Innovations in Teaching Mechanics of Materials in Materials Science and Engineering Departments

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Abstract

Traditional mechanical design employs experimentally obtained or handbook material properties in selection and sizing to develop a product. This approach is increasingly inefficient as designs come to employ modern materials whose processing and resulting properties are themselves an adjustable part of the design process. Both the design process and the engineering curricula used in educating designers can profit from an integration of the materials science and traditional mechanics of materials approaches, as opposed to an artificial separation of these two interlinked disciplines.

The Materials Science and Engineering department at MIT is large enough to offer its own Mechanics of Materials subject, and this subject naturally seeks to blend the materials and mechanics aspects of the discipline. A series of NSF-sponsored, web-available modules is being prepared to support this approach, along with Java applets and other electronic teaching aids. The paper provides an overview of this effort, emphasising the teaching of fracture mechanics and microstructural failure mechanisms.

I. Introduction

Most engineers are involved in *design*, and they generally design articles of commercial importance using selected *materials*. (Software engineers might be an exception.) University curricula in engineering are aimed at providing the underlying fundamental knowledge needed in design work, and often try to teach or at least provide some experience in aspects of the design process itself. In the case of load-bearing structural items, design requires at least two major disciplines: *mechanics*, the primarily mathematical description of the stresses and strains induced in an object by applied loads; and *materials*, the description of how the material will respond to these stresses and strains.

Structural engineering students encounter the mechanics aspect of mechanical design in a sophomore or Junior-level subject usually named Mechanics of Materials, using texts such as those of Beer and Johnston[1] or Gere[2]. These texts usually follow the approach pioneered by the great mechanics educator Stephen P. Timoshenko (1878-1972)[3], and deal principally with stress analysis of simple structures assuming linear elasticity. Most of these traditional texts are of fine quality, although over the years they have become considerably larger than can be covered in a single term. Further, they have little coverage of the relations between the material's mechanical response and its chemistry or microstructure, nor do they deal much with softer, anisotropic and time-dependent non-metallic materials now becoming increasingly important in biomedical design and other newer aspects of engineering practice.

It is common in engineering curricula to require students to take a subject in Materials Science, using a text such as that of Callister[4] or Shackelford[5]. This, along with core chemistry and physics subjects, is intended to supply a sufficient coverage of the materials aspects of structural analysis and design. Unfortunately, only a small fraction of the syllabus typically covers topics dealing with mechanical response. This leaves the student to discern the linkage between these two aspects of mechanical design, and it is easy to perceive the materials and mechanics subjects as unrelated entities. This leaves the materials subject as an "academic promontory," with structural engineering students wondering why they had to take it.

The situation in materials departments is somewhat inverted in comparison with the structural disciplines. At MIT, the School of Engineering has eight departments, and only the Department of Materials Science and Engineering (DMSE) does not have a "materials subgroup" within it. In DMSE, materials is the "main group," and mechanics is a subgroup. Similarly, DMSE students are strong in the materials aspects of engineering, but perhaps weaker in aspects of stress analysis and mechanical design. Materials graduates need competence in mechanics in order to design correctly with their carefully developed materials, and some materials departments address this need by requiring a traditional Mechanics of Materials subject taught by one of the structurally-oriented departments (typically Mechanical, Civil, Aerospace, or Applied Mechanics). If the connection between the mechanics subject and the materials curriculum is unclear, the mechanics subject then becomes the academic promontory.

Recently, several educators in both Mechanics and Materials departments have argued[6] that the separation of these two subjects as they often occur in the curriculum is excessive and unnatural, and that a stronger linkage between the two disciplines would improve both institutional efficiency and student learning.

II. A Materials-Oriented Mechanics Subject

As elaborated in an extensive review conducted by the National Research Council[7], Materials Science and Engineering is a study of theoretical and experimental relations among:

- A material's *processing*, to include its chemical synthesis as well as subsequent thermomechanical treatment and shaping,
- The material's *microstructure*, as arising from its processing,
- The material's *properties*, arising from its microstructure, and
- The material's *performance* in an engineered structure or product, as dictated by its properties.

Traditional mechanical design employs principally the last two steps, using handbook material properties in selection and sizing to develop a product. This approach has worked for millennia, but is increasingly inefficient as designs come to employ modern materials whose processing and resulting properties are themselves an adjustable part of the design process. A stronger linkage between Mechanics and Materials would increase the coverage of the first two steps – processing and microstructure.

The Department of Materials Science and Engineering at MIT is large enough to offer its own Mechanics of Materials subject, and this subject naturally seeks to blend the materials and mechanics aspects of the discipline. A text for the subject has been written with this perspective[8], and has been used for approximately the past five years. The text was assembled from years of experience in teaching this subject, and follows the day-to-day teaching syllabus. It was intended from the first as a teaching text, rather than a general technical reference. It includes some topics that usually cannot fit into the time constraints of a single term, in order to allow for student exploration and flexibility in tailoring the syllabus from year to year, but not many. The text is therefore much smaller than the Timoshenko-style standard texts. The text also progresses gradually from elementary to relatively advanced mathematical formalisms, and moves along the stress-strain curve from linear elastic and viscoelastic response, to rubbery elasticity, to yield and finally to fracture.

III. Web-based Instruction

The remarkable growth of web and other computer network technologies has added a large number of potential tools to the engineering educator's arsenal. This community is not of one mind regarding how best to use these new tools, and we are currently in a period of exciting experimentation. It is undeniable that the web provides an efficient means of administering subjects, for instance in publishing the syllabus and keeping the class grade list (coded to preserve confidentiality) up to date. It can also provide links to supporting auxiliary material, such as film clips of actual designs and laboratory experiments. The web page for the 1999 MIT/DMSE Mechanics of Materials subject is at URL http://web.mit.edu/course/3/3.11/www/; this is a modest but useful web implementation for teaching. It uses very plain HTML constructs, without the need for page design software.

