OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

This document has been produced without formal United Nations editing. The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries, or its economic system or degree of development. Designations such as "developed", "industrialized" and "developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names or commercial products does not constitute an endorsement by UNIDO.

FAIR USE POLICY

Any part of this publication may be quoted and referenced for educational and research purposes without additional permission from UNIDO. However, those who make use of quoting and referencing this publication are requested to follow the Fair Use Policy of giving due credit to UNIDO.

CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

Advances in Materials Technology: MONITOR

Issue Number 16 January 1990

MATERIALS DEVELOPMENTS IN SELECTED COUNTRIES

Dear Reader,

The Issue No. 16 of UNIDO publication "Advances in Materials Technology: Monitor" is not devoted, as in the past, to a selected material, a material-related technology or a group of materials. Instead we have tried to look into the materials situation and institutional mechanisms of selected developed and developing countries. The status and prospects of R&D programmes, applications and development strategies of these countries are brought to your attention as well as how the developing world can exploit the opportunities from the current revolution in the field of new materials.

The articles relating to the materials situation in selected Asian countries were prepared for presentation at the UNCSTD/ESCAP Regional Workshop on Advanced Materials Technology and Development in Asia and the Pacific (Minsk, USSR, 29 May - 2 June 1989).

We are hoping that our readers will read this Monitor with great interest and would appreciate it very much to receive views and opinions on it. We invite you also to share with us your knowledge related to the situation in any particular country.

If any of our readers are interested in advertisements in the Monitor or would like to have meetings or seminars included, please do not hesitate to contact the Editor.

Our appreciation to all our readers for the returned questionnaires. We also take careful note of all your comments and suggestions which are of great help in editing the Monitor.

Industrial Technology Development
Division

CONTENTS

1. MATERIALS SCIENCE AND ENGINEERING FOR THE 1990s
SUMMARY

MAINTAINING COMPETITIVENESS IN THE AGE OF MATERIALS

Committee on Materials Science and Engineering. Solid State Sciences Committee, Board on Physics and Astronomy, Commission on Physical Sciences, Mathematics, and Resources, and National Materials Advisory Board Commission on Engineering and Technical Systems. National Research Council (National Academy Press, Washington, D.C. 1989)

Contents

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The contents of the entire report, from which this summary is extracted, are listed below.

1. WHAT IS MATERIALS SCIENCE AND ENGINEERING?

2. MATERIALS SCIENCE AND ENGINEERING AND NATIONAL ECONOMIC AND STRATEGIC SECURITY

3. RESEARCH OPPORTUNITIES AND FUNCTIONAL ROLES OF MATERIALS

4. RESEARCH OPPORTUNITIES AND THE ELEMENTS OF MATERIALS SCIENCE AND ENGINEERING

5. MANPOWER AND EDUCATION IN MATERIALS SCIENCE AND ENGINEERING

6. RESOURCES FOR RESEARCH IN MATERIALS SCIENCE AND ENGINEERING

7. COMPARISONS OF EFFORTS IN MATERIALS SCIENCE AND ENGINEERING OF SELECTED NATIONS

APPENDIXES: ISSUES IN MATERIALS RESEARCH

The summary is available from the Board on Physics and Astronomy, National Research Council, 2101 Constitution Avenue, NW, Washington, DC 20418.

The complete volume is available for sale from the National Academy Press, 2101 Constitution Avenue, Washington, DC 20418.

Below is an excerpt from the Summary of this report.

Role of materials in industry

Chapter 1 briefly discusses the significance and development of materials science and engineering as an interdisciplinary endeavour that profoundly affects our quality of life in many ways.

Chapter 2 examines the role of materials science and engineering in eight US industries that collectively employ more than 7 million people and have sales in excess of $1.4 trillion, and it summarizes the materials science and engineering needs of each of those eight industries - aerospace, automotive, biomaterials, chemical, electronics, energy, metals and telecommunications. Several important facts emerged from the industry surveys. Within each industry, several companies were asked to indicate their materials needs; it proved to be possible to describe the needs of those companies in a given industry in generic terms. Furthermore, the lists of generic needs of the various industries had a wide overlap. Finally, industrial materials needs and problems often led scientists and engineers to the frontiers of research in search of solutions. The committee concludes:

- Materials science and engineering is crucial to the success of industries that are important to the strength of the US economy and US defence;

- There is considerable overlap in the generic materials problems of the eight industries studied; solutions to many of these problems lie at the forefront of research in materials science and engineering.

Two pervasive elements of materials science and engineering that appeared throughout the industry surveys were (1) synthesis and processing and (2) performance of materials. The industry survey participants saw opportunities to improve the effectiveness of all the sectors involved in materials science and engineering. They saw industry as having the principal role in maintaining competitiveness. Accordingly, the committee concludes:

- The industry surveys revealed a serious weakness in the US research effort in synthesis and processing of materials. There are opportunities for progress in areas ranging from the basic science of synthesis and processing to materials manufacturing that, if seized, will markedly increase US competitiveness;

- Increased emphasis on performance, especially as it is affected by processing, is also needed to improve US industrial products for world markets;

- Industry has the major responsibility for maintaining the competitiveness of its products and production operations. Greater emphasis on integration of materials science and engineering with the rest of their business operations is necessary if US firms are to improve their competitive positions in domestic and international competition. Incentives for top-quality people to become involved in production will have to be introduced to achieve such an emphasis. Collaboration with research efforts in universities and government laboratories can enhance the effectiveness of R&D programmes too large for any one company. The objective of all of these steps would be renewed emphasis on effective long-range R&D in industry.

Opportunities in materials science and engineering

The practitioners of materials science and engineering have much to say about the challenges and excitement of the field. More than 100 scientists and engineers from many different disciplines and institutions (e.g., universities and industry and government laboratories) participated in this study. Based on evaluation of their contributions, this committee concludes the following:

- The field of materials science and engineering is entering a period of unprecedented intellectual challenge and productivity.

Various properties (or phenomena) that make materials interesting are discussed in chapter 3. The open intellectual terrain ahead is apparent in each of the materials classes discussed. The structure and properties of materials are understood and are subject to control in ways that were unheard of a decade ago. For example, artificially structured materials can be built up from selected atoms one atomic layer at a time. This reality is deepening and reshaping the concept of what materials science and engineering is. A common element that links the great diversity of work in materials science and engineering is the controlled combining of atoms and molecules in large aggregations in ways that endow the resulting materials with properties that depend not only on the chemical nature of the atomic and molecular constituents but also on their interactions in the bulk of the material and on its surfaces. Calculation of materials properties from first principles is increasingly used by scientists and engineers to understand the origin of properties and to achieve desired characteristics.

The committee concludes:

- Materials scientists and engineers have a growing ability to tailor materials from the atomic scale upwards to achieve desired functional properties;

- In many industries, the span of time between insight and application is shrinking, and these processes are becoming increasingly interactive and iterative. Scientists and engineers must work together more closely in the concurrent development of total materials systems if industries depending on materials are to remain competitive.

These conclusions surfaced in discussions of research opportunities in structural, electronic, magnetic, photonic, and superconducting materials. From strip casting of metals through the synthesis of new nonlinear optical media in photonic materials, advances in technologies that depend on performance at the cutting edge to remain competitive require the best co-operative contributions of engineering and science.

Emerging unity and coherence of the elements of materials science and engineering

Materials and their applications are diverse, and materials problems involve many science and engineering disciplines. None the less, as discussed in chapter 4, this committee recognizes an emerging unit and coherence in the field, stemming from the fact that materials scientists and engineers all work on some aspect of materials with the aim of understanding and controlling one or more of the four basic elements of the field. These four elements include:

1. The properties or phenomena that make a material interesting or useful;

2. Performance, the measure of usefulness of the material in actual conditions of application;

3. Structure and composition, which includes the arrangement of as well as the type of atoms that determine properties and performance; and

4. Synthesis and processing, by which the particular arrangements of atoms are achieved.

The scope of materials science and engineering includes not only areas whose utility can be identified today, but also those in which researchers seek a fundamental understanding whose utility may be unforeseen. History has shown time and again that such fundamental understanding leads, often in unexpected ways, to innovations so profound that they transform society. The quantum Hall effect and high-temperature superconductivity are two examples of phenomena involving the collective behaviour of electrons in solids that could not have been envisioned a decade ago and whose full implications for our understanding of materials are still evolving. Science in the materials field must include not only those areas whose utility is clear but also basic work that provides fundamental understanding of the nature of materials. Achieving such a fundamental understanding often leads ultimately to important contributions to practical materials problems.

At the engineering end of the spectrum covered by materials science and engineering, there is currently much excitement about the growing ability to exploit the relationships among the four basic elements of the field to develop and produce materials that perform in new or more effective ways. Examples of recent successes extend from the miniaturization of electronic components to steadily improving productivity and quality in the steel industry. Examples of future challenges extend from the practical realization of high-temperature superconductivity to the development of more economical methods of fabricating automotive components from polymers and polymer composites. Thus the committee concludes:

- Materials science and engineering is emerging as a coherent field;
- An effective national materials science and engineering programme requires healthy, balanced and interactive efforts spanning basic science and technology, all materials classes, and the four elements of the field: properties, performance, structure and composition, and synthesis and processing.

Instrumentation and modelling

Without advanced instruments, it is impossible to carry out research at the frontiers of science and engineering. In chapter 4 also, the committee develops the idea that renewed emphasis is needed on research leading to advanced instrumentation and also emphasizes that state-of-the-art instruments are needed to carry out research in the university setting. Such instruments range in size from those at the laboratory-bench scale serving a single investigator to synchrotron radiation facilities serving large numbers of scientists and engineers; they are needed for analysis and for synthesis and processing of materials.

The United States is a leader in the creative use of computers to solve research and engineering problems. Materials science and engineering can be advanced by exploiting this leadership in several areas, from the calculation of electronic-based structures, through simulation of nonequilibrium processes, to real-time monitoring and control of processing. The committee concludes:

- Progress in the four elements of materials science and engineering can be enhanced through increased R&D on and use of advanced instrumentation ranging from the laboratory-bench scale to major national user facilities, and through increased emphasis on computer modeling and analysis of materials phenomena and properties based on the underlying physical and chemical principles.

Education

The practitioners in the field come from materials science and engineering departments as well as from various disciplinary backgrounds, including physics, chemistry, and allied engineering fields. Chapter 5 asserts that educating students for careers in materials science and engineering requires a recognition of both the diversity and the coherence of the field. The committee concludes:

- The total number of degrees granted by materials-designated departments plus those granted in solid-state physics and chemistry and in polymer physics and chemistry in the field of materials science and engineering has remained essentially constant for more than 20 years, while opportunities in the field have expanded. If they are implemented, the initiatives recommended in this report will create an additional demand for highly qualified personnel in materials science and engineering;
- There is a critical need for curriculum development and teaching materials for educational programmes in materials science and engineering to reflect the broadening intellectual foundation of the field and the increased awareness of the importance of synthesis and processing.

Infrastructure and modes of research

Materials science and engineering is practised at university, industry, and government laboratories. Chapter 6 emphasizes that, although the size of groups working on materials problems varies, most of the effort is carried out on a small scale by individuals or small teams who follow their line of research with modest resources, although some work involves major national facilities. Other work involves larger interdisciplinary teams, and some is carried out by large multidisciplinary groups addressing all four elements of a materials problem (synthesis and processing, structure and composition, properties, and performance). In the long run, there will be a growing need for work on small and large scales to meet the materials challenges of a competitive international marketplace.

Research in materials science and engineering at universities typically is dominated by faculty working independently or in small, sometimes multidisciplinary teams. In contrast, materials science and engineering in industry involves larger, usually multidiscipinary teams. These different approaches will continue to be needed.

The surveys of eight industries referred to above suggest that industry leaders generally consider collaboration with universities desirable and in some cases even essential to address materials problems that must be solved to meet international competition. The commitee's survey of materials science and engineering at national laboratories (chapter 6) suggests that they are also an important resource that is only now beginning to be tapped. Thus the committee concludes:

- Small-scale research carried out by a principal investigator, sometimes with a small team, is cost-effective and is a major contributor to innovation. The United States has excelled in this mode of research;
- Large multidisciplinary teams are an effective mode for addressing industrial materials science and engineering problems;
- At the national level, industry, university, and government laboratories have the technical strength to mount major efforts and to exploit breakthroughs in the field. All three have been found to be receptive to joint materials science and engineering programmes that would be supportive of more rapid commercial development.

Materials science and engineering in selected countries

For the last 40 years the United States has led world industry on the strength of its pre-eminence in science and technology. As Western Europe and Japan have built up their strengths in science and technology, the gap between their status and that of the United States has begun to close. In some areas these nations have caught up with or even overtaken the United States. Chapter 7 points out that the governments of our trading partners have made strong commitments to industrial growth and to co-ordinated R&D in three areas: biotechnology, computer and information technology, and materials science and engineering. The committee concludes:

- The governments of the major US commercial trading partners and competitors, including Japan and the Federal Republic of Germany, have targeted materials science and engineering as a growth area and as a result have developed strong competence in selected materials science and engineering areas;
- These governments have taken a proactive role in deciding which areas of materials science and engineering will be emphasized on the basis of their contribution to enhancing industrial competitiveness;
- The various governments use differing mechanisms for achieving national co-ordination of programmes in materials science and engineering, with varying degrees of success.

RECOMMENDATIONS

The recommendations of this committee are divided into three parts. The first part concerns strengthening the field; the second, maintaining and improving the infrastructure for research in materials science and engineering; and the third, recognizing and developing the unifying trends in the field.

Strengthening materials science and engineering

Finding: Materials science and engineering is a field that is both scientifically and technically exciting and important to mankind through the daily impact of materials on the quality of life. Hence, a strong national effort is justified. The committee's first recommendation is as follows:

- The national programme should include strong efforts in all four basic elements of materials science and engineering - synthesis and processing, structure and composition, properties, and performance. The programme should include work that explores the relationships among the four elements and that spans the range from basic science to engineering;
- The elements of synthesis and processing as well as performance in relation to processing are currently relatively weak and should be emphasized within this national programme.

Finding: Federal support for materials science and engineering over the past decade shows a downward trend. As a result of the decline in support, the national materials effort is not exploiting new opportunities sufficiently rapidly. In some areas, such as synthesis and processing, there is a shortage of skills and resources. Accordingly, the committee recommends:

- The federal materials science and engineering programme should be restored over the next several years to the levels that prevailed in previous decades in order to exploit the renewed opportunity to make accelerated progress.

Finding: The general magnitude of the requirements for an adequate national effort in synthesis and processing was discussed with industry representatives. It was apparent that several hundred million dollars would be required to support fully the needs of the electronics and photonics industries alone. Clearly, meeting the needs of all the industries surveyed for this report would require much more support.

Synthesis and processing together form a critically important element of materials science and engineering that has too often been neglected by universities, industry, and government. It is the activity that is responsible for boosting the strength of advanced alloys and composites, for increasing the number of components on integrated circuits, and for producing new superconductors with higher transition temperatures and current-carrying capacities. Work in this area ranges from synthesis of artificially structured materials (with such advanced techniques as molecular beam epitaxy) to engineering of new alloys. Synthesis and processing, which are central to the production of competitive high-quality, low-cost products, lead to new materials with new properties and performance. Work in this area also leads to new and improved production processes with resulting lower costs. The element of synthesis and processing is therefore a crucial determinant of industrial productivity and, ultimately, international competitiveness. The committee recommends:

- New federal funds should be allocated for support of a national initiative in synthesis and processing. The initiative should provide support for facilities, education, and the development of research personnel. The strengths of universities, industry, and government should be brought into play, and the interactions of these three groups should be directed towards promoting the reduction of materials science and engineering results to commercial practice in the most effective possible manner.

Finding: Another element of materials science and engineering that needs attention is performance. The properties of materials are put to use by society to achieve desired performance in a device, component, or machine. Some measures of performance include reliability, useful lifetime, speed, energy efficiency, safety, and life cycle costs. Performance is circumscribed by fundamental properties of materials (such as carrier mobility, which influences the switching speed of high-performance transistors, which in turn determines the speed of computers in which such transistors are used). Research to improve performance has received little emphasis in long-range programmes, especially in universities, and there has been far too little linkage of this research to the other three elements of materials science and engineering. Some examples of areas representing opportunities for research to improve performance include prediction of the strength and lifetime of complex components and devices, development of improved nondestructive testing techniques, and modelling of systems for optimum material and process selection. The committee recommends:

- Research on performance (including quality and reliability) should be increased, especially in relation to processing, but also in relation to the other elements of the field of materials science and engineering.

Finding: Two additional areas of materials science and engineering need greater emphasis: (1) analysis and modelling and (2) instrumentation. In analysis and modelling work, three factors are leading to an explosion of activity, opportunities, and results. The first is the increasing speed, capacity, and accessibility of computers and the concomitant decreasing cost of computing. The second is the growing complexity of materials research and manufacturing. The third is the need in industry to speed the introduction of new designs and new processes into production and to improve production processes and products. Progress in these areas will serve to strengthen fundamental understanding of materials science and engineering and to integrate this understanding with applications. The committee recommends:

- Increased emphasis should be given to computer-based analysis and modelling in research programmes in materials science and engineering.

Finding: The capability to measure and analyse composition and structure at increasingly smaller levels is surely one of the great engines of progress of modern materials science and engineering. Of equal importance to materials science and engineering progress today is the ability to control structure and composition in new ways and at new levels of precision. Instruments, especially new and sophisticated instruments, will continue to enhance progress in materials science and engineering. The committee notes that the level of support allocated to development of new and unique instruments in universities is small and that US industry is losing its ability to take basic inventions in this area and convert them into business opportunities. The effect of this deterioration in capability is that advanced instrumentation does not diffuse rapidly throughout the academic and industrial research communities. National laboratories, through their large facilities and capabilities in instruments and facility development, may be able to make a unique contribution to this activity. The committee recommends:

- Government funding agencies should devote a portion of their materials science and engineering programme budgets specifically to R&D on and demonstration of new instruments for analysis and synthesis and processing of materials, including instruments that analyse processes in real time.

Maintaining and improving the infrastructure for research in materials science and engineering

Finding: The field of materials science and engineering is broad. The products of research in this field must meet the exacting standards of intellectual pursuit in an academic setting and of international competition in commerce and defence. The way research is funded and organized in materials science and engineering must reflect this range of goals.

The principal investigator mode of research has made the United States one of the strongest nations in basic research. There is a wealth of good experience with this approach, and the committee has found no evidence to suggest a need to change it. Accordingly, the committee recommends:

- The US national asset of excellence in the principal investigator mode of research should be preserved and strengthened in the field of materials science and engineering.

Finding: In recommending preservation of research headed by a principal investigator, the committee recognizes that individuals may join to form small groups to share resources or to attack problems requiring different skills. The committee also recognizes that many principal investigators together may make use of a local resource, for example, a materials laboratory with specialized equipment. On a national level, such investigations can involve co-operative use of a synchrotron light source or a new facility for processing. The committee therefore recommends:

- A balanced national programme of resources, including major national user facilities for materials science and engineering, materials research laboratories, and other regional facilities, should continue to be developed.

As necessary as an ensemble of principal investigators to carry out research for programmes with broad commercial or defence objectives is the involvement of people who understand applications based on new materials or, more frequently, the incremental improvement of existing materials and processes. In order for materials science and engineering to be applied, the coupling between needs and opportunities must be strong. Applied programmes need more structure: mutual understanding among those who generate knowledge and those who apply it is essential. This committee has carried out an assessment of the field in this spirit. But materials science and engineering is evolving too rapidly for major decadal surveys such as that done by the National Research Council's Committee on Science and Materials Technology study (COSMAT, Materials and Man's Needs. National Academy Press, Washington, DC, 1975) and the present study to be sufficient in themselves. The committee therefore recommends:

- Researchers who produce knowledge and those who apply it should continue to work together to identify the needs and opportunities in materials science and engineering, extending the work of this study through periodic reappraisals in selected areas. Such assessments should involve people from university, industry, and government laboratories.

Finding: The committee has concluded that materials science and engineering is carried out effectively at university and industry laboratories. The committee has observed that government laboratories, including national laboratories under the Department of Energy and the National Institute of Standards and Technology under the Department of Commerce, have considerable strength in people, equipment, and infrastructure to do research in materials science and engineering. Government laboratories have made notable contributions to this field. The strength of all three institutions - universities, industry, and government - should be directed to solving materials problems. Programmes developed jointly have several advantages - they define goals, establish needs, identify opportunities, and promote collaboration and communication. The committee recommends:

- Universities, industry, and government laboratories should develop joint programmes in areas of national importance. Government laboratories should play a central role in this effort.

Recognizing and developing unifying trends in the field of materials science and engineering

Finding: The broad conclusions of this study are that the field of materials science and engineering encompasses all materials classes; that it spans the full spectrum from basic science to engineering; and that its relation to industrial and other societal needs is strong. The field derives great strength from its relationships to these various entities - the various materials classes, both basic and applied research, and the economic and strategic well-being of the nation. The growing unity of materials science and engineering has implications for universities, industry, and government, as outlined below. The committee recommends:

- Universities, industry, government, and professional societies should strive to support and to accelerate the unifying trends that already exist in materials science and engineering.

Finding: The subject-matter in the majority of materials courses offered in US universities can be taught in a manner that is generic to all materials classes. An adequate curriculum will still contain a few subjects focusing on specific materials (e.g., semiconductors, glasses, metals, and polymers) or on specific functional classes of materials (e.g., optical materials, structural materials, and electronic materials). Such a generic approach to materials science and engineering education depends on exploiting the idea that the field is made up of the elements of properties, performance, structure and composition, and synthesis and processing; this concept provides a unity of subject matter irrespective of materials class or whether a materials problem is examined with the tools of chemistry, physics, or engineering. However, there is a dearth of teaching materials to support such an approach. In some universities, reorganization or new organizational entities may be needed, especially at the graduate level, to achieve a programme that will endow materials science and engineering professionals with the breadth and unified view of the field that is now beginning to be expected.

Finding: The most critical resource in any field is well-educated, well-trained personnel. There is a shortage of such individuals in materials science and engineering, especially in the area of synthesis and processing, at all academic levels. The committee anticipates that the increased emphasis on synthesis and processing urged by this study will create an increase in demand for personnel in this area. The committee recommends:

- Academic programmes at the undergraduate level should be oriented to the elements of the field: synthesis and processing, structure and composition, properties, and performance;

- At both the undergraduate and the graduate level, increased emphasis should be given to developing new courses and new textbooks that deal generically with all materials. The broadening intellectual foundation of the field and the importance of synthesis and processing should be reflected in these efforts.

Finding: A recurring theme in this study has been the need for stronger university-industry interactions in the field of materials science and engineering. Industry has much to gain from rapid access to advanced basic research activities, to bright future graduates, and to advanced instrumentation. Universities, if they are to remain at the forefront of the field in the teaching and research, must have close and continuing contact with industrial researchers and technologists, and they increasingly will need the financial support of industry. Many ways exist to achieve such a coupling between universities and industry, including joint research activities, joint teaching responsibilities, lifelong education, adjunct professorships, personnel exchanges, scholarship and fellowship support, and support of junior faculty. The committee recommends:

- Industry and universities should each take the initiative to work together in materials science and engineering with or without government as a partner.

Finding: Given the unifying trends in the field, it is desirable and appropriate that various efforts within relevant agencies have already been consolidated into clearly recognizable units dedicated to materials science and engineering. Renewed efforts to co-ordinate programmes in different federal agencies would be a valuable extension of this accomplishment. Agencies carrying out both extramural and intramural research in materials science and engineering have an opportunity to reinforce their efforts by organizing programmes in a way that recognizes the increasingly strong link between the engineering and scientific aspects of the field. A long-range interdisciplinary approach to the entire field is the best approach to capitalizing on the extensive opportunities that it presents. Accomplishing this end is best achieved through formulation and dissemination of broad, long-range goals that go beyond programmatic and disciplinary boundaries. The committee recommends:

- The government should recognize the essential unity of materials science and engineering in its planning, funding, and co-ordinating activities.

Finding: The government plays a leading role in advancing materials science and engineering by supporting basic research at universities and at national laboratories, constructing and operating major user facilities, supporting the enhancement of generic technology in collaboration with industry, performing materials science and engineering germane to the specific missions of each government agency, and developing test methods and reference materials needed for accuracy in characterization of materials.

Finding: The government has additional opportunities to advance materials science and engineering by taking a more active role in the following facilitative functions:

1. Building consensus. The government should create mechanisms that will result in the development of consensus among the many sectors that are involved in particular areas of materials science and engineering. Consensus is needed on such topics as evolving research opportunities, the identification of barriers to development that demand broad efforts directed towards their removal, and the understanding and proposing of actions to attack deficiencies in personnel.

2. Promoting co-operative interactions. The government should serve as an enabling organization for bringing together various sectors to work on common problems. Objectives could include stimulating the creation of industry consortia, encouraging joint industry-university programmes, stimulating joint industry-national laboratory co-operation, and identifying and removing barriers to joint efforts.

3. Identifying industrial needs. The government should encourage the various sectors of industry to identify important materials problems that they anticipate must be solved if they are to improve their competitiveness in the international marketplace. Such problems might include (a) materials needs for products and processes and (b) limitations on analytical capabilities and on availability of data that create barriers to the rapid design, testing, and use of new materials.

4. Communicating industry needs. The government should communicate a continuing assessment of the needs of industry that were identified in the eight industry surveys described in chapter 2 to all members of the materials science and engineering community, including the agencies responsible for supporting materials research.

5. Balancing federal programmes. The government should establish an annual review process for the federal programmes related to materials, including those in research, development, and procurement, to ensure that they are balanced and are responsive to the needs of the nation and the opportunities that are available for accelerating progress.

The committee recommends:

- The government should assume a more active role in bringing together the various groups involved in materials science and engineering and in enhancing communication, interaction, and co-ordination among the many sectors affected by materials science and engineering.

Finding: Many small businesses that are involved in the materials field can benefit from the availability of new technology and a broader interaction with the larger materials community. State programmes that are being established to accomplish these objectives are likely to be more effective than federal ones. The involvement of the State-supported universities, the creation by the States of entities that can effectively experiment with new means of interacting with local businesses, and the willingness of States to invest resources in local enterprises are important and useful developments.

Finding: The hundreds of laboratories funded by the federal government and sometimes by state governments have many capable personnel and large capital resources that could benefit industry. In particular, the national laboratories funded by the Department of Energy have many scientists and engineers with special talents in materials science and engineering. Reorientation of the missions of the national laboratories towards industrial materials science and engineering interests could have a salutary effect on US industrial competitiveness.

- The committee endorses the goals adopted by the Congress in setting up the National Critical Materials Council, which should work with other agencies to ensure that the government carries out the facilitative functions as well as the more specific tasks identified above;

- To accomplish the data collection and analysis that are critical to carrying out these tasks, the committee recommends that the National Critical Materials Council co-operate with other organizations such as the Office of Science and Technology Policy's Committee on Materials, the National Science Foundation, the Department of Energy, the National Institute of Standards and Technology, the National Research Council, and the professional societies.

2. CURRENT REVOLUTION IN NEW MATERIALS: OPPORTUNITIES FOR THE DEVELOPING WORLD

Pradeep Rohatgi
Department of Materials
University of Wisconsin - Milwaukee
P.O. Box 784
Milwaukee, Wisconsin 53201, USA

1. Introduction

The activity in materials technology is age-old starting from the use of agricultural materials, stone, bronze, iron, clays and ceramics. However, most of the developing countries have missed out on the scientific and the industrial revolution of the last 300 years to varying degrees, including the revolution in materials technology. This has resulted in the lack of availability of materials per capita in developing countries both in quality as well as in quantity, as compared to the availability of materials in the advanced countries. The developed world is undergoing yet another revolution in materials an example of which is high-temperature superconducting materials. It is imperative that the developing world is adequately prepared to exploit the opportunities opened up by these new materials. The overall question is of building capability in the developing world to exploit the opportunities from the new revolution in materials while warding off the threats from the same revolution. Capacity building in materials will involve multidimensional activity including building capacity for technology forecasting, technology assessment, formulating materials policy, education, training, research, development, manufacturing, testing and standardization.

