ADVANCED PROCESSING OF CERAMIC COMPOUNDS

Dynamic Compaction Technology, Self-Propagating High-Temperature Synthesis, Plasmachemical Technology

by

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Foreword

This book describes both established and potential technology for the processing of advanced ceramic compounds, materials which would satisfy key performance functions and properties in aerospace and defense applications and, subsequently, in the industrial sector. Particularly covered are dynamic compaction technology, self-propagating high-temperature synthesis, and plasma-chemical technology, the first two of which are on the leading edge of materials technology, and, when fully investigated, are expected to be of great value to commercial interests. The book covers research in the U.S. and the U.S.S.R. The future increase in performance requirements of unique materials underlies the importance of these specialized processing techniques.

Rapid market growth during the next ten to fifteen years has been predicted for products fabricated from advanced ceramic compounds. Examples of the wide range of products which might be fabricated by the processes discussed include: high temperature engine components such as combustion liners, blades, nozzles, and shrouds; electronic hardware such as thermistors, insulators, and substrates for integrated circuits; other refractory structurals such as furnace elements, heat-exchanger components, and metal-refining electrodes; energy storage devices; materials-finishing accessories such as grinding wheels, polishing pastes, and machining tool bits; and wear and abrasion hardware.

Specific applications of processing technologies in government programs are presented in the book, and representative materials compositions and manufacturing procedures are briefly described. Sample assessments of the commercial potential for several ceramic products are also provided.

The information in the book is from *Advanced Materials Technology Project—Final Technical Report,* prepared by William L. Frankhouser of System Planning Corporation for the U.S. Department of Defense, Defense Advanced Research Projects Agency, May 1986.

The table of contents is organized in such a way as to serve as a subject index and provides easy access to the information contained in the book.

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The research was ably assisted by Linda Glickman, Nicholas Mercury, Phyllis Moon, and other members of SPC's Technical Library staff.

The text was edited by Len Eggert and Ellen Levenseller. Typing was provided by Doreen Kelley and Janice Taylor, who are extremely tired of spelling Soviet names.

The many reports prepared under this effort were illustrated by SPC's Visual Department and reproduced by the Publications Center.

Guidance from the Program Manager at DARPA, Dr. Steven Wax, and from SPC management, specifically Jack Fagan and John Drain, helped immeasurably.

Overall, the program has been a gratifying experience. Although the investigative subjects are on the leading edge of materials technology, practical applications are now in sight.

NOTICE

The materials in this book were prepared as accounts of work sponsored by the U.S. Department of Defense, Defense Advanced Research Projects Agency. The views, opinions, and findings contained in this report are those of the author and should not be construed as an official Department of Defense position, policy, or decision, unless so designated by other official documentation. On this basis the Publisher assumes no responsibility nor liability for errors or any consequences arising from the use of the information contained herein. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the Agency or the Publisher.

Final determination of the suitability of any information, procedure, or product for use contemplated by any user, and the manner of that use, is the sole responsibility of the user. The book is intended for informational purposes only. Expert advice should be obtained at all times when implementation is being considered, particularly where hazardous materials or processes are encountered.

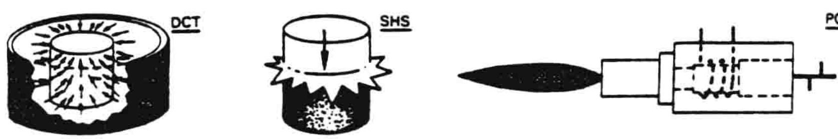
Contents and Subject Index

I. Executive Summary

A. PROJECT DESCRIPTION AND ORGANIZATION OF REPORT

A final technical report on System Planning Corporation's (SPC) Advanced Materials Technology Project has been completed for the Defense Advanced Research Projects Agency (DARPA). This report integrates information presented previously in quarterly progress reports and semiannual technical reports with information on activities performed during the present quarter of the 2-year contractual period.

Laboratory development of advanced materials processing technology has been sponsored by MSD at Battelle (BTL), Lawrence Livermore National Laboratory (LLNL), and Los Alamos National Laboratory (LANL). Emphasis in laboratory programs has been on fabrication of advanced refractory ceramic compounds by new technologies that promise quality products not otherwise available at reasonable cost. The processing techniques are dynamic compaction technology (DCT), self-propagating high-temperature synthesis (SHS), and plasmachemical technology (PCT).



