Engineering Materials - A Necessary Component of a Course on Manufacturing Processes

Prince N. Anyalebechi

Padnos School of Engineering
Grand Valley State University
Grand Rapids, MI

Abstract

Courses on manufacturing processes vary significantly in content from one engineering program to another. This is usually predicated on the mission of the particular engineering department. This, in turn, is conditioned by the local industry around the school and the academic and industrial backgrounds and experiences of the faculty. The depth, breadth, and technical rigor is usually determined by whether it is a traditional engineering or an engineering technology program and whether it is an ABET approved course. Traditionally, courses on manufacturing processes in many engineering departments emphasize just design and/or metal machining processes and little of anything else. Often the courses are devoid of two important elements namely the: (i) the interactions between design and manufacturing processes, and (ii) interaction between materials and process variables. This approach usually produces graduates who are limited in their ability to solve non-machine related production problems. In this paper, the case is made for making the knowledge of engineering materials and how they affect product (even machine) design and interact with process variables a necessary and critical component of a manufacturing processes course.

1. Introduction

Engineering materials have always been an integral part of the culture and civilization of humanity. This fact is captured very well in the following comments:

> *"The materials which we use for everyday purposes influence our whole culture, economy, and politics far more deeply than we are inclined to admit; this is indeed, recognized by the archaeologists when they talk about the "stone age", the "bronze age", and the "iron age.""* (J. E. Gordon, The New Science of Materials[1])

> *"The economic prosperity, environmental well being, and quality of life are linked to the development of advanced materials and processing technologies. Improved materials and processes can contribute to a*

number of national priorities: energy efficiency, environmental quality, national security, health care, information and communication, infrastructure, and transportation." (Dr. John H. Gibbons, Former Director, US Federal Office of Science & Technology[2])

"Engineering is the profession in which the knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgment to develop ways to utilize economically, the materials and forces for the benefit of mankind." (Definition of Engineering adopted by ABET[3])

Based on the above observations, it is not surprising that in 1987 engineering materials was identified by the US National Research Council as one of the areas of research and fundamental learning with the potential to offer the greatest return on investment.[4] Some countries acknowledged that the knowledge of engineering materials is fundamental to the future competitiveness of their industries by designating new materials technology as one of the areas in which industrial research should be encouraged.[5,6]

Depending on the discipline, all engineers are involved in either, the design, production, selection, repairs, analysis, or management of technical products and/or in their use in technical and manufacturing systems. This dictates that engineers, irrespective of discipline, must possess a basic understanding of the unique characteristics and areas of application of engineering materials. The products that different engineering disciplines make and the systems they develop, monitor, and maintain, involve parts and components that require a potpourri of engineering materials. These materials possess specific characteristics and properties necessary to meet the required demands of a given engineering discipline. With the exception of metallurgical and materials engineers, many other engineering disciplines do not normally develop materials to be used, but they must work closely with materials and metallurgical engineers in the selection, processing and enhancement of the materials required for their products and systems. In addition, engineers from disciplines other than metallurgy or materials science/engineering design most of the parts or components made out of materials. Consequently, engineers, irrespective of discipline must understand the interdependence between design, materials, manufacturing processes, and product performance (Figure 1). They must also appreciate the significant impact of environment and cost on materials and process selection decisions. The increase and rapid change in the sophistication and number of newly developed engineering materials and manufacturing processes have increased this need.

By definition, manufacturing involves the application of physical and/or chemical processes to transform less valuable materials into products or items of greater value by altering their state, geometry, microstructure, properties, and/or appearance.[7] The primary goal of manufacturing processes is therefore to produce components of a selected material at the lowest possible cost with the required geometrical shape and optimum properties for the proposed service environment. Thus, for all intent and purposes, manufacturing processes deal with the fabrication of and use of engineering materials. Of course, manufacturing also includes assembly of multiple parts made out of engineering materials to make products.