Different developing countries are in different stages of materials cycle and presently represent a spectrum of capabilities to deal with the new materials revolution. In view of this, uniform prescriptions cannot be given for all developing countries. In this paper only broad directions are discussed, and imperatives for individual countries will have to be derived through normative exercises.

The current average availability of manufactured materials 6-19/ and energy 20/ per capita in the developing world is often 100 times less than the advanced countries (tables I, II). In addition the present costs of materials in relation to incomes in developing countries are very high, and this results in further inequitable distributions of even these small quantities of materials. Much of the modern manufactured materials are in the possession of the rich élite in these countries leaving the poor even more impoverished in terms of availability of materials. The abundant supply of materials, and the services produced using materials, such as food, drinking water, housing, energy, health and clothing could go a long way in reducing human misery in the developing world, and even in poorer sections of populations in advanced countries.

The equitable and abundant availability of materials at low costs affordable by the people of developing countries can eliminate international conflicts, national and local conflicts. For developing countries, and even for the poorer sections in advanced countries, the linkage between materials and the basic human needs as mentioned above are more important than the linkages between materials and weapon systems, materials and faster aircrafts, and materials and other secondary desires.

The materials field is undergoing a revolution with the emergence of advance materials engineered without the restraints of thermodynamic equilibrium to meet specific needs; these materials can now be tailored to meet the property or performance targets. While the science-pushed basic advances in materials science appear to be common to the whole world, the directions in which materials science and technology should be driven to meet the needs of development for the third world countries, and the poor in advanced countries, points to additional imperatives which will be the focus of this paper. Monitoring and forecasting developments in materials science and technology and taking preparatory steps like identifying and establishing centres of excellence are some of the imperatives of the day.

2. Challenges for materials technology for development

The existing data on the per capita GDP in different countries of the world shows a linear log-log relationship 6/ with the per capita availability of different materials including steel, copper, aluminium, cement, zinc and tin in these countries. This indicates that the process of development reflected as well as it can be by rapidly increasing per capita GDP in different countries, will inevitably require production of, and availability of 10 to a 100 times additional quantities of materials in many of these countries, as compared to production levels today. Most of the developing countries are at a stage where the unit inputs of materials and energy to produce an additional unit of GDP are likely to continue to increase for several years. Any reductions in requirements of materials per capita due to miniaturization and substitution by lighter weight high-strength materials and parts consolidate, would more than likely be offset by increasing requirements of materials due to rapidly increasing populations, and the increasing materialism and consumerism in most of these countries. The challenge for materials technology for development, for at least the next 50 years will be to increase the availability of materials required for housing, water, food, energy and health care, by as much as 10 to a 100 times in many of the developing countries without pressures on resources, energy requirements, environment and employment. The populations in most of these countries would have more than doubled in 50 years and by that time these countries would be trying to reach the standards available in the advanced countries today (table I). Even the basic advances in materials science which could enable the materials technology of the future to meet this challenge should be derived in a normative way, and be accelerated in time by increased inputs compared to basic advances required for new materials for new weapon systems. The paradigm for materials technology for development should lead to basic need-based materials 21/ (table III) which are smaller, lighter, longer lasting, low cost, low energy and recyclable based on abundant and renewable resources which can be locally processed using simple and employment generating non-polluting technologies.

Many of the knowledge driven advances in materials science including rapidly solidified structures, macro molecular materials 22/ plasma sprayed and vapour deposited materials, mechanically alloyed materials, materials which have three-dimensional structure architecture at nano, micro and macro scales, materials with controlled interfaces made from super ultra-fine powders where the bulk properties do not remain valid, and surface processed materials should be deliberately steered in directions to meet these developmental needs of materials.

3. Issues and options for developing countries

3.1 Housing

Housing remains 16-19/ one of the most important problems of development due to lack of availability of materials, and this is an area where miniaturization cannot be applied beyond a certain point. One of the major challenges is reduction in the cost of materials for housing and increase in the performance of construction materials, particularly those based on local renewable or abundant resources. The high priorities here will include a greater attention to materials science and technology of alumino silicates, earth, stone, laterite and clay-based products which can be readily made everywhere. There is need to improve the performance of bricks from common clay and develop biomass or solar energy sources to fire them, or to develop low-temperature binders and sintering agents. The other area is application of modern materials science and technology to renewable resources, particularly locally available plant-based resources; some examples of these resources for materials of construction include bamboo, *Impoemea carnea*, fibres from plants like coconut, sisal, banana, sunhemp, grasses, and large agricultural wastes like paddy straw, and wheat straw.

A shortage of cement and its high price are great barriers in increasing the supply of housing in developing countries. It is necessary that greater attention be paid to using rice husk ash, fly ash and mineral waste type materials to increase the volume of cement and bring down the cost of new high tech cements like zero defect cement, rapid setting cement, chemically bonded cement, fibre reinforced cement, the price of which is presently beyond the reach of the poor. Millions of people in the developing world use plant-based materials like coconut thatch for roofing, which do not provide adequate protection from nature and require replacement every year. Inputs of modern materials science and technology are required to increase the life and performance of these plant-based materials for housing and to make them more resistant to elements of nature and fire.

3.2 Bio-processing of materials

A certain amount of advanced research in genetic engineering would be in order to possibly increase the strength of wood and fibres available from fast growing trees, in addition to the present focus on increasing the yield; the development of plants which can get nitrogen from air will reduce considerable pressure of manufacturing fertilizers from minerals in developing countries.

Biological routes to production and preservation 14/, 23/ of materials requires greater attention in the context of development. Some of the areas that require research include microbiological process to extract metals from ores and ocean nodules, and to remove sulphur and silica from minerals like coal and bauxite. Newer methods of microbial degradation can be used to extract fibres and ultra fine ceramic powders at low energy costs from agricultural products and wastes.

The problem of moisture absorption in these natural fibres needs to be solved by techniques such as acetylation. Greater attention needs to be paid to make silicon carbide whisker type high-performance materials from other agricultural resources in addition to rice husk with reduced inputs of energy. Modern microbiological techniques to extract fibres and ultra-fine powders of silica and other minerals from rice husk and other similar plant-based materials to make advanced ceramics, and silicon for solar cells should have a high priority. Attention should be given to possible controlled production of high-strength ceramic fibres for advanced composites by pyrolisis of natural fibres. There are opportunities of producing polymeric materials from large quantities of agriculture resources and agricultural wastes. For instance an agricultural waste like cashew nut shell liquid can be converted to very high-performance polymers for composites.

3.3 Strategic materials

Many developing countries do not have resources for strategic metals like nickel, cobalt, tungsten and chromium and it is necessary to synthesize high-performance materials with abundant elements like aluminium, silicon, oxygen, nitrogen, and carbon. The synthesis of structural ceramics like silicon carbide and silicon nitride, and composites like aluminium-silicon carbide and aluminium-graphite can eliminate the need of special metals which are in short supply in many countries. Greater emphasis is needed on these kinds of ceramics and composites particularly to decrease their costs of production and increase their performance especially in regard to toughness. In view of the use of coarse ceramics, the developing world is still very much in the stone age compared to the metals age in advanced countries, and it should leapfrog into the world of advanced ceramics and composites without necessarily going through the cycle of high-performance alloys which will eventually be replaced anyway.

3.4 Utilities

The need to develop inexpensive membranes and filters of ceramics, composites and polymers to purify and desalinate water is an important requirement of the developing world and this deserves the attention of modern materials science and technology.

In the context of development, the advances in understanding the structure and processing of newly emerging materials need to be applied to materials required for food production, transport and storage. Development of lighter, stronger and more durable and inexpensive clothing material, recyclable paper and other materials required for increasing literacy in the developing world are important imperatives of materials technology for development. The demand for new inert and bioactive materials for transplants and health care will be much greater in the highly populated developing world. It is necessary that the cost of these materials comes down by orders of magnitude to be accessible to the poor. Some of the health-care materials of the future will be smart structures in the form of composites with embedded sensors, actuators, microprocessors, and their costs need to be reduced.

3.5 Recycling

In the context of development, advances in materials science and technology related to recyclable materials, 21/ and materials that do not degrade or can be maintained by inputs of human labour are extremely important. This is necessary since the availability of resources of materials and energy are going to be major constraints; regeneration of new material by recycling takes much less material and energy than extracting it from its source. Design of alloys and components which lend themselves to recycling and multifunctional uses and which can be used in a series of cascading progressively downgraded applications is necessary. Increased understanding of surfaces and interfaces from a basic atomic and electronic viewpoint, is necessary to generate surfaces which resist corrosion, oxidation, wear and fatigue, and extend the life of materials.

3.6 Energy

Materials for energy generation 20/ and transmission, and materials which can be made using decreasing amounts of energy remain major imperatives for development. In view of this, ceramics and composites leading to higher efficiencies in energy conversion systems, higher performance, lower-cost materials for solar energy and for fusion energy are important for development. New optoelectronic materials for transmitting energy and information will relieve the constraints in these critical areas. Technologies for direct reduction of iron and aluminium, or technologies which can make use of solar and biomass energies (e.g., plant based reductants and fuel) are very important. It is obvious that production of these primary materials will increasingly shift to the developing world to take advantage of mineral resources, low labour costs and the present absence of pollution problems and regulations. The science and technology to produce these conventional materials with low energy inputs, in small plants with low-capital, high-labour inputs are important imperatives for development. Materials with high-temperature superconducting properties which have been discovered recently could have large implications for the developing world.

3.7 Materials processing

Materials processing needs to be driven in directions of near-net-shaped components and low energy consuming processes which can generate employment needed in the developing world. Computer-aided design and simulation should be used to reduce redundant factors of safety in order that smaller quantities of materials will suffice. However, automation and robotization should be used only selectively where absolutely necessary to obtain quality and reliability. The information input that goes into materials processing should be as high as possible but the actual process should be as simple a technology as possible which can be maintained in the most primitive developing environments. Materials in the context of development should be made as far as possible using local resources, 16-19/ local manpower, and simple technologies which can be maintained and established in the developing world without vast inputs of capital. It will be worth while to upgrade the large numbers of traditional materials and processes which have been used in the developing world for ages by inputs of modern materials science and technology. A new trend in materials technology, namely parts consolidation, leading to fewer parts resulting from single step moulding of complex shapes could be very important.

The economy of several developing countries is very heavily linked 21/ to the export of a given mineral. For instance, the economies of several countries in Africa are based on the export of copper. In view of the development of glass communication cables it is necessary that materials science and technology is directed to find new uses of resources like copper, otherwise the economies of these countries will collapse and a global advance in materials science will be locally counter-productive in terms of development.

4. Conclusions

In summary, materials scenarios in the developing world, and in the poorer sections of advanced countries, are typified by very poor availability of materials per capita both in quantity and quality. In the context of development, materials which relate to basic human needs like food, housing, clothing, energy and water are more important than materials which relate to advanced weapon systems, faster aeroplanes and other secondary desires. While some of the knowledge-driven advances in rapidly solidifed materials, plasma and vapour deposited materials, surface processed and interface tailored metals, ceramics and composites and nano-structured materials 22/ will indirectly contribute to development, they need to be selectively steered to accelerate the availability of materials for development. Materials technology leading to development in terms of availability of increasing quantities and qualities of materials per capita will require smaller, lighter, stronger, longer-lasting recyclable materials made from local renewable and abundant resources using high information simple processes requiring low energy, preferably in the form of solar biomass, low-capital but high-labour content. Materials based on plant based products and abundant resources like clays, stones, rocks, aluminium, silicon and oxygen should receive increasing attention along with biological processes to process and preserve materials. Materials for solar energy and fusion energy should receive high priority along with materials for food production and storage, and cloth and paper, and materials for purification of water, and health care.

5. Recommendations

The important question is what the developing world should do in view of the new materials revolution signalled by the arrival of materials like high-temperature superconductors and optical fibres for telecommunication. Without adequate timely response from the developing world, the benefits of these new materials will again flow primarily to the developed world, further increasing the gap in the quality and quantity of materials available per capita in the developing and developed worlds.

The first and foremost response of the developing world should be to establish mechanisms to monitor the most significant developments (for instance high-temperature superconducting materials) at the earliest possible stages. These emerging developments can be monitored through mechanisms of formal technology forecasting, followed by technology assessments from the viewpoint of individual countries to arrive at the priorities amongst several signals. The technology assessments would be followed by action plans to derive maximum benefits from a particular new development to the country or region in question. One of the responses could be setting up centres of excellence in developing countries, and this has been discussed at some length here.

Mechanisms for monitoring of advanced signals of the future materials technologies in terms of monitoring of scientific papers, patents, and company reports will have to be established in institutions doing teaching, research and development or production of materials in developing countries. Their activity will require world class scientists trained to pick up advanced signals of future materials technologies from scientific literature.

In view of the recent advances in modern materials setting up centres of excellence could enable developing countries to benefit from the new opportunities that are opening up. In the advanced countries, for example the United States, several centres of excellence in materials science have been set up in the last 10 years. Among the developing countries, India has some experience in setting up centres of excellence in universities in the area of materials. These have been set up in the form of materials research laboratories in universities which already have strong programmes in materials. In addition to these materials research laboratories, engineering research centres have been funded, for instance centres for composite materials and ceramics have been established. It will be difficult for developing countries to establish a large number of centres because they are quite expensive, requiring considerable equipment. It is necessary to pick up a few good academic teaching departments and build excellence in research and development around these departments. This will be the least expensive way to grow such centres in developing countries.

In view of certain recent trends it will be appropriate to develop centres on composite materials and ceramics including new high-temperature superconducting ceramic materials. These centres should have scientists of world class training, and they should be equipped with modern materials science equipment. The scientists in the developing countries from these centres should periodically visit the most advanced centres in the developed world to bring back the knowledge that is yet to be published. In addition, scientists from developed countries should visit these centres and train and upgrade the information base of the scientists in developing countries. It will be worth while for the developing countries to look at the performance of the centres of excellence in materials in advanced countries especially the United States, and in developing countries like India. In some cases it may be useful for several developing countries to get together and put up one common centre of excellence to reduce the cost to each. A parallel example in agriculture is the International Rice Research Institute. Here was an example of a commodity of interest to several developing countries and a single institute of international stature serves a large part of the developing world. For instance, in materials, several developing countries could get together to set up centres of excellence in solar energy materials, room temperature superconductivity, fibre optic materials for telecommunications, advanced composites and ceramics.

In the area of materials, one type of centre of excellence could concentrate on synthesis and preparation of a large number of advanced materials. These facilities could include fabrication from solid, liquid and vapour states. Another type of centre of excellence could be on the characterization of these materials including the characterization of atomic arrangements, chemical composition and properties both at microscopic and macroscopic levels. These two types of centres for synthesis and characterization could be jointly set up by several developing countries in the form of international institutes.

While setting up these centres of excellence, it must be realized that these centres will at the most develop an information base in the developing countries. They will not necessarily lead to an increase in the production and the consumption of these advanced materials. The production and use of these advanced materials would require setting up of manufacturing facilities either with the know-how generated in these centres or through transfer of technology in terms of plant machinery and know-how from the developing world.

The centres of excellence of materials in developing countries coud be a basis for promotion of co-operation in research and development. For instance in the area of high-temperature superconductivity it will not be proper for the centres of excellence in developing countries to duplicate what has already happened in the developed world or, for instance, to spend time in understanding the basic structure of these high-temperature superconductivity materials. It will be most useful to concentrate on the processing aspects of these high-temperature superconductors in the manufacturing facilities that are available in the developing countries. Co-operative research agreements can be established where the flow of basic and non-proprietary information takes place very quickly from developed countries to centres of excellence in the developing countries. The developing country scientists and technologists should try to then develop the technology to produce and characterize these materials in the manufacturing environment in these countries. It is in this location-specific role that the centres of excellence in developing countries differ from those in developed countries.

There are large resources of materials which are location-specific in several developing countries and have not received much attention in the developed world. Some examples would be materials based on local plant-based materials, for instance the coconut tree-based resources. Since know-how on these materials will not be generated in the developed world, they would be ideally suited for centres of excellence. Likewise, there are certain mineral resources, for instance copper, which are important for the economies of several developing countries. These materials could be substituted by some of the new emerging materials and can devastate the economies of some developing countries. Optical fibres and high-temperature superconductors both pose a threat to the copper markets. Centres of excellence to counter such threats in materials would also be in order.

The organizational structure of a centre of excellence should be such that it has a greater impact than equal investments made through the conventional approaches without the centres. Higher investments in centres would deprive certain institutions outside the centres and repercussions of these should be taken care of in advance. As mentioned earlier, one form of centres of excellence in materials technology can consist of state-of-the-art facilities for the characterization of materials, for instance including facilities for electron microscopy with capabilities of directly observing atoms in materials. Such a facility is expensive, and only concentrated resources of a centre allow the acquisition and maintenance of such facilities. However, to be most effective, such a facility should be accessible to materials scientists physically present outside the centre. A centre for materials technology should, therefore, primarily act as a mechanism for large-scale team effort in a given area, instead of merely physically concentrating people and equipment in a given location. A centre for excellence in materials policy should be conceived, in addition to centres for physical research in specific materials or processes, or preparation and characterization of materials. Such centres should include participation of planners, economists and forecasters.

References

1/ M. Cohen, ed., "Materials Science and Engineering, Its Evolution, Practice and Prospects", Materials Science and Engineering, Vol. 37, No. 1 (1979) Elsevier Sequoia S.A.

2/ M. Cohen, "Materials and Man's partnership with Nature", Alpha Sigma Mu Lecture, ASM News, July 1979.

3/ "Trends and Opportunities in Materials Research", Division of Materials Research, National Science Foundation, Washington, D.C. 20550 (as reported in Journal of Metals, December 1984, p. 58).

4/ J. A. Cornie, "Materials Policy in the United States and Advanced Structural Materials - A Global Perspective", Massachusetts Institute of Technology, Cambridge, Mass., USA. Presented to "Ambiente E Risorse", XIII Convegno Nazionale, Bressanove, Italia, Sede Estivba Universita Di Padova, 2 September 1985.

5/ M. C. Flemings, "Materials Science and Engineering - Its Past and Its Future", Massachusetts Institute of Technology, Cambridge, Mass., USA, 1985. Presented at Yukawa Memorial Lecture, Iron and Steel Institute of Japan, 4 October 1985.

6/ A. Lahiri, "Conservation of Mineral Resources in Commerce", (India). Annual Number, 1976.

7/ B. Bowonder and P. K. Rohatgi, Technology Forecasting Social Change, 7 (1975) p. 233.

8/ P. K. Rohatgi and C. Weiss, Technology Forecasting Social Change, 11 (1977) 25.

9/ P. K. Rohatgi, B. J. Vyas and B. Bowonder, Indian Fndry. J., 1(2)(1978) 24.

10/ Technology Forecast, Surveying 70's Metal Prog., 99(1970) 17. Also January Issue of Metal Progress on Technology Forecast 1973-1986.

11/ A. Wittmeser, K. Stainack and R. Hofmann, Br. Foundry., 65(1972) 73.

12/ D. Suresh, S. Seshan and P. K. Rohatgi, Solar Energy, 23(6)(1979) 553.

13/ Tomorrow's Revolution, Microbe Power, edited by Bram Pond (Macdonald and Jane's Publishers Ltd., London) 1976.

14/ Bacterial Leaching Seminar Member, NML Tech. J. 15(4)(1973).

15/ P. K. Rohatgi, K. Rohatgi and B. Bowonder, "Technology Forecasting: India Towards 2000 AD", Tata McGraw Hill, 1979. Republished by Research Reprints, 1865 Trinagar, New Delhi 110035, India, 1985.

16/ P. K. Rohatgi, S. Mohan and K. G. Satyanarayа, "Materials Science and Technology in the Future of India", Regional Research Laboratory (Trivandrum), CSIR, Trivandrum, Kerala, India, 1980.

17/ P. K. Rohatgi, S. Mohan and K. G. Satyanarayа, "Materials Science and Technology in the Future of Kerala", Regional Research Laboratory (Trivandrum), CSIR, Trivandrum, Kerala, India, 1981.

18/ P. K. Rohatgi and P. Egbote, "Materials Science and Technology in the Future of Madhya Pradesh", Regional Research Laboratory (Bhopal), CSIR, Bhopal, M.P., India, 1985.

19/ P. K. Rohatgi, B. Nagraj and K. Rohatgi, "Future Technologies for Metals and Materials in India", Journal of Scientific and Industrial Research, Vol. 41, June 1982, pp. 351-360.

20/ "Materials for Economic Growth", Scientific American, October 1986.

21/ D. Altenpohl, Materials in World Perspective, Springer Verlag, 1980.

22/ A. L. Bement, "The Greening of Materials Science and Engineering", ASM and TMS Joint Distinguished Lecture in Materials and Society, Orlando, Florida, 1986.

23/ R. F. Decker, "Biotechnology/Materials: The Growing Interface", 1985. Campbell Memorial Lecture, American Society for Metals, 1985. Published in Met Transactions, 1986.

24/ A. R. C. Westwood, "The Challenge of New Materials", ASM and TMS Joint Distinguished Lecture in Materials and Society, ASM Annual Meeting, Cincinnati, October 1987.

TABLE I

Per Capita Consumption of Metals in Selected Countries (Average Values for 1967-69)

No.	Country	Per Capita (GDP US$)	Per Capita Consumption (kg)					
			Aluminum	Copper	Lead	Zinc	Tin	Crude Steel
1.	Argentina	853	1.16	1.73	1.610	1.102	0.076	91.0
2.	Australia	2503	8.047	5.39	8.636	0.331	0.331	468.5
3.	Austria	1604	9.10	4.465	3.151	3.306	—	283.5
4.	Belgium-Lux	2174	16.52	11.465	5.028	13.361	0.283	401.0
5.	Brazil*	326	0.90	0.512	0.301	0.482	0.024	51.0
6.	Canada	3234	10.02	10.354	2.959	4.979	0.215	469.0
7.	Chile	609	—	2.40	—	—	—	71.0
8.	Denmark	2620	1.40	—	3.836	2.020	—	346.0
9.	Finland	1861	2.62	6.00	—	1.312	—	281.0
10.	France	2556	6.37	5.193	3.613	4.292	0.209	359.5
11.	Greece	856	1.54	—	—	0.640	—	95.5
12.	India	88	0.23	0.083	0.090	0.151	0.008	12.0
13.	Italy	1430	4.17	3.339	2.542	2.928	0.117	323.5
14.	Japan	1413	6.41	6.579	1.750	5.181	1.224	501.0
15.	Mexico*	557	0.53	0.969	1.451	0.312	0.034	73.5
16.	New Zealand	1938	—	—	—	2.469	—	267.5
17.	Netherlands	1968	12.67	2.729	4.039	2.703	0.351	341.5
18.	Norway	2398	12.89	3.710	—	5.351	—	375.5
19.	Portugal	543	—	0.922	—	0.526	—	65.5
20.	South Africa	738	1.44	1.549	0.746	2.350	0.085	187.0
21.	Spain	833	3.11	2.476	1.979	1.890	0.052	187.5
22.	Sweden	3311	8.10	10.924	6.898	4.388	—	603.0
23.	Switzerland	2719	11.70	6.109	3.595	4.398	0.142	349.5
24.	Turkey	382	0.37	—	—	0.188	0.027	25.0
25.	UK	1926	6.83	9.646	4.990	4.959	0.315	404.5
26.	USA	4300	17.25	8.950	5.431	5.900	0.288	560.5
27.	West Germany	2275	8.84	9.761	4.719	5.883	0.193	523.5

*Average of 1967 and 1968 figures

TABLE II

Per Capita Consumption of Metals by Regions
Extrapolated Values 2000 AD

Region	Per Capita Consumption			
	Steel	Aluminum	Copper	Zinc
Western Europe	710	20.24	10.50	6.83
Japan	1450	45.86	21.40	13.19
Other developed countries	680	22.32	11.98	8.58
USSR	850	17.47	7.84	3.92
Eastern Europe	610	13.87	5.41	5.92
Africa	20	0.24	0.16	0.07
India-Low growth	26	0.51	0.20	0.32
High growth	51	0.98	0.44	0.70
Asia	30	0.50	0.22	0.31
Latin America	100	1.72	0.91	0.95
China	60	0.79	0.63	0.54
USA	890	52.25	14.63	9.41
World	240	7.27	3.06	2.09

Source: Lahiri, A. Conservation of Mineral Resources in Commerce, Annual Number, 1976, 47-49.

TABLE III

Some Important Targets for Materials Technology for Development

- Genetic engineering for plants to get nitrogen directly from air.
- Genetic engineering for plants with stronger timber and fibers which can be pyrolized to form high performance fibers and carbon-carbon composites.
- Microbial processes to extract metals from ores and ocean nodules, and to remove sulphur and silica from coal, bauxite and other minerals.
- Microbial processes to extract fibers and ultrafine ceramic particles from agricultural products and wastes.
- Solar photovoltaic materials with increasing efficiencies and decreasing costs; solar furnaces for processing materials.
- Materials for fusion energy.
- Membranes made for polymers, ceramics and composites with decreasing costs and increasing performances for purification of water.
- Improved and inexpensive materials for housing from abundant and renewable resources like sand, clay, rock, stones, laterites, plant based materials.
- Composites and ceramics with improved performances based on abundant elements like Al, Si, C, N and plant materials.
- Direct Reduction of iron and aluminum using low energy processes, using solar and biomass energy.
- Recyclable materials with cascading downgraded application with longer life and resistance to corrosion, oxidation, wear and fatigue.
- Rapidly solidified materials for reducing energy losses.
- Surface and interface processed materials with tailored structures and properties to meet specific needs.
- High performance nano-structured materials, nonequilibrium and metastable structures.
- Room temperature superconductors.
- Insitu polymer composites.
- Tough ceramics.
- Net shaped materials fabrication.
- Parts consolidation through single step molding of complex shapes.

3. ADVANCED MATERIALS IN THAILAND: STATUS AND PROSPECTS

Following is an excerpt from Advanced Materials in Thailand: Status and Prospects, written by Panya Srichandr, School of Energy and Materials, King Mougkuts Institute of Technology, Bangkok 10140, Thailand.

Trends, policies and the roles of advanced materials

As has been indicated, the trends of the industrial scene in Thailand are of two opposite directions. On the one hand, there is a pressure to integrate backwards to manufacture parts and components as well as basic raw materials and production facilities so as to reduce imports and increase value added of the "locally" made manufactured products. On the other hand, there is also a tremendous pressure for forward integration of resource-based industries so that the finite resources could be optimally utilized. Both of these are in fact adopted as major industrial and technological policies by the present Thai Government. It is realized that the labour-intensive, low technological content type industries cannot be here in Thailand forever as they must naturally move on to still less developed countries. The future maufactured products must have higher technology content and higher value added in order to compensate for the rising labour cost and more expensive raw materials. The technology will play much more important roles in the competitiveness of the Thai industry in the future. Advanced materials and processes will definitely play a critical role in the production of high-technology, high value-added items.

In preparing for such future scenario, various steps have been taken by the Thai Government, including:

(i) The establishment of the Science and Technology Development Board (STDB) in 1985. The major objective of the STDB is to promote the technological development in the three high priority areas of which materials technology is one (the other two being biotechnology and electronics). Its function at present is mainly screening and funding of research and development projects in the three areas.

(ii) The establishment of the National Centre of Metals and Materials Technology (NCMM) in 1986 under the Ministry of Science, Technology and Energy (MOSTE) with the same objective as the STDB (i.e. the development of materials technology). Its major activity at the present time is also limited to screening and funding of research and development projects including feasibility and survey type projects which incidentally are not supported by the STDB. The NCMM will have its own specialized R&D centres in the future.

As a result of such undertakings, funds are now available for more R&D projects. Prior to the establishment of the two organizations, there was very little R&D activity in materials technology. There are still further problems, however. The absorptive capacity is limited due to the lack of technical personnel in the field. Further steps were therefore taken in order to create the critical mass of materials scientists an engineers for R&D as well as other functions.

(iii) Four graduate programmes in materials science and technology have recently been established in various universities. The objective is to train higher-level technical personnel as well as building u the technological infrastructure. Several difficulties are being faced including understaffing problems and lack of teaching facilities and equipment. A massive further investment in manpower development and the creation of facilitie is necessary.