SPC has supported both MSD and the laboratory participants through investigations of commercial potential of the processing technologies and opportunities for technology transfer and by assessments of Soviet progress in materials science and engineering. The four specific task assignments are:

- Technology applications in commercial industry (Task 1)
- Technology applications within the defense community (Task 2)
- Relevant Soviet materials technology (Task 3)
- Commercial potential of technology (Task 4).

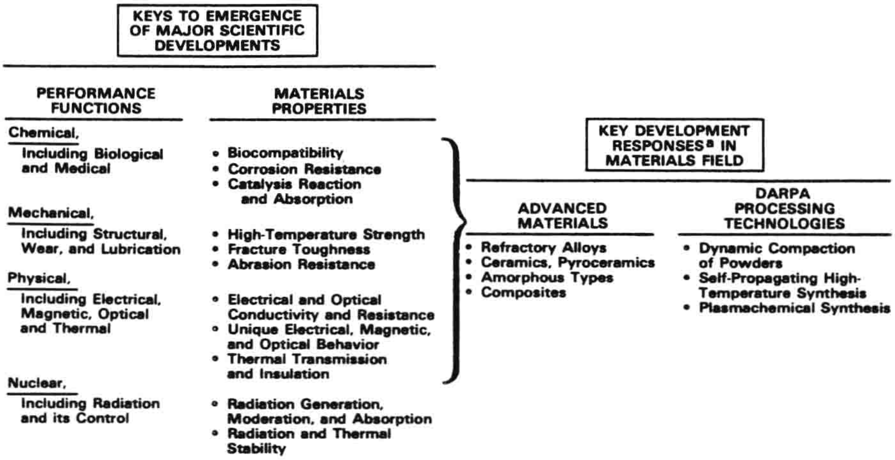
Activity highlights for the four tasks are presented in Section C of this chapter. More detailed accounts of activities follow in Chapters II through V, where locations of key information in prior SPC reports also are identified.

B. SIGNIFICANCE OF ADVANCED CERAMICS AND MSD FABRICATION TECHNOLOGIES

Implications attributed to top scientists [Refs. 1 through 13] regarding emergence of major scientific developments during the remainder of this century follow:

- Performance functions requiring unique materials properties underlie emergence of the most significant developmental technologies into new industrial products.
- Many property requirements reach beyond performance capabilities of existing materials.
- Space and energy systems that operate at high levels of efficiency, at extreme temperatures, and in harsh environments dominate development of new materials technologies.
- Most new products that satsify these needs must be fabricated through powder processing operations, and many of these products are advanced ceramics.

As demonstrated in Figure 1, the DARPA development of advanced processing technologies is an appropriate response to crucial needs of emergent scientific developments. The program concentrates on processing advanced ceramic materials that will satisify many key performance functions and properties.



[a]WIITH RELEVANCE TO DARPA PROGRAM

FIGURE 1. SIGNIFICANCE OF THE DARPA MATERIALS PROCESSING PROGRAM TO MAJOR SCIENTIFIC DEVELOPMENTS

C. STUDY HIGHLIGHTS

1. Technology Transfer to Commercial Industry (Chapter II)

The task assignment was to facilitate technology transfer to commercial industry. The approach was to make industry aware of the DARPA program and to encourage flow of information between the laboratory participants and interested industrial organizations. The effort was centered on fabricating advanced ceramics and composites by SHS and DCT technologies, with greater emphasis on the former; PCT development was not considered to be sufficiently mature to warrant a comprehensive effort.

The largest volume market applications anticipated for advanced ceramic and composite products in six industrial fields are identified in Table 1. Each product is associated either directly with specific needs of major emergent technologies or indirectly through support industries.

In regard to SHS technology, the interest in commercial industry is judged to be intense:

- Thirty-five points of contact in industry have been briefed individually on SHS.
- Fifteen to 20 industrial companies were represented at the program review that was held in Florida during October 1985.
- A book describing U.S. and U.S.S.R. programs in SHS has been published [Ref. 14].
- SHS was the subject of a feature article in Advanced Materials & Processes during February 1986 [Ref. 15].
- The technology has been described to a sizeable group of industrial representatives in a 2-day seminar on advanced materials processing technologies.
- An industrial consortium is being organized to support continued technology development at LLNL as financial support is phased out by DARPA

TABLE 1

ADVANCED INDUSTRIAL PRODUCTS POTENTIALLY FABRICABLE BY DARPA PROCESSING TECHNOLOGIES

HIGH-TEMPERATURE ENGINES

- Combustion engines (e.g., combustion liners, chambers)
- Turbine engines (e.g., blades, nozzles, shrouds)

