Materials Matter in Mechanical Engineering at RIT

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Success in design and manufacture of a product depends critically on the properties of materials selected. For a given material, the set of properties desired during processing may be quite different from that needed in service. Thus, a mechanical engineer needs to know about the properties, performance and processing of a wide range of materials, and be able to use this knowledge in designing a product. Eight years ago, our department initiated major laboratory development and curricular changes to revitalize the materials sub-curriculum^{1,2} and its integration in students' design activities³. This paper describes briefly the curricular innovations, challenges encountered, and their impact on the preparation and performance of our students.

Curricular Innovations

Science of Materials: A new course 273: *Introduction to Chemistry of Materials* + 274: *Lab* was developed to replace the traditional second chemistry course. This new course with the co-requisite lab course focuses on solid materials, and provides a better overview of polymeric materials. Thus, the new course sequence [208: *College Chemistry I* → 273+274: *Chemistry of Materials* → 344: *Materials Science*] provides students a better background in scientific aspects of materials. 344 has been revised accordingly to provide a deeper insight into the structure, properties and processing of metallic materials. In addition, students are introduced to advanced materials such as composites and ceramics.

Design and Manufacturing with Materials: Recognizing that engineers select material/process combinations from those with which they are most comfortable, another course sequence [343: *Materials Processing* → 311: *Computer-aided Design* → 464: *Design for Manufacture*] was streamlined. Each course in this sequence culminates in an individual or team project. In 343, students obtain hand-on experience with lathes, milling machines, drill presses etceteras. In 311, students learn a computer-aided design software such as *Pro Engineer*, and also learn geometric dimensioning and tolerancing. The course is being split into two courses to better accommodate students transferring into our program from other universities and community colleges. 464 introduces students to the concurrent or simultaneous engineering approach to product design, manufacture and assembly. Students become skilled in software techniques to calculate assembly design efficiencies, part and part tooling costs.

Design Electives in Materials: To address the wider range of materials becoming available to an engineer, the department developed a new course 644: *Introduction to Composite Materials*. In recent years, a significant number of our seniors took 515: *Plastics Processing Technology* and

516: Plastics Product Design and Material Selection offered by another department as design electives. All three courses require a team project where students redesign an existing product with composite or plastic materials. Students need to specify materials and processing methods, and evaluate the feasibility and the benefits of their redesign. The success and popularity of these courses has led the department to consider developing another elective course on designing with plastics.

Although *644* is a Mechanical Engineering technical elective, a third of the course is devoted to the materials science aspects of composites. Because students' knowledge of composite materials is limited to the brief introduction they received in their introductory materials course (*344*), the first weeks of the course introduce the structure, chemistry, and processing techniques for composite materials. The mechanics of composites and design issues is then introduced. The unifying theme throughout the course is the successful use of composite materials in design. To put this theme into practice, the students are required to complete a team project where they redesign an existing product using composite materials. Students research the current product, and then begin their redesign by specifying the reinforcement/matrix combination to be used as well as the processing technique. Students also perform a complete stress analysis of their redesigned product. The benefits of their redesign are evaluated, and an economic analysis is performed to determine the feasibility of their design. The project culminates in a presentation of their redesign as well as a final report detailing their design work. Some products that have been redesigned in the past are snowshoes, a boat trailer, and automobile leaf springs.

Curricular Impacts: These curricular innovations have had a profound impact on material/process combination students are selecting in their capstone senior design projects. For example, in the last Winter quarter (19962) a student group designing a musical scale selected all-plastic parts joined by advanced adhesives; another group designed an auto-focus camera lens assembly that used prototype parts created by stereolithography. Students who have taken *644* are also taking advantage of their knowledge and experience with composite design for their senior design projects. One team designed and built a replica of the Chanute Glider using only advanced materials, specifically carbon fiber composites. This replica is now on permanent display at the Soaring Museum in Elmira, NY. Another team redesigned the handlebars currently used on Trials bikes. The existing bars, made of aluminum, were heavy and were easily deformed and damaged. The new bars were made from multiple layers of S-glass/epoxy, with an outer layer of a carbon/Kevlar hybrid. The bars are currently being tested in actual competitions. A third project that makes extensive use of advanced composite materials is the design and fabrication of a five person racing bicycle. The use of a carbon fiber frame for this bike is currently being evaluated. In several projects where the final design product is not intended to be made from composite materials, students are using composites to quickly and easily fabricate a prototype, and evaluate their design concepts.

Student performance in design competitions sponsored by ASME and other professional groups has been excellent. RIT has been very active in the SAE Formula car design competition, finishing either second or third for several years in a row. A contributing factor for this is their use of advanced materials in their design. Examples of which are a composite body, uprights, and part of the exhaust system.