(iv) A number of Thai students (approximately 300) are to be sent overseas for further education and training in the fields of metallurgy, materials science as well as in other related fields (e.g. mechanical and production engineering).

All these and other measures being taken by the Thai Government illustrate the seriousness of the country to support and promote materials-based technologies. The importance of materials technology to the development of the Thai industry and economy is well recognized. The size of the problems being faced is also well appreciated.

It is difficult to be specific about exactly which advanced materials would play a prominent role in the Thai economy in the near future as this would, to a large extent, also depend upon the changes in the world economic and technological environment at large. From the availability of raw material point of view, those derived from rare earth seem to have great potential. Amorphous alloys would play an important role in energy saving of which Thailand is very conscious. Recent measures by the Government to curb deforestation would mean that substitutes for wood as materials for light construction (e.g. in furniture industry, transport equipment etc.) have to be found. Polymer-based composites are promising. The rapid growth of electronic and automotive industries suggest that the demand for high-precision, high-tech parts, e.g. powder metallurgy products, would also be rising. Modern surface technologies, e.g. glass coating for energy conservation, powder spray coating for repair of worn parts, would also play some important roles.

The present status of advanced materials in Thailand

As has been mentioned, the majority of the Thai industries are at present based on conventional basic technologies. A good deal of the technology importation is on the turnkey basis. A number of small firms even prefer second-hand production facilities due to the low prices. The roles of advanced materials in the industrial scene in Thailand at present are therefore minimal. There are a few firms which have started and plan to start in the near future the manufacture of sintered products such as tools materials, electronic components (ferrites) and sintered bearings.

A number of research projects on advanced materials and processes have, however, been initiated and are being supported by relevant organizations. Examples of such projects are listed in the following table. It should be noted that these projects have been initiated very recently and significant results are being awaited.

As for the future, due to the changes in the structure of the Thai industry resulting naturally from the development process, advanced materials would certainly play a highly significant role in the manufacturing sector of the Thai economy as has already been indicated.

Major impediments

The recently completed 18-month project by Thailand Development Research Institute (TDRI), a sort of think-tank organization for the Thai Government, revealed that the major impediments for technological capability development in Thailand include:

(i) Manpower shortage. This is true for all levels: skilled workers, technicians, scientists/engineers and specialists. In the field of materials, let alone advanced materials, the short supply of technical personnel is very serious indeed.

(ii) Inadequacies in technical and information services. The availability of and accessibility to such services are absolutely essential in the development of advanced materials technologies. The presently available systems are much to be desired quantitatively and qualitatively.

(iii) Lack of specialized centres. Existing organizations often have a multiplicity of objectives leading to the attempt to do too many things at a time with limited personnel and financial resources. This leads to inefficiency and ineffectiveness in resource utilization.

(iv) Other problems include lack of supportive industries (i.e. suppliers and buyers), inappropriate taxation systems, short-term profit seeking of some managers and intellectual property right issues.

Table

Some R&D programmes on advanced materials and processes

1. Extraction and utilization of rare earths from tin tailings
2. Amorphous alloys
3. Powder metallurgy
4. Ferrites
5. Advanced surface technology (sputtering, ion implantation)
6. Superconductors
7. CAD/CAM/CAE
8. Composite materials (FRP, foams)
9. Superplastic forming
10. Piezoelectric ceramics
11. Thermoplastic elastomers
12. Fabrication of prototype semiconductor pressure transducer for biomedical application
13. Opto-electronics
14. Design and fabrication of the prototype of silicon rectifier for mass production
15. Design, fabrication and development of DMOS power MOSFET

Source: Ministry of Science, Technoloy and Energy

4. NEW MATERIALS AND DEVELOPMENT - HOW ASIA CAN MEET THE CHALLENGE

K.A. Shoaib, G. Sikandar Khan, N.M. Butt,
Pakistan Institute of Nuclear Science and
Technology, P.O. Nilore, Islamabad, Pakistan

I. INTRODUCTION

The Asia-Pacific region is comprised of countries starting from Iran in the west to Japan in the east and from Mongolia in the north to New Zealand and Australia in the south. It has a population of approximately 2.84 billion 1/ which is about 57 per cent of the total world population (1988). 2/ The population of these countries is in the range of 0.3 million (Brunei) to 1,087 million (China) and the per capita GDP ranges from $US 135 (Bangladesh) to $US 20,830 (Japan). 1/ Economically, these countries can be grouped into three categories:

(1) Advanced countries, comprising Japan, Australia and New Zealand, which have a per capita income in the range $US 7,000-21,000;

(2) Advanced developing countries, which include the so-called "Four Dragons" of South Korea, Hong Kong, Singapore and Taiwan; with a per capita income of the order of $US 3,000-7,000; and

(3) The developing countries, which consist of the rest and have a per capita income less than $US 2,000.

The literacy rate in countries of the region is between 12 per cent (Afghanistan) and 99.7 per cent (Japan). 1/ Except for the "advanced" countries and the "advanced developing" countries of the area, the total financial outlay for education is rather small. The allocation of financial resources for R&D in science and technology in the developing countries of this region is even smaller because of more compelling and pressing demands of public welfare on the meagre financial resources of these countries, most of which belong to what is known as the "Real South".

Table I gives the population, total GNP and expenditures on education and science and technology in some of the countries of this region. 1/,3/,4/,5/ It is evident that, except for Japan, Australia, Korea, New Zealand, India and Malaysia, the expenditure on science and technology is very small. Separate data for expenditure in the field of materials research is not available. However, since the economic impact of new materials is not realized in "developing" countries, funding in R&D in this sector is likely to be even smaller.

It may be assumed that the standard of living of a country is directly proportional to the production of high technology new materials in the same way as it is related to the per capita consumption of energy. Thus, per capita income, or GDP, and materials production are interrelated. It is, therefore, useful to review the economic aspects of the countries of the Asia-Pacific region as an indicator of the status of new materials technologies in these countries.

II. ECONOMIC STATUS OF THE COUNTRIES IN THE ASIA AND PACIFIC REGION

(a) Agricultural produce

The economy of most of the developing countries of this region is basically agrarian. Table II gives the contribution of agricultural, manufacturing, mining and energy production sectors to the GDP of selected countries of this region. 16/ Figure 1 shows the contribution of the agricultural sector to the economics of selected countries. As could be expected, in the developing countries with low per capita income, the share of agriculture in the GDP is large, while in the case of advanced countries the situation is the reverse.

(b) Output of the manufacturing sector

The details of manufacturing output based on materials of some of the selected countries in the Asia-Pacific region is given in Table III. 6/ It is clear that, while the advanced countries of the region are mainly producing goods with a large component of knowledge-based added value, such as motor vehicles, electronics instruments, machinery/military hardware, etc., the manufacturing output of the developing countries is largely comprised of consumer goods and traditional products such as cement, textiles, sugar and other agriculture-based commodities with high raw material component and meagre technological value-addition.

Figure 1 also shows the contribution of the industrial activity, i.e. the sum of the manufacturing, mining and energy sectors, to the GDP of these countries. The upward trend of per capita income with industrial activity is not so obvious since in many of the so-called "advanced" countries of the region a large part of the GDP is derived from economic activities such as business and trading, community services, construction and communication, etc., which are hallmarks of prosperity.

(c) Energy resources

Generally, the countries of the Asia and Pacific region are poor in energy resources. Many of them are dependent on imported oil from outside to meet their energy requirements. Table IV gives the production and consumption of electricity, petroleum, coal and gas in selected countries of this region. 7/ In the advanced countries of the region the per capita energy consumption is very large, while poorer countries, such as India, Pakistan and the Philippines, consume only a fraction of the world average. Figure 2 illustrates the well-known phenomenon of increasing per capita income as a function of increasing energy consumption.

(d) Minerals production and potential

Barring a few exceptions, such as tin and tantalum, the estimated metallic reserves and the mining production of Asia forms less than 10 per cent of the total world reserves. 8/ The production and consumption of refined metals such as aluminium, copper, steel, nickel, etc., is also 20 per cent of the world figures or less. 8/ The mineral production of the countries of this region is given in Table V. Except for Australia, China and India, the region is extremely poor in metallic resources. Moreover, most of these countries lack the infrastructure for the exploitation and processing of these resources. The minerals are often exported as raw materials or in semi-processed form.

III. RAW MATERIALS

Historically, mankind has adopted the naturally occurring materials such as clay, stone, wood, animal tissue and the natural fibres for its use and benefit. Later, it moved on to the smelting of metals and the making of alloys. The trend has been towards an increase in the refining and processing of the materials, to the understanding of the properties of available materials, and to the application of existing materials with desired qualities and properties for the fulfilment of the contemporary and future needs of mankind.

This was the situation till the recent past. But now the availability of very sophisticated and superior experimental techniques and the advances in the theoretical knowledge about the structure of matter has radically altered this situation. Instead of the needs and requirements being altered and modified according to the properties of the available materials, it is now becoming possible to design and engineer materials with many of the properties and characteristics aimed at specific technical applications. These are the so-called "new materials". Many of these new materials are improved and modified versions of the conventional materials, while others are radically different in structure and composition.

The importance of the development and use of new materials is summarized by a well-known industrial scientist from the United States of America, 9/ as follows:

> "As a result of dramatic technological developments over the past two decades, the discovery and development of new materials has become a national imperative, not only for the United States but also for our major world competitors and adversaries:
>
> - As technologies in conventional industries are transferred to developing countries, it is inevitable that the US must change its industrial structure, based on new technology, to maintain current standards of living or to achieve further increases in per capita added value.
> - Future energy developments require technologies that create conditions far beyond the conventional, such as ultra-low temperature, ultra-high temperature and pressure, super-vacuum, ultra-high magnetic fields, and ultra-intense and energetic radiation environments.
> - There is a growing search for higher accuracy at the atomic and molecular levels for new machining, measuring, and processing developments. This is especially being sought after in the DoD program in ultra-small electronics research (USER), which is attempting to extend electronic devices and circuit technologies to the molecular scale of dimensions (that is, 10-20 nm).
> - New public needs and demands for new lifestyles are growing out of expectations from the information revolution.
> - Our future national security depends on new technologies to conserve and substitute for energy and other scarce resources.
> - Technology is becoming increasingly essential as a major force multiplier in the development of new strategic and tactical weapons and battle management systems.
>
> "All of these emerging requirements are based on higher technological dimensions, and these higher dimensions will not be realized without new materials."

(a) World-wide trend in materials

Modern materials may be divided into five broad categories: 10/

(i) Metals and alloys;

(ii) Semi-conductors and electronics materials;

(iii) Ceramics and refractories;

(iv) Composite materials; and

(v) Plastics and polymers.

Metals and alloys

Metals and alloys have been the mainstay of the present-day advancement since the Industrial Revolution. Consumption of these materials, and especially of steels, is directly related to the industrial status and per capita income of the user countries. This would be evident from table IV, 6/,11/,12/ which gives the per capita consumption of crude steel and of non-ferrous metals for some of the countries of the world, while figure 3 illustrates the per capita consumption of steel as a function of per capita income of selected developing nations. The alloys most commonly used are ferrous alloys like plain carbon steel, low alloy steels or stainless steels, non-ferrous alloys based on nickel or copper and light alloys of aluminium, magnesium or titanium. The typical application of various metals and alloys is summarized in table VII. 13-16/ While traditional metals and alloys would continue to form the backbone of the conventional industry for years to come, modified or new metallic materials and processes would form the cutting edge of advanced technology.

Advances in new metallic materials have been made on three fronts: 10/,17/,18/

(a) Modification in composition or microstructure of basic alloys to improve strength or corrosion resistance;

(b) Development of new materials of desired properties; and

(c) Improvements in, or development of, new processing methods for materials.

In the case of conventional low alloy steels, micro-alloying additions of Nb and Ti are being made to provide strength and formability. There has been a major development in stainless steels where duplex alloys, consisting of a predetermined ratio of austenitic and ferritic phases, are coming into increasing use. The austenite provides good weldability and general corrosion resistance while the ferrite increases strength and resists stress corrosion cracking. High alloy superaustenitic steels have been developed for good metal-to-metal wear resistance and better formability and weldability.

New alloy development is a continuous process. A major effort is going on in three alloy systems. A new breed of nickel-base superalloys for high temperature applications is being developed with solute additions of Ta, Zr, C and B using rapid solidification techniques. Intermetallic materials with good hot strength and oxidation resistance are gradually coming out of infancy. While improvement in ductility by B addition is being tried in the most promising material, Ni_3Al, intermetallics containing Fe, Ni, Ti and Be are under investigation. Significant advances have been made in new Al-Li alloys which are much lighter than the traditional light alloys and have moderate to high strength.

There have been many improvements and advances in the materials processing techniques. Vacuum melting is producing ultra-low carbon steels with better toughness, ductility and weldability. Conventional melting techniques such as electroslag re-melting and vacuum arc melting are applicable in case of intermetallics, while electron beam and cold hearth melting methods are required for high purity Ti alloys.

Casting techniques have been improved to achieve near-net shape continuous casting of strip, rod and thin slabs. These methods are particularly coming in vogue for conventional and stainless steels. Methods for surface protection against corrosion or wear are becoming more superior. Coating of ordinary steels with Zn-Ni alloys, or cladding with ferritic, martensitic or austenitic stainless steels, or with Cu and Cu-Ni alloys, has produced materials with ideally balanced bulk and surface properties.

Innovative processing based on powder metallurgical techniques is being used in dispersion hardened Al-alloys, superalloys and intermetallic compounds. Novel methods, like rapid-directional or single-crystal-solidification, plasma and electron beam refinement hot isostatic pressing, superplastic forming and injection moulding are being investigated or increasingly used for advanced materials like Al-alloys, superalloys or intermetallic materials.

Fine ceramics

Fine ceramics are non-metallic inorganic materials which have improved and sophisticated characteristics. The compositions, particle sizes and the purity levels of the starting materials for these ceramics are rigidly monitored and controlled. In recent years, there has been a growing interest in fine ceramics because of their great potential use in diverse sectors of industry, in contributing to energy conservation, as well as to better performance.

At present (in Japan) about two thirds of the output of these fine ceramics materials is being used as electromagnetic materials, about one fourth as mechanical structural materials and a small portion of the output is employed as optical materials, but the growth rate is high for this last application. 19/

The applications of fine ceramics for the manufacture of cutting tools, in the manufacture of mechanical seals and as high temperature corrosion-resistant materials is growing at a fast pace. Research for the use of ceramics in the diesel and gas engine parts is also progressing rapidly. Figure 4 shows the typical applications of fine ceramics.

The industrial application of fine ceramics in many fields, such as in gas turbines and diesel engines, die-casts and metal claddings, tools and heat-resistant fixtures, paper-making and chemical equipment, is anticipated in future. These applications can be realized only after ceramic materials having high impact and wear resistance and which are able to withstand corrosion and high temperature have been developed. For this purpose, special processing and manufacturing technologies and characterization and evaluation techniques will have to be developed.

Composites of ceramics and metals have important electromagnetic applications. It is a growing field which is of much importance to the countries of the Asian and Pacific region having large skilled manpower resources.

Advanced composite materials

In composite materials such as carbon fibre reinforced plastics, two or more than two materials are mixed in order to obtain properties superior to the individual components. For applications between 100° to 200°C, a polymer is usually employed as a matrix. Fibreglass is a typical composite which is made by embedding glass fibres in polyester. Glass fibre is widely used for reinforcing plastics because of its high modulus of elasticity. Table VIII 20/ gives the toughness of glass, ceramics, and their composites.

For high temperature applications, metals such as aluminium, titanium and nickel are used which are reinforced with single-crystal whiskers, commonly composed of alumina (Al_2O_3) or silicon carbide (SiC). For use at still higher temperatures, ceramic materials are employed as matrices. The ceramics are reinforced by mixing the ceramic powder with short metal fibres, having matching coefficients of thermal expansion, and then hot-pressing the material to near-net shape. 21/

The plastic matrix composites are finding growing applications in the automotive industry. It is estimated that, with composite vehicles, reductions of up to 50 per cent are possible on investment costs for facilities, capital and tooling, as compared to steel. Although many production problems remain to be solved, it can be safely predicted that composites will be increasingly used as industrial structural materials in future.

(b) New materials in the regional context

Increasing industrialization of the countries of the Asia-Pacific region would result in an increasing demand for advanced materials. To keep pace with this demand and to reduce dependence on the western world, the countries of the region would have to develop indigenous materials. It is evident from Table V that these countries are generally poor in metallic mineral resources. The only metals available in reasonable quantity are tin, iron, aluminium and copper. Development of industrial alloys based on these metals would, therefore, have far-reaching industrial and economic impact.

Ultra-low carbon steels and duplex stainless steels are fundamental industrial materials and can be locally produced from the available ore. Similarly, light alloys based on aluminium, for use in the aircraft industry, can be developed using the local reserves of the metal. High strength intermetallics like Ni_3Al have been projected for wide industrial applications. Indigenous resources of aluminium can be combined with imported nickel to produce these materials which may be modified for improved properties.

One of the drawbacks of the existing alloy production sector, except in countries like Japan and Australia, is its relative smallness. Another is that it is all based on outdated processing methods. To produce any of the new alloys it is crucial to modernize metallurgical practices. It is most essential to convert to modern vacuum-based melting techniques. Powder metallurgy methods, necessary for the production of high temperature materials, have wide applications and should be introduced in the region. Newly developed near-net shape casting techniques should also be adopted for increased efficiency and reduced losses.

Countries of the region are also poor in fossil fuel reserves. It is, therefore, necessary to develop materials for solar energy and nuclear energy production. Pure silicon may be developed from natural resources or from agricultural produce like rice husk. Advanced methods required for conversion of raw silicon into solar panels need to be explored. Techniques connected with the generation of nuclear power, which are based on modern materials, have to be mastered.

The countries of the Asia-Pacific region have an age-old tradition of producing good pottery and ceramics. Almost all countries of the region are endowed with ceramic raw materials. Advanced ceramics are projected to have immense economic and technological impact in industry due to their superior mechanical and chemical properties. Development of improved ceramics and composites is undergoing rapid changes and advances. This is the right time for the countries of the region to enter this field which holds great potential for the future.

In addition to the areas of those advanced materials which have wide and an almost immediate application, fields of research in specialized materials should not be neglected. High temperature superconducting materials promise a very rosy future for power transmission, communications, switching, etc. These materials can be fabricated easily but their further development and technological application still requires a great deal of scientific input. Similarly, modification of surface properties of materials by laser irradiation or ion implantation could have specialized, but significant, utilization in industry.

(c) High Tc superconducting materials

Superconducting materials, which have to be cooled a couple of hundred degrees Celcius below zero, allow a large amount of electric current without energy loss during transmission. Their applications have mostly been made in making very strong electromagnets, in medical diagnostic instruments, high energy physics, nuclear accelerators, etc. Several metals and alloys like Nb, Pb, Nb_3Sn, V_3Si, Nb_3Ge, etc., have been the most common superconducting materials in the past.

Bednorz and Mueller 22/ startled the whole world in 1986 by their discovery of ceramic compounds (normally insulators) of La-Ba-Cu-O as superconducting materials at a temperature of about 35° K. The discovery, a few months later, of another ceramic Y-Ba-Cu-O by Chu 23/ which was superconducting at 90° K (i.e. above liquid nitrogen temperature) was even more important. The applications of such superconductors are envisaged in power transmission (losses will be almost zero in transmission lines), in making levitating trains, in making strong electromagnets, for fast switching in computers, etc.

The current situation on high T_c superconductors is that a critical temperature T_c of about 125° K has been achieved while the aim of the scientists is to develop "new materials" which are superconductors at room temperature or above. Such materials are expected to be develcped in the near future, and by the year 2010 several applications have been foreseen by Japanese scientists.

These high T_c superconductors would heavily influence the economy of the developing countries. It is a research which can be well within the resources of the third world countries.

(d) Cold nuclear fusion and materials technology

Nuclear fusion at room temperature was announced by two scientists, Pons and Fleischmann, at a press conference held on 23 March 1989. The observation was made during the electrolysis of heavy water using palladium (Pd) as cathode and platinum (Pt) as anode. 24/ The deuterium produced during electrolysis reaches the cathode (Pd) and is heavily packed into the lattice causing probably a fusion of deuterium. The claim of Pons and Fleischmann to have measured an energy output four times that of input is under strong doubt and controversy. If, however, this process, called "cold water fusion", comes true it will solve many problems of the energy-hungry world. Its development will also be well within the reach of the third world countries. The R&D on Pd and other materials suitable for such a process may have to be developed.

The involvement of the Third World countries in the R&D on Cold Nuclear Fusion is, therefore, of great interest and a vigilant eye should be kept on the outcome of the confused state of this discovery. If the seemingly "world-shaking" discovery is proved authentic, it would have great economic and defence repercussions.

IV. OPTIONS FOR ASIAN-PACIFIC COUNTRIES

1. It is imperative to undertake a broad-based information-dissemination programme on new materials both for the industry and for the general public, encompassing the properties and the economic benefits of the large-scale use of these materials. The introduction of advanced materials and products in the existing industries would make them more competitive in the world market. Since industry is, in general, shy of accepting novel processes and ideas, governments will have to offer economic incentives for adopting and incorporating machinery and components based on advanced materials in existing production lines. Local entrepreneurs should be encouraged, through tax incentives, to set up new industries based on advanced materials and technologies. The industry may also be required to develop R&D facilities and to establish contacts with national institutes of higher learning and research.

2. In order to achieve self-reliance, a two-pronged approach may be adopted by countries of the Asia-Pacific region for the transfer of technology from advanced countries:

(a) For the realization of quick short-term goals, a policy for implantation of existing or newly developed technologies may be followed in the initial stages. This, in fact, is the approach which has been adopted by most developing countries of the region;

(b) A long-term policy for the development of indigenous capability should be assiduously pursued. The basic requirement for this, other than material resources, is a reasonable number of good research scientists and engineers.

3. In the context of development of the infrastructure for the growth of modern materials and technologies, the major thrust at fundamental level should be towards the grooming of scientific

and engineering manpower. Table IX 25/ gives the number of scientists and engineers, and technicians, engaged in research and experimental development in some of the countries of the region, which is very small in most of the cases. Figure 5 illustrates the large difference in the number of scientists and engineers and in the R&D expenditure between the developing and the advanced countries of the region. A major effort is, therefore, required to enhance the scientific and technical manpower in the countries of the region. While higher intake and output of universities and technical institutes is desirable, the standard of the imparted education, knowledge and practical experience needs to be of the highest order.

4. The countries of the region should allocate adequate funds for the establishment of infrastructural facilities for R&D in materials science and technology related to the needs of agriculture, housing and construction, transport, mineral processing, etc., in accordance with the national requirements. Each country has, of course, to decide for itself its materials research priorities but it can be said that, for the developing countries, the aim should be:

(a) To process their raw materials in order to add value to them for obtaining higher returns;

(b) Labour-intensive techniques should be preferred over capital-intensive processes; and

(c) Further investment of capital and technology should be made in the sectors already well established such as agriculture, wood and forestry, construction and housing, ceramics, mining, mineral processing and basic metallurgical infrastructure.

V. REGIONAL COLLABORATION AND CENTRE FOR ADVANCED MATERIALS

R&D work on the new materials is absolutely essential but financial and scientific manpower resource constraints can limit the contribution and participation of individual countries to a narrow portion of the new materials spectrum. Most developing countries possess neither the critical mass of research facilities nor do they have the critical number of engineers and scientists for R&D in materials science and technology. It may be advisable, therefore, to pinpoint areas of common interest with other countries, both developing and the advanced, in order to jointly undertake R&D work in the defined areas.

An Asia-Pacific Materials Research Society may be set up to promote regional co-operation. Members of the society may identify fields of mutual interest and select research centres which are keen on bilateral or multilateral collaboration. The interregional movement of scientists should be encouraged, for which the Society may tap adequate funding. For the training of manpower in the relevant fields, the "advanced countries" of the region have an important role to play by providing the required training facilities and, wherever possible, the funds for this purpose.

Since R&D in materials science and technology is cost-intensive, it may not be possible or advisable to undertake R&D work in all the fields of national interest and it may be more cost-effective for the developing countries to pool their resources and to establish regional centres for R&D in materials science and technology, such as those for materials characterization, for product evaluation or for standardization. A centralized "Regional Centre on Advanced Materials" may be set up in one of the developing countries of the area.

The proposed Regional Centre for Advanced Materials may have the following objectives:

(1) The Centre may establish research groups working on the development or investigation of advanced materials based on indigenous resources. These materials may be broadly classified as:

(a) Metallic materials and alloys;

(b) Ceramics and composites;

(c) Plastics and polymers; and

(d) Materials related to electronics and power generation;

(2) The Centre may provide on-site research facilities which are too specialized or too expensive for most of the individual countries of the region to establish;

(3) The Centre may establish research facilities of a general nature and of wide application, such as those for the physical and chemical characterization of materials;

(4) The Centre may co-ordinate research efforts in various national centres and stimulate collaboration among them;

(5) The Centre may serve as a training laboratory for manpower;

(6) The Centre may act as a source of information dissemination by holding regional conferences and symposia and by maintaining a comprehensive library for the distribution of literature to national centres.

For the location of the proposed Centre, a country which has fairly developed infrastructural facilities and trained manpower, such as Pakistan, may be appropriate. The Centre may work under a governing body consisting of well-known materials scientists drawn from countries of the region. Some members of the body may also be taken from aid-giving agencies like the Asian Development Bank, the United Nations, etc. The Centre may be run under the umbrella of an international organization such as the United Nations, UNCSTD, ESCAP, UNDP or RCA.

The funding for the proposed Regional Centre for Advanced Materials could be forthcoming from many sources. The land and the building may be donated by the country in which the Centre is located. Research equipment could be donated by advanced countries of the region, while some funds could also be obtained for this purpose from UNDP. The running expenses of the Centre could come from regular contributions from the regional countries and from the Asian Development Bank, etc.

VI. CONCLUSIONS

The majority of the countries of the Asia-Pacific region have agrarian-based economy, low per capita income, low investment in industry and low priority for R&D in applied and materials sciences. The countries of the area are generally poor in energy and mineral resources. Whatever materials and minerals these nations produce are often exported in raw or semi-processed form due to the absence of scientific and technological infrastructure for value-addition.

To remedy the situation in the field of materials science and technology, the following short- and long-term measures are proposed.

A. Development of materials

(1) Advanced alloys based on the indigenous resources of metallic minerals should be developed.

(2) Fine ceramics and composites should be developed from the abundantly available raw materials.

(3) The study of revolutionary materials, such as high temperature superconductors, should be given due emphasis.

(4) New developments in energy resources like the current hot but controversial topic of "Cold Nuclear Fusion" should not be left untapped.

B. Involvement of local industry

(1) Industry should be encouraged to adopt new materials technologies by giving suitable incentives.

(2) Transfer of technology from advanced to developing nations should follow a two-pronged approach. For the achievement of short-term results, advanced methods may be "implanted". In order to achieve self-reliance, this must be complemented with the development of local capability for the evolution of new processes and techniques.

C. Development of R&D potential

(1) A considerable increase in the number of scientists and engineers engaged in R&D on materials is required. For this purpose an increase in the output from universities in the relevant fields is imperative.

(2) Materials science departments may be opened or expanded in the existing universities and research institutes. Specialized national research centres may also be established for the investigation and development of advanced materials and processes.

(3) The R&D organizations should maintain close liaison with industry in order to keep it abreast of new developments. Facilities may be offered by these organizations for the training of selective manpower from the industry in the field of advanced materials.

D. Regional collaboration

(1) Regional collaboration is most essential for gradual transfer of technology from advanced countries of the region to the developing countries.

(2) Bilateral and multilateral co-operation among different R&D institutions is recommended in order to compensate for manpower and financial resource limitations.

(3) Establishment of a Regional Centre on Advanced Materials is proposed in order to provide a central institute of advanced research. It would play an important role in the dissemination of scientific literature and data, as a meeting-place for scientists from various countries of the region and for the provision of sophisticated and expensive equipment for research under one roof. Such a Centre should act as a strong focal point for interaction with national centres. Figure 6 summarizes the central role that would be played by the Regional Centre in this context.

