COMPOSITE MATERIALS

An Educational Need

TONY E. SALIBA and JAMES A. SNIDE
University of Dayton
Dayton, Ohio 45469

This paper deals mainly with incorporating the concepts and applications of advanced composite materials into existing chemical engineering programs.

CHEMICAL ENGINEERING is a dynamic discipline. However, the petroleum and traditional chemical industries are no longer expanding and the result is dwindling employment opportunities for chemical engineers. Although chemical engineers will continue to play a major role in these industries, the future of chemical engineering can and should be enhanced by identifying new areas in which students can be appropriately trained. This would be mutually beneficial to both students and industry since it would not only expand the employment horizon for students but would also supply industry with engineers for new technologies.

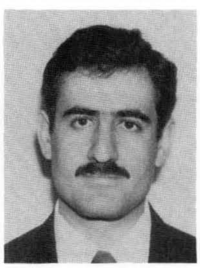
Several emerging technologies (including biochemical/biomedical engineering, microcomputer applications, process control and safety, synfuels, and advanced materials) have been identified as natural extensions to traditional chemical engineering [1,2]. This paper deals mainly with incorporating the concepts and applications of advanced composite materials into existing chemical engineering programs. Ideally, the chemical engineering curricula should have at least four electives which allow a concentration in one of the emerging technologies listed above [3]. However, due to general education requirements and/or other constraints, chemical engineering programs do not allow much flexibility for the selection of technical electives. The solution proposed here would expose students to various areas of composite materials, and that, in turn, would expand their employment opportunities to the aerospace and automotive industries.

BACKGROUND

Composite materials consist of reinforcing particulates or fibers such as glass, graphite, metals, or ceramics in a matrix that can be polymeric, metallic, or ceramic. The type and composition of the constituents and the processing procedure can be varied in order to tailor the composite properties. These properties, which are superior to those of the individual constituents, include a high strength-to-density ratio, a high stiffness-to-density ratio, high or low conductivity, and resistance to corrosion, fatigue, and stress rupture.

The industrial applications of composite materials span a wide range from advanced satellites to the simple golf club. Applications include aircraft components such as wings, helicopter blades, satellites, missiles, and engine components. In the automotive industry, body panels, brackets, drive shafts, and springs are made of composites. The consumer industry uses composites in boats and in sporting goods such as racquets, golf clubs, and fishing rods.

The processing methods vary depending on the type of reinforcement and matrix. For thermoplastic materials, the techniques include injection molding, compression molding, and cold stamping. Thermoset processing may employ contact molding, matched die molding, reaction injection molding, pultrusion, filament winding, or vacuum bag autoclave molding.



Tony E. Saliba is an assistant professor of chemical and materials engineering at the University of Dayton. He has conducted research on contracts from Wright Aeronautical Materials Laboratory, McDonnell Aircraft Company, The Edison Materials Technology Center, and Chrysler Motors Corporation. He has over thirty publications in the area of process modeling and control of advanced composite materials.

James A. Snide is Director of the Graduate Materials Engineering program at the University of Dayton. He served as a Visiting Scientist at the AFWAL Materials Laboratory to help develop a laboratory capability to conduct failure analyses of advanced composite materials. His most recent work has been in the evaluation of failure modes of composite materials used in automotive applications, and he has compiled a book on materials and process selection.

JUSTIFICATION

There is a critical need for personnel with some training in the design and processing of composite materials. The current demand is estimated at eight hundred engineers while the supply is only eighty to one hundred fifty [4,5]. The composite industry is believed to be growing at an annual rate of twenty percent [4]. A U.S. Office of Technology Assessment report indicated that 22 million pounds of advanced composites were produced worldwide in 1984 and estimated that the production would increase to 200 million pounds by year 2000 [4]. Most composite education is obtained in graduate schools, with most of the graduates working in research and development. Newly graduated BS engineers are still needed for design and development, manufacturing, and technical sales (where forty percent of the available jobs are) [6].

One undergraduate program in composite materials engineering has been started at Winona State University. However, this one program cannot meet the demand in view of the tremendous growth of the composite materials industry (raw materials usage by the composite industry is projected to grow to $10 billion by 1992 [4]). Only a few other schools have started similar programs, and most other programs have curricula with only one, or no, technical electives. An alternative approach would be to incorporate the various concepts into existing classes with example problems, lecture materials, and/or class projects.

CONTRIBUTIONS AREAS

Several traditional chemical engineering principles are essential in the composite materials industry. The processing of composites consists of applying heat and pressure. The heat is needed to initiate chemical or physical changes, and the pressure is needed to compact the product to its final shape. Heat transfer theories are needed to understand and to design the various processes. Fluid flow theory is needed to predict resin flow, which thus predicts suitable processing parameters and results in appropriate fiber and resin content and distribution. Mass transfer concepts are necessary to study environmental effects of moisture and solvents during the composite part as well as to manage void formation and growth during the manufacturing process. Chemical kinetics information is required to follow the chemical reactions in thermosets and crystallization in thermoplastics as well as to determine the heat generation rate. Traditional process design principles can be applied to product, process, and plant design. Many chemical engineering concepts are used in composite materials engineering. Our proposal is to introduce the students to examples depicting the application of basic engineering concepts to composite materials and to encourage the students to become familiar with the terminology, thus providing them with a starting point for further learning.