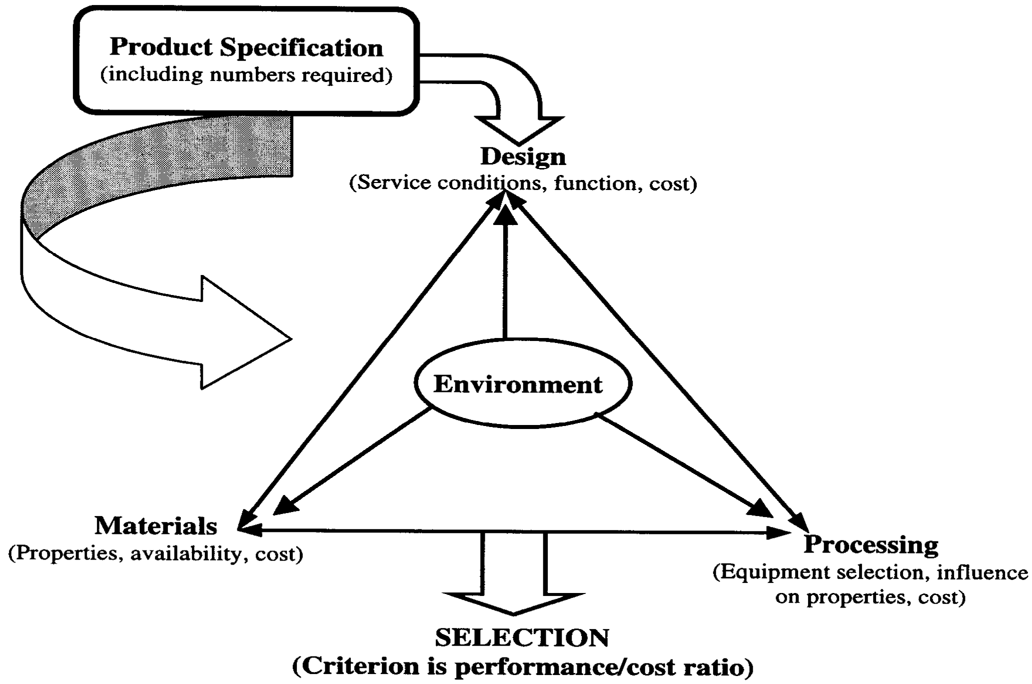

Figure 1: Inter-relationship among design, materials, environment, and processing

2. The Need for Including Engineering Materials in Courses on Manufacturing Processes

The fact that all engineering disciplines interact with engineering materials and that the latter is coupled with manufacturing processes suggests that courses on manufacturing processes in various engineering programs should include elements that recognize the interdependence between materials, processes, design, cost, and environment (Figure 1). These factors have become so inseparable that in the development of new products and processes many companies use integrated product/process development teams. This ensures that all of the important factors are taken into consideration before the latter stages of a product and/or process development to avoid late costly design modifications. The effectiveness of such integrated teams depends on the team member's understanding and appreciation of the interdependence between process, design, materials, cost and environment.

In good engineering programs, students are introduced to this concept at the early stages of their academic training. For example, in Padnos School of Engineering (PSE), engineering students are introduced to the concept of designing and manufacturing in the first laboratory exercise of the first engineering course. They are asked to design, using the Pro/Engineering CAD software package, and manufacture a key chain on a CNC milling machine. This concept is reinforced throughout the engineering program by a variety of "design-and-build" projects that students are assigned in different courses. This type of hands-on and experiential learning approach is augmented in the classroom with carefully chosen engineering case studies that involve the interactions of materials, processes, design, cost and social issues. In PSE, we are careful to avoid the potential pitfalls of oversimplification and negligence of theoretical principles that can occur with the design-and-build approach. In some engineering programs, engineering students spend significant amount of their time in the machine shop or workshop building or rebuilding components without any appreciation or understanding of the mutual influence of the materials and process conditions. Graduates of such programs usually do not have the technical wherewithal to make worthwhile contributions in integrated product or process development teams. They usually lack the problem-solving skills and knowledge of basic engineering principles and so will not be able to help their industry employers. In most cases, they may become good laboratory technicians but not good engineers

To adequately prepare engineering students for life in industry, a course on manufacturing processes should build on and integrate prior knowledge of engineering materials that students acquired in the materials science and engineering courses. This type of training will enable engineering graduates to get optimum performance out of materials, processes, and systems. This can only come about if the course: (a) helps them understand the microstructure-properties-process-product performance continuum (Figure 2); (b) makes them aware of how properties of materials can be controlled by the manipulation of their microstructures; (c) gives them an insight into the information available about materials, their processing and performance in service; (d) helps to know when to seek specialist advice and the ability to understand and apply the advice; and (e) teaches them a systematic approach to materials and process selection which takes into account all relevant factors, rather than basing selection solely on established practice.