REFERENCES

1/ Asia Yearbook 1989, Far Eastern Economic Review, Hong Kong (1988).

2/ Encyclopaedia Americana, Grolier Incorporated, Connecticut, USA, Vol. 22, p. 403 (1988).

3/ Abdus Salam, Notes on Science, Technology and Science Education in the Development of the South, The Third World Academy of Science, Trieste, Italy (1989).

4/ R.L. Sivard, World Military and Social Expenditures 1987-88.

5/ UNESCO Stastical Digest 1987, United Nations Educational, Scientific and Cultural Organization, Paris (1987).

6/ Statistical Yearbook for Asia and the Pacific 1987, Economic and Social Commission for Asia and the Pacific, Bangkok (1988).

7/ 1986 Energy Statistics Yearbook, United Nations, New York (1988).

8/ M. Kuersten, G. Bluemel, L. Lahner and H. Schmidt, Bulletin of the Advance Technology Alert System, Centre for Science and Technology for Development, United Nations, New York, Vol. 5, p. 24 (1988).

9/ A.L. Bement, Jr., High-Temperature Alloys: Theory and Design, ed. J.O. Stiegler, The Metallurgical Society of AIME, Pennsylvania, USA, p. 3 (1984).

10/ Frontiers in Materials Technologies, eds. M.A. Meyers and O.T. Inal, Elsevier, Amsterdam (1985).

11/ P. Rohatgi, Bulletin of the Advance Technology Alert System, Centre for Science and Technology for Development, United Nations, New York, Vol. 5, p. 8 (1988).

12/ Federal Institute of Geosciences and Natural Resources, Hannover, Federal Republic of Germany.

13/ Metals Handbook, eds B. Bardes and H. Baker, American Society for Metals, 9th ed., Vols. 1-2 (1978-79).

14/ Metals Progress 1978 Databook, American Society for Metals (1978).

15/ Metals Progress 1980 Databook, American Society for Metals (1980).

16/ Metals Progress 1982 Materials and Processing Databook, American Society for Metals (1982).

17/ Advanced Materials and Processes, Metals Park, Ohio, No. 1 (1988).

18/ Advanced Materials and Processes, Metals Park, Ohio, No. 1 (1989).

19/ Science & Technology in Japan, p. 17, October - December 1983.

20/ D.C. Phillips, High-Temperature Fibre Composites, Materials Development Division, AERE Harwell (UK).

21/ R.J. Kubel, Jr., Advanced Materials and Processes, No. 10, p. 47 (1987).

22/ J.G. Bednorz and K.A. Mueller, Z. Phys. B, 64, 189 (1986).

23/ C.W. Chu et al., Phys. Rev. Let. 58, 405 (1987)

24/ M. Fleischmann and S. Pons, J. Electroanal. Chem. 261, 301 (1989).

25/ Statistical Yearbook 1988, United Nations Educational, Scientific and Cultural Organization, Paris (1988).

TABLES

TABLE I: EXPENDITURE ON EDUCATION, SCIENCE AND TECHNOLOGY

Country	Population (Million)	GNP (10^9 US$)	GNP Per Capita (US$)	Educational Expenditure (% of GNP)	S&T Expenditure (10^6 US$	
						% of GNP
Burma	41.1	7.0	190	2.0	n.a	n.a
India	816.8	191.3	250	3.1	1,721	0.9
P.R. China	1087.0	322.7	310	2.8	n.a	n.a
Indonesia	177.4	86.0	530	3.4	258	0.3
Pakistan	103.8	36.1	380	1.8	72	0.2
Philippines	63.2	32.8	600	1.8	66	0.2
Malaysia	17.0	32.0	2,050	6.1	211	0.8
Rep. of Korea	42.6	88.6	2,180	4.8	886	1.1
New Zealand	3.3	23.7	7,310	4.4	214	0.9
Singapore	2.6	19.3	7,420	5.3	95	0.5
Australia	16.5	171.2	10,840	6.0	1,880	1.1
Japan	122.7	1,366.2	11,330	5.1	35,520	2.6
U.K.	56.5	474.4	8,390	5.1	9,962	2.1
France	51.1	526.5	9,550	5.3	4,721	1.8
F.R. Germany	61.0	668.1	10,940	4.6	16,701	2.5
U.S.A.	238.0	3,916.0	16,400	5.0	101,818	2.6

Figures mostly for 1985, except for population which is for 1988
Figures based on Ref. [1,3,4,5].

TABLE II: CONTRIBUTION OF AGRICULTURAL AND INDUSTRIAL SECTORS TO TOTAL GDP

Country	GDP (10^9 US$)	GDP Per Capita (US$)	Agriculture*	Manufacturing*	Mining*	Energy*
Burma	7.3	190	27.9	10.7	0.01	0.54
India	182.5	209	37.0	25.0	2.66	1.93
P.R. China	295.0	234	31.0	46.0	n.a	n.a
Indonesia	57.0	292	25.8	14.4	16.24	0.81
Pakistan	38.5	390	24.8	20.0	2.19	2.00
Philippines	33.9	460	25.5	25.3	1.95	1.37
Malaysia	33.1	1,953	21.0	25.0	11.11	1.77
Rep. of Korea	121.3	2,826	11.4	30.3	1.34	3.31
Taiwan	91.3	4,573	5.2	43.5	n.a	n.a
New Zealand	25.0	6,984	7.1	26.4	1.15	3.09
Australia	182.5	9,188	4.1	17.0	6.20	3.40
Japan	2545.6	20,833	3.0	33.8	0.47	2.96

Data mostly for 1987

* Figures for Agriculture, Manufacturing, Mining and Energy given as percentage of GDP.

Figures based on Ref.[1,6].

TABLE III: MAJOR MATERIALS-BASED MANUFACTURING OUTPUT

PRODUCT	Burma	India	P.R. China	Indonesia	Pakistan	Philippines	Malaysia	Rep. of Korea	New Zealand	Australia	Japan
PETROLEUM PRODUCTS	1,066	29,061	65,810	20,218	4,758	7,643	-	21,484	3,252	29,877	127,884
CEMENT	429	310,903	145,950	9,940	4,698	3,072	3,128	20,424	863	5,680	72,847
PLATE GLASS	-	18,213	-	-	-	-	-	-	-	-	-
PLASTICS & RESINS	-	226	-	-	-	-	-	-	-	-	7,046
STEELS											
PIG IRON	-	9,701	43,840	-	-	-	-	8,833	-	5,331	81,958
STEEL INGOTS	-	10,963	46,790	-	-	-	-	4,851	-	6,311	98,275
ROLLED STEEL	-	-	-	-	-	-	-	534	-	-	-
NON-FERROUS METALS											
ALUMINIUM	-	235	410	-	-	-	-	-	-	-	1,098
LEAD	-	-	195	-	-	-	-	-	-	-	285
ZINC	-	-	190	-	-	-	-	-	-	-	739
COPPER	-	-	400	-	-	-	-	-	-	-	936
TIN	-	-	18	21	-	-	45	-	-	3,483	1
MAGNESIUM	-	-	7	-	-	-	-	-	-	-	-
LOW LEVEL FABRICATION											
TV/RADIO INSTRUMENTS	-	1,209	-	-	-	-	-	6,392	-	398	30,723
BICYCLES	-	5,646	-	463	-	-	-	943	-	-	-
SEWING MACHINES	-	322	-	-	67	-	-	80	-	-	-
HIGH LEVEL FABRICATION	-	-	-	-	-	-	-	-	-	-	-
MOTOR VEHICLES	-	-	-	-	-	-	-	-	105	-	-
MERCHANT VESSELS	-	-	-	-	-	-	-	-	-	11	8,906

Data mostly for 1985/86 - Data based on Ref. [6]
All figures in 10^3 tonnes.

TABLE IV: ENERGY PRODUCTION AND CONSUMPTION

Country	Electricity		Petroleum		Coal		Gas		Consumption	
	Production	Consumption	Production	Consumption	Production	Consumption	Production	Consumption	Total	Per capita
Burma	4	4	60	41	2	8	42	42	95	3
India	212	211	1,312	1,561	4,111	4,178	210	210	6,160	8
P.R.China	360	364	5,468	3,001	17,973	17,858	547	547	21,771	21
Indonesia	26	26	2,973	1,023	51	66	1,120	277	1,392	8
Pakistan	51	51	80	313	41	65	322	322	751	7
Philippines	38	38	14	312	25	53	-	-	403	7
Malaysia	15	15	1,038	381	-	12	369	82	489	31
Rep.of Korea	116	116	-	966	467	912	-	3	1,998	48
New Zealand	83	83	57	116	54	46	140	140	384	115
Australia	59	59	1,156	1,197	3,490	1,295	571	571	3,122	196
Japan	923	923	27	7,266	412	3,054	83	1,657	12,900	106
F.R.Germany	490	509	235	4,569	3,354	3,296	465	1,724	10,097	166
U.K.	227	243	5,335	3,120	3,168	3,289	1,747	2,206	8,858	157
USA	2.595	2,725	20,185	29.923	19,622	17,513	16,019	16.605	66,766	278
USSR	1.356	1,252	25,794	15,271	15,350	14,877	23,698	21,270	52,671	187

Data mostly for 1986

Units 10^{15} Joules, except per capita consumption which is 10^{9} Joules

10^{10} Joules=9.48×10^{6} Btu=0.38 tce.

Data based on Ref. [7].

TABLE V: MAJOR MINERAL RESOURCES

Country	Iron	Copper	Zinc	Bauxite	Tungsten	Tin	Manganese	Lead	*Gold	*Silver	Others*
Burma	-	166	4	-	945	2	-	22	-	18	-
India	27837	50	53	2209	-	-	482	-	1.85	26	Magnesite: 420, Chromium: 175, Asbestos: 30
P.R. China	69095	185	190	1650	15	18	480	160	-	-	Magnesite: 2,000, Mercury: 700, Asbestos: 16
Indonesia	-	233	-	830	-	22	4	-	0.23	2	-
Pakistan	-	-	-	2035	-	-	138	-	-	-	Antimony: 6, Chromium: 3, Magnesite: 3
Philippines	2	226	-	-	-	-	-	-	33.06	52	Chromium: 100
Malaysia	182	-	-	492	11	37	-	-	0.22	-	-
Rep. of Korea	542	-	90	-	4	-	-	18	2.40	51	Asbestos: 5
New Zealand	-	-	-	-	-	-	-	-	1.40	-	-
Australia	63500	252	734	32400	1902	7	970	491	48.85	1038	-
Japan	338	43	253	-	538	510	6	50	5.31	339	-

Mostly 1985 data

All figures in 10^3 tonnes unless otherwise mentioned

* : Tonnes

Figures based on Ref. [6]

TABLE VI: PER CAPITA CONSUMPTION OF STEEL AND NON-FERROUS METALS

Country	GNP per capita (US $)	Per capita consumption of steel (Kg)	Per capita consumption of non-ferrous metals(Kg)
Burma	190	n.a.	-
India	250	18	1
P.R. China	310	54	7
Pakistan	380	7	n.a.
Indonesia	530	n.a.	n.a.
Phillippines	600	4	n.a.
Malaysia	2,050	48	n.a.
Rep. of Korea	2,180	247	13
Taiwan Province	3,690	238	17
New Zealand	7,310	224	22
Australia	10,840	363	35
Japan	11,330	607	35
U.K.	8,460	257	21
F.R. Germany	10,940	504	44
U.S.A	16,690	440	36

Figures for 1985-86

Data based on Ref. [6,11,12]

TABLE VII: TYPICAL APPLICATIONS OF INDUSTRIAL ALLOYS.

Alloy/Type	Tesile Strength (MPa)	Typical Applications
STEELS.		
Plain low carbon	325-485	Nails and wire, pipes, low temperature puressure vessels, automobiles, structural applications.
High strength low alloy (HSLA)	435-655	Truck frames and railway carriages revetted structures, low temperature uses.
Plain carbon	605-1280	Crankshafts, bolts, hammers, knives and hacksaw blades.
Alloy steels	786-2170	Springs, hand tools, shafts, pistons gears and aircraft tubing.
Tool steels	-	Pipe cutters, drills, punches, dies and saws.
STAINLESS STEELS		
Ferritic	448-452	Automotive exhaust, values (high temperature), glass moulds.
Austenitic	552-586	Food processing, welding, construction
Martensitic	483-1790	Ammunition components, cutlery, surgica tools.
Precipitation Hardenable	897-1480	Knives, springs.

Cont'd ... TABLE VII

COPPER ALLOYS		
Wrought alloys	220-372	Ammunition components, welding rods, saltwater piping, rivets, springs diaphragm, radiators.
Cast alloys	234-584	Battery clamps, bearings, bushings, gears and valve seats.
ALUMINIUM ALLOYS		
Wrought, Nonheat-Treatable Alloys	90-195	Sheet metal work, Cooking utensils, Bus and truck uses.
Wrought, Heat-Treatable Alloys.	485-570	General structures, aircraft structural parts, trucks.
Cast, Heat-Treatable Alloys	230-250	Crank cases, aircraft wheels, Water-colled cylinder blocks.
MAGNESIUM ALLOYS		
Wrought Alloys	255-350	Missile and aircrraft use, highly stressed extrusions, forgings of maximum strenghth for aircraft.
Cast Alloys	160-230	Pressure-tight castings, parts for cars, lawnmowers, luggage.
TITANIUM ALLOYS	517-1220	High strength fasteners, aircraft parts, rocket motor cases, chemical and marine uses.

Data based on Ref[13-16]

TABLE VIII: TOUGHNESS OF GLASS, CERAMICS AND THEIR COMPOSITES

	Strength, MPa	Work of fracture, J m^{-2}	K_{Ic}, MPa·$m^{1/2}$
Glass	100	2-4	0.5
Alumina	500	40	4
Silicon carbide	500	40	4
Silicon nitride	600	100	5
Fully stabilized zirconia	180	—	2.4
Partially stabilized zirconia	600-800	—	6-8
Zirconia toughened ceramic	300-800	—	10
Tetragonal zirconia polycrystalline	1,000-2,500	—	7-12
Whisker-reinforced Si_3N_4	400-800	—	6-9
Short fiber-reinforced glass	50-150	600-800	7
Continuous fiber-reinforced ceramic/ glasses	700-1,000	10^3-10^4	10-20

Source, "High-Temperature Fibre Composites," by D.C. Phillips, Materials Development Div., Harwell Laboratory, UK.

TABLE IX: NUMBER OF SCIENTISTS AND ENGINEERS, AND TECHNICIANS, ENGAGED IN RESEARCH AND EXPERIMENTAL DEVELOPMENT

Country	Year	Scientists & Engineers		Technicians	
		Total	per 10,000	Total	per 10,000
Burma	1975	1720	0.4	500	0.1
India	1984	100,136	1.3	72,233	0.9
P.R. China	-	n.a.	-	n.a.	-
Indonesia	1986	29,621	1.7	n.a.	-
Pakistan	1986	9,919	0.9	14,028	1.4
Philippines	1982	5,919	1.0	2,577	0.4
Malaysia	1983	n.a.	-	n.a.	-
Rep. of Korea	1986	47,042	11.6	30,465	7.5
New Zealand	1979	n.a.	-	n.a.	-
Australia	1985	29,236	18.6	14,916	9.5
Japan	1986	575,292	49.3	101,861	8.7

Figures based on Ref. [25].

FIGURE CAPTIONS

Fig.1.	Agricultural and industrial out put vs. GDP per capita income.
Fig.2.	Energy consumption vs. per capita income.
Fig.3.	Consumption of steel vs. per capita income.
Fig.4.	Function and use of fine ceramics.
Fig.5.	No. of R&D scientists and engineers, and R&D expenditure, as a function of per capita income.
Fig.6.	Regional co-operation scheme for new materials development.

....

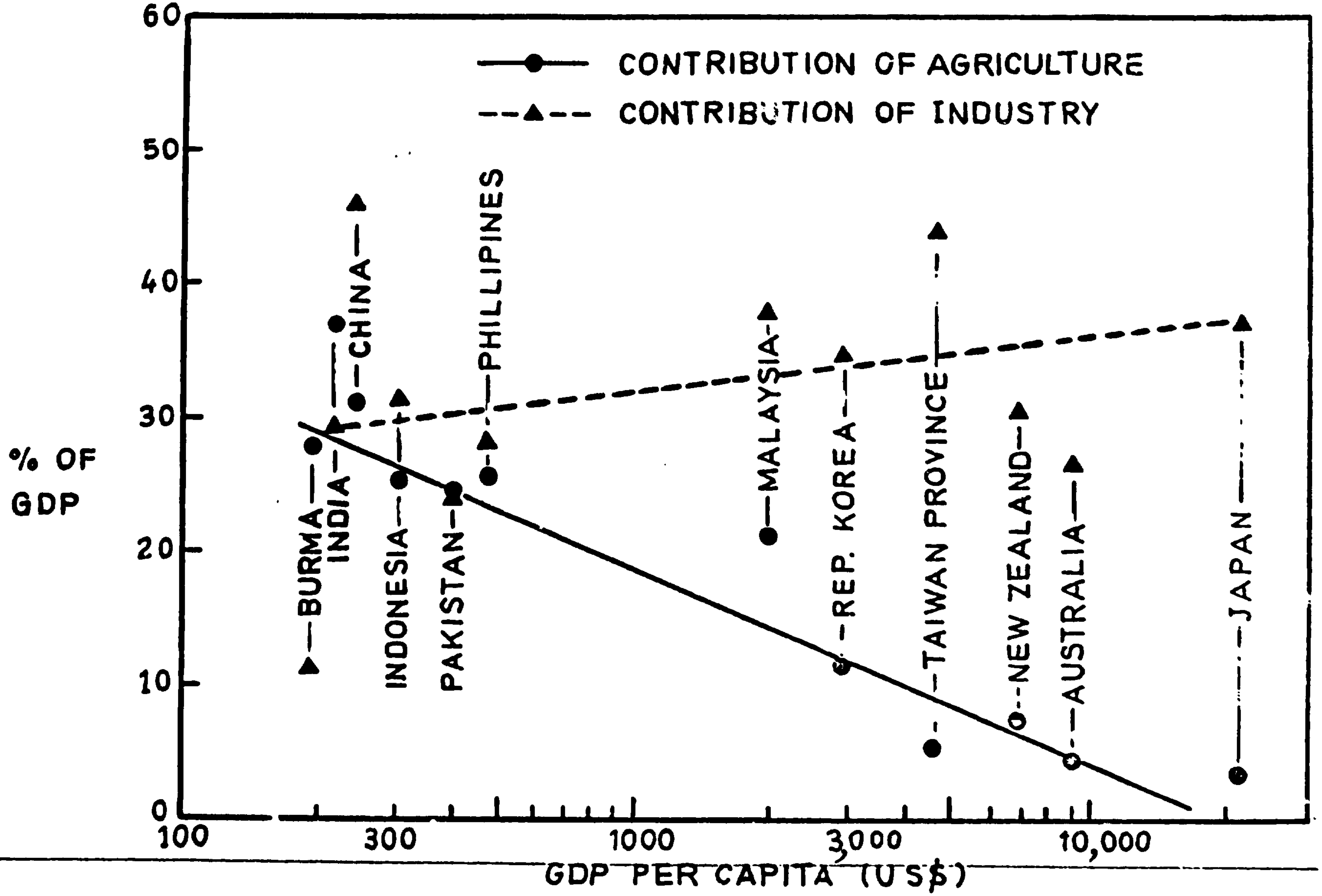


Fig.1 AGRICULTURAL AND INDUSTRIAL OUTPUT AS A FUNCTION OF PER CAPITA INCOME (1987)

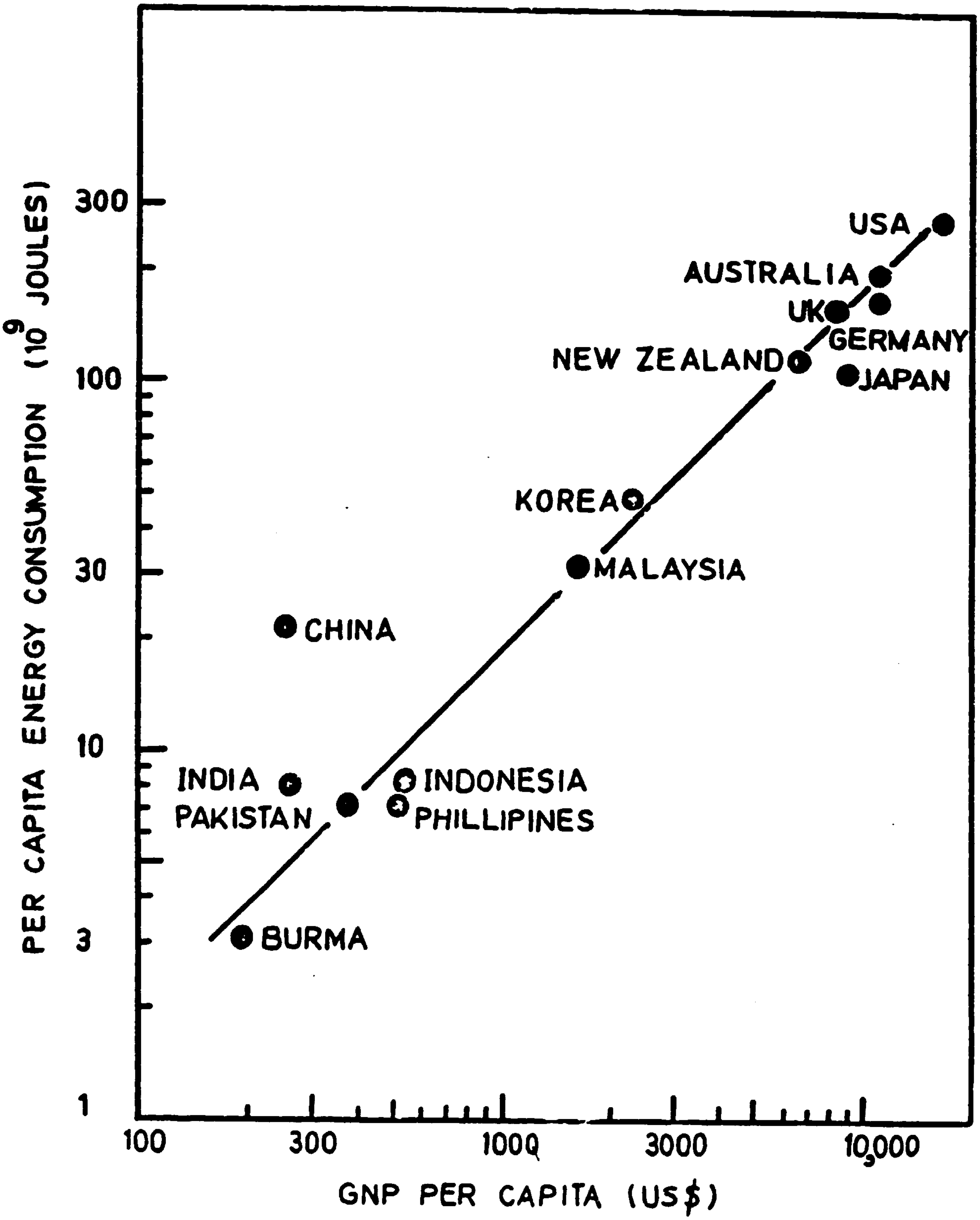


Fig. 2 ENERGY CONSUMPTION AS A FUNCTION OF PER CAPITA INCOME (1986)

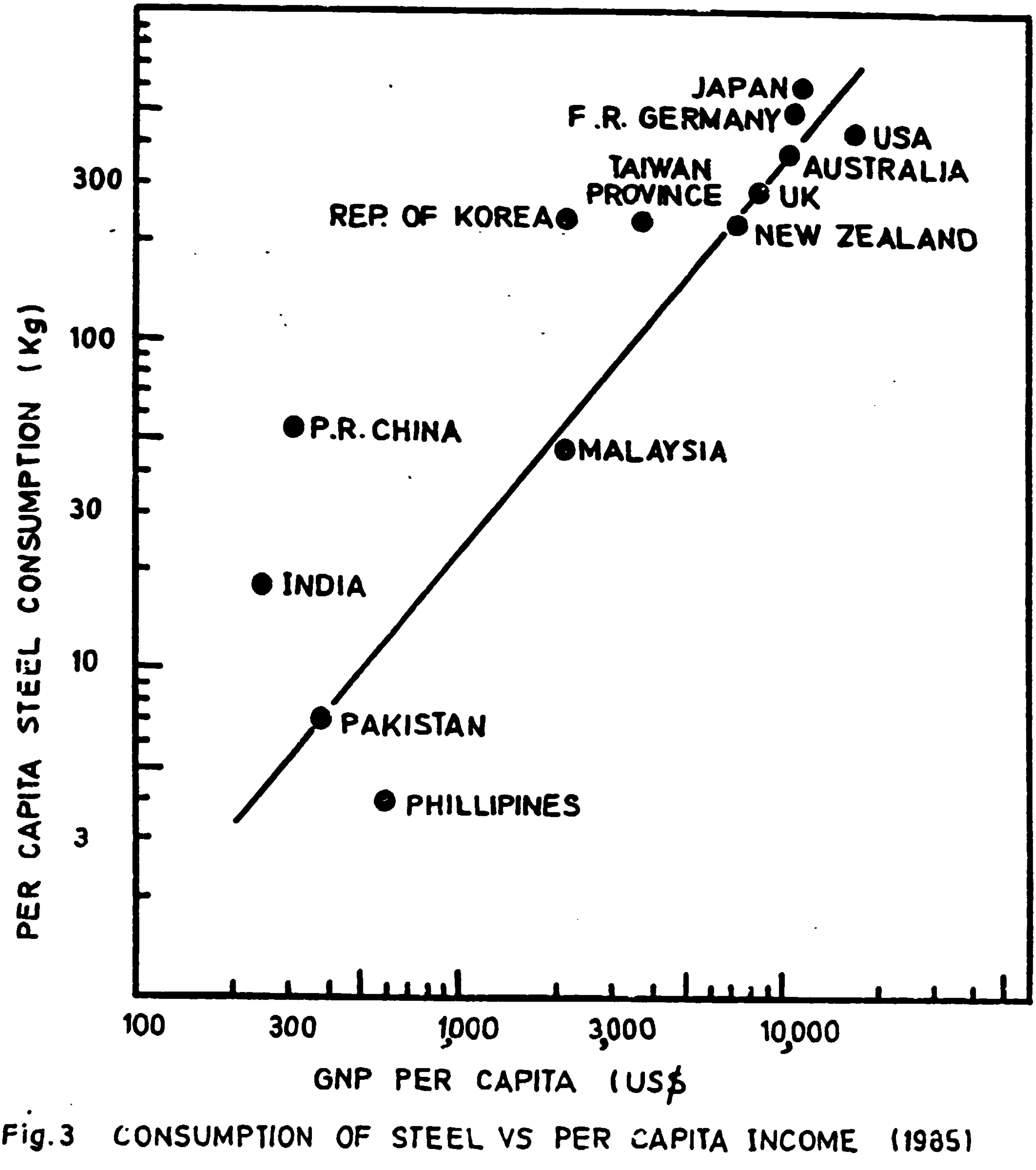
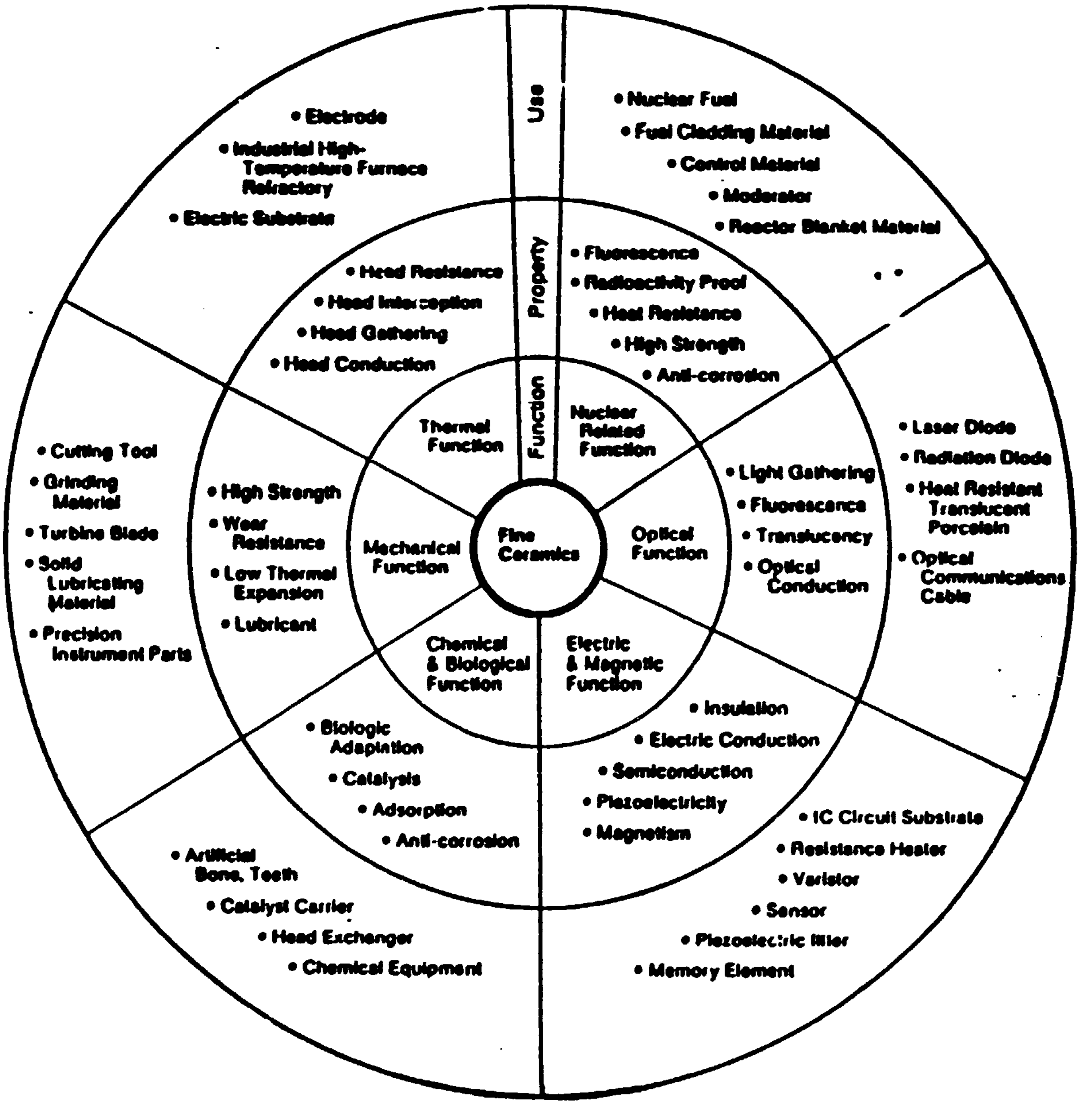


