Integration of Materials Science into an Industrially-Sponsored Engineering Design Course

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Abstract

An industrially-sponsored aluminum product design elective course offered over the past six years has dealt with a range of design projects principally chosen from the transportation and structural field. Engineers from industry present the problem and a panel of engineers reviews the end-of-semester oral and written reports. As with many mechanical engineering component design courses, this course tended to primarily emphasize the stress analysis portion of the design process. However, feedback from the sponsors over the years has made it clear that material selection, behavior and a good understanding of manufacturing processes and economics deserves enhanced coverage in such projects. In courses with limited materials science content, it is impossible to cover all the detail and background information really needed. Because the structure-property correlation in materials is a centerpiece in materials science, the authors have utilized it as a bridge between courses that have borderline materials content and truly materials-centric courses. An instantiation of this bridging effort is presented in this paper in the description of a shared project between a graduate-level materials characterization course and the aluminum product design course referred to above. Test specimens from the aluminum course were analyzed by the characterization class and the interaction provided the aluminum class students with specific structural detail and a basis for the micro-level mechanisms which originate the continuum properties required for mechanical design.

Introduction

Design, be it design of structures, manufacturing processes, or software, is becoming a function that involves more than technology/engineering [1]. Designers who decide upon and outline the main features of products and processes need to extend their talents/skills beyond the technology aspects of a business enterprise. The education and training of 'designers' must prepare them for commercial as well as technical aspects of the design processes of the 21st century.

The 21st century design engineer will not only account for the performance and manufacturing aspects of the product, but also attempt to optimize the product to accommodate operational and commercial aspects of the business enterprise such as: capacity/profitability tradeoffs in using existing facilities/processes, the methods and mechanics of product delivery/distribution, customer specific attribute preferences, etc.

The authors and their collaborators at the industrial sponsor (Alcoa Technical Center) have been working to shape the education process for engineering design students by collaborating in the offering of a course on aluminum design. This is in concert with the mechanical engineering department's research focus on advanced and light structural and smart materials. Industry participation in the classroom and critique of design solutions introduce the students to the latest technology issues as well as business enterprise issues, beyond technology, which ultimately driving product design decisions.

These aspects of design were considered in the original planning and implementation of the 3-semester-hour course [2], formally titled 'Aluminum Based Product Design and Manufacturing.' This has been offered annually since 1995 to entering graduate students and to senior mechanical engineering students as a technical elective. Owing to the applied nature of the course and the offering of a fresh industry-generated project each time, the course has been popular especially with students that are looking for learning experiences with industrial relevance. This typically includes graduating seniors and graduate students that have gone directly to graduate school without gaining industrial experience.

Course Scope

The course is modular in nature – the lecture material, provided to students in ring binder form [3] includes modules on

- Material Properties
- Manufacturing Processes
- Economic Considerations
- Design Principles
- Case Studies

References and teaching resources used with the notes include videos of aluminum design and manufacturing, as well as design manuals and references such as the Aluminum Design Manual [4] and videos such as [5].

The cornerstone of the course is a semester-long design project co-developed for every offering by the sponsoring company's engineers along with one of the authors of this paper. The projects focus on the design of mechanical components and/or assemblies with a design objective of low weight, ease of manufacture, and reliable performance. Students are expected to perform stress analysis and geometry design based on a logical selection of material and manufacturing process. An engineer from the company presents the problem to the class at the start of the semester and provides the industrial motivation for the project. The course instructor guides the students through the work and serves as intermediary to the project sponsor. The highlight of the course is a student visit to the sponsor's R&D center in Pittsburgh, PA, for a project presentation to a panel of engineers, followed by a question and answer session and a tour of the center's research labs and development facilities. The students are always enthused by the level of commonality between their classroom design procedures and those procedures used by the people they want to become – successful engineers in industry. The panel provides detailed feedback to the instructor on student performance as well as course technical content.

Past design projects have included the design of an automobile control arm, a bicycle frame, the side panels of a railroad bulk goods freight car, and for 2001, the design of a automobile cross-member of minimum weight and/or cost capable of sustaining specified static and fatigue loads.