IMPLEMENTATION

The application of chemical engineering principles to composite materials design and manufacturing can be included in several traditional chemical engineering classes. As shown in Table 1, a brief introduction to the role materials play in a typical chemical engineering assignment, followed by an introduction to composite materials, can be covered in an introductory class in chemical engineering.

The concepts outlined in Table 2 can be introduced

TABLE 1
First Chemical Engineering Introductory Class

1. Introduction to Composite Materials
   - A. Definition
   - B. Classes of composites
   - C. Industrial applications
   - D. Why composites
     - E. Specific properties
   - F. Brief history

2. Constituent Materials
   - A. Fibers / Reinforcements
   - B. Matrix Materials

TABLE 2
Transport Phenomena

I. ***Fluid Mechanics***
   1. Resin Flow During Autoclave Cure
      - A. Flow between parallel plates (University of Michigan Model)
      - B. Flow around plates and cylinders (McDonnell Douglas)
      - C. Flow through porous media (University of Dayton, MIT)
      - D. Resin loss, compaction rate, and fiber volume fraction
   2. Other Processes
      - A. Pultrusion
      - B. Extrusion

II. ***Heat Transfer***
   1. Thermophysical Properties of Anisotropic Systems
      - A. Resistance analogy
      - B. Volume average
      - C. Empirical formula
      - D. Transport properties
   2. Heat Transfer Codes
      - A. Modeling heat transfer in an autoclave (convective BC)
      - B. Heat transfer in a press (temperature and heat flux BC)
      - C. Heat generation term due to exothermic chemical reactions
      - D. Coupled heat transfer and fluid flow in an extruder

III. ***Mass Transfer***
   1. Diffusion of Water/Solvents in Composites
   2. Void Nucleation and Growth

in fluid mechanics, heat and mass transfer, or an equivalent transport phenomena class. The basic principles are still the same; the applications are different. The topics cover modeling of the transport processes and the determination of various composite thermophysical and dimensional properties. In a transport phenomena laboratory, measurement of composite materials transport properties can be implemented as shown in Table 3. Other experiments for temperature and pressure measurements can also be incorporated.

The basic concepts pertaining to polymerization and crystallization kinetics described in Table 4 can be covered in a kinetics or a reactor design class. These topics deal with reaction mechanisms as well as the introduction of nucleation and growth rate effects on the crystallization kinetics.

The composite manufacturing techniques listed in Table 5 can be introduced in a unit operations class and/or laboratory. Studying the effect of the various process parameters on the properties of the final product can help students become familiar with the unit operation itself and manufacturing aspect of composite materials.

TABLE 3
Transport Phenomena Laboratory

In this laboratory, experiments related to composite materials can be developed and used. These could include:

- Measurement of temperature distributions during the cure of a composite material and comparison with predicted temperatures from heat transfer calculations.
- Estimation of the diffusion coefficient of moisture in composite using percent weight gain measurements and available diffusion codes. (This experiment will require several weeks.)
- Viscosity measurement during the cure of composite materials using rheometrics, dielectric monitoring or acoustic attenuation techniques.
- Measurement of the apparent thermal conductivity of composite materials using temperature and heat flow measurements.

TABLE 4
Kinetics and Reactor Design

1. Polymer Kinetics
   A. Polycondensation reactions
   B. Free radical addition polymerization
   C. Non-radical addition polymerization
   D. Copolymerization
   E. Available kinetic models
2. Crystallization Kinetics
   A. Avrami equation
   B. Avrami equation-based polymer crystallization models

Perhaps the most flexible area for the introduction of composite materials applications is in the design area. Most universities have two design classes. The first design class, covering an overview of general design considerations and the use of economic factors and optimization as applied to traditional chemical engineering design problems, can remain unchanged. The second design class can be modified to introduce product and process design requirements as applied to composite materials and to implement a composite segment with applications in the aerospace, automotive, and consumer industries. A design class is an ideal place for a class project that incorporates and summarizes the concepts learned in the first three years. The project could consist of choosing a specific novel application for an advanced composite. The product requirements for the specific application, as well as the manufacturing process, could then be iden-

TABLE 5
Unit Operations

Unit operations used in composite materials manufacturing include:

1. Filiment Winding
2. Prepreg Layup
3. Autoclave Molding
4. Injection Molding
5. Compression Molding

TABLE 6
Product and Process Design

1. ***Process Modeling and Optimization***
2. ***Material Selection Criteria***
   A. Geometric considerations
   B. Properties requirements
   C. Cosmetic requirements
   D. Processability/maintainability
   E. Product quality
   F. Cost
3. ***Design Concepts***
   A. Cost of design and manufacturing
   B. Coordination between design, tooling, and manufacturing
   C. Product quality assessment and control
   D. Mathematical analysis
   E. Joint design
   F. Design databases
   G. Computer programs for design (LAMRANK, CLASSIC)
   H. Life-cycle analysis
4. ***Project***
   A. Justification for using composite materials
   B. Constituent materials selection
   C. Manufacturing techniques chosen
   D. Meeting design requirements
   E. Quality assurance
   F. Modifications and recommendations

tified [7,8]. The concepts covered in this class and the project outline are listed in Table 6.