Fig.3 CONSUMPTION OF STEEL VS PER CAPITA INCOME (1985)

Fig. 4: Function and Use of Fine Ceramics (Examples)



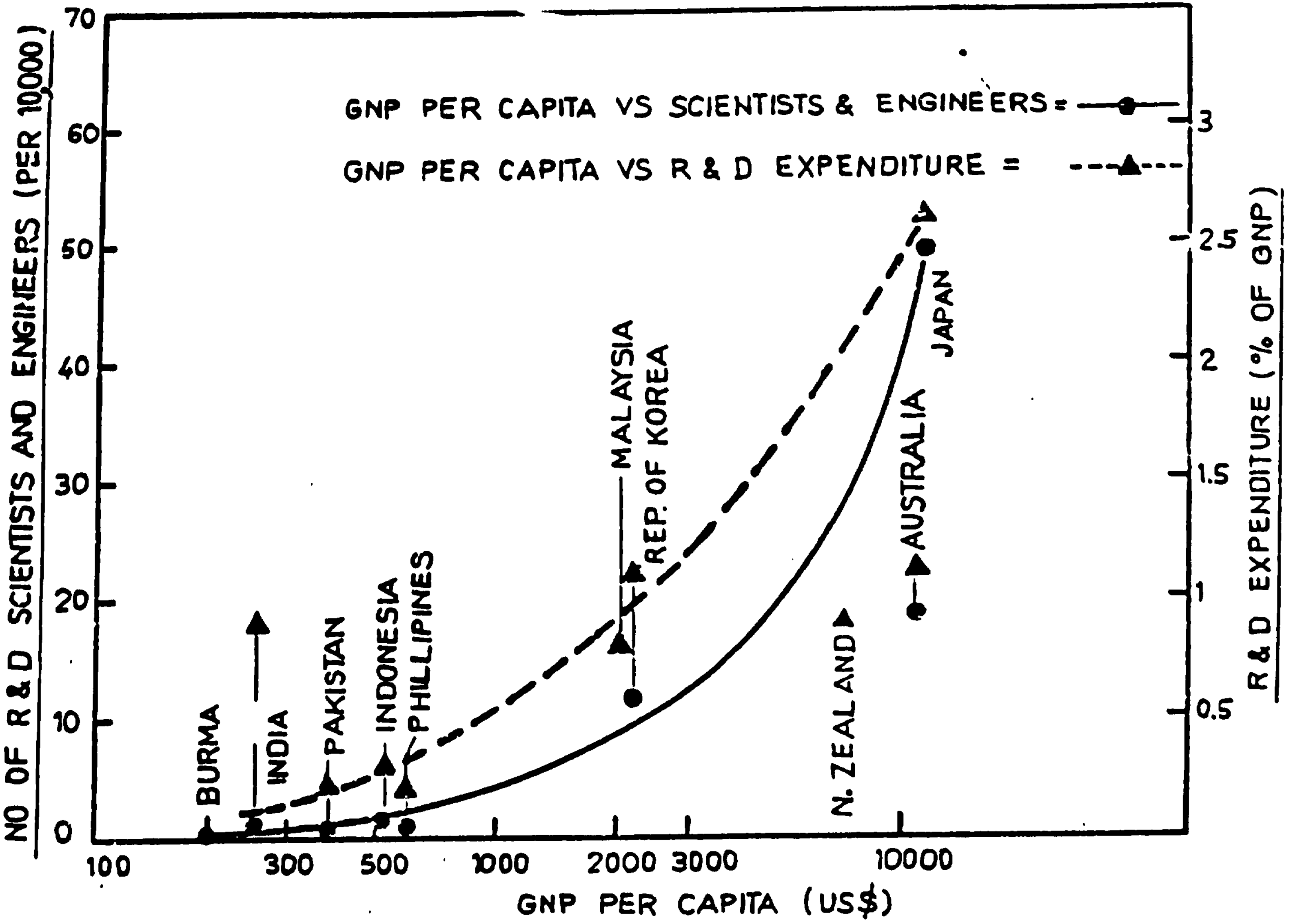
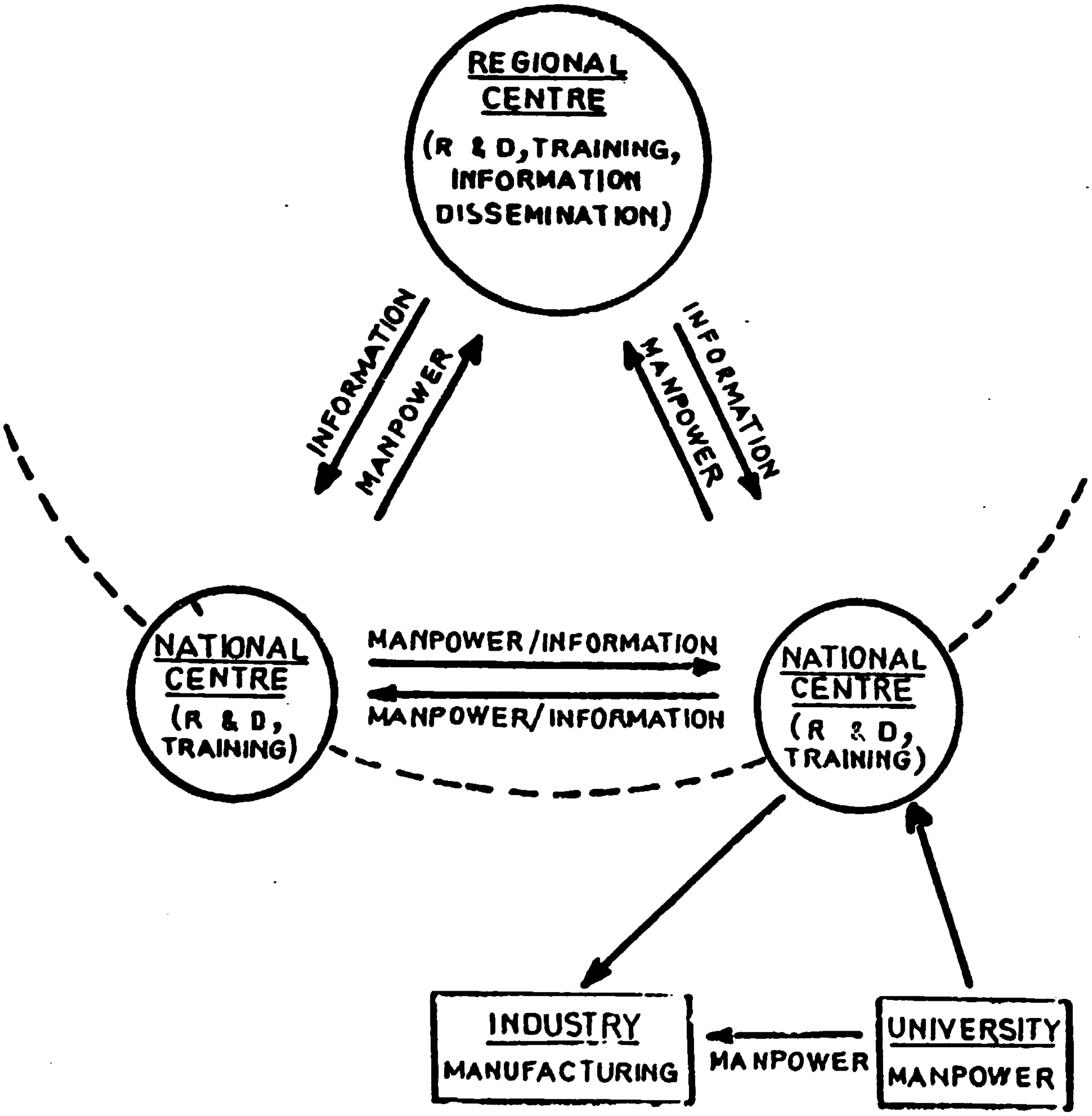


Fig.5. NUMBER OF R & D SCIENTISTS AND ENGINEERS, AND R & D EXPENDITURE, AS A FUNCTION OF PER CAPITA INCOME (1985).

Fig.6. REGIONAL COOPERATION SCHEME FOR NEW MATERIALS DEVELOPMENT



5. ADVANCED MATERIALS AND DEVELOPMENT - HOW ASIA CAN MEET THE CHALLENGE

by Dr. P. Ramakrishnan, Professor, Department of Metallurgical Engineering, Chief Co-ordinator, Power Metallurgy and High Temperature Materials Centre, Indian Institute of Technology, Powai, Bombay - 400 076, India.

Introduction

Materials have played a key role in our development right from the primitive stage, as is evident from the evolution of the civilization from stone age, bronze age, iron age and the current multi-materials age. Modern technological developments are increasingly interrelated with the progress of the advanced materials and these are further stimulating the growth of many sectors of our economy. The achievements made during the last decades such as the harnessing of nuclear energy, breakthrough into outer space, development of computers, microelectronics, lasers, biotechnology and communication systems are all indebted to the ready availability of the right kind of materials and these have made a profound impact on the overall development of our society. The emerging requirements are based on higher technological dimensions and have to be realized with new and improved materials. Hence materials scientists and engineers are working not only on the traditional challenges of increasing strength, modulus, toughness, corrosion and high temperature resistance of structural materials but also on innovative aspects of a variety of materials ranging from alpha alumina, silicon carbide, silicon nitride to transformation toughened zirconia. They are also creatively working on how to develop optical fibres capable of transmitting laser light for hundreds of kilometres without the need for repeaters, on heterostructure devices for laser diodes, on superconducting oxides, on conductive or self-reinforcing polymers, on composites containing complex combinations of metals, ceramics, polymers and glasses and on diamond thin films.

The distinction between basic and applied research is breaking down because of the increased pace of development; the period of time between discovery and application has reduced substantially, as is evident from table 1.

In the field of microelectronics, the period between the conception of a device and its mass-production can be reduced to less than two years. The traditional discipline-oriented approach to science and engineering is increasingly being replaced by the use of interdisciplinary teams focused on emerging technologies for manufacturing and communications. The highly competitive environment today is bringing science and practice closer together than ever before, and materials technology is enabling the concepts of theoreticians and design engineers to become tomorrow's useful products.

Advanced materials and development

Materials are important inputs as well as outputs, leading to industrialization and economic development. Radical changes are taking place in the development and usage of materials in the industrialized countries. The general trend is to use less material per unit of output or for a given product. 1/ The degree of sophistication reduces the amount of materials required as reported in figure 1. Here the amount of materials per unit of product is plotted against the amount of sophistication attached to the use of a given material. In this model the gravity centre of several major materials-producing industries has been indicated with a vector, shown as an arrow to indicate the future trends in the next decade or so. As an illustration, industries like steel and cement have limited possibilities to move the gravity centre of their product mix towards more sophisticated use.

The basic steel industry will move only slowly out of its present position. However, specialized steels such as high strength low alloy (HSLA) steels have a bright future as these and dual phase steels are considered important materials for the automotive industry. Opportunities for high temperature materials, lightweight materials like plastics, aluminium, titanium and magnesium are more dynamic. The automobile industry will move like most other materials-using industries to the upper left of the model. For the vectors indicating innovative moves, research and development and new technologies will have a considerable impact. The microprocessor industry would be placed around electronic materials in the upper left of the model. Similarly composite materials will substitute the previously used materials in many applications.

Advanced materials are not only meeting the needs of the industries but are also providing new technologies. These materials are assembled into components critical to the successful performance and operation of such large complex systems as aircraft or space vehicles, electronic devices, automobiles and so on. Hence advanced materials are essential for the growth of these and other related industries. The strength-to-density ratios of today's advanced composite materials are about 50 times better than those of cast iron, an important material of the previous century. The efficiency of an engine to convert heat into energy is directly related to the operating temperatures. Thus the engine operating temperatures have been increasing steadily from the steam engine of the year 1900 to more than 1,200°C for the modern turbojet engines.

This is significant because each 150° increase in temperature can result in a 20 per cent increase in engine thrust and a substantial improvement in fuel economy. These improvements have been possible because of the development of advancud superalloys including mechanical alloys, ceramics and carbon-carbon composites. In order to achieve the speed of Mach. 8 envisaged for an advanced aircraft like the Orient Express that could fly from New York to Tokyo in three hours, advanced materials are to be developed. Similarly developments are also taking place in nuclear power generation as a result of advanced nuclear fuel materials such as uranium oxide, plutonium-bearing mixed oxide and carbide fuels. Today's magnetic materials based on Nd-Fe-B are 100 times stronger than the early steel magnets of 1900. Systematic analysis can trace the development of improved materials such as ferrites, Al-Ni-Co alloys and rare earth cobalt magnets. The progress made in the tool materials from carbon steels, with a cutting speed of 10 m/min during 1900; over a period through materials like high speed steel, cemented carbides, coated tools, oxide ceramics and silicon nitride could increase the cutting speed to the current level of over 200 m/min thereby increasing productivity. Other interesting developments include shape memory alloys like nitinol, a wide variety of biomaterials and superconducting materials ranging from Nb-Sn, Nb-Ti to high temperature superconducting oxides.

Materials processing by powder metallurgy

In order to fulfil the potential of advanced materials it is essential to develop appropriate synthesis, processing and fabrication of these materials into useful components and devices reliably and economically. A large number of processing technologies such as molecular beam epitaxy (MBE) or metal organic chemical vapour deposition (MOCVD), rapid solidification, directional solidification, super plastic forming, powder metallurgy, etc. are found to be very promising. Several of the processing technologies which are being investigated in laboratories today are expected to reach a stage of application and marketability in due course. In this context powder metallurgy processes will play a predominant role in the development of advanced materials.

Powder metallurgy techniques are being increasingly used for the production of traditional engineering components advantageously as well as for the development of advanced and new materials for the emerging technologies. 2/ Powder metallurgy conserves energy and raw material in the production of precision engineering components with fewer steps and minimum machining along with the capabilities of producing high performance alloy systems and materials which are impossible by the conventional methods. The latter category includes two phase alloys with large differences in structure, melting point and density. The most important of these materials are the cemented carbides of the hard metal industry. Others include electrical contact materials such as tungsten-silver, copper-tungsten, carbon-silver, etc. and high temperature materials like ceramic-metal (cermet) materials. High melting point metals such as tungsten, molybdenum, tantalum, etc. and light metals such as beryllium are processed by powder metallurgy because of the attainment of the required structure and properties on the one hand and economy of the process on the other. On account of these reasons, along with the technical advantage of avoiding segregation, more and more ferrous materials with high amounts of alloying additions are increasingly being processed by powder metallurgy. These include high speed steels, superalloys and a variety of high temperature materials. One of the main advantages of powder metallurgy is the possibility of producing complex shaped parts in large numbers with close dimensional tolerances. Powder metallurgy is competing with other manufacturing techniques such as casting, machining, welding and more particularly with rolling, extrusion and forging. The field of powder metallurgy is constantly expanding because of the development of new production tecnniques and materials technology.

The global market for powder metallurgy products is projected to grow from $US 5 billion to $US 6 billion in 1987 to about $US 15 billion to $US 18 billion by the year 2000, representing an annual growth rate of 8 to 10 per cent. Early empirical knowledge and technological experience of the powder metallurgy industry is being replaced by sound scientific and engineering knowledge supported by sophisticated instrumentation, diagnostic technology and press and furnace equipment. The global market for metal powders is estimated at 655,000 tons as reported in table 2.

The automotive industry is the largest consumer of international powder metallurgy industry for iron and copper-base products. In North America the automotive powder metallurgy market is about 60 to 70 per cent of total output and in Japan it is about 75 per cent, in the UK about 70 per cent, in the Federal Republic of Germany more than 60 per cent, while in Italy around 60 per cent. Powder metallurgy parts should see more usage in such markets as computer peripheral equipment, power tools and lock hardware, lawn and garden equipment and appliances. The interest is very high in the metal injection moulding process, powder forging, high temperature sintering and in new materials.

The rapid changes in the high technology industries and the increasing competition have promoted the development of powder metallurgy net and near-net-shape manufacturing processes that are both materials and energy efficient. Another important factor responsible for the rapid progress of powder metallurgy is the innovations in powder production and consolidation through continuous research and development.

Advances in powder preparation

Consider the most widely used metal powder, namely iron powder. About 30 years ago there were only a few grades of iron powder but today there are more than 50 specialized grades on the market. The range of powder grades available today include super compressibility powder for high density parts, MnS additions for improved machinability, special powders for improved fatigue life for powder forged gears and connecting rods for cars, Fe-Cr-Mo-Cu-P-C alloy powders for higher wear resistance and to reduce the weight of camshafts for automobiles, stainless steel powders for high temperature and corrosion resistant applications including applications like filtration. Other developments include tool steel powders for cutting and wear parts; irregular iron powders with large surface areas and low density for the high performance required for friction applications such as heavy duty brake pads and linings. The interest in the carbonyl process which is capable of producing fine spherical iron powders of 3-4 µm, 6-7 µm, 8-9 µm, etc. particle sizes with high purity has been revived recently because of the high interest in the research and development of metal injection moulding process.

The estimated world wide consumption of iron powder for powder metallurgy applications in 1987 is reported in table 3. 3/

The important methods for iron powder production are atomization, gaseous reduction of oxides, reduction with carbon, electrolysis and carbonyl decomposition.

The atomization method of powder production provides some of the best combinations of powder chemistry, cleanliness, size and shape characteristics for reactive alloys. The constant research and development of commercial water and gas atomization have led to the development of rotating electrode processes which provide very clean spherical powders with a high degree of compositional and microstructural control. Different melting procedures such as electron-beam melting, plasma melting and laser melting have been used in conjunction with rotating electrode process to produce reactive melting and alloy powders such as titanium and zirconium suitable for net-shape manufacturing by hot isostatic pressing. In the traditional commercial gas atomization, the cooling rates are low - of the order of 10 to 10^2 degrees per second - and the particle sizes are relatively coarse. Further these powders suffer from trapped porosity and fine satellite formation resulting in the lower packing density of the powder and heterogeneity in the microstructure of the compact. The rotating electrode processes does not use a crucible for melting and thereby reduce the contamination of reactive metals and alloys. The cooling rate in the rotating electrode process can be increased by additional supply of gases for heat extraction from the powders during atomization.

The cooling rate during atomization of molten metals can be increased to 10^2 to 10^4 degrees per second by water and steam atomization. But these media are inexpensive and they will lead to more oxidation of the powder. Hence the process is used for low alloy steels where subsequent reduction is possible. An important development to increase the cooling rate of gas atomization to 10^3 to 10^5 degrees per second is the ultrasonic gas atomization. In this process a series of shock wave nozzles impose pulsed ultrasonic gas on the liquid metal stream. The gas jets are generated at high pressure of the order of 5 MPa and high frequency of the order of 100 K c/s with an exit velocity of the order of 2 Mach. Fine powders with an average particle size of the order of 20 μm have been produced by this method. Higher cooling rates of 10^6 degrees per second and above could be achieved by metallic substrate quenching such as melt extraction and melt spinning. The high cooling rates will enable production of alloys with metastable phases consisting of glassy or microcrystalline materials in the form of staple fibres or filaments, which are to be pulverized for producing the powders.

Progress in alloy development and materials

The alloy systems produced by the usual processing methods of melting, casting and working have reached the limit of their performance capabilities. This is the case with aluminium alloys, nickel and cobalt base superalloys developed in the 1960s for gas turbine engines and other high temperature applications; high speed tool steels developed in the 1970s and other alloys with large amounts of alloying additions. The powder metallurgy techniques offer a solution to the limitations of conventional ingot processing thereby providing materials with superior properties. Through continuous research and development it has been possible to produce by powder metallurgy new aluminium alloys, titanium alloys, superalloys and high speed tool steels with improved properties and performance. The new powder metallurgy techniques make it possible to create new alloys and combinations of materials such as non-equilibrium compositions produced in rapidly solidified powders, combinations produced by mechanical alloying and composite materials. Another incentive to use these new technical advances in powder metallurgy is the opportunity to realize significant cost savings in the case of processing expensive materials by reducing the scrap generated in fabricating the finished components through near-net-shape manufacturing capability of the process.

The powder metallurgy process takes full advantage of alloying elements and allows for use of large amounts of alloying elements. The superior microstructure improves the hot hardness and wear resistance in comparison with conventional high speed steel. Powder metallurgy tool steels are used for milling cutters, reamers, taps, drills, broaching tools, gearhobs, punches, dies, blanking tools, etc. and these tools provide substantial cost reduction through improved performance and increased productivity. Similarly superalloys such as IN-100, Rene 95, Mar-M 509, etc., mechanical alloyed INCONEL-MA753, INCONEL-MA-600, etc., processed by powder metallurgy have shown superior mechanical properties than the conventional superalloys. Powder metallurgy - rapid solidified aluminium alloys (Al-Zn-Mg-Cu-Zr-Ni) in the extruded condition exhibited up to 30 per cent improvement in strength and as much as 40 per cent advantage in toughness compared to the conventional high strength 7075 alloy. Similarly Al-Li alloys processed by powder metallurgy have shown substantial improvement in properties. Modified 7075 aluminium alloy with 1 per cent Ni and 0.8 per cent Zr processed by experimental liquid dynamic compaction has provided tensile strength of 816 MPa and elongation of 8.6 per cent. SiC reinforced aluminium matrix composite 6061-T6 have shown a tensile strength of 795 MPa and modulus of 140 GPa in comparison with 290 MPa strength and 70 GPa modulus of a conventional 6061-T6 alloy. Titanium (Ti-1Al-8V-5Fe) alloys processed by powder metallurgy have provided a tensile strength of 1,480 MPa compared to 965 MPa of a conventional Ti-6Al-4V alloy; thereby the former alloys are being considered as potential materials to replace heavier steel in aircraft landing gears.

Development in powder consolidation

While considering powder metallurgy we have at one end of the spectrum the traditional and long-standing pressing and sintering industry which utilizes cold die pressing and elevated temperature sintering to produce a wide range of products. At the other end of the spectrum are special alloys and materials which are not amenable to die compaction and sintering. They are processed by isostatic compaction, metal injection moulding and other forming processes such as wire drawing, extrusion, rolling forging, hot pressing, hot isostatic pressing and spray forming.

The near-net-shape technology using metal or ceramic moulds permits complex configuration such as multi-stage compressor spool, impeller, turbine disk, valve body, etc. to be formed in single unit components while retaining the properties equivalent or superior to the conventionally processed parts. In addition to hot isostatic pressing many pseudo-hot isostatic pressing (HIP) processes have been developed in order to reduce the capital cost of the equipment and to reduce the production cycle time from several hours. These include ceracon process, rapid omnidirectional compaction and stamp process. In the ceracon process, the porous preform produced by cold consolidation is densified under pseudo-hot isostatic condition using a hot granular ceramic medium in a die by using a press. A variety of alloy steels, stainless steels and superalloys have been consolidated by using the soft tooling process. The rapid omnidirectional compaction involves the use of hermetically sealed mould-powder assembly with the configuration of the component such as a jet engine disk. The assembly is then heated to the consolidation temperature in a furnace and then transferred to a hot die and consolidated using a conventional press. After consolidation the mould is removed by machining, acid leaching or by melting. A variety of materials such as mild steel copper - 10 per cent nickel alloys and ceramics have been used as moulds. In the stamp process the powders produced by horizontal atomization are filled in a steel container and sealed hermetically. The containers are then heated to a temperature of the order of 1,100°C and transferred to a hydraulic press for consolidation to the desired density level which will vary from 95 per cent to full density, depending upon whether these billets are subsequently processed by rolling or forging. A variety of low alloy steels, tools, steels, etc. have been processed by the stamp process. Consolidation under atmospheric pressure - CAP - is another development in which steel powders are treated with boric acid to promote sintering. These powders are loaded into glass moulds, sealed and then heated in crucibles in air atmosphere furnaces. The sintered products with densities of the order of 95 to 99 per cent are worked to full density billets.

Considerable research and development has been carried out on the roll compaction of metal powders into strip. The materials investigated include iron, copper, cobalt, stainless steel, aluminium alloys, titanium alloys, nickel alloys, etc. There are very few commercial production plants and these are located in the UK, Canada, the USA and USSR. Powder consolidation to full density by hot extrusion is another potential production process. The different methods of powder extrusion include extrusion of loose powder, extrusion of cold compacted or hot pressed compact and extrusion of powder sealed in an evacuated container. The latter method is commonly used for aluminium alloys, tool steels and superalloys. Currently considerable research is going on dynamic compaction in which shock waves pass through powder and generate very high pressures of the order of 100 GPa in a few microseconds. The shock wave includes interparticle shearing and surface melting of the metal powder particles, resulting in high densities of the compact. Dynamic compaction offers the possibility of retaining the metastability inherent in rapidly solidified powders after consolidation. Spray forming is a promising net-shape powder processing in which the spray of liquid metal droplets impinges on a substrate, which build up a thick net-shape preform. The important spray forming processes are the spray deposition, simultaneous spray peening, spray rolling and spray forging. Spray forming is a shorter route to the final product. Rapid solidification plasma deposition is another recent development to produce fine grained homogeneous microstructures of several composites in addition to superalloys. Liquid dynamic compaction is another promising process in which ultrasonic gas atomization is used for spraying in order to achieve attractive solidification rates, refined structures and outstanding mechanical properties.