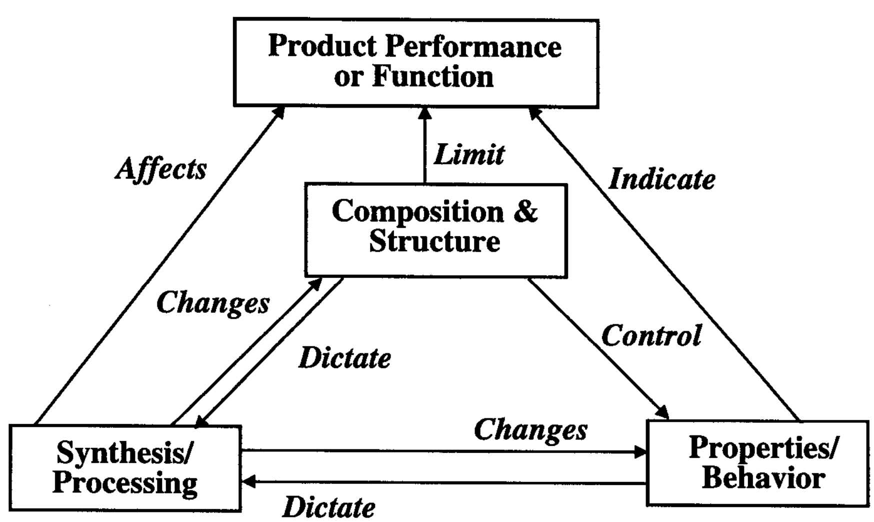

Figure 2: Schematic showing the microstructure-properties-process-product performance continuum.[8]

3. Suggested Approach

The question arises as to the appropriate pedagogical approach to the teaching of manufacturing processes in engineering (and non-engineering) academic programs. This is not an easy question to answer since different disciplines of engineering require different emphasis on engineering materials. Besides, there is merit in diversity of approach to suit particular engineering disciplines and to best use the available resources in the department and institution. Specifics of the approach are not as critical as the fact that various aspects of the structure and properties of engineering materials must be included in courses on manufacturing processes. These should include *structure-property relationships, characterization and interpretation of the microstructures of materials, measurement of properties of materials*, and *the interaction between materials and manufacturing processes.*

Understanding of manufacturing processes and the use of engineering materials requires knowledge of the microstructure and properties of materials and how they evolve during processing. Figures 2 and 3 show the relationships between structure, property, processes and applications of materials. Undergraduate engineering students should be made aware of how properties can be controlled by the microstructural characteristics such as grain size and arrangement, the type, size, quantity and distribution of second phases, and the presence and distribution of lattice defects. In fact, properties of materials and product performance can be predicted by the knowledge of these microstructural features. It is also noteworthy, that these microstructural features affect the behavior of materials during processing. For example, in material removal processes, a popular topic in courses on manufacturing

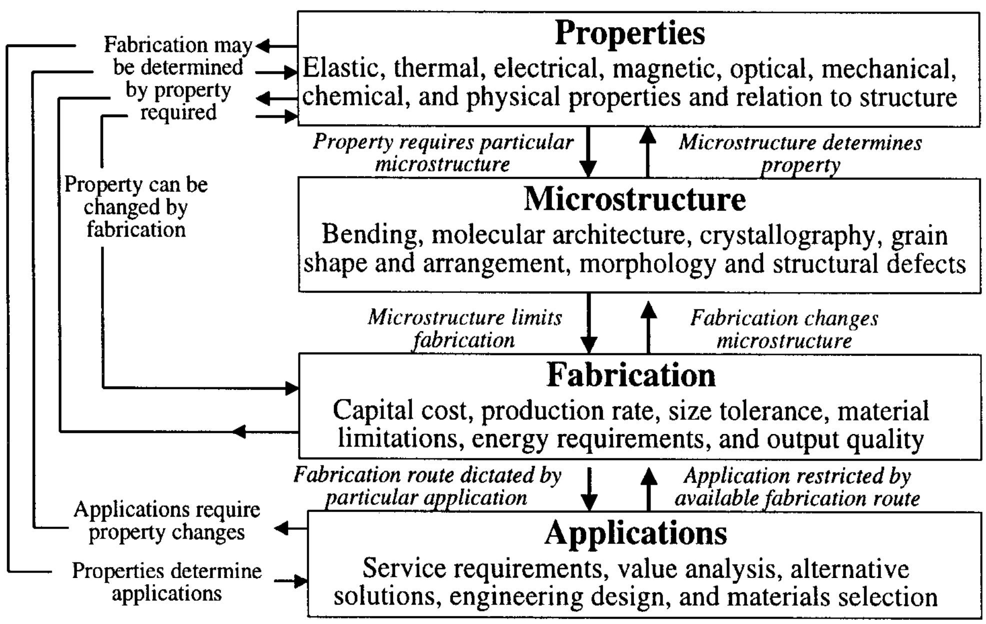

Figure 3: Relationships between structure, property, fabrication and application of engineering materials.[9]

processes, machinability (expressed in terms of either surface finish or tool wear) is profoundly dependent on both the types of materials being machined and their prevailing microstructures. Students should also know that microstructures of materials can be manipulated to obtain specific types of microstructures, which will result in certain properties. For example, in accordance with the well-known *Hall-Petch* relationship, yield strength is proportional to the reciprocal of the square root of grain size. A senior engineering student should know the differences in the microstructures produced by different processes such as casting, mechanical and thermal processing, and should be able to explain why. As indicated above, student engineers should be cognizant of the fact that the goal of manufacturing processes is not only to produce the required geometrical shape at the lowest possible cost but also to deliver the finished shape with the optimum properties for the proposed service environment.