Course offerings in 1999 and 2000 resulted in feedback from the sponsor suggesting that more materials and manufacturing information would benefit the course content, as a better understanding of structure-property-process interactions is necessary in the age of designer and smart materials. In courses with limited materials science content, it is impossible to cover all the detail and background information really needed.

Since structure-property-process correlation is a centerpiece in materials science courses, the authors tried to bridge the gap between courses that have borderline materials content (such as this one and the traditional machine design class) and truly materials-centric courses (such as materials science and materials engineering). In this instance, the bridging effort was initiated by shared project between a graduate-level materials characterization course (Digital Microscopy) and the 2001 offering of the aluminum course referred to above.

Materials Science Aspects Introduced into Aluminum Course

This semester, one of the authors with a materials science background guest-lectured the aluminum class on the FCC crystal structure of aluminum, which is the basis of many of its properties including its high ductility and fracture toughness. Dislocations were explained to be the cause of plastic deformation at stresses significantly lower than the theoretical values, and obstructions to dislocations as the principal way to strengthen materials. The number of active dislocation slip systems in FCC and BCC crystals were enumerated and compared. Metal strengthening mechanisms were reviewed in detail, in particular; precipitation hardening. The formation of different precipitates and phases in typical aerospace (2000 and 7000 series alloys) based on their principal alloying elements (Cu, Zn etc) were also discussed.

Shared Course Topics and Student Interactions

Part of the materials supplied by the sponsor this year were post-tested fatigue specimens used to evaluate variants of 7075 aerospace grade aluminum alloys. These specimens were intended to provide fracture design data, and were of miniature tension type. These specimens provide the shared topic between the aluminum course and the materials characterization / image analysis course taught to graduate students. Interaction was facilitated by two graduate students who were registered in both courses. The graduate course students were exposed to the practical applications of their work. Since they were free to choose their design topics, they chose to integrate their thesis research into the project. One of the graduate students attending both courses used the graduate course to determine the fiber diameter distribution in tows of alumina fibers being tension tested in his research project. Students in both classes were exposed to the experimental intricacies of this project.

The specimens provided (on a post-testing basis) by the sponsor were miniature tension with 3-mm diameter and 15 mm gage length. These were scored with a razor blade and then fatigued at various load and cycle combinations to obtain various pre-crack lengths. These were then tension-tested to obtain K_{IC} value. The challenge was to make these specimens meaningful to the design class. This was done by having the characterization class examine the specimens, and provide the results to the design class. The examination was via optical and scanning electron microscopy, using Image-Pro software [6].

Figure 1 shows a typical specimen fracture surface. The scored notch, the fatigue induced pre-crack, and the final fracture area are clearly seen. The fibrous nature of the surface indicates the ductility and notch-insensitivity of the materials. In view of a spectacular tail-rudder brittle failure in a recent airplane crash, high fracture toughness was emphasized as desirable for mission-critical structural members. Nine tensile fatigue specimens were examined by the students from which they learned that the fracture surface was generally quite ductile, regardless of the size of the initiating crack. Brittle failure or evidence of cleavage was not observed. This is a reflection of the ductile nature of the alloy under consideration and aluminum in general. The materials characterization course instructor provided the aluminum class to some topics relevant to the mechanical properties of aluminum.