ELECTRONIC HARDWARE

- Thermistors, semiconductors
- Insulators
- Substrates for integrated circuits

OTHER REFRACTORY STRUCTURALS

- Furnance elements
- Heat exchanger components
- Heat pipes
- Metal refining electrodes

ENERGY STORAGE

- Advanced electromagnetic batteries
- Hydrogen storage systems

MATERIALS FINISHING ACCESSORIES

- Grinding wheels, polishing pastes
- Machining tool bits

WEAR AND ABRASION HARDWARE

- Metal-forming dies
- Pump components (e.g., seals)

Although the DCT program was not briefed as widely to commercial industry as SHS technology, considerable industrial interest has been apparent. An effort has been initiated recently to present a seminar on DCT to a large group of industrial representatives. Also, many industrial products that can be fabricated by dynamic compaction of metal or ceramic powders have been identified to representatives of the laboratory development programs.

The PCT program at LANL was described in an independent technology transfer briefing at that facility. This technology was one among many LANL developments described to industry.

2. Potential Defense Systems Applications (Chapter III)

The task assignment was to establish program interfaces for eventual defense applications of the DARPA materials processing technologies. The approach was to identify potential applications and to develop appropriate contacts between the materials processing program and Government systems programs. The effort was centered on DCT and SHS technologies, with greater emphasis on the former. PCT development was not considered to be sufficiently mature to warrant a comprehensive effort.

Since advanced ceramics are important to future defense applications and other Government development programs, a comprehensive assessment was made of the expected evolution of an advanced ceramics industry during the remainder of this century. Results indicate that:

- The industry is expected to demonstrate one of the most rapid market growths during the 1980s and 1990s among all industries in developed countries.
- Many of the potential applications are attributable to processing capability in synthesizing compounds, compacting powders, or coating substrates.
- The greatest potential processing payoff is combined synthesis and compaction of dense products.
- Rapid solidification technology (RST) and DCT make an ideal processing combination by which new amorphous materials (e.g, metallic glasses and complex ceramic compositions) can be formed as powders and subsequently densified into monolithic product shapes without undesirable crystallization.

Specific applications for DARPA processing technologies in Government programs are presented in Table 2 for six product types, and representative material compositions (e.g., aluminides, nitride/carbide and metal/ceramic composites, hydrides) and manufacturing procedures are described in Chapter III. The capability of DCT and SHS technology in bonding macrocomposite structures and in making microcomposite compositions is exploited in these applications.

Points of contact were established between the DARPA advanced processing technology program and other Government programs:

- Approximately 25 program managers were provided with briefing information on the DCT and SHS technology programs.
- Seven of these managers attended the DCT program review in September 1985, and nine Government organizations, in addition to MSD, were represented at the SHS program review in October 1985.
- A follow-on program to continue development of DCT in the armaments field when DARPA funding is phased out has been planned by these contacts.

3. Surveillance of Relevant Soviet Programs (Chapter IV)

The task assignment was to assess relevant Soviet work in developing and processing advanced materials and to assess their product applications. The approach was to monitor open (unclassified) Soviet literature on materials science and engineering. In cases where commercial translations of Soviet publications into English were not available, translations were made and forwarded to all participants in the DARPA program. Greatest emphasis was on PCT since this was considered to be in the earliest development stage among the three processing technologies.

Soviet development of PCT and SHS continues to lead progress in the United States:

- Both technologies have been included as discrete items for several years in the Soviet national plan for advancement of technology.
- National Soviet centers have been established to exploit each technology.

TABLE 2

POTENTIAL PRODUCT APPLICATIONS IN GOVERNMENT PROGRAMS[a]

Applications	Potential Products Fabricable by DARPA Processing Technologies
Armaments	Lightweight ceramic armor Ceramic gun barrels or liners Composite (metal/ceramic) penetrators
Ceramic Engines	Combustion components and hardware Spark plugs Turbine blades Bearings
Electronic and Optical Hardware	Stacked-layer capacitors and semiconductors Fiber optic wave guides on ceramic substrates
Other Structural Components	Composite (metal/ceramic) periscope tubes Deep-submergence vessels Space reactor heat pipes Memory-alloy connectors
Nuclear Power	Advanced fuels Waste isolation matrices High-efficiency neutron shields Refractory alloys and nonmetallic compounds (for heat pipes, structurals, liquid metal service, etc.)
Mechanical	Tool hardware High-temperature lubricants

[a]Some of the broader industrial applications previously listed in Table 1, although applicable, are not repeated.