Assignment 2 (lead TA: SD)**		
25/2	**Tue 8-10**	**Lecture 13 (LA) in HA2** Energy release rate, DCB	LN[1]	
25/2	**Tue 10-12**	**Lecture 14 (BB) in HA2** design principles, Cohesive zone modelling of delamination, Introduction to Assignment 3	LN[1]	
26/2	**Wed 8-10**	**Tutorial 9 (SD) in HA2** Interlaminar stresses, design principles		Interlaminar stresses, Cross member design (P2a – 20130830)
28/2	**Fri 8-10**	**Computer class (DC/SD) in MT11, MT12** Assignment 3: Structural assessment		
28/2	**Fri 10-12**	**Lecture 15 (BB) in HA2** Cohesive zone modelling of delamination + Intro to advanced failure modelling (new)	LN[1]	
3/3	**Tue 8-10**	**Lecture 16 (BB) in HA2** Manufacturing		
3/3	**Tue 10-12**	**Tutorial 10 (SD) in HA2** Energy release rate, cohesive models		XXX XXX
4/3	**Wed 8-10**	**Computer class (DC/SD) in MT11, MT12** Assignment 3: Structural assessment		
6/3	**Fri 8-10**	**Computer class (DC/SD) in MT11, MT12** Assignment 3: Structural assessment		
8/3	**Sun 17:00**	**DEADLINE: Assignment 3**		

9/3	All day	**Assignment presentations, CA3 in Leif's office, room 3170 (M-building)**		
10/3	**Tue 8-12**	**Lecture 17 (LA) in HA2** Repetition	LN[1]	
11/3	**Wed 8-10**	**Tutorial 11 (DC) in HA2** Solution of exam problems		
13/3	**All day**	Industrial **Seminar** (Palmstedtssalen) LIGHTer seminar		
18/3	**Wed 08:30**	**EXAM!**		

[1] LN = Lecture notes

[2] A1, A3, A4, C1, C2 and C4 refer to extra problems from Hult et al., cf the course homepage

[3] p_VD1 – p_VD3 refer to the extra problems on damping available on the course homepage