

## Integration of Research and Industrial Practice in an Undergraduate Materials Processing Course

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### Abstract

In light of the existing educational climate in materials, and with support from a new NSF initiative, the authors have developed a two-course sequence on 'Advanced Materials Processing'. The thrust of the NSF initiative is to combine completed or mature research with curriculum development in technological areas of national importance, with the objective of stimulating heightened educational involvement of faculty researchers. The research performed by the authors has been primarily in the generic area of processing with emphasis on clean metals technology, gas injection processes, melt atomization, spray casting, and powder processing. The two-term course sequence under development utilizes the results of this research as a foundation. The overall scope of this NSF-funded Combined Research and Curriculum Development program is to transfer the results of recent and on-going research into the undergraduate curriculum. Research carried out by the authors in the areas of clean metal technology, gas-injection processes, melt atomization, spray forming, and powder processing has been combined with a relevant introduction to rate processes in two upper class electives. The concurrent exposure to research results and industrial practice in the five areas cited is expected to spawn increased student interest in this important area of materials technology. Unique characteristics of our approach are the integration of engineering science, design and operation of these processes, together with process economics and engineering practice. About one-fifth of the course, consisting of engineering practice and economics, was taught by industrial practitioners and personnel from national laboratories.

Evaluation consisted of questionnaires distributed at the end of the course and informal discussions conducted by the (caching faculty on a regular basis. Almost all students said that they enjoyed the multiple instructors and especially the industrial lecturers. The students expressed the view that the lecturers brought to the class room the practical aspect of the technology and a beneficial non-academic point of view.

### Introduction

Materials synthesis and the development of processing systems for their manufacture are considered important areas which impact on the health of the US economy.<sup>(1)</sup> There is consensus that the nation's research base in materials must be enhanced in order to insure the availability of new materials and a pool of creative people to strengthen the competitive position of US industry beyond this century. One approach is to expose undergraduate science and engineering students to recent research carried out in the domain of materials and with a particular focus on processing.

### Course Development: Goals and Approach

Our primary goal is to integrate the science and practice of technology, in the present case materials, in a two-quarter course in a modular form aimed at upper class students. To enhance the learning experience, the course topics are introduced from a practical point of view followed by an in-depth consideration of the associated fundamental engineering science concepts, both qualitative and quantitative. Starting with a description of the process, questions such as how processes are designed are raised. The course includes process systems design and operation as integral components. Process operation and the constraints and realities of the industrial world are presented by industrial lecturers who are hands-on practitioners in the



technologies selected. Approximately 15% of the course is allocated to lectures by industrial personnel who are experts in process modeling and its applications. Industrial lecturers included Dr. C. Ed Eckert (Apogee Technology, Verona, PA), Dr. Iver Anderson (Ames Laboratory, Iowa), Dr. John Benjamin (Alcoa, Alcoa Center, PA), Dr. Praveen Mathur (Praxair, Tarrytown, NY), Dr. B. Lynn Ferguson (Deformation Control Technology, Inc.) and Chris Schade (Lukens Steel, Coatsville, PA).

For the topics included in the two-quarter course, the engineering science base resides in one or more of the following areas: solid mechanics, fluid mechanics, heat transfer, mass transfer and diffusion, and reaction kinetics. Because of the intrinsic interdisciplinary nature of the course material and the somewhat differing backgrounds of the students, the organization and delivery of topics is lateral rather than sequential. Thus, the necessary fundamental engineering science analysis and the physics/chemistry of each process were discussed concurrently with the attendant processing methodology, design and operation. This approach of integrating fundamental science with engineering applications in the context of practical need, has been found to be successful in the E<sup>4</sup> (Enhanced Educational Experience for Engineers) program at Drexel University (3-5). The new Drexel University Engineering Curriculum, developed under the auspices of Gateway Coalition,<sup>(6)</sup> is a direct outgrowth of the E<sup>4</sup> experiment.