Most engineering educators seem to feel the web and other such technologies will augment rather than replace traditional lecture-and-chalkboard methods. The seemingly tedious method in which students copy material as the instructor chalks it onto the board actually seems to transmit technical information at approximately the right pace for comprehension, and using transparencies or web pages to speed things up can easily produce information overload. Further, engineering faculty have come to realise that preparation of even marginally complicated web presentations is very time consuming, and involves a set of skills they do not necessarily have or wish to develop.

The easy availability of web pages, however, does promise a possible remedy to a serious problem with the materials-based approach to Mechanics outlined above. Since the approach is novel and nontraditional, it may be difficult for faculty to swallow it all at once. A more flexible approach, now being implemented under NSF sponsorship, includes rewriting the MIT/DMSE Mechanics topics as discrete web-available modules (see http://web.mit.edu/course/3/3.11/www/modules.html). This would permit an instructor to use only those portions she finds effective for the current term, without being locked into a new book. Such a modular approach might be useful in many subjects beyond Mechanics or even engineering. Almost no one finds a text perfectly matched to their particular needs, and this would allow each instructor to tailor-make a text for her own desires. Problems with copyrights and payments arise, but if the value and demand are there these could certainly be overcome.

IV. Fracture

Fracture is a natural example of the potential value of discrete web-based modules for teaching introductory Mechanics of Materials. This topic is of vital concern in many branches of engineering, and structural engineering students often take subjects devoted to it in their upper-tier curriculum. However, students in non-structural branches of engineering may never see the topic, in spite of its importance in their fields. This is certainly true of materials students, who may take only a single mechanics subject. Even instructors in the structural disciplines might wish to introduce fracture in greater depth than is found in the traditional texts, which could well make the later specialized subject more meaningful. Further, fracture is very materials-dependent, and provides links to processing and microstructure than are lacking in linear-elastic stress analysis topics such as beam bending. It also provides a wealth of chilling examples of incorrect or ignorant design, and can do much to liven up the classroom. Having a module available that can introduce the topic in a few lectures provides a good deal of flexibility for such purposes.

The module on fracture includes several aspects of the phenomenon:

- An overview of the statistics of fracture, leading to an introduction to Weibull analysis. Statistics is a vital aspect of modern engineering practice, but is not always included in the engineering curriculum (it is not required in the MIT DMSE curriculum, and several graduates have been very critical of this). This section introduces at least the basics of statistical inference of experimental data, using fracture of graphite/epoxy composite as a working example.
- A kinetic model of time-dependent fracture due to Zhurkov[9] is included, both for its inherent engineering utility and as a link to physical chemistry subjects found elsewhere in the curriculum.
- The Griffith energy balance for fracture mechanics is presented, drawing on the concepts found in Gordon's writing[10]. This provides a link to several energy-balance developments found elsewhere in the materials curriculum, such as the critical size for a growing second-phase particle.
- An outline of the stress intensity view of fracture mechanics is presented, as this is dominant in engineering practice. It also reinforces earlier modules on stress functions and stresses near flaws.
- The role of grain size in determining fracture toughness is outlined, which serves to relate materials processing and microstructural features to mechanical properties. This helps reduce the abstraction of the mechanics aspects of fracture.

V. Conclusion

It is not a simple matter to add materials concepts to existing Mechanics of Materials subjects, since these subjects are already full to bursting. However, the availability of discrete modules, easily available on the web, might make modest and incremental changes possible. Fracture is a starting point worth considering, since there is considerable value in seeing this topic early in the curriculum. Further, it provides a natural linkage with materials concepts.

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David Roylance is Associate Professor, Department of Materials Science and Engineering, Massachusetts Institute of Technology. He received his BSME and Ph.D. in Mechanical Engineering from the University of Utah in Salt Lake City. After military service in Viet Nam, he was a research engineer at the Army Materials Technology Laboratory until joining the MIT faculty. His research and teaching interests have concentrated on the mechanical properties and processing of polymeric and composite materials. He has been active in curricular development, and has served three terms as Departmental Undergraduate Chairman.

Innovation Initiative. The Engine. Diversity.Â Teaching Assistants. Fellowships. Outside Employment.Â Informed by the Center for Disease Control (CDC) and the Massachusetts Department of Public Health, MIT is acting to keep our community safe and stop the spread of COVID-19. The health and safety of students, faculty, staff, and their families are of the utmost importance to all of us. MIT updates are posted at now.mit.edu. Spring semester move-in date for undergrads will be Feb. 13â€"15, and in-person instruction begins March 1. DMSE-specific information is linked below. UPDATED - January 27. Spotlight. There are very few innovations in mechanical engineering that have had as much influence as the wheel and axle. The modern world would look very different without them. The wheel and axle is one of the six simple machines as defined in antiquity and expanded during the Renaissance. The first depictions of wheeled-vehicles appear on an earthenware Bronocice pot from Poland, and date to around 4000 BC.Â They are some of the most fundamental mechanical engineering innovations in history. Any change in torque made with the use of gears and cogwheels necessarily creates a mechanical advantage, thanks to the phenomenon of the gear ratio. A gear can also mesh with a linear toothed part, called a rack, producing translation instead of rotation. Quantum Mechanics for Scientists and Engineers. David A. B. Miller. 4.3 out of 5 stars 45.Â This book is designed to meet the changing quantum mechanics needs of general and applied physicists in such areas as solid state research, quantum electronics, materials science, etc. It recognizes that these needs go significantly beyond most elementary texts, and at the same time have become sufficiently distinct from the traditional advanced treatment of quantum mechanics.