Materials Manufacturing

Thomas W. Eagar, Guest Editor

The behavior of successful manufacturing companies has changed in response to the accelerating pace of technological development in recent years. Manufacturing firms are under greater pressure than ever to bring new products and processes to market rapidly, with lower costs and higher quality than achieved in the past. In addition, the establishment of a global economy no longer dominated solely by the United States has required firms to expand their outlooks and horizons. Successful firms must take a multinational view, understanding and serving local customer needs while maintaining the efficiency of a global enterprise.¹ This requires greater flexibility in manufacturing and distributing new products.

As the business environment for materials manufacturing changes, so too does our measure of materials performance. Traditionally, materials scientists and engineers have emphasized processing, structure and properties, and the way they come together to produce performance of a product in a given application. However, as shown by Figure 1, there are several additional dimensions to performance. In particular, successful commercial performance depends not only on the physical properties of the material but also on our ability to shape it into a useful object in an economical and timely manner. Without shape, the product cannot serve its intended function, and without economical production, the product's usefulness is limited to fewer, higher value applications. Achieving more rapid and more consistent commercial success from advanced materials requires emphasizing not only the process by which the material is made but the process by which the material achieves its geometry and function, while at the same time maintaining the ability to bring these materials to market rapidly at an economical price. Indeed, the cost delay in commercializing a new material can be the key to success or failure.¹

To be successful, a materials manufacturing firm must take an integrated view of the manufacturing enterprise. As seen

in Figure 2, manufacturing operations lie at the core of the business while applied science and product/process engineering, marketing, administration, human resources, finance, and accounting must all work together with the customer, the government, the vendors and suppliers, and the community in a new partnership.

Why Manufacturing Matters

*To live well, a nation must produce well.²
Productivity isn't everything but in the long run it is almost everything.³*

A nation which does not produce well will not, in the long run, lose jobs for its citizens; but its citizens will find that the quality of their jobs and their standard of living will deteriorate in comparison to nations that do produce well.

Manufacturing and productivity matter because 23% of our Gross National Product consists of manufactured goods. Approximately 85% of our international trade consists of goods; only 15% is services. Manufacturing industries account for about 90% of nongovernmental R&D funding.⁴ In total, about 40% of all the jobs in the United States are involved directly or indirectly with manufacturing. The problem is that productivity growth in the United States has been at its lowest point over the past 20 years than at any other time during the past century. Our productivity growth during the Great Depression was 20 to 30% greater than it has been over the last two decades. As a result, productivity in the United States is becoming lower than that of other countries (see Figure 3), and we can expect our standard of living in comparison to the rest of the

Figure 1. Diagram of how materials science, manufacturing science, and fabrication all contribute to product performance.

The Total Enterprise Approach

Figure 2. The integrated manufacturing enterprise illustrating overlapping functions, disciplines, and activities.

world to decrease in the future.

There are many reasons for this decline. Table I lists the six reasons identified by an MIT Commission that studied this problem for 18 months.² Although technology is clearly part of the problem, it is not all of the problem, and for this reason, technology alone cannot solve the entire problem. One must take a holistic approach that includes all the parts of the enterprise, as described in Figure 2.

What is Total Quality Management?

In 1987, the Department of Commerce established the Malcolm Baldrige National Quality Award to be given to the most outstanding manufacturing companies in the United States. The award criteria are broken down into 99 areas. These areas do not define a specific approach by the company, but they do outline the steps that must be taken to achieve Total Quality Management (TQM). Table II provides a short list of key steps.³

Prof. Shoji Shiba of Tsukuba University describes Total Quality Management as a "thought revolution in management which

provides the means to achieve a higher quality of products and services."⁶ He describes the increasing levels of "fitness" of a product for its use. The lowest level involves conformance to a standard. This inspection-oriented attitude has no focus on the customer. The next level, fitness for use, is driven by marketplace needs. Next is fitness for explicit requirements, which usually combines multiple requirements, such as high quality with low cost. At this level, the use of continuous feedback from the customers and the process is essential, and tools such as statistical quality control are widely employed.

On the next level, fitness for latent requirements, feedback from customers is irrelevant since the producer is attempting to supply a need the customers do not even know they have. For example, the Sony Walkman fulfilled a need for portable music for millions of people who never even knew they were missing this opportunity to enjoy music during other activities. In the future, the need to manufacture products harmonious with the environment will likely create the next level of "fitness."

Articles in This Issue

The articles in this issue of the *MRS Bulletin* describe this new approach to producing materials and components and the new partnerships among customers, suppliers, employees, and management. B. Barnett, H.K. Bowen, and K. Clark describe the measures by which successful materials manufacturing companies will be judged in the future and why it is necessary for companies to risk the long development times and high costs associated with commercializing advanced materials.