Emerging products, processes and materials

A recent international forum on "Design and manufacturing of powder metallurgy components in the automotive industry" at the International P/M-88 Conference, Orlando, USA, during 1988, indicated that although the P/M industry had proved itself capable of producing a large number of complex shapes for automotive applications the industry has been slow to expand its technology base and to create new opportunities for production of highly stressed parts. For example in developing powder forged connecting rods, priority must be given to developing the optimum material composition, microstructure and properties in order to meet the endurance limits and fatigue testing and the production process must at the same time lend itself to consistent process control. Other products having good prospects in the immediate future in the automotive industry include differential gears and other transmission parts, valve seat inserts, cylinder liners, valve guide bushing and drive sprockets.

Another powder metallurgy process development is the metal injection moulding which has evolved from the embryonic stage and entered into the growth portion of the business life cycle with an estimated sale of $US 15 million in the USA in 1987. According to a forecast the market for metal injection moulding will continue to expand over the next 10 years, growing to between $US 200 million and $US 300 million a year in domestic sales. A large number of organizations all over the world are engaged in research and development of the process to make it faster, cheaper and amenable to large components. New companies are also entering into this field in the USA, Europe and Japan. The annual growth rate in metal injection moulding and powder forging is projected to be of the order of 25 per cent.

On a commercial scale considerable successes have been made in the conservation of materials through recycling of powder metallurgy products. This is particularly true in the case of cemented carbides. Feasibility studies have been established in the recycling of certain iron, steel, brass, titanium, heavy metal and superalloys scrap by powder metallurgy processes. In our own laboratory low grade ferrous scrap such as cast iron and steel machine turnings have been processed by powder metallurgy techniques to advanced dual phase steels and high strength steels with a tensile strength of 950 MPa, resulting in better resource conservation and utilization. 4/

Research and development in the field of powder metallurgy has led to the development of a large number of emerging technologies. Production of high speed tool steels, stainless steel, aluminium, titanium and superalloys of newer composition have already demonstrated their superior properties along with substantial cost reduction in the component manufacture or economy of the overall process and increased productivity. A large number of new and improved special materials have also been developed for high performance applications. These include improved carbide, oxide, nitride, boride, composites and polycrystalline diamond for cutting, forging and wear parts; mixed uranium oxide and plutonium oxide and carbide fuel materials for nuclear reactors; Sm-Co, Fe-Nd-B magnetic materials; Ni-Ti base shape memory alloys; niobium and ceramic base superconducting materials; Co-Cr-Mo, tantalum base materials for orthopaedic joint/bone replacement; a variety of oxide, carbide and nitride base structural ceramics and particle, fibre and whisker reinforced composite materials.

Advanced structural ceramics

Advanced ceramics are unique engineering materials for high performance applications. The slower growth in the commercialization of these materials is related to the technical problems associated with production and fabrication. However several types of advanced ceramics have progressed from laboratory or pilot plant production to commercial production. Research is continuing in acquiring the basic knowledge, characterization of these materials and developing the technology required to ensure the production of reliable, reproducible and cost-effective ceramics products. Advanced ceramics are materials made up of consolidated high purity oxides, nitrides, carbides, borides, etc. of accurately defined composition and particle size, shape and distribution. The estimated world sales in 1985 of advanced ceramics is of the order of $US 5,000 million, currently dominated by the USA and Japan whose hold on the electronic ceramics market gives them the commercial lead. These materials can be classified accordingly to chemical composition and can be divided into oxide ceramics which include alumina, zirconia and beryllia and non-oxide ceramics such as silicon carbide, silicon nitride, boron carbide and the sialons which are based in varying degrees on silicon, aluminium, nitrogen and oxygen.

The processing of these materials in general consists of mixing the powdered ceramic with a binder to enable compaction or shaped through one of the routes such as extrusion, isostatic compaction, slip casting, injection moulding and finally heated to a high temperature causing the material to densify. The manufacturing processes are continually being developed with the main objective of reducing the inherent brittleness of the ceramics. In general, the smaller the particle size of the starting material and the narrower the size distribution, the more reliable the end product. Hence chemical synthesis methods are being used for preparing extremely fine powders in the solid state and gas phase reactions, while methods like sol-gel or inorganic polymer technology are very promising. The future of advanced ceramic materials appears to be very favourable from the world-wide market projections as reported in table 4. 5/

Advanced structural ceramics offer numerous performance advantages such as higher strength at elevated temperatures, light weight, lower wear and less need for lubrication. The abundance of raw materials of ceramics offer the industry an opportunity to conserve rare and expensive metals by developing appropriate structural ceramics for demanding applications. Ceramics based on zirconia, silicon nitride and silicon carbide have potential structural application in advanced heat engines such as gas turbines, diesel engines and many other heat and wear resistant applications. These components comprise rotor blades, statar vanes, combustion chambers, piston caps, cylinder liners, etc. Higher temperature operation leads to increased thermal efficiency and decreased specific fuel consumption. The lower weight results in lower stress in rotating components, greater thrust-to-weight ratio, lower potential life cycle cost and decreased complexity due to the use of non-cooled components. Finally the use of ceramics also reduces dependency on the use of strategic materials like cobalt, chromium, refractory metals, etc.

The last 15 years have seen major advances in the development of ceramic tool materials achieving high cutting speeds with long tool lives. These tools require rigid machine tools with higher power motors and a change in tool design. 6/ Ceramic tool materials may be classified as alumina or silicon nitride based and these base compositions give rise to families of materials with alloying additions. Another development is the SiC whisker reinforced composite ceramic tools. Ceramic tools exhibit very high hardness and wear resistance, high resistance to plastic deformation, chemical stability, etc. They presently constitute about 5 per cent of the total estimated indexable insert market for metal cutting and are used in the automotive industry predominantly for high speed machining of grey cast iron for producing brake drums, brake discs and flywheels. They are also used for high speed machining of superalloys, hard chill cast iron and high strength steels.

The favourable properties of advanced structural ceramics provide a significant advantage for potential use in car and truck engines. Ceramic coatings and ceramic parts are just being introduced by the motor vehicle industry. Currently Japanese auto-makers are using advanced ceramics turbocharges and other small engine components in autos. A prototype diesel engine with ceramic pistons, cylinders and heads and without cooling systems also has been built which is claimed to be capable of operating for 800,000 km. Engines with ceramic blocks and small parts are being tested in both Japan and the US but will not be considered commercially feasible until early in the next century. The projected ceramic engine component market penetration is reported in table 5. 7/

A recent US Department of Energy study for ceramics in heat engines, based on the world Delphi survey, provides a very interesting projection on the economy. 8/ The predicted world market share for ceramics in heat engines in the year 2000 is shown in figure 2. The experts' judgement on leading nations in the year 2000 show Japan in front with a 40 per cent share of the world market followed by the US and the Federal Republic of Germany. World-wide competition is still open and any of the leading nations could play a major role. The economic benefits of leadership in producing engine ceramics are significant, as shown in figure 3. In the medium scenario, the US GNP could differ by $US 37 billion (in 1982) in the year 2000, depending on whether the US or another nation leads in production. As indicated in figure 3, the US economy could expand by $US 11 billion of the US leads or it could decline by $US 26 billion if foreign manufacturers have the lead. Besides the direct economic benefits of advanced ceramic technology, their commercialization can have an effect on the use of other ceramics also.

Advanced composite materials

The search for new materials with improved properties has provided the impetus for the development of composite materials. The use of fibre reinforced polymer matrix composites during the past two decades has revolutionized the engineering materials world. The field of application of glass fibre reinforced plastics has spread over a wide spectrum of consumer goods, construction, chemical plant, marine and road transportation to aerospace components. 9/, 10/ The development of advanced composite materials with fibres of carbon, boron, aramid, silicon carbide, etc. having properties considerably superior to those of earlier composites have extended their applications to high performance components of advanced aircraft and the space shuttle. The down-to-earth applications of composites include automotive, orthopaedic, consumer type - luxury leisure activities, electronic and energy generation industries.

The purpose of reinforcement is to increase the strength and stiffness and modify the failure mechanism advantageously. Special cases fibres can conduct or resist electricity or can conduct heat and resist chemical corrosion. The reinforcing materials can be continuous or discontinuous. Whiskers are single crystal fibres almost free from defects with polygonal cross-sections. The diameters of whiskers may range from 0.1 μm to 1 μm and length of the order of 100 μm to 1,000 μm with very high strength levels approaching theoretic l, in those cases which are finer and free from defects. Whiskers of metals, inter-metallics, oxides, carbides and nitrides are frequently produced and the latter are of particular interest to composites. Typical properties of fibres and whiskers are reported in table 6.

A large number of methods have been developed for the fabrication of polymer, ceramic and metal matrix composites. The understanding and tailoring of the interface region is critical to the development of all types of advanced composite materials. For polymer matrix composites a bond must develop at the interface, requiring that the matrix in its liquid form must wet the fibre. Molten metals can wet fibres of Al_2O_3 and SiC. In the case of ceramic composites the major requirement for enhanced toughness necessitates bonding which is weak during crack propagation but still strong enough for load transfer under tensile loading. In the case of C/C composites a bond of intermediate strength is desired. Frequently a coating is required to facilitate the wetting and subsequent development of intermolecular forces or chemical reaction which establishes a bond between the fibre and matrix. Generally the excessive reaction between the fibre and the matrix is of limited concern with polymer matrix composites. But the melting and consequent rapid reaction rates can lead to an excessive reaction zone in metal matrix composites which can lead to degradation in the mechanical properties. For metal matrix composites the matrix-fibre reaction zone is to be controlled even during solid state processing like hot pressing or diffusion bonding.

There is a visible change in the pattern of usage of materials in the automotive and aircraft industry. The projected auto-material trends from a study by the University of Michigan show that the use of plastics and composites in an average size car is steadily increasing while the usage of iron and steel is declining as shown in figure 4. 11/ The use of plastic and composite body panels is expected to increase from the current 5 per cent level to 70 per cent by the year 2000. Of course a considerable amount of planning, development and engineering is needed for a transition of this magnitude to be accomplished economically. Composites can provide some major benefits that can lead to significant improvements in performance and productivity. The ability of composites to tailor the properties is a special advantage for translating new design concepts to reality.

Aircraft structures are predominantly made by aluminium, steel and titanium. The bulk of the airframe weight of a modern subsonic plane such as a Boeing 757 consists of 78 per cent aluminium alloys. This percentage will drop to 11 per cent between 1990 and 2000 and the replacement will be made by composites. However the development of new aluminium alloys such as aluminium-lithium alloys can change the situation to some extent. The military and aerospace market is currently the major user of advanced composite materials. The material weight distribution of an advanced technology aeroplane is shown in figure 5 and the projected materials requirement for a supersonic commercial aeroplane is shown in figure 6. 10/ The future markets for advanced composite parts is shown in table 7. 12/ Aerospace materials for the twenty-first century will be expensive, but with the increase in market the price will decline in conjunction with increased automation and a full-life engineering approach. The advanced structures will be made out of more than one single material. The supersonic space aeroplane may have a fuselage made of heat-resistant metal alloys, wings and fins of C/C composites, engine inlets, ducts and nozzle from ceramic matrix composites, landing gear of metal matrix composites and fittings with titanium.

Options for the future

For a new material to reach the production level certain criteria have to be fulfilled. These include necessity, maturity, opportunity, availability and cost. The necessity concerns the limitations of the existing materials while maturity relates to the risks involved in the new material. In the implementation process if the costs are exorbitantly high then the opportunities for introducing the new material are limited. But if the situation demands, then it is easy for a new material to be introduced. Similarly in certain circumstances a high cost may be tolerated if the increased performance warrants the additional expense. It may take about 10 to 30 years for a new technology to reach full maturity. Part of this gestation period is involved in the initial basic research, applied research, development, data gathering, scale-up and validation following the go-ahead.

The widespread technological changes are creating major new opportunities for advanced materials. Obviously these emerging trends will lead to a declining intensity of traditional materials. The estimated current relative market maturity of major metals and other materials are shown in figure 7. 13/ This concept is helpful in explaining how as an economy grows and matures the growth in consumption of tonnage metals first exceeds, eventually parallels and finally trails that of the economy as a whole. This illustrates the broader concept of market maturity in general. The figure is helpful in demonstrating the general life cycle after market saturation and as the inexorable evolution of technology proceeds there will be eventual displacement and decline. The curve provides an estimate as to where several materials including advanced materials are deployed in relation to one another on a collective materials market maturity curve. The figure also reveals the contraction of tonnage metals like carbon steel which should be offset at least partially by opportunities and expansion of more specialized materials. The relationship between material supplier and material user is fundamentally changing. From a commodity predominated supplier - we have a metal, how much do you need - to a customer oriented perspective - how to synthesize a new material to solve your problem. Thus, one can expect a transition from metals economy to materials economy as shown in figure 8. 13/ The recent contraction in metal industries is expected to be followed by a much milder decline while most of the firms in these industries will gradually diversify into other areas and a few will concentrate their efforts in specialized metals. Advanced materials will encounter many obstacles and stiff resistance along the way from research laboratory to widespread commercial usage, but the expansion of advanced materials is inevitable. In all the developed countries co-ordinated efforts are being made for overall materials development, every part of the cyclic process of innovation. The broad view of product-process development includes research and development, design, manufacturing, marketing and distribution.

In the United States the federal Government is not only providing funding and facilities of research and development but also playing a leadership role in helping industries to develop new strategies for international competitiveness, in helping bring industries and universities together and to lead in the re-orientation of missions of national laboratories more effectively. Studies like the economic implications of leadership in producing engine ceramics have provided the necessary incentive for significantly increasing support for new materials. Many countries have centralized planning, co-ordinated research and development and specific goals such as the European Research on Advanced Materials (EURAM) and European Research Co-ordinating Agency (EUREKA). In Japan the Ministry for International Trade and Industry (MITI) is co-ordinating the efforts. New competition is also emerging in the world marketplace and more countries are participating in it. The international trend is towards more applied research in solving the materials problem. Advanced materials have become the vehicle through which high technology advances and thereby overall development - the choice is obvious.

How Asia can meet the challenge

Most of the advanced materials developments are taking place in the industrialized countries. There are developing countries and countries not so fortunate. In Asia we have a heterogeneous assemblage of nations with several cultural, ethnic and historic backgrounds. There are countries developed socially and culturally but not so technologically and economically. The patterns of technological growth are not at all uniform. There are nations like the USSR and Japan technologically well developed and developing countries like India, China, the Republic of Korea, etc., and not so developed countries like Iran, Iraq, Turkey, Pakistan, Malaysia, Singapore, Indonesia, the Philippines, Sri Lanka, etc. In these countries the distribution of natural resources varies. Countries like the USSR, India, China, Indonesia, Malaysia and the Philippines have varying degrees of selected metallic ores, while there are countries like Japan and many of the developing countries with very limited reserves of minerals.

A country like Japan with limited natural resources could become a highly industrialized country today. First of all the socio-economic traits and national traits of the people along with the procurement of an educated population sufficient in quantity and superior in quality through the implementation of widespread education have played a critical role. 14/ During the First and Second World War, Japan was able to achieve a fast rate of growth because of the right internal atmosphere as well as monopolizing the vast raw material resources and market of the Asian continent, while becoming the first and only nation in Asia at that time to experience an industrial revolution. The post-war period was the time when the Japanese economy underwent reorientation towards the liberalization of war-time control systems. Business accelerated the development of technology providing the opportunity to facilitate post-war technological innovation. The accumulation of domestic technological capacity through imitative manufacturing and their readiness for taking in foreign technologies, cultivated from the accumulation, was the main cause Japan could succeed in vast technological importation and adaptation. They were able to assimilate and absorb these technologies and went one step further to modify and improve them to an extent that domestic reserves could enable the nation to facilitate technological innovation. As a consequence Japan was able to succeed in its industrial growth efforts through the use of imported technology. Thus the country overcame the dependency of foreign technology which is faced by many Asian countries today. This does not mean that the experience of Japan can be directly applied to other Asian countries.

Countries like the USSR, India, China, the Republic of Korea, Taiwan, etc. have evolved their own patterns for development. But the experience of these nations can provide some guidelines to the nations who want to make some progress and to come out of their technological backwardness. Again it is difficult to devise a common development approach which would be appropriate to all the weaker and developing countries of Asia. Acquiring the needed technology through transfers and local adaptations is not an easy job. Hence the amount of technology a country possesses and the extent of its capacity to adopt technologies to its particular needs become crucial factors in the industrialization process. But the technological development policies will play a prominent role in the outcome of economic development. Further, an essential precondition for economic and social development in the cultivation of a capacity to absorb and develop technological know-how and skills which must be transferred from the more advanced countries.

In spite of the differences in the socio-economic conditions, natural resource position and level of industrialization, the Asian countries should co-operate for the common goal of development.

The advanced materials, processes and technologies will alter the global industrial scene thereby widening the economic gap between the industrialized and less developed and developing countries. Because of prevailing conditions of a country and the requirement of a large variety of advanced materials, a selective approach is to be adopted. Each country will have to identify specific materials based on a materials policy, guided by such factors as the country's natural resources, import and export, possible use of local substitute materials, energy implications, local conditions, skills and facilities to use them. Even though each country can have its own material policy the outcome of the co-operation will play a central role that materials play in the industrial and economic development in such a way that all countries could benefit from the formulation and adoption of a comprehensive materials policy.

In this context it will be interesting to note the successful outcome of a recent ESCAP seminar with the support and co-operation of the Department of Scientific and Industrial Research (DSIR) of the Ministry of Science and Technology of the Government of India on "Technical, economic and social aspects of powder metallurgy and its application", in Bombay, India, during February 1989. The seminar was attended by the ESCAP member countries like India, Islamic Republic of Iran, Republic of Korea, Malaysia, Philippines and Thailand. The main objective of the seminar was to promote the development and application of the technology of powder metallurgy in member countries by facilitating not only the exchange of national and international experience and information in this field but also by assessing the possible technological and other implications in a regional context. Several important recommendations were made 15/ including the exchange of experiences and knowledge between and among the developing countries within and outside the region in the field of P/M technology will continue to play a significant role in the promotion and awareness and development of indigenous technological capabilities.

Asia can meet the challenge of advanced materials through co-operation among the countries by utilizing schemes such as training programmes, joint ventures, establishment of required processing and production facilities, the conduct of market surveys and technology assessment, feasibility studies, preparation of technology profiles and other consultancy services. The financial institutions such as ADB and UNDB, UNIDO and ESCAP as well as other relevant agencies may provide appropriate resources for implementation. Because of the importance of keeping abreast of developments in the field of advanced materials in Asia as well as the need for common facilities for the training and retaining of personnel and for facilitating the exchange of information and data, establishment of regional design engineering and consulting facilities or advanced materials promotion institutes or associations with the assistance of suitable United Nations bodies is highly recommended. Since the advanced materials and technologies are related to the national economies there is a need for materials development. On account of the large investment required for this purpose a co-operative effort among the Asian countries is necessary and desirable. The monopolies on ideas will not last long. We should be willing to experiment and find new ways to co-operate with the educational institutions, R&D organizations, industries and even nations. Advanced materials promise major contributions to the national prosperity and better quality of life.

References

1/ Materials in world perspective, A. G. Altenpohl, Springer Verlag, Berlin, p. 201, 1980.

2/ P. Ramakrishnan, Trends in the research and development in powder metallurgy, background paper, ESCAP Seminar on technical, economic and social aspects of powder metallurgy and its application, Bombay, India, pp. 20-27, February 1989.

3/ B. Williams, Metal Powder Report, Vol. 43, No. 5, p. 296, 1988.

4/ P. Ramakrishnan, Reclamation and recyling of ferrous scrap by powder metallurgy process, Report NSF, USA, Grant INT 8511412, December 1988.

5/ T. J. Dwyer and R. B. McPhillips, Ceramic Bulletin, Vol. 67, No. 12, p. 1,894, 1988.

6/ E. O. Ezugwu and J. Wallbank, Review of the manufacture of ceramic cutting tools, Advances in Materials Technology Monitor, 12, 1, 1988.

7/ Advanced Materials and Processes, Vol. 135, No. 1, p. 29, 1989.

8/ Robert Larsen, Anant Vyas and Arvind Teotia, The application of ceramics to heat engines. An economnic assessment based on the world dephi survey, Energy and Environmental Systems Division, Argonne National Laboratory, September 1988.

9/ T. Takamatsu, Intl. J. Composite Polymers, Vol. 1, No. 1, p. 1, 1988.

10/ Advanced Materials and Processes, Vol. 135, No. 1, p. 59, 1989.

11/ Advanced Materials and Processes, Vol. 133, No. 1, p. 63, 1988.

12/ F. H. Froes, Materials Edge, No. 11, p. 17, 1989.

13/ L. J. Sousa, Problems and opportunities in metals and materials, an integrated perspective, report, US Department of Interior, Bureau of Mines.

14/ Bases for science and technology promotion in developing countries, Hyung Sup Choi, Asian Productivity Organisation, Tokyo, p. 75, 1983.

15/ ESCAP Seminar on technological, economic and social aspects of powder metallurgy and its applications, 20-27 February 1989, Bombay, India, report.

Table 1 : The time between discovery and application

	Discovery	Application	Time elapsed
Electric motor	1821	1886	65
Radio	1887	1922	35
X-ray	1895	1913	18
Atomic Reactor	1932	1942	10
Radar	1935	1940	5
Transistor	1948	1951	3
Solar Cell	1953	1955	2

Table 2 : Estimated world wide Metal Powder Shipment for Market Economy countries in 1987.

Material		Tons
Iron and Steel	-	470,000
Copper and Copper alloys	-	45,000
Aluminium	-	50,000
Stainless steel	-	15,000
Nickel	-	40,000
High speed tool steel	-	10,000
Tungsten and Tungsten carbide		25,000
Total shipments	-	655,000

Table 3 : Estimated world wide consumption of iron powders

Region	Consumption in tons
North America, U.S.A and Canada (S.T)	185,000
Western Europe	65,000
Eastern Europe (Soviet Union included)	45,000
Japan	77,000
South America (Argentina, Brazil, Mexico)	9,000
China	20,000
Australia, South Africa, South Kores, Tiwan and India	15,000
Total	416,000

Table 4 : Worldwide Advanced Ceramic Market Projections

Industry	1985 ($M)	1990 ($M)	2000 ($M)
Automotive	53	634	5700
Electronic	1708	3740	11360
Integrated optics		1	111
Advanced energy systems			360
Cutting tools	14	92	500
Other industrial	80	225	690
Other aerospace	20	30	65
Bioceramics		10	30
Total	1875	4732	18818

Table 5 : Projected ceramic engine component market penetration

Component	Development stage	Median[2]	Interquartile range[3]
Turbocharger rotor	Introduction to the market	1990	1989–1990
	5 % of market share	1995	1995–2000
	Cost equality with metals	2000	1998–2010
Rocker arm/cam follower	Introduction to the market	1990	1989–1991
	5 % of market share	1995	1995–1997
	Cost equality with metals	2000	1998–2005
Valve	Introduction to the market	1995	1995 -
	5% of market share	2000	1998–2000
	Cost equality with metals	2010	2003–2010
Valve guide	Introduction to the market	1992	1990–1995
	5 % of market share	2000	1995–2000
	Cost equality with metals	2003	2000–2009
Valve seat	Introduction to the market	1993	1991–1995
	5 % of market share	2000	1995–2000
	Cost equality with metals	2005	2000–2005
Piston cap	Introduction to the market	1995	1993–1995
	5 % of market share	2000	1998–2005
	Cost equality with metals	2005	2000–2010
Piston	Introduction to the market	2000	1999–2000
	5 % of market share	2005	2005–2010
	Cost equality with metals	2020	2010–2020
Piston pin	Introduction to the market	1995	1994–1997
	5 % of market share	2000	1998–2005
	Cost equality with metals	2010	2005–2010
Cylinder liner	Introduction to the market	1995	1993–2000
	5 % of market share	2002	2000–2010
	Cost equality with metals	2010	2005–2015
Piston rings	Introduction to the market	1995	1992–2000
	5 % of market share	2000	1999–2005
	Cost equality with metals	2005	2003–2010
Exhaust port liner	Introduction to the market	1990	1989–1990
	5 % of market share	1995	1994–1995
	Cost equality with metals	2000	1998–2000

[1] Cars/light-duty trucks, [2] Median opinion of respondents, [3] Interquartile range represents midrange of data (from 25th to 75th percentiles) and provides an idea of consensus.

TABLE – 6 : Typical properties of fibres

Material	Form	Diameter filament µm	Density gm/cm^3	E G.Pa	U.T.S. G.Pa	Melting/Softening/Decomposition ~ °C
E.glass	Tow	9	2.6	72	3.45	700
S.glass	Tow	9	2.49	87	4.6	840
Quartz	Tow	10	2.2	69	0.9	1050
Kevlar-49(Aramid)	Tow	16	1.44	124	4.1	250*
Spectra-900 (Polyolefin)	Tow	38	0.97	117	3.0	120*
Carbon						
High strength	Tow	7-8	1.7 - 1.8	220 - 250	2.5 - 3.5	3650
High modulus	Tow	7-8	1.8 - 1.9	340 - 380	2.2 - 2.4	3650
Ultra-high modulus	Tow	8-9	1.9 - 2.1	520 - 550	1.8 - 1.9	3650
Alumina (Al_2O_3)						
ICI	Tow	3	3.3	300	2	>2000
Dupont	Tow	20	3.95	377	1.4	2045
Sumitomo	-	17	2.3 - 2.5	200	1.5	-
Boron on W. Wire(12.5µm)	Mono filament	100-140	2.5	400	3.45	2300
SiC on C	Mono filament	140	3	430	2.4	2700
SiC fibre	Tow	10 - 20	2.55	500	2.0	2700
SiC	Whisker	0.1 - 1.0	3.19	400 - 700	3 - 14	2700
Steel	Wire	>15	7.75	200	4.1	1400

* - useful temperature

Table 7 : Future markets for advanced composite parts ($m.)

Matrix	1982	1987	1988	1993	2000	AARG (%)
Polymers						
Defence-related	1,100.0	1,716.0	1,889.4	3,153.0	4,295.0	10.8
Commercial	652.0	1,062.0	1,167.6	2,278.3	4,777.0	16.3
Metals						
Defence-related	-	NA	16.9	53.6	180.5	21.8
Commercial	-	NA	3.1	15.2	48.3	25.7
Ceramics						
Defence related	-	-	26.8	35.0	51.0	5.5
Commercial	-	39.1	50.4	167.5	576.0	22.5
Total						
Polymers	1,752.0	2,778.0	3,057.0	5,431.3	9,072.0	9.5
Metals	-	-	20.4	68.8	228.8	22.5
Ceramics	-	39.1	77.2	202.5	627.0	19.1
Grand Total	1,752.0	2,817.1	3,154.2	5,702.6	9,927.8	10.0

NA = Not Available, Source: Business Communications Company.

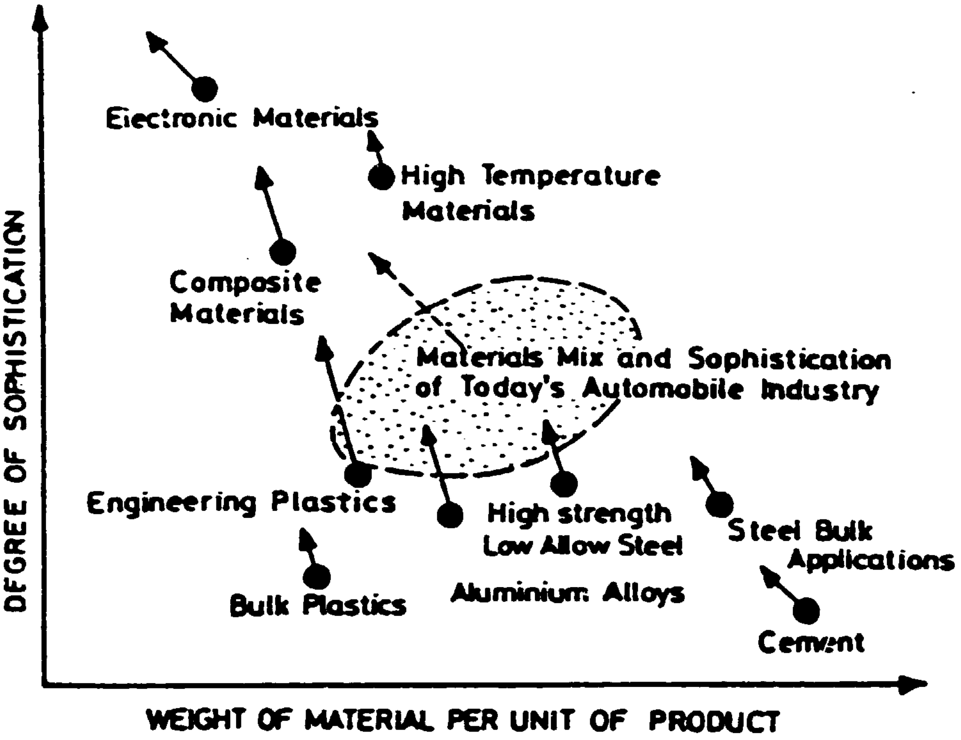


FIG. 1_ A MODEL PROVIDING CORRELATION BETWEEN THE QUANTITY OF MATERIAL PER UNIT OF PRODUCT AND DEGREE OF SOPHISTICATION.