### **Modular Organization of Course Material**

Course material is presented in the form of several one or two-week self-contained modules, each involving 8 to 10 hours of instruction. In this context, self-contained means that any background material relevant to the topic under discussion that goes beyond the sophomore year is a part of each module. This approach facilitates in-class discussion of cross-disciplinary topics without a significant departure from the main topic under consideration.

Each module includes a written outline of lectures, questions, discussion points, illustrative problems, homework problems, and suggestions for further reading. Background concepts needed to understand a module and the new concepts illustrated in the module are included. Each module deals with a specific process while sub-modules within it illustrate one or several processing concepts, or cover background material. A suggested order of selecting the modules (or sub-modules) in increasing order of difficulty is given.

### **Course Content : Advanced Materials Processing I & II**

Advanced Materials Processing I was offered for the first time in the Spring Quarter, 1994. The second course was offered in the Spring Quarter, 1995. Detailed course content has been described in our paper presented at the ASEE conference in 1995<sup>(7)</sup>. A brief summary is presented here for ease of reference.

#### Advanced Materials Processing I

The three major topics covered in the first course are clean metal technology, melt atomization, and spray forming.

Clean Metal Technology. The intent of this segment of the course is to rationalize the need for clean metal, and to then develop the necessary process models using the principles of fluid and solid mechanics and rate processes. Industrial practices of molten metal filtration technology were discussed by Dr. C. Ed Eckert, Apogee Technology, Verona, PA. The capstone segment of the clean metals technology module is the design and selection of melt filtration processes for ferrous and non-ferrous metals. Practical design problems are posed and solved in class.

Melt Atomization. This segment of the course introduces the need for melt atomization and then develops the various mechanisms and transport processes involved in the production of metal powders by atomization. Physical modeling and atomizer design considerations were discussed by Dr. Iver Anderson, Ames Laboratory, IA.



Spray Forming. The objective of this segment is to introduce the nature of the spray processes that yield bulk net or near-net-shape' components of a variety of alloys. The discussion includes process technology and the effect of operating and design variables. For example, the effects of superheat, atomizing gas pressure, working distance and substrate motion are detailed. Commercial aspects of the spray forming of aluminum flat sheet and strip were discussed by Dr. John Benjamin, Alcoa, Alcoa Center, PA.

## Advanced Materials Processing II

Two major topics are covered in the second course, namely gas injection processes, and powder processing.

Gas Injection Processes. In this segment of the second course, the role of gas injection technology in the production of metals and composites is defined. Discussion includes gas fluxing reactions for refining and degassing methodology. A plant visit to Lukens Steel provided an opportunity for students to see the operations discussed in class. During the course, students designed a supersonic nozzle. It was fabricated and its performance then tested in a group laboratory experiment. Instruction focuses on fluid and gas dynamics, as they pertain to industrial processes. In the course, the industrial practices of gas injection technology were discussed by Dr. P. Mathur, Praxair, and by Chris Schade, Lukens Steel.

Powder Processing. In this segment of the course attention is directed to the fundamentals and technologies associated with metal powder manufacturing processes. Methods of powder consolidation, mechanisms and modes of densification, and rapid solidification technology are the primary topics. Emphasis is placed on fundamental principles in powder densification and processing-microstructure-property relations. Empirical, statistical, and mathematical models are applied to several powder densification processes to illustrate design, process improvement and optimization. Mathematical models and practical powder processing technologies were discussed by Dr. B. Lynn Ferguson, Deformation Control Technologies, Inc.

## **Student Response to Advanced Materials Processing I & II**

A total of 14 (Spring 1994) and 16 (Spring 1995) undergraduate students, took the first offering of Advanced Materials Processing I and II. They consisted of approximately two-thirds Materials Engineering majors with the remainder primarily Chemical Engineering majors. Evaluation consisted of questionnaires distributed at the end of the course and informal discussions between the teaching faculty and students on a regular basis.

To the question "How would you rate this course?" on the questionnaire students gave a score of 4.9/5, where 5 means excellent, 4 is Very Good, etc. To the question, "Was the course challenging and did it enhance critical thinking?", the students responded with an average of 4.8/5.