Finally, a seminar can be used to invite chemical engineers from the composite industries to share their experiences and to introduce the students to various composite industry problems and solutions.

FINAL THOUGHTS

Both the mechanical behavior of composite materials and the effect of processing parameters on the mechanical properties are important areas of composite materials manufacturing and design. Although the mechanics of composites topics are more appropriate in a mechanical engineering curriculum, chemical engineering students might choose to take a strength of materials class where the concepts of anisotrophy and mechanical behavior are introduced.

Despite the importance of composite materials and the essential need for engineers knowledgeable in this emerging technology, introducing composite materials topics into the existing curricula should be done without compromising the basic engineering sciences. The principles currently covered should remain intact, but the examples and the application of these principles could be tailored to composite materials.

In order to implement the plan, the department should have faculty members working in the area of composite materials who can bring their experience and expertise to the classroom (our department has five faculty members who work in the polymer/composite materials area). A department looking for a new direction, but without expertise in the field, could retrain faculty who have an interest in this area through short courses, conferences, and industry/government facility summer internships. Another mechanism for implementation could be through the use of part-time faculty who have extensive experience in the composite materials industry.

CONCLUSIONS

A strategy for introducing composite materials concepts into existing classes has been proposed. Implementing the application of basic chemical engineering principles to composite materials is necessary if we are to meet the demand for chemical engineers knowledgeable in this emerging technology. It is an alternative that can be used in schools where concentrations in the areas of new technologies cannot be introduced. Finally, this approach will not require reaccreditation since classes and the basic principles remain the same; only the examples and the applications would change.

REFERENCES

1. Eisen, E.O., "A Survey on Emerging Technologies in Chemical Engineering," presented at the American Institute of Chemical Engineers Annual Meeting, Chicago, IL (1985)
2. National Research Council, Frontiers in Chemical Engineering, Executive Summary and Recommendations, National Academy Press, Washington, DC (1988)
3. Saliba, T.E., and J.A. Snide, "Introducing Concentrations in Emerging Technologies in Traditional Disciplines," University of Dayton; to be published
4. Sponseller, M., "Cash in on the Composites Revolution," Graduating Engineer, McGraw-Hill, New York (1988)
5. Saliba, T.E., and J.T. Johnson, "Composite Materials: Educational Opportunites," presented at the 2YC3 Joint US/Canada Conference, Toronto, Canada, June (1988)
6. U.S. Office of Technology Assessment, New Structural Materials Technology, Washington, DC (1986)
7. Browning, C.E., "Composite Materials...," class notes, University of Dayton, Dayton, OH (1985)
8. Saliba, T.E., and J.M. Whitney, "Curriculum for a Bachelor of Science in Composite Materials Engineering," Winona State University, Winona, MN (19878) ❒

ChE books received

Advanced Inorganic Chemistry, 5th Edition, by F. A. Cotton and G. Wilkinson; John Wiley & Sons, Inc., 1 Wiley Dr., Somerset, NJ 08875-1272; (1988) 1455 pages, $44.95

Large Scale Cell Culture Technology, Edited by B. K. Lydersen; Oxford University Press, 200 Madison Ave., New York, NY 10016; (1988) 252 pages $69.00

Plastics Additives, 2nd Edition, by Gachter and Muller; Oxford University Press, 200 Madison Avenue., New York, NY 10157-0913; (1988) 754 pages $80.00

Active Carbon, by Bansal, Donnet, and Stoeckli; Marcel Dekker, Inc., 270 Madison Ave., New York, NY 10016; (1988) 496 pages $125.00

Particulate Phenomena and Multiphase Transport (5 volumes), Verizoglu (ed); Hemisphere Publishing Co., 79 Madison Ave., New York, NY 10016; (1988) 3072 pages, $700.00

Catalysis of Organic Reactions, by P. N. Rylander, H. Greenfield, and R. L. Augustine (eds); Marcel Dekker, Inc., 270 Madison Ave., New York, NY 10016; (1988) 456 pages, $99.75

HEDH, Heat Exchanger Design Handbook, Supplement 4, edited by Schlunder; Hemisphere Publishing Co., 79 Madison Ave., New York, NY 10016-7892; (1988) 512 pages, $140.00

Innovation in Process Energy Utilization, edited by Rogers, Steel, *et al;* Hemisphere Publishing Corporation, 79 Madison Ave., New York, NY 10016-7892; 445 pages, $98.50 (1988)

Fluid Mixing III, Edited by N. Harnby; Hemisphere Publishing Co., 79 Madison Ave., New York, NY 10016; (1988) 290 pages, $67.50

Advances in Thermal Modeling of Electronic Components and Systems, Vol. 1, by Bar-Cohen and Kraus; Hemisphere Publishing Corporation, 79 Madison Ave., New York, NY 10016-7892; 469 pages, $90.00 (1988)