GENERAL PREREQUISITES OF THE USE OF ADVANCED STRUCTURAL MATERIALS

Education and Training

The expanding opportunities for ceramics and composites will require more scientists and engineers with broad backgrounds in these fields. At present, only a handful of universities offer comprehensive curricula in ceramic or composite materials. There is also a shortage of properly trained faculty members to teach the courses. The job market for graduates with advanced degrees in ceramic or composite engineering is good, and can be expected to expand in the future. Stronger relationships between industry and university laboratories are providing greater educational and job opportunities for students.

There is a great need for continuing education and training opportunities for designers and engineers in industry who are unfamiliar with the new materials. In the field of polymer composites, for example, most of the design expertise is concentrated in the aerospace industry. Continuing education is especially important in "unsophisticated" industries such as construction, which must purchase, rather than produce, the products they use. Universities and professional societies are offering seminars and short courses to fill this gap; these opportunities should be publicized and made more widely available.

Beyond the training of professionals, there is a need for the creation of awareness of new materials technologies among technical editors, managers, planners, vice presidents, and the general public. In recent years, the number of newspaper and magazine articles about the remarkable properties of ceramics and composites has increased, as has the number of technical journals associated with these materials. The success of composite sports equipment, including skis and tennis rackets, shows that new materials can have a "high-tech" appeal to the public, even if they are relatively expensive.

Multidisciplinary Approach

Progress in materials development often requires a team effort. For example, for a typical ceramic component, the team might consist of one or more specialists from each of the disciplines in table 15. Materials research lends itself naturally to collaborative institutional arrangements in which the rigid disciplinary boundaries between different fields are relaxed. The successes of numerous multidisciplinary materials centers based at universities and national laboratories across the country reflect this fact. A consensus is developing within the materials community that the exploration of new mechanisms for collaborative work between university, industry, and government laboratory scientists and engineers would have a salutary effect on the pace of advanced materials development and utilization. This topic will be examined in greater detail in the final report.

Table 15.—Hypothetical Multidisciplinary Design Team for a Ceramic Component

Specialist	Contribution
Systems engineer	Defines performance
Designer	Develops structural concepts
Stress analyst	Determines stress for local environments and difficult shapes
Metallurgist	Correlates design with metallic properties and environments
Ceramist	Identifies proper composition, reactions, and behavior for design
Characterization analyst.	Utilizes electron microscopy, X-ray, fracture analysis, etc. to characterize material
Ceramic manufacturer	Defines production feasibility

SOURCE J.J Mecholsky, "Engineering Research Needs of Advanced Ceramics and Ceramic Matrix Composites," contractor report for OTA, December 1985.

Integrated Design

Advanced ceramics and composites should really be considered structures rather than materials. Viewed in this light, the importance of a design process which is capable of producing highly integrated and multifunctional structures becomes clear. Polymer matrix composites provide a good example. Perhaps the greatest single economic advantage of composites, beyond their superior performance, is the potential for reduction in the cost of manufacture achieved by reducing the number of parts and operations required in fabrication. For example, a typical automobile has about ***1500*** structural parts. It has been estimated that, with an integrated composite design, this total could be reduced to a few hundred parts, with major savings in tooling and manufacturing costs.[62] Because composites can be tailored in so many ways to the various requirements of a particular engineering component, the key to optimizing cost and performance is a fully integrated design process which is capable of balancing all of the relevant design and manufacturing variables. Such a design process will require an extensive database on matrix and fiber properties, as well as sophisticated software capable of modeling fabrication processes and three-dimensional analysis of the properties and behavior of the resulting structure. Development of expert systems software for the design of both materials and structures will also be important, particularly for engineers who are new to the field. Perhaps the most important element in the development of integrated design algorithms will be an understanding of the relationships between the constituent properties, microstructure, and the macroscopic properties of the structure. Many of the research and development priorities listed above are intended to provide this information.

The view of ceramics and composites as structures also sheds light on the often-stated need for a "database" for design purposes. The discussion above suggests that the "customized" nature of advanced structural ceramics and composites militates against the very idea of standardized structures with specified properties which could be cataloged in a database. However, depending on the application, a two-tracked approach to standardization and data-collection may be the best overall solution. For design of integrated, multifunctional structures, the best approach may be a database containing the properties of constituents and unidirectional composites, coupled with standardized algorithms for modeling and analysis. Destructive testing of the finished structure would provide data to validate the models. For applications in which standard ceramic or composite components are desired, such as brackets, elbows, or beams, the properties and composition of the structures would be specified and standardized,

Systems Approach to Costs

It is often stated that the three biggest barriers to the increased use of advanced materials are cost, cost, and cost. In a narrow sense, this observation is correct. If advanced materials are considered on a dollar-per-pound basis as replacements for steel or aluminum in existing designs, they cannot compete. This is very often the perspective of potential user industries, who are oriented toward metals processing, and has been the source of great frustration among ceramics and composites suppliers. However, the per-pound cost and part-for-part replacement are rarely valid bases for comparison. This is the reason that the costs of ceramics and composites have not been stressed in this report. A more fruitful approach is an analysis of the overall systems costs of a shift to advanced materials, including integrated design, fabrication, installation, and lifecycle costs.

The high per-pound cost of advanced materials is largely a result of the immaturity of the fabrication technology and the low production volumes. Large decreases in materials costs can be expected as the technologies mature. For example, a pound of standard high strength carbon fiber which used to cost $300 now costs less than $20, and new processes based on synthesis from petroleum pitch promise to reduce the cost even further.[63] If high-strength carbon fibers in the $3

[62] Reifsnider, op. cit., December 1985.

[63] The world's foremost manufacturer of pitch-based carbon fiber, Kureha Chemical Industry Co. of Japan, has developed a new high-strength fiber said to cost one-third as much as polyacrylonitrile (PAN) -based fibers. See *Iron Age*, June 20, 1986, p. J6.

to $5 per pound range became available, major new opportunities would open up for composites in automotive, construction, and corrosion-resistant applications.

Two other economic factors which can affect the competitiveness of ceramics and composites deserve mention: they are energy costs and labor costs. The cost of the energy required to manufacture ceramic and composite components is a negligible fraction of the overall production costs; however, energy savings in service are a major reason for the use of advanced materials in such applications such as heat exchangers, engines, and transportation structures. Persistent low energy costs are likely to reduce the incentives to introduce advanced materials into these applications.

Throughout this report, the vision presented of the materials factory of the future has been one of extensive automation and computer-controlled processing. The reliability and reproducibility requirements of ceramic and composite structures demand a minimum of human intervention. These considerations indicate that the ceramics or composites factory of the future will not be a labor intensive operation. In fact, labor costs, which are currently a large fraction of overall production costs of advanced structures, are a key target for future cost reduction. Thus, rising labor costs could accelerate the utilization of ceramics and composites.

Technical, economic, and institutional factors will all influence the incorporation of ceramics and composites technologies into commercial production. Many of these factors have been discussed in this interim report. However, several key issues are mentioned without discussion. These include: the need for improved cooperation between industry, universities, and government labs; the dramatic changes which new materials will bring to manufacturing; and government policy options which could enhance the international competitiveness of United States advanced materials users and suppliers. The final report will explore these issues in detail.