A majority of students said that they enjoyed the multiple instructors and especially the industrial lecturers. The students expressed the view that the lecturers brought to the classroom the practical aspect of the technology and a different point of view. One student responded, "Enjoyed having industrial people come in. Good break from the normal routine, glad to see that there is an application to our study." Another comment was, "The multiple instructors gave to the course their extensive knowledge in their respective areas. I found this very beneficial to get different viewpoints on similar material."

Students were impressed with the enthusiasm exhibited by the instructors. One commented, "This was one course that I felt the professors were very eager to see me succeed and any interest that I showed was more than doubled by the faculty". There were also the usual complaints such as, "Why start at 9 am?" and "Too many handouts and too much to read."

In summary, the course appears to have made a strong impression on the students and the organization of the course appears to impact positively on the learning process.

## **Advanced Materials Processing and The Drexel Engineering Curriculum**

Begun in 1988 as the E<sup>4</sup> program (Enhanced Educational Experience for Engineering Students) funded by NSF and several large corporations, the new Drexel Engineering Curriculum was implemented fully in



1994/95. It emphasizes “up front” engineering, computer and communication skills, lifelong learning, teamwork and professional development in the first and second years.

Drexel University is the lead institution for the NSF Gateway Coalition<sup>(6)</sup> with the central initiative of innovation in engineering education. At Drexel University we are focusing on the upper level curriculum and a major goal is to develop engineering-science courses with a strong science base to provide the science component removed from the first two years.

As a result of E<sup>4</sup> and the Gateway Coalition, the new undergraduate curriculum in Materials Engineering includes four new required engineering science courses: Advanced Materials Laboratory, Transport Phenomena - Manufacturing Fundamentals, Quantum Structure of Materials, and Engineering Computational Laboratory. In addition, students must select up to three interdisciplinary technical elective courses. The two-quarter course developed under the NSF Combined Research and Curriculum Development Program will be available to students as part of the interdisciplinary technical elective course offerings. Similarly, in the new undergraduate curriculum in Chemical Engineering, traditional courses in Physical and Organic Chemistry have been replaced by Process Physical Chemistry and Process Organic Chemistry, which are team taught by faculty from Chemical Engineering and Chemistry. In addition, sequences in Transport Phenomena are now offered with a manufacturing emphasis. In the Senior year, the new curriculum allows students to select six electives, of which two must be technical. The Advanced Materials Processing sequence described in this paper meets this technical elective requirement.

Availability of the two-quarter course on Advanced Materials Processing as a technical elective will be publicized widely in both the Colleges of Engineering and Arts and Sciences. It is anticipated that upperclass majors in electrical engineering, mechanical engineering and in chemistry and physics will find the course content complementary to their required core curricula.

### **Anticipated Benefits**

It is anticipated that the two-quarter course sequence described here will enhance significantly the exposure of undergraduate students to important areas within the field of materials processing. The concurrent exposure to research results and industrial practice in the five areas cited is expected to spawn increased student interest in this important area of materials technology. Thus, potential for career paths in materials processing should increase - consistent with the manpower needs identified in the NRC report (1).

### **Exporting the Courses**

A suitable textbook for the two-course sequence does not exist, and it is not the intent of the authors to prepare one. Rather, we will compile discrete and dedicated modules of the lecture notes in a publishable form. In this way the material will be available to students, faculty and practicing engineers at other schools, institutions, and industry. Each module is self-contained and can be used independent of the balance of the course.

### **References**

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Alan Lawley, the Grosvenor Professor of Metallurgy and Head of the Department of Materials Engineering at Drexel University, received B. SC. (1955) and Ph.D. (1958) degrees from the University of Birmingham, England. He is a Fellow of ASM, a former President of the Metallurgical Society (1982) and of AIME (1987). Research interests are in physical and mechanical metallurgy, powder metallurgy, composite materials, materials engineering design and engineering education.