Laboratory Development

X-Ray Diffraction: With partial financial support from the Center for Materials Science and Engineering (CMSE) at RIT, the x-ray diffractometer was interfaced with a modern easy-to-use PC-based system for data acquisition, analysis and instrument control (DAQC). Students now obtain a diffraction pattern of an unknown metallic sample, index it, identify the metallic phase present, and determine its precise lattice parameter. Within a few weeks, the system will be upgraded to allow students to search and match a pattern with those in the Powder Diffraction File (PDF) database on a CD-ROM.

Mechanical Testing: With partial support from CMSE, the existing Instron testing system was interfaced with a PC-based DAQC system. Now, in a two-hour lab on mechanical testing, students can compare the tensile behavior of an aluminum-copper alloy before and after precipitation hardening treatment, and of annealed mild steel before and after cold rolling. Students also measure the Rockwell hardness profile along the axis of tensile specimens to study the effect of varying plastic deformation. In addition, the mechanical testing equipment has been used in several independent undergraduate research projects.

Quantitative Imaging: Equipped with an NSF grant (USE-8950897), the lab introduces students to digital image acquisition, processing and analysis of microscopic images. Students work with images of hardness indentations as well as annealed plain carbon steel microstructures⁴. Many students utilize their digital image processing skills in other curricular areas and design projects.

Stereolithography: Equipped with an NSF grant (USE-9250614), the stereolithography apparatus permitted students to build rapid prototypes of their designs, and test them for their form, fit and sometimes function⁵. We are currently evaluating other rapid prototyping techniques that are more economical, efficient and easier to learn and operate to replace stereolithography.

Scanning Probe Microscopy: Equipped with another NSF grant (DUE-9451220), the lab introduces students to sub-micron sized aspects of materials systems. Using the atomic force microscope (AFM) in tapping mode, students explore the surface roughness of a superbly polished specimen, and examine the morphology of carbide in a low-carbon annealed steel⁶. In the last Winter quarter (19962), we developed another educational module using the magnetic force microscopy (MFM) mode to study the topography of and magnetic bits on a hard disk drive⁷.

Curricular Impacts: These state-of-the-art labs have attracted many students in the 5-year integrated BS/MS program to pursue research projects in interdisciplinary areas of materials, mechanics and microelectronics. For example, one BS/MS student has fabricated micron-sized cantilevers using microlithography to study micro-electro-mechanical systems (MEMS). The micromechanical properties of these cantilever beams will be evaluated using the AFM. Another student has used the AFM to study the wear properties of dental composites. A third BS/MS

student used the techniques of robust design to evaluate the environmental degradation of composite materials.

The materials laboratories have also attracted several undergraduate students to pursue independent research projects. One student is using the Instron system to evaluate the effect of various surgical techniques on the fatigue properties of bones. Another student performed independent research on CV joints in automobiles. A third student used the AFM to compare the surface properties of several indirect dental composites. Much of this work has been presented at conferences, and has resulted in technical publications⁸. In each of the last two summers, the labs helped us host a student in the NSF Research Experiences for Undergraduates program (DUE-9424025).

Concluding Remarks

Enrollments: The “science of materials” course sequence is taken by all mechanical engineering (BSME) students (~140 students per year), and by all industrial engineering (BSIE) students (~40 students per year). The “manufacturing with materials” course sequence is taken by all BSME students (140/year). In the last two years, the average annual enrollment in *644: Introduction to Composite Materials* has been 40 whereas approximately 29 and 10 BSME students took *515: Plastics Processing Technology* and *516: Plastics Product Design and Material Selection* respectively each year.

Continuing Developments: The materials sub-curriculum continues to evolve. Opportunities for better linkages with other courses exist that may permit economies in presentation, and allow time to introduce newer concepts. In cooperation with another department, an elective course on *Robust Design* was offered in the Spring quarter (19963). Development of a new *Rapid Prototyping Lab*, and an associated course on *Computer-aided Design & Manufacturing* are under active consideration. The materials testing activities in *348: Mechanics of Materials Lab* are being re-examined, and may lead to a newer, more meaningful set of experiments.

Adoptability: Every hands-on design-oriented mechanical engineering program should be able to adopt (and adapt) the curricular innovations described above. Curricular materials, and in some cases, good quality textbooks are readily available. The lack of state-of-the-art lab equipment may not be a serious drawback. Videos and multimedia simulations are often available from the equipment vendors or research laboratories that can be used for lab demonstrations. Experimental data that can be adapted for in-lab data analysis by students is available in the published literature, on Internet or from us.

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