Theory of Martensitic Phase Transformation

Course Information

Course No ME 698G

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Department Mechanical Engineering

Units (L-T-P-D-U) 3-0-0-0-4

Schedule LEC: MWF 11:00-12:00pm TB210 (slot and venue subject to change)

Course website `http://home.iitk.ac.in/~bls/Homepage/ME698G_2008.html`

Prerequisite Introductory course on continuum mechanics or self study of theory of nonlinear elasticity, basic course containing a discussion of calculus of variations, exposure to theory of crystallography is a plus.

Note The course is offered (only once in two consecutive years) and structured as an (open) elective for postgraduate students and advanced undergraduate students. Anyone else interested may take permission of the instructor[1].

Description

We will study the stress induced structural (displacive) phase transformations in this course, with an emphasis on development of a rigorous mathematical theory of austenite-martensite phase transformation. Continuum theory for phase transitions and twinning in crystals, developed over the last three decades, has been a remarkably successful approach in which a new viewpoint on material symmetry, motivated by atomistic theories, plays a central role. This course will utilize a nonlinear elastic approach to twinning and displacive phase transition in crystalline solids. We will develop geometry, kinematics, and symmetry/invariance in crystals with the purpose of investigating the actual mechanical aspects of the phenomena, particularly in an elastostatics framework with some discussion of dynamics as well (if time permits). We will discuss the applications of this theory to the special case of shape memory alloys where the theory aims at investigating the formation of microstructures. Relevant to a variety of disciplines, including mathematical physics, continuum mechanics, and materials science, such course on continuum models for phase transitions and twinning in crystals is an opportunity to explore these current research methods and topics.

Contents

- Review of basic concepts in continuum mechanics and the theory of nonlinear elasticity. Discussion on a purely mechanical theory vs thermomechanical continuum theory.
- Introduction to some crystallographic concepts and their representations, for example, crystallographic symmetries. The Cauchy-Born hypothesis and Ericksen-Pitteri neighbourhoods.
- Martensitic phase transformation: one dimensional models: equilibria and introduction to the study of dynamics, energy minimization (energy wells) based approach for study of equilibria using calculus of variations. Austenite-Martensite interface. Discussion on shock wave motion vs phase boundary motion.
- Martensitic phase transformation: three dimensional models: introduction to the study of equilibria and dynamics. If time permits, the three dimensional case may be explored further. Martensitic variants, twinning. Austenite-Martensite interface.
- Shape-memory effect.
- Discussion on discrete models vs continuum models for the study of phase transformations.
- Conclusion of the course with discussion on some open problems in the mathematical theory of martensitic phase transformations.
- *There may be a few guest research seminars in this course, given by various professors, in order to motivate this subject. Two or more such lectures will discuss the importance and applications of this subject in different branches of engineering, metallurgy and materials processing, designing new materials by combining various elements as well as their phases through a thermomechanical process resulting in some interesting geometries at small and large scales coupled with interesting mechanical behavior. In addition to the latter, some future directions will also be discussed in the context of scientific research as well as applications of this subject. A few lectures or reading assignments may be devoted to some interesting results in the theory of martensitic phase transformation which find application in diverse areas of engineering and sciences such as shape memory alloys.

[1] In the first lecture there will be a short written quiz and those students who do not pass the quiz may still take the course but they need to work extra and *revise* the prerequisites mentioned above. If the average score on the quiz is too low then first two lectures will revise certain basic concepts in continuum mechanics.

Grading policy

The system of grading is **Q0-Q5-MI-MII-E-H** with weightage **0-15-15-15-45-10**.

- **Q0:** The concept of $Q0$ means that there will be a short 30 minute written quiz in the overview lecture. Those students who do not pass the quiz may still take the course but they need to work extra and *revise* the prerequisites mentioned above. If the average score on the quiz is too low then first two lectures will revise certain basic concepts in calculus and linear algebra.

  No weightage of this quiz towards the final grade.

- **Q5:** The concept of $Q5$ means that during the first/last 5 minutes (i.e. 12:00 − 12:05 pm) of *somelectures* (except guest lectures) there will be a quiz based on any topic from all previous lectures. Total number of such quizzes is 5 and the weightage of each quiz will not be the same and will remain *unknown* (for students). The students need not worry about preparing for the quizzes as the attendance in lectures will suffice to answer them, for example they may be fact based quizzes, multiple choice type, yes or no, fill in the blanks etc.

  The total weightage of $Q5$ towards the final grade is 15, i.e. equal to one midsem.

  The graded quizzes will be made available (as a minibook) for view (to be returned).

  The cumulative scores will be displayed/shared regularly.

  Quiz/exam scores may not be limited by the maximum score as *bonus* points will be rewarded for exceptionally good answers and therefore some students may have scores more than the maximum score from all quizzes and exams held till date.

- **Midsem I, II:** *Total weightage of 15 points for each midsem.* Exams based on any topic from all previous lectures.

- **Endsem:** *Total weightage of 30 points for the endsem.* Exam based on any topic from all lectures.

- **Homework:** *Total weightage of 10 points for the homeworks.* The assigned set of problems that will be given as *homeworks will be for submission.* Some homeworks will be also given as practice questions from the textbook and other reference books which will should not be submitted.

Thus, we have Quiz 1 (20 min): 5%, MidSem I (1 hr): 15%, Quiz 2 (20 min): 5%, MidSem II (1 hr): 15%, Quiz 3 (20 min): 5%, EndSem (3 hr): 45% (thumbrule: 4 min of exam times for each point out of 90). All quizzes and homeworks will assume that the student had previous training in real analysis, calculus, tensors, linear algebra, tensor algebra, tensor analysis and tensor calculus.

Text Book and References

1. Bhattacharya, K., 2004. Microstructure of Martensite: Why It Forms and How It Gives Rise to the Shape-Memory Effect. Oxford University Press [Textbook: Chapters 1–9 only].

2. Pitteri, M. and Zanzotto, G., 2003. Continuum theories for phase transitions and twinning in crystals. Chapman and Hall.

3. Abeyaratne, R., Knowles, J. K., 2006. Evolution of Phase Transitions. A Continuum Theory. Cambridge University Press, New York.

4. Khachaturyan, A. G., 1983. Theory of Structural Transformations in Solids. John Wiley and Sons, New York.

5. Wayman, C. M., 1964. Introduction to the crystallography of martensitic transformations. Macmillan company, New York.

6. Gurtin, M. E.,1982. An Introduction to Continuum Mechanics, Academic Press.