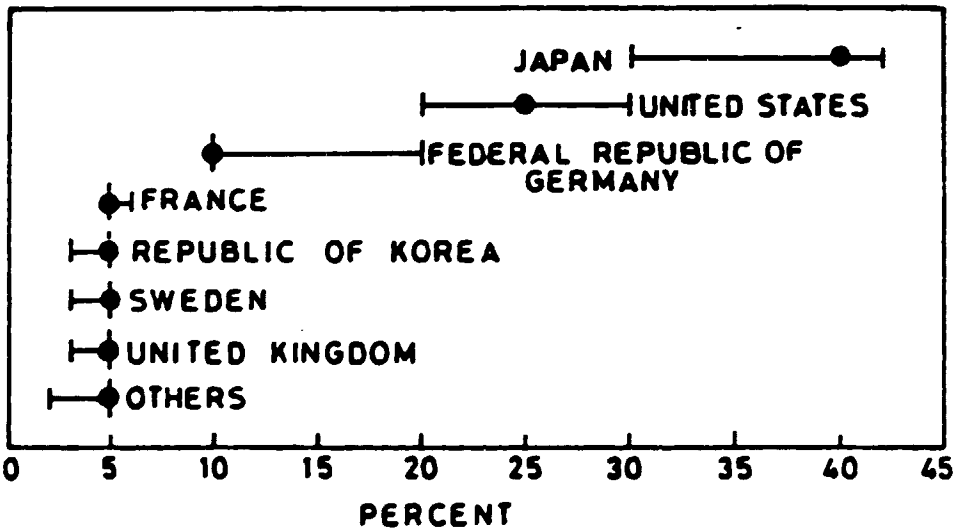


FIG. 2_ WORLD MARKET SHARE IN 2000 AS PREDICTED BY RESPONDING EXPERTS (DOT IS MEDIAN: BAR SHOWS INTERQUARTILE RANGE)

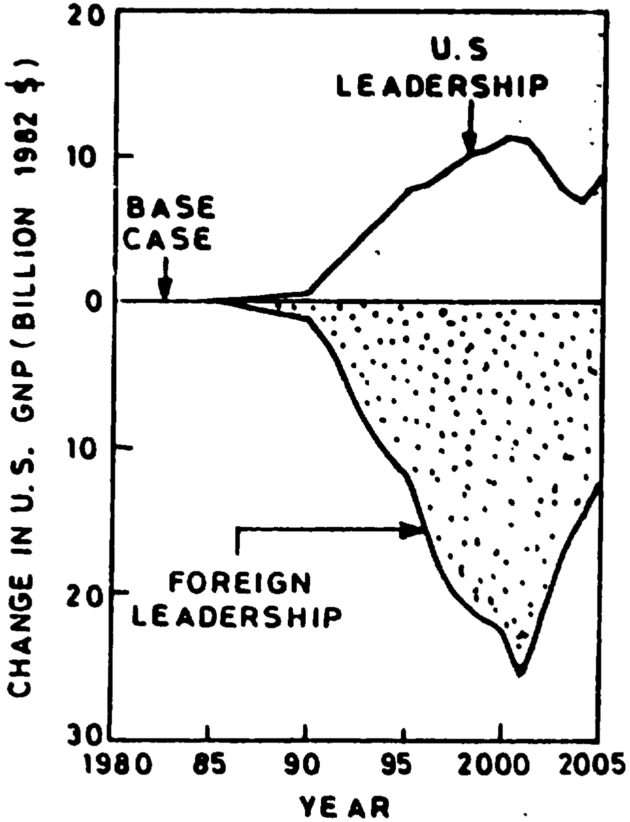


FIG. 3_ PREDICTED U.S. GNP UNDER U.S. AND FOREIGN LEADERSHIP IN ENGINE CERAMICS (PRELIMINARY RESULTS, SHOWN AS MEDIAN VALUES)

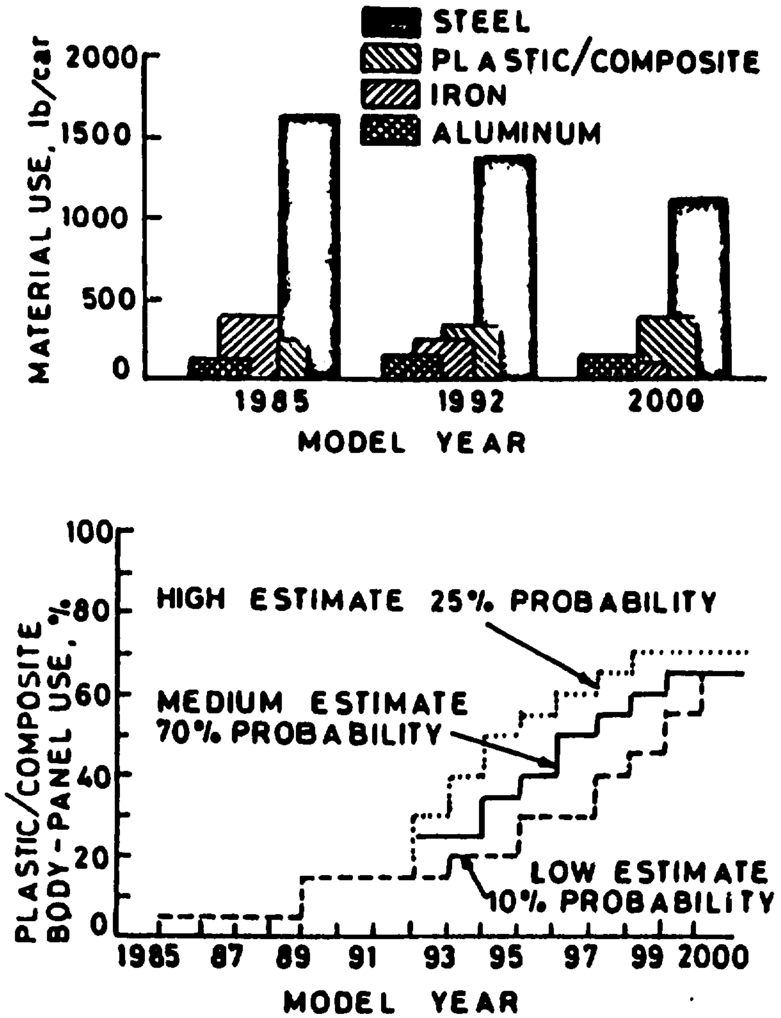


FIG.4 _ A RECENT STUDY SHOWS PLASTICS AND COMPOSITES USE IN AN AVERAGE CAR ON THE RISE AT THE EXPENCE OF IRON AND STEEL, TOP, AND CONSERVATIVELY ESTIMATES THAT ABOUT 65% OF AUTO-BODY PANELS WILL BE MADE OF COMPOSITE MATERIALS BY THE YEAR 2000

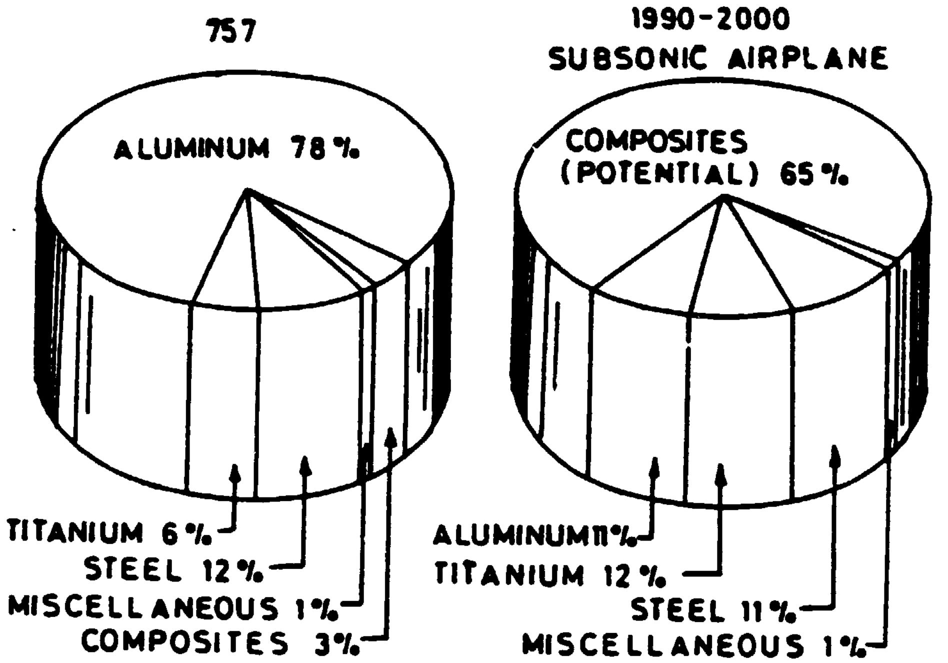
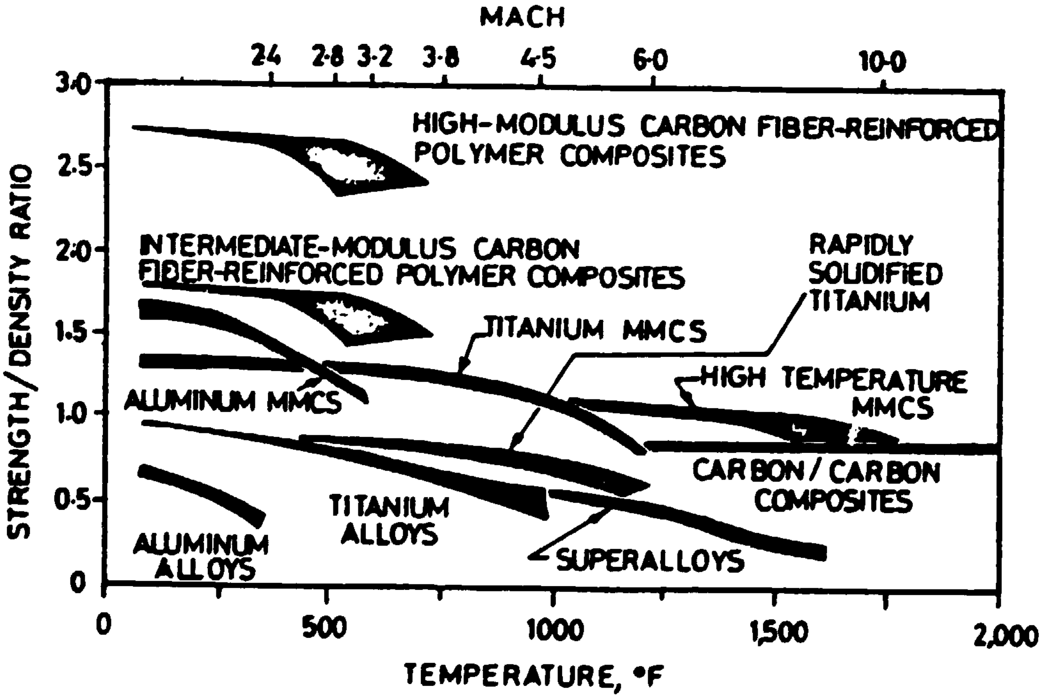


FIG. 5_ MATERIALS WEIGHT DISTRIBUTION OF ADVANCED TECHNOLOGY AIRPLANE



PROJECTED MATERIALS REQUIREMENTS FOR A SUPERSONIC COMMERCIAL AIRPLANE.

FIG. 6

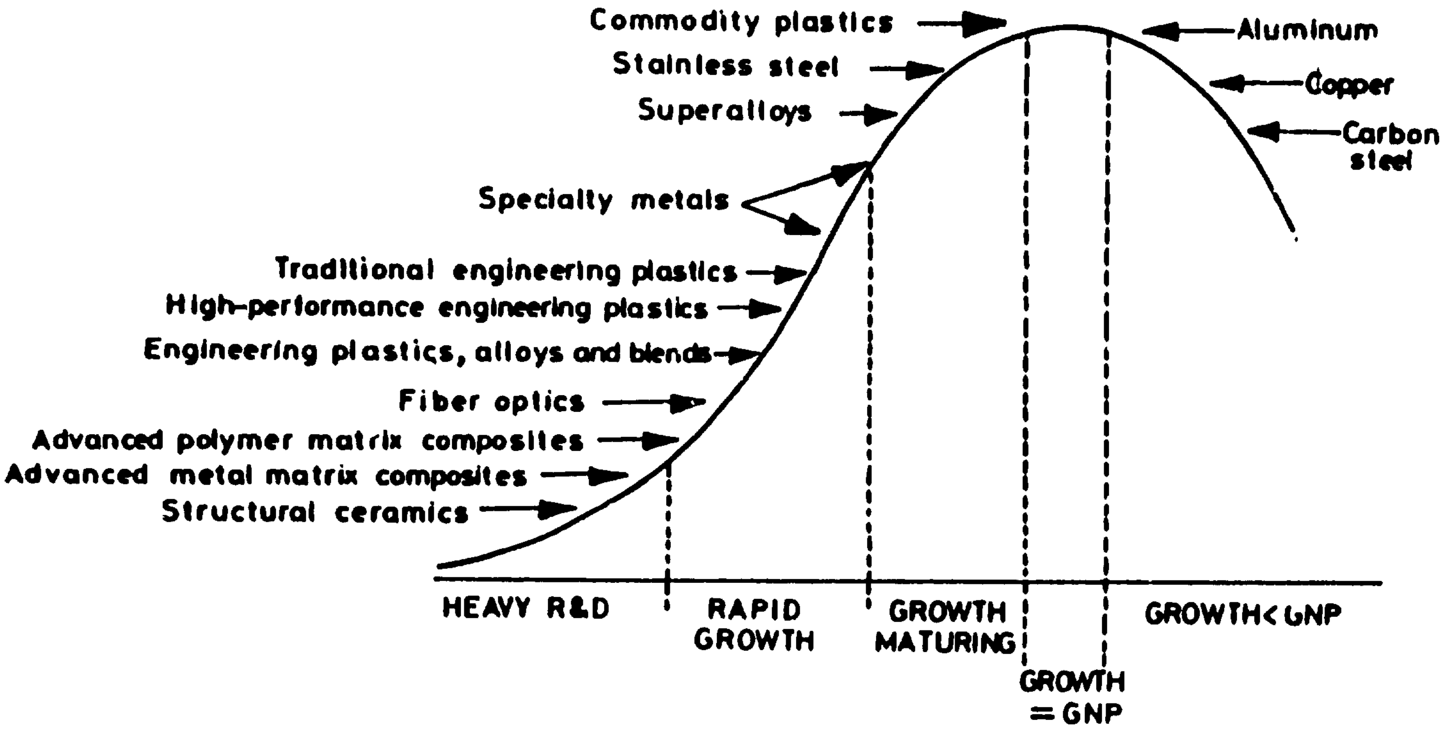
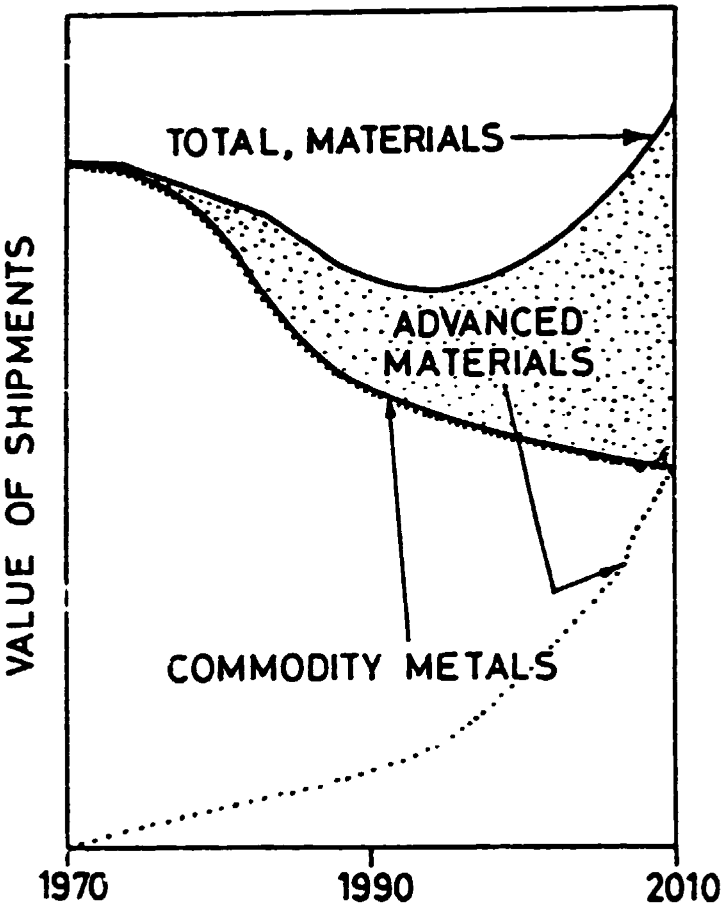


FIG. 7 ESTIMATED CURRENT RELATIVE MARKET MATURITY OF THE MAJOR METALS AND OTHER MATERIALS.



TRANSITIONING FROM A METALS ECONOMY TO A MATERIALS ECONOMY

FIG. 8

6. Status and Prospects of New Materials Technology in Korea

- Applications and Development Strategies -

Chunghi Rhee
President, Korea Standards Research Institute
P.O. Box 3, Taedok Science Town, Taejon 305-606
Republic of Korea

ABSTRACT

New materials are commonly categorized as follows : advanced metals, composites, fine ceramics, polymers and semiconductor materials. They have already penetrated into our daily lives and have changed our life patterns in many ways. Because of their impacts on the developments of other technologies and the future market share, research and development on new materials are getting accelerated. The main characteristics of new materials are high additive values and advanced functions. Therefore, in order to use a newly developed material to practical applications, it is necessary to characterize and evaluate those advanced functions. In Korea, research and development on new materials have been carried out by many research institutes. However, it has been concentrated onto new materials which have already had quite a sum of market share. As more and more new materials being developed and their applications getting wider, the technology for characterizing these new materials is becoming even more important. We need new methods of characterization and their standardization. Recently, Korea Standards Research Institute has initiated research work on the characterization technology. Examples are developments of high precision measurement technology and researches related with extreme environments. The development of a new technique can be accomplished in a country, but its standardization requires international cooperations. Hence, it is proposed to set up a regional cooperational body to enhance the effectiveness of standardization activities among the Asia and the Pacific nations.

Contents

1. Introduction

Korean economy has grown rapidly through six successive five-year economic development plans since 1962, and now, Korea has become one of the ten biggest trading countries in the world with the annual exports of 60 billion U.S. dollars and the GNP per capita of 4000 dollars. In the sixth five-year economic development plan in the years of 1987-1991, Korea aims at attaining 80 billion dollars in export and GNP per capita of 5500 dollars. The economic strategy of the Korean Government was to achieve export expansion by promoting heavy and chemical industries. Korea, which is poor in natural resources but has skilled labor, has only way to facilitate economic growth by increasing exports of high additive-value products.

The industrial structure has changed from labor-intensive light industries such as textiles in the 1960s, to technology - intensive precision machinery and heavy industries such as automobiles, ships, and steels in the 1970s, and to high-technology electronics and information industries such as computers, communication equipments and 4 M DRAM VLSI in the 1980s.

The development of these high-technology industries has resulted in the increased demand for new materials. While most of the conventional materials such as steels and polymers are supplied domestically, most of the new materials are imported from abroad or produced domestically under technical license agreements. Because of technology protective policies of developed countries, however, secured supply of new materials becomes increasingly costly and difficult. And so the importance of domestic development and production of new materials is increasing.

In this paper, I am going to present the definition and importance of new materials, the status and prospects of demand/supply of new materials in Korea, new materials development strategy of the Korean Government, and finally propose international cooperations on standardization of new materials evaluation.

2. Definition and Importance of New Materials

New materials or advanced materials are defined as innovative materials with new or advanced functions such as advanced metal, composites, fine ceramics, polymers, and semiconductor materials. New materials often have high additive values, and the examples of such materials are shown in Table 1. Figure 1 shows how new materials technology provides the base for promoting future high-technology industries such as aerospace, precision machinery/mechatronics, new energy, information/communication, semiconductor/electronics, welfare/environments/medicare. The roles and applications of new materials are described in Table 2.

3. Status and Prospects of Demand/Supply of New Materials in Korea

3-1. Materials Industries in Korea

As the heavy and chemical industries have been developed in the 1970s, the base materials such as steel and some nonferrous metals, were produced extensively. As shown in Fig. 2, steel production in Korea has increased rapidly since Pohang Iron and Steel Company (POSCO) began operation in 1973, and total steel production in 1988 reached to 20 million tons equivalent to 2.4 % of the world production. In case of nonferrous metals, productions of copper and zinc reached substantial level.

However, in general, Korean industries focused heavily on the export of final products, and materials and component industries were underdeveloped. Consequently Korean industries import substantial amounts of materials and parts from foreign countries including U.S., Japan, and ECC. The amount of imported materials reached 4.25 billion dollars in 1986, and increased to 5.7 billion dollars in 1987, corresponding to 34 % annual increase. The 80 % of the imports is from Japan, and such trend is expected to be continued for a while.

Table 1. Examples of new materials and their applications

Classification	New Materials	Applications
New Metals	Ferrite single crystals, Rare earth magnets, Amorphous silicon, Lead frame alloy	VCR Head, Solar cell, Biomedical alloy, VLSI
Composites	Carbon fiber, Glass fiber, Aramid fiber, GFRP, CFRP, MMC, CMC	FRP pressure vessel, Sporting goods, Aerospace materials
Fine Ceramics	Si N , SiC, ZrO_2, Al_2O_3, WC, TiN, PZT, Dielectrics, Ferrites	Gas turbine, Sensor, Bearing, Cutting tool, Artificial tooth and joint, Piezoelectric lighter, Condenser, Substrate
Polymer	Engineering plastics, Phenol, Poly-butadien, Optical polymer, Special rubber	Bond, Paint, Automobile, Magnetic tape
Semiconductor Materials	III-V compound, Si, SiC single crystal, Diamond film	VLSI, ULSI, Sensor, Copier

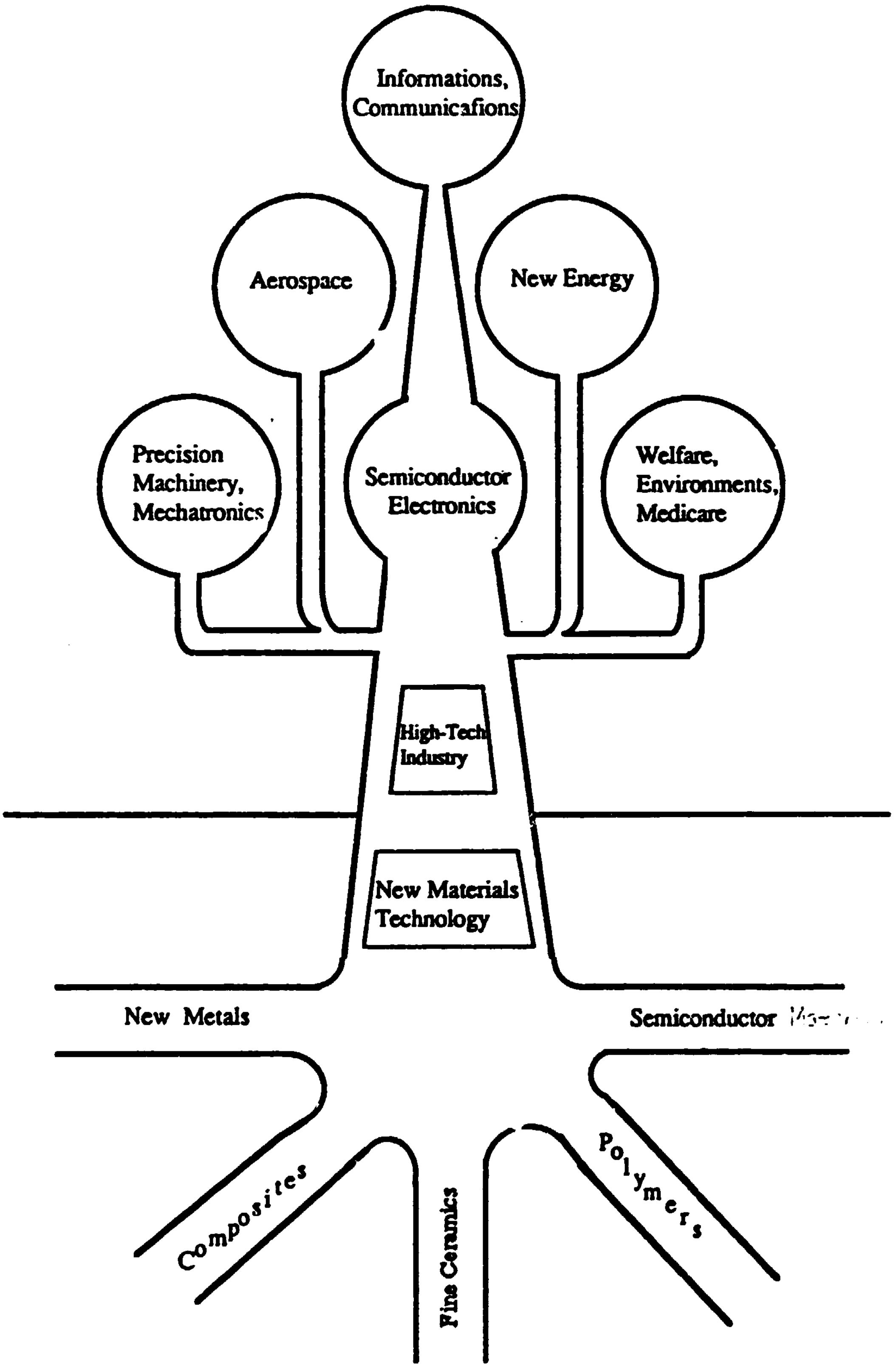


Fig. 1. Relations between new materials technology and high-technology industries.