In my opinion, all engineering students, irrespective of discipline, should be exposed to microstructural examination techniques, namely optical microscopy and metallographic preparation of metal samples. In addition to acquiring the technical knowledge of how to interpret microstructures, these activities will teach students desired skills such as proper preparation, attention to detail, observation, and ability to distinguish significant features, writing, and ability to make qualitative judgements. This type of training gives engineers whose main discipline is not materials an appreciation of a materials engineer's approach to a problem. This will help them establish a useful dialogue on materials and process related problems the solutions of which are frequently microstructure related. Wherever feasible, student engineers should also be introduced to advance techniques that are used to characterize microstructures and composition; e.g., the scanning electron microscopes. It is important for them to be aware of the capabilities of these modern techniques and to be able to ask for relevant information from them.

Measurement of the effect of processes on properties should be a necessary component of manufacturing processes laboratory studies. For example, measurement of hardness and/or tensile properties as a function of heat treatment conditions and alloy composition is probably the easiest and simplest means of helping students understand the interactions between process and materials. Engineering students also need to be aware of other properties (such as fatigue, creep, wear and corrosion) which can limit the performance and service lifetime of components and how they can be affected by various processing conditions.

Because of the interactions and interdependence of engineering materials and their processing procedures, it is imperative for students to be aware and take into consideration these influences when selecting fabrication routes. They need to know that selection of certain types of materials, a priori determines the range of processes that can be used to make a part and even the subsequent performance of that part.

Most of these concepts can be taught in lectures and reinforced with case studies and laboratory exercises and experiments that include the effects of the type of materials.

Laboratory exercises are probably the best means of incorporating these concepts so long as students are made to explain the results of their tests and experiments. The nature of the engineering program and the background of the students determine the level of difficulty of the laboratory exercises. In Grand Valley State University's Padnos School of Engineering, metallographic preparation, optical microscopy, and property measurements are currently taught as part of the laboratory studies in the materials science and engineering course. Consequently, in the manufacturing processes course, students are expected to use these tools in their study of the interactions between design, materials, and processes, and to explain their results.

4. Concluding Remarks

A case has been made here for inclusion of engineering materials and increased emphasis on the interaction between materials, processes and design in courses on manufacturing processes. Exclusion or neglect of the material component in courses on manufacturing processes will result in engineers that are not adequately prepared for life in industry. Also, incorporation of the above aspects of engineering materials in courses on manufacturing processes will make it easier to meet the goals behind the design requirements of the ABET accreditation criteria. The concepts teach students creativity and the ability to deal with open-ended and poorly defined problems that have more than one correct solution. Problems that involve materials, processes, design and cost teach students how to propose practically realistic solutions that satisfy both technical and non-technical constraints. In addition, these types of problems give them an understanding and appreciation of the effect of non-technical constraints such as ethics, aesthetics, and socio-political impact on engineering decisions.

5. References

1. J. E. Gordon: *The New Science of Strong Materials or Why You Don't Fall Through the Floor*, 2nd edition, Pelican Books, 1981.

2. John H. Gibbons: Advanced Materials & Processing, 1993.

3. ABET: The Accreditation Board for Engineering and Technology.

4. *Directions in Engineering Research,* Report of the Engineering Research Board, US National Research Council, Academy Press, 1987.

5. GIRD - Grants for Industry, Research and Development, Canberra, 1987, *Materials Australia*, Jan/Feb 1988.

6. A. Blicblau: *Metals and Materials*, April 1990, pp. 216-221.

7. M. P. Groover: *Fundamentals of Modern Manufacturing - Materials, Processes, and Systems*, 2nd edition, John Wiley and Sons, Inc. New York, 2002, p. 4.

8. *Materials Science and Engineering for the 1990s*, Report of the National Research Council, National Academic Press, Washington, DC, 1989, p.29.

9. Accreditation and Training Committee of the Institution of Metallurgists (M. P. Stammers): "Materials Teaching - a Working Party Report*," The Metallurgists and Materials Technologist,* 1984, pp.391-393.

PRINCE N. ANYALEBECHI obtained his Ph.D. in Metallurgy from Brunel University, UK. He is currently an Assistant Professor in Padnos School of Engineering at Grand Valley State University where he develops and teaches undergraduate and graduate courses on materials science and engineering, manufacturing processes, and materials and process selection. He spent 12 years in industry. Research and teaching interests include physical metallurgy, materials processing (casting, thermomechanical processing, etc.) and product failure analysis.