In "Materials in Electronic Manufacturing," R. Pfahl illustrates several important principles. First, he shows that achieving high levels of process capability allows eliminating inspection and repair, thus achieving low cost as well as high quality. Second, his examples show that the high levels of defects tolerated only a decade ago were defined by the process designer. If the designer planned repair capacity for 4% of the product, then the process engineers would improve the process to that level and stop. One conclusion is that the only way to eliminate inspection and repair is to set a process goal of zero defects.

Prof. J.A. del Alamo's description of "GaAs Integrated Circuitry Manufacturing Cost" indicates that the primary barrier to increased use of GaAs is cost and that these costs can be reduced if understanding and controlling the production process are emphasized.

K.K. Wang explains how mathematical models of the injection molding process and the rheological behavior of the polymer can be used to improve the quality and design of plastic components. This project also shows how advanced technologies developed at a university can be integrated to produce a useful industrial manufacturing tool.

Source: International Productivity Center, U.S. Dept. of Labor

Figure 3. Manufacturing productivity in the United States versus that in Japan.

Table I: Reasons the United States Has Lost the Productive Edge in Manufacturing over the Past Two Decades.²

Outdated Strategies
Short-Time Horizons
Technological Weakness in Development and Production
Neglect of Human Resources
Failures of Cooperation
Government and Industry at Cross-Purposes

Although somewhat removed from materials manufacturing science, the article by M. Choudhary is an excellent example of overcoming some of the nontechnical barriers to improved production. Referring to the factors described in Tables I and II of this article, one can readily see that the education and commitment of the workforce is a key to successful implementation of TQM.

The article by M.A. Pate from Alcoa describes how statistical process control can be used in a high-volume, commodity material manufacturing process to achieve higher quality and so obtain an edge over the competition.

L. Bird and S. Frederick of Corning Inc., describe "Quality Architecture," a pioneering concept to build quality control into the design of a product from the outset. The quality architecture, which is set down in the form of a flow diagram, includes process feedback information and quantitative quality specifications.

Conclusions

Key to the success of any product is an understanding of the manufacturing process. Indeed, in the many studies undertaken in recent years to define the most important areas of future materials re-

Table II: Partial List of the Critical Success Factors Used to Evaluate Applicants for the Malcolm Baldrige National Quality Award.⁵

- Senior executives must be personally and publicly involved, getting training on quality topics themselves and training others, recognizing employee contributions, and spreading news of the company's quality activities.
- The company's mission statement must stress its quality values through statements like "Be the supplier of choice by providing value to our customers; you will achieve this by empowering our employees, treating them with respect, and listening to customers."
- The right data must be chosen for collection and analysis, and then used.
- A documented quality plan must be in place.
- There must be clear evidence of employee acceptance of and involvement in quality activities.
- Quality control and improvement efforts must penetrate all the firm's systems and must involve suppliers.
- Internal measures of quality must show positive trends and document a claim to industry leadership.
- Inventory levels, energy use, first-time success rates, lead times, rework rates, and other quality-related business activities must show improvement.
- Customer satisfaction should be rising through identification and fulfillment of customer requirements.

search, process understanding has been at or near the head of the list in every case. The recent report by the National Research Council, *Materials Science and Engineering in the 1990s: Maintaining Competitiveness in the Age of Materials*, highlights materials synthesis and processing as the most important area of expanded emphasis over the next decade. Indeed, every nation's success as a global manufacturer and the improvement of our standard of living requires that we develop manufacturing processes capable of producing high-quality products rapidly, with exceeding economy, and in an environmentally acceptable manner. While materials scientists and engineers have much to contribute to this process understanding, it is important that they recognize the many other dimensions of successful manufacturing. The final goal can only be achieved by paying

attention to each part of the Total Enterprise we call Manufacturing.

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Sixth Materials Research Symposium University of California, Los Angeles ■ May 8, 1992

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Brent Barnett, research fellow at Harvard Business School, examines the technology management and new product development in the materials industries, and is working on a study of company management practices in the United States, Japan, and Europe. Barnett received his PhD degree in ceramics in 1988 from the Massachusetts Institute of Technology and his BS degree in physics from Brigham Young University in 1983. His current work involves studying the organizational processes by which firms develop new products, and how these processes vary according to their technology and business strategy. The research integrates empirical data collection, statistical comparison, and process modeling.

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Robert C. Pfahl Jr., director of Advanced Manufacturing Technology for the General Systems Sector of Motorola, Inc., is responsible for developing and introducing advanced manufacturing technology and advanced electronic packaging into production. His organization's areas of activity include reflow soldering, cleaning, advanced electronic packaging, factory control systems, and advanced electronic materials. Pfahl invented, developed, and implemented "vapor phase" soldering for reflow soldering of temperature-sensitive assemblies, and developed infrared solder fusing, liquid immersion solder fusing, and flat flexible cable termination. His work includes heat transfer experiments and analyses. Pfahl has published 18 technical articles on heat transfer, materials, and reflow soldering.

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