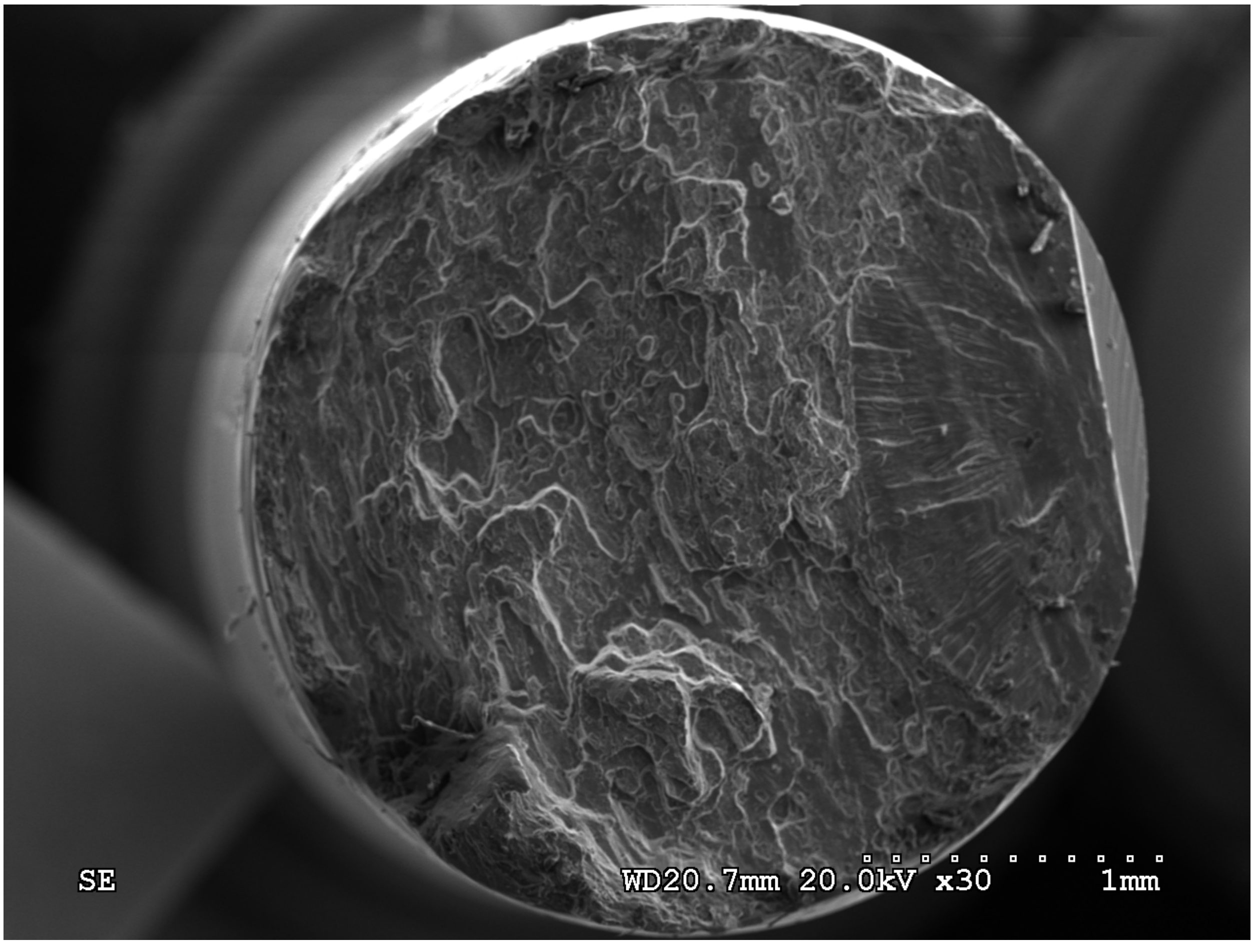

Figure 1 Fracture surface of miniature tension fatigue specimen (Al 7075 alloy)

Summary Observations

Enhanced materials and processes coverage was provided to students of an aluminum product design class in response to industry desire for heightened materials awareness among its design engineers in light of the emerging popularity of 'designer' materials. Collaboration between a senior-graduate aluminum design class and a graduate materials characterization class led to synergistic benefits. The aluminum students were able to get a better feel of the structure-property-process interactions that help them select and work with the right materials for their applications. The graduate students were able to apply the theoretical digital microscopy and characterization techniques learned in their class to real-world engineering materials with published property data.

On a larger scale, students were able to appreciate first-hand the benefits of an interdisciplinary approach to a problem as well as of team work. The aluminum course has received favorable annual reviews and funding renewal from Alcoa based on Alcoa scientists and engineers favorably rating the project presentations, as well as based on favorable responses from alumni and graduating students about the practical value of this course.

Acknowledgments

Alcoa Foundation provided financial support for course development and has continuously provided design project support since the course's inception. We are grateful to Alcoa Technical Center personnel Bill Herbein, James Burg, Rich DeBlasio, R. J. Bucci and Calvin Bates for their technical support. Materials characterization facilities were provided by the NSF - Center for Advanced Materials and Smart Structures at the authors' institution.

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