Table 2. Roles and applications of new materials in industries

Industry	Roles of New Materials	Related New Materials	Applications
Energy	• Light weight • Better efficiency	• Superconductor • Ceramic fiber reinforced metal • Superalloys • Structural ceramics	• Solar cell • Fusion reactor • Airplane • Automobile
Information	• Higher density • Faster speed • Smaller size	• Amorphous Si • Optical fiber • III-V compound semiconductor	• VLSI chips • Magnets • Optical communication • Sensor
Aerospace	• Higher strength • Lighter weight • Better anticorrosive property	• Al-Li alloy • Superalloy • Diffusion bonded materials • Ceramic steel	• Light weight-high strength structure • Jet engine
Precision Mechinery, Mechatronics	• Artificial Intelligence • Smaller size	• Thin film • High purity semiconductor • VLSI sensor • AI sensor	• Robot sensor • NC machine • Home electronics • Medical equipments • Environment monitoring equipments
Medical Equipments	• Better precision • Better reliability	• Bioengineering materials • SQUID	• Artificial organs • Medical equipments

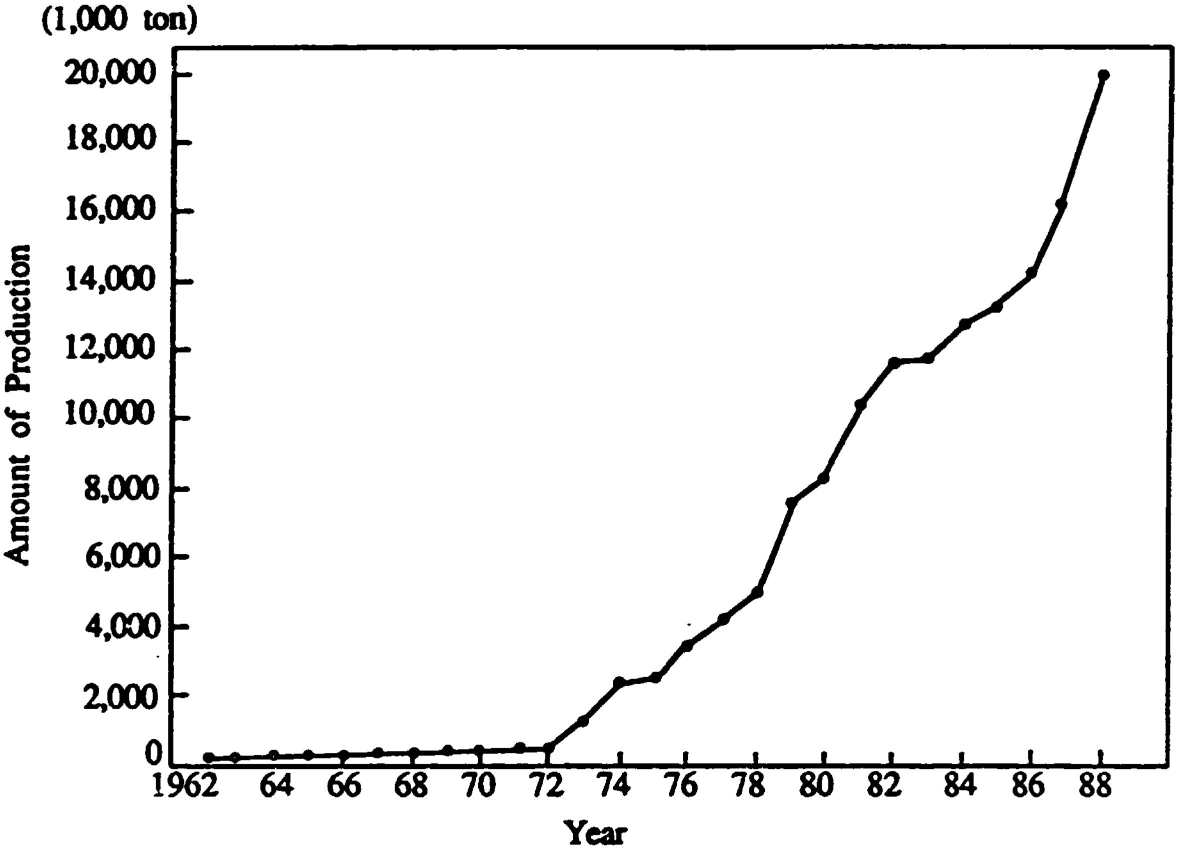


Fig.2. Yearly trend of steel production in Korea.

3-2. Status and Prospects of Demand/Supply of New Materials

As Korea becomes industrialized, high-technology industries such as semiconductor, computer and electronics have been developed in the 1980s. This resulted in the expansion of the domestic market of the high-technology products and accordingly new materials, which were necessary for manufacturing the products, were in great demand, and market size of new materials has been increased rapidly.

As shown in Table 3, the market size of new materials in Korea was at the level of 0.7 billion dollars in 1984, and it is expected to be around 2 billion dollars in 1990 and around 6.7 billion dollars by the year of 2000.

Table 3. Market size of new materials in Korea

(Unit : million U.S.$)

Year Classification	1984	1990	2000
Fine ceramics	277	570	1,710
Composites	15	107	570
New metals	191	557	1,790
Others	217	766	2,630
Total	700	2,000	6,700

Since the new materials technology in Korea is just in the beginning stage except for a few areas, Korea imports major new materials from Japan and the United States. For the case of fine ceramics, demand/production are compared in Table 4. In 1987, the demand of fine ceramics was 510 million dollars and only 30 % of the demand was supplied by Korean industries. Thus 70 % of the demand has to be met by imports. In 2000, the demand is expected to increase to 1.48 billion dollars, about three fold of that in 1987.

There are now 62 manufacturers in Korea participating in the production of fine ceramics: 4 in structural ceramics, 15 in insulators, 6 in capacitors, 9 in piezoelectrics, 10 in semiconductor and sensors, and 18 in ferrites. These manufacturers are now in the early stage of research and development for the commercialization of fine ceramics. Except a few products such as ferrite resistor, they can only make final products from imported semimanufactured goods. Therefore, it is urgently needed to undertake systematic R & D on new materials.

Table 4. Demand and production of fine ceramics in Korea

(Unit : million U.S $)

Year Items	1984		1987		1995	2000	Applications
	Demand	Prod.	Demand	Prod.	Demand	Demand	
Structural, wear resisting ceramics	5.5	1.2	15.8	4.4	26.4	35.5	Ball mill liners, Thread guides, Tool-bits, etc.
Insulators	62.5	1.2	103.3	4.0	178	253	IC package, Substrates, Metallized ceramics
Ceramic capacitors	32.3	25.5	83.2	41.6	190	349	Disk, MLCC, B-L, F-T, etc.
Piezoelectrics	23.7	-	46	8	105	193	Filters, Quartz, Buzzer, Ignitors, etc.
Ferrites	78.5	38	227.7	94.2	387.1	542.1	Softferrites, Hardferrites, Magnetic heads, Recording media, Calculator, etc.
Semiconducting ceramics	10.8	-	34	2.8	68.5	107	Thermistor, Sensor, Varistors, etc.
Total (Prod./Demand %)	213.3	65.9 (30.1)	510	155 (30.4)	955	1,479.6	

4. Development Strategies of New Materials in Korea

4-1. Development Status of New Materials

The total amount of the investment for research and developments in Korea is 3 billion dollars equivalent to 2.1 % of GNP in 1987 and will increase to 5 % of GNP in the 2000s. The government initiated the national R & D projects and increased R & D investments in public sector every year for developing high technology. R & D invest- in private sector is also increased to about 70 % of total R & D investments. About 11 % of the Government funded R & D are carried out through the national R & D projects started from 1982.

The national R & D projects supported by the Ministry of Science and Technology (MOST) include five research areas such as information science, materials related technology, industrial infra-technology, energy/resources technology, technologies for public welfare and large-scale integrated engineering. Among those, the highest investment is given to the materials-related technology, for which 26.8 % of the national R & D project funds are allocated. Materials-related technology is again divided into four groups: fine chemicals, biotechnology, new materials, and manufacturing processes. Table 5 shows that the investments on new materials are about 7 % of those on national R & D projects.

Table 5. Yearly Government's investments on national R & D projects and new materials projects.

(Unit : million U.S.$)

	'82	'83	'84	'85	'86	'87	'88	'89 planned
National R & D Projects (A)	19	31	31	43	74	79	93	228
New Materials Project (B)	1.3	1.6	1.4	2.3	4.7	5.9	6.7	15.1
B/A (%)	7	5	5	5	6	7	7	7

Many of the developed new materials have already been commercialized with patents. Some of the successful cases conducted by the autonomous research institutes/industries under national R & D projects on new materials are given in Table 6.

Table 6. Examples of successful development of new materials supported by national R & D projects.

Item	Investigator	Accomplishments
Aramid pulp	KAIST and Kolon Co.	- High strength, high modulus material - U.S. Patent ('85) - Substitutes asbestos - Commercialized by Kolon Co.
Cu-alloys for lead frame	KAIST and Poongsan Metals Co.	- Conductors for transistor and IC - U.S. Patent ('85) - West German Patent ('86) - $30 million market share in 1990
Thin gold wire	KIMM and Mikyongsa Co.	- High purity Au wire for IC - Domestic supply since '86 - $45 million substitution in 1990
Si polycrystals	KRICT	- New technique by fluidized bed reaction - Pending U.S. and other patents
Biomedical alloys	KAIST and Sesin Ind.	- Strong and anti-corrosive fixtures for fractured bone - $10 million import substitution per year
Fiber reinforced plastics	KIMM and Hankook Fiber Co.	- Various import goods - $25 million substitution per year
Ceramic cutting tool	KAIST and Ssangyong Cement Co.	- Wear and heat resistant tool - U.S. Patent ('86)
Coated films for condensers	KAIST and Seongmoonjon Chemicals Co.	- High effciency, high precision condensor - $5 million substitution per year

Development pattern of new materials in Korea include two types. One is development of new materials by our own original technology, and the other is development of new materials by technical joint venture or technical licence agreement with foreign countries. The latter cases is adopted for new materials which need immediate commercialization, have good market share and require lots of time and investment to develop. Productions of new materials by technical licence is expected to increase for a while with the progress of new materials-related industries. Table 7 shows typical examples of new materials developed by technical joint venture with foreign countries.

Table 7. Examples of new materials developed by the technical joint-venture with foreign countries.

New Materials	Investigators/Company	Countepart	Applications
Anisotropic Si-steel	POSCO	Alsco, USA	Transformer, Turbine generator
Sn-plated brass	Poongsan Metals Co.	Fuji Plant Co. Japan	Connectors, switches, Relays
Fe-42 Ni alloy sheet	Poongsan Metals Co. Dongyang Haeraus Co.	West Germany	Lead frame for IC
Sintered friction element	Daewoo Heavy Ind. Co. KAIST and KIMM	Ferrodo Co. UK	Airplane brake disk, Automobile clutch disk
Optical lenses	KAIST, Dongwon Optics, Samsung Minolta, and Gold Star	Japan	Camera lens, Microscope, Telescope
Cu-alloys for lead frame	Poongsan Metals Co. Gold Star Comm. Corp. Dongyang Haeraus Co.	West Germany	Transistor and IC

4-2. Development Strateics of New Materials

The major goal of the long-range national development plan on new materials is to develop importing materials and to develop future advanced materials by new materials technology which is essential for a highly industrialized society.

MAJOR GOAL

Development of new materials technology for highly industrialized society

- Development of materials technology for information industries
- Development of materials technology for energy saving
- Development of importing new materials for promoting industrial infrastructure
- Development of materials technology for public welfare

To achieve the major goal, the research and development plan will be carried out in three stages by the year of 2001. In the first stage (1987-1991) the goal will be to develop importing new materials to lay down the foundation for R & D, in the second stage (1992-1996) to perform full scale R & D on the essential new materials, and in the third stage (1997-2001) to create future new materials and to promote new materials industries. These plans are summarized in Table 8.

New materials development areas include high Tc superconductors, new metals, fine ceramics, composites, materials for aerospace and their applications to sensors and thin films. These were selected by the long-term national research and development plan for the advancement of science and technology in the 2000s and by the recommendations of related working groups and advisory committees. The committee members are from industries, univerities and research institutes. Selection criteria are technological and economic impacts, high additive values, trade balance and import substitution. National R & D projects and research institutes participating in developments of new materials are given in Table 9.

Table 8. Goals by stages in the long-range national development plan on new materials.

First stage (1987 - 1991)	Second stage (1992 - 1996)	Third stage (1997 - 2000)
· Development of importing new materials - Ferrite single crystals - GaAs semiconductors - High coercivity permanent magnets - Engineering plastics	· Development of essential new materials - Optomagnetic recording media - Multilayered ceramic substrates	· Development of future new materials - Optoelectronic materials - Superlattice - High performance polymers
· R & D for advanced processing technologies - Thin films - Fine powders	· R & D for advanced processing technologies - Multilayered thin films - Ultra-fine powders - Materials processing at atomic level - Processing under extreme environments	· R & D for new materials design technology - Atomic structure control

Table 9. National R & D projects on new materials and participating research institutes.

Project	Principal investigator	Collaborating investigator
New metals technology	KAIST	KIMM
Fine ceramics technology	KAIST	KIMM
Composite materials technology	KIMM	KAIST
New polymers technology	KAIST	KRICT
Semiconductors technology	ETRI	KAIST
High Tc superconductor	KSRI	KAIST
Sensor technology	KAIST	KSRI
Aerospace materials technology	KIMM	KAIST
Thin film technology	KAIST	KIMM
Analysis and evaluation technology	KSRI	KAIST

* KAIST : Korea Advanced Institute of Science and Technology
* KIMM : Korea Institute of Machinery and Metals
* KRICT : Korea Research Institute of Chemistry and Technology
* KSRI : Korea Standards Research Institute
* ETRI : Electronics Technology Research Institute

4-3. Common/Base Technologies for New Materials Development

Major common/base technologies for new materials development are technologies for beam generation, extreme environment generation and analysis/evaluation. Development of these common/base technologies is important for successful creation and application of new materials.

Beams are used for microlithography, annealing, milling, elimination of defects of ceramics, surface quality improvement of organic conducting materials, etc. Types of beams include electromagnetic waves such as γ-rays, X-rays, ultraviolet rays, etc., and particle beams such as electrons, positrons, neutrons, protons, atoms, ions, etc. Extreme environments generation technology is indispensable for studying new phenomena and creating new materials, applicable to precision measurements under extreme environments, and essential for analysis/evaluation of new materials. Also analysis/evaluation technology for new materials is essential for creation, application and assurance of new materials. The status of new materials analysis/evaluation technology in several countries is shown in Table 10.

In Korea, basic researches on analysis/evaluation technology of new materials are undertaken as a part of national R & D project by Korea Standards Research Institute (KSRI) as the principal investigator. KSRI was established in 1975 as a central authority of the national standards system and have established the national measurement standards in 80 measurement fields, and have conducted researches and developments on precision measurement technology, advanced precision instruments, extreme environment generation technologies such as ultra low temperature, ultra high temperature, ultra high pressure, ultra high vacuum and ultra clean room environments, and beam generation technology for new materials analysis.

5. Standardization of New Materials Evaluation Methods and International Cooperations

Characteristics of new materials should be evaluated by reference criteria. If the evaluation criteria vary from country to country, effective applications and trade

Table 10. Status of new materials analysis/evaluation technology in Korea and other countries.

Korea	Other Countries
• KSRI is undertaking basic research on analysis/evaluation technology - Evaluation of materials strength at 4.2 K - Characterization of piezoelectric materials - Characterization of Si-steel - Analysis of inorganic materials at ppb level with GD-MS • Increasing demand from research institutes and industries for evaluation technology. Development of new materials evaluation technologies by KSRI as a national project.	• NIST(USA) plays a leading role in research of characterization echnologies - Has developed ion microscope and can analyze chemical composition of surface layer in atomic scale - Standardization of wear and strength testing methods of fine ceramics • NPL(UK) is developing new materials evaluation technology for fine ceramics • Japan is developing new materials related technologies, i.e., process, evaluation, and application technologies - Has established new materials evaluation centers

of new materials among countries would be very difficult. Therefore, the cooperation on standardization of evaluaton methods and criteria among countries is more important than any other cooperation concerning new materials. That is why the leaders of the West's seven developed countries, when they met for the Economic Summit at Versailles in 1982, endorsed the Versailles Project on Advanced Materials and Standards, known as VAMAS.

The principal aim of VAMAS is to stimulate the introduction of new materials into high-technology products and to encourage international trade by collaborating on the developments of data base, test methods, design methods and other new materials technologies, and also on the standardization of new materials evaluation. The technical working areas of VAMAS and participating countries are given in Table 11. It is interesting to note that most of the participating research agencies in this project are the national standard research institutes such as BAM, NIST, NPL, etc. This implies that the role of a standard research institute is very important in the development and application of new materials.

One of the characteristics of this project is that the participating countries carry out the researches with their own fund without any international financial support. Nevertheless, the project has been found out to be quite successful because it was born out of the common feeling of the necessity. However, VAMAS is not open to other countries besides the seven listed in Table 11.

Table 11. Technical working areas of VAMAS and participating countries.

Countries	Aims	Technical working areas
• Canada • U.S.A. • France • W. Germany • Italy • Japan • UK • CEC*	• Collaborations on - Data base - Test methods - Design methods - Materials technology • Standardization of new materials characterization	• Wear test methods • Surface chemical analysis • Ceramics • Polymer blends • Superconducting and cryogenic structural materials • Bioengineering materials • Hot salt corrosion resistance • Weld characteristics • Materials data banks • Creep crack growth • Efficient test procedures for polymer properties

* Council of the European Communities.

Then, would it be possible and desirable for the developing countries to collaborate on standardization of new materials evaluation? VAMAS may be working because of the uniformity of the technological levels and the similarity of the needs among the seven participating countries. However, it may not be so easy for all the countries in Asia-Pacific region to participate in a certain project at the same time as in VAMAS because of the large difference in the level of economic development as well as in the fields of interest and the degree of necessity for the standardization. Therefore, to promote participation of Asia-Pacific countries in regional cooperations on standardization of new materials evaluation, it is desirable to select working areas of common interests and to operate the cooperational body on voluntary basis.

6. Conclusions

New materials industry does not require large investment, because new materials are produced in small amount. On the other hand, they are high value additive and their technological impacts to the future high technologies are very large. Developments of even a few new materials, therefore, can contribute a lot to the economic development of a developing country. However, R & D in new materials can not be accomplished by the development of new materials alone. New materials evaluation technology is essential to produce final products and to make their practical applications possible.

Research and development on new materials have been actively carried out in Korea, and KSRI is providing common/base technologies and also analysis/evaluation technologies. However, the R & D on standardization of new materials evaluation, which should be internationally applicable, can not be carried out effectively by one country alone. Therefore, I would like to propose to organize a cooperational body to promote collaborations on standardization of new materials evaluation among the Asia-Pacific countries.

References

1. "Science and Technology Annual 1988", Ministry of Science and Technology, 1989.
2. "Korean Economic Yearbook 1987", The Federation of Korean Industries, 1988.
3. "Major Statistics of Korean Economy 1987", Economic Planning Board, 1988.
4. "Korean Economic Annual 1988", Economic Planning Board, 1989.
5. "Development and Prospects of Future Industries in Korea", Korea Institute for Economics and Technology, 1987.
6. "Structural Analysis and Prospects of Korean Electronic Materials Industry", Korea Institute for Economics and Technology, 1986.
7. "Development Stratages and Structure of Korean Electronic Components Industry", Korea Institute for Economics and Technology, 1985.
8. "Development and Application of New Materials for Energy and Resource Saving", Korea Institute for Economics and Technology, 1985.
9. "A Study on the Development Strategy of the Key Material Technology", Korea Advanced Institute of Science and Technology, 1988.
10. "New Materials Technology Development Program for 2000s", Korea Advanced Institute of Science and Technology, 1989.
11. "Symposium-New Materials, 2000", Korea Advanced Institute of Science and Technology, 1989.
12. "Feasibility Study on the Development of Characterization Technology of Advanced Materials" Korea Standards Research Institute, 1989.
13. "International Collaboration in Prestandards Research on Advanced Materials within the Context of VAMAS", Standardization News, pp.28-33, Feb. 1989.

7. The Impact of Advanced Materials on World Development

Helena Maria Martins Lastres*

January, 1990

Paper prepared for the New Technology Unit, UNIDO - United Nations Industrial Development Organization.

*Science Policy Research Unit - SPRU, University of Sussex, England

1-Introduction

The rhythm of expansion experienced by the world-wide economy after II World War started to show signs of cooling off in the late 1960s. In the main this basic condition has forced advanced countries and institutions to move from a state in which incremental innovations, rationalization and optimization of production processes prevailed to a radically new situation where the emphasis is placed on the search for different patterns of growth and development.

The most impressive features resulting from efforts made during the subsequent decades can be summarized by the advance and progressive consolidation of the so-called high-tech areas (such as information technology, biotechnology, advanced materials); by the attempts at transforming and reorganizing the production process (with its increasing flexibility and growing scientific and knowledge content); and by the strong possibility of alterations in the international division of labour and international technological and economic leadership. Evidently all these aspects are linked and much attention has already been focused on them and on their interconnections.

The central objective of this paper is to discuss the importance of the development and introduction of advanced materials into this scenario of global transformation, their diffusion throughout the world economy and the impact they are already producing and are expected to produce on developing countries.

The advent of advanced materials, in close association with the spread of information technology, is considered capable of playing an important role in the process of industrial restructuring, affecting patterns of investment, organization, employment and trade. Developments in most sectors that are now promoting and using high technology rely and depend upon improvements in the materials front.

Many attempts have been made to define and characterize advanced materials (AMs) Given the elementary and fundamental importance of a correct understanding of this notion, the different approaches are discussed in section 2. As indicated there, one can find extremely precarious and biased the usual interpretations of the concept of AMs. Probably the main reason for this is the fact that this term has grown up in an environment of national and international policy making. It has, then, to be understood in this precise context.

It is recognized, nowadays, that a major step forward in the ways of analysing and understanding the structure and properties of matter has been achieved. This is considered a crucial aspect that set the basis for an inversion in the logic of production. A given product no longer relies on a given material nor on given inputs. Instead, several materials compete to assume a given function. In section 3 it is emphasized that these recent changes can neither be considered simply as a spontaneous and neutral movement, nor as only the result of incremental innovations. In addition to the analysis of the tendency to open up a wider availability of raw materials for the production of AMs, the importance of the information-intensive character of their production is examined. The fact that AMs can play an important role in terms of contributing to changing the present patterns of economic and technological leadership is also discussed in this section.

The revolutionary advances in materials science and technology have been produced by policies (some of which implicit) implemented mainly by governments and firms in the most advanced countries. As indicated in section 4, during the 80s, specific policies aimed at the development of advanced materials were pursued. This period was marked by different attempts to alter the pattern of consumption and production of materials. The main objective was obviously to explore the possibility of establishing leadership in this strategic area.

In section 5, the analysis concentrates on the discussion of the main characteristics of Japan's long term policies for the development of advanced materials. The intense Japanese effort to build up a capability aimed at changing the materials base of future industrial development from metals to advanced ceramics is discussed.

In section 6, Impacts of the Introduction of AMs, the declining trend in "traditional" materials consumption and production is analysed. The consequences of such a movement are discussed. The central focus falls on the impact of such changes on those developing countries which are major producers of basic metals. Most of all, the fact that these recent changes lead to far more complex industrialization processes - where comparative advantages depend increasingly on innovation (both technical and organizational), rather than on purely physical factor endowment - is stressed.

2-Definition and Characteristics of Advanced Materials

Despite the growing importance attributed to the development, production and impact of advanced or new materials in the world economy, one could argue that the relatively [illegible] comprehensive studies yet undertaken probably fail to give an exact definition of these terms. Moreover, it can be pointed out that at least two aspects contribute to making the definition of advanced materials a difficult task.

Firstly, it can be considered that the terms employed to define these materials display rather static features compared with the dynamism of the area. This is not an exclusive characteristic of this specific area. The adoption of some adjectives (such as for instance: new, advanced, high technology, fine, etc.) to qualify the development of new economic activities could be most criticized for lacking rigour.

However, most of those who try to define new or advanced materials do not usually go further than the definition *ipsis literis* that those adjectives permit. This kind of "keeping to the strict sense of the adjective" comprehension produces many sorts of difficulty. The first is the apparent paradox that relates to the fact that the "age" of each specific material (i e., when it was discovered or formulated) does not really matter. Some of the so-called AMs consist of recently developed substances, as is mainly the case with the new ceramic superconductors. Some were developed two or even more decades ago (as with the cases of silicon, optical fibres and composites) and still others are established materials submitted to new technological improvements (as some advanced metals and alloys).

The second aspect to be considered is that if one pays attention to how many and what materials are being considered by the related literature as advanced, it will be conclude that they do not form what is traditionally called a homogeneous category, and also that there is no cabalistic quantity used to identify the so-called new or advanced materials.

The understanding one has about advanced materials will vary in accordance with many factors. As a result, the materials considered as advanced sometimes differ greatly from country to country or from institution to institution within the same country.

It would not be unfair to say that those who write about such a subject usually avoid confronting these problems. One could also argue that the greater part of the bibliography on advanced materials is much influenced by S & T evolution. This is quite understandable given the novelty of the subject and also its strong S & T basis.

As the majority of the authors who write about the issue have a strong technical background, it can be said that most of the attempts to define these materials tend to result in descriptions of: their impressive physical or chemical characteristics, properties and functions; their potential fields of application; the sophisticated processes used for their production; the purity required of their inputs, etc. Despite the high quality and importance of these studies, there is also the necessity to respond to, at the least, questions such as the following:

-What makes these advanced materials so important for the recent development of the world economy? What makes them so special?

-When were they developed and why are they being introduced into the market at this particular moment?

-Is it really necessary to establish a different category to distinguish these materials from others?

-What can actually be considered as advanced materials? In other words, where ought the boundary between advanced and traditional materials to be drawn?

In trying to answer such questions some authors define advanced materials as those developed to satisfy sophisticated and specific needs in response to the new requirements of market evolution or else as the result of scientific and technological advances.[1]

Regarding such definitions, the most important argument (which will be developed later on) refers to the fact that the recent changes cannot be considered simply as another incremental innovation in terms of materials evolution. And, most of all, what should be stressed here is that this is a movement guided by the perspectives of gains in competitiveness rather than considered as any natural or neutral kind of evolution.

Indeed, such a movement seems to be the very result of a vigorous effort towards the goal of opening up new areas of economic growth and gaining competitive advantages in national and international markets. With the development and diffusion of AMs, those countries and institutions (who have the necessary potential to understand and take advantage of the recent changes) are paving their way to increasing their competitiveness in both scenarios.

Advanced materials have been developed and (most importantly) are being introduced into the market in accordance with the main objectives emphasized by the new mode of world production introduced in the late 70s that is of saving raw-materials, energy and labour inputs and also of adding flexibility to the production processes.

In this sense, I would argue that the genesis, implications and impact of AMs are directly related to the long term changes in the techno-economic paradigm, as defined by Freeman, Perez, Soete, Dosi and others.[2] And in this precise context, I would suggest, advanced materials should be understood. The recent advances and changes in terms of materials evolution cannot be considered any more as the result of mere incremental innovations. Some of them consist in fact of radical innovations, which combined with incremental innovations, result in far reaching changes (either technical and organizational) needed to support the current techno-economic restructuring.

As the literature concerning long waves indicates, each period has been associated with the development of some industrial sectors and also

---

[1] Among many others, Ray(1986), for instance, points out that: '**Many of the "new" materials were discovered or developed as the outcome of a specific need under wartime or market pressure. Others were the result of spontaneous and random scientific/ technological advance**' (p. 58). Flemings (1988 a) stresses that: '**The combination of "market pull" and "technology push" is driving structural materials forward at a faster rate than ever before in history**' (p. 31). Forney (1988) also agrees that: '**Two routes of research lead to innovative advanced materials: discovery-driven or market driven**' (p. 178).

[2] For instance in one of their work, Freeman and Soete (1987) found that in all sectors (despite the great variety of specific incremental and radical innovations in almost every industry) there was evidence of a change of 'paradigm' from the capital-intensive, energy-intensive inflexible, mass-and flow-production technology of the 1950s and 1960s to an information-intensive flexible, computerized technology in the 1970s and 1980s

some groups of materials. The age of steam power was associated with the development of the coal and iron industries. The spread of the railways' systems was closely linked to the steel industry. Throughout the 20th. century the period of prosperity connected to the upsurge and consolidation of the car and electricity industries was strongly linked to the birth and development of the oil, chemical and metal industries.

In the same way, the development of advanced materials has been associated with the world's new production cycle led by information technology and, together with biotechnology, is seen as one of the three major areas that are now affecting and reorganizing the whole industrial basis as well as opening up new perspectives on development.[3]

Advanced materials can therefore be understood as those technology-intensive materials developed to fulfil increasingly sophisticated product specifications in order to satisfy the necessary conditions required for the establishment of this new economic cycle. In this sense, they reproduce, (and largely because of their pervasive role in the economy) consolidate and expand the main characteristics of the dynamics which are shaping the new pattern of international development, in other words, the new techno-economic paradigm.

Thus, the improvement of advanced materials is seen nowadays as one of the keys to the expansion and consolidation of new areas (such as information technology) as well as to the maintenance and restructuring of those sectors which are willing to strengthen their competitive power (as is mainly the case in the automobile industry). In this sense, the development of these so-called advanced materials (AMs) is seen as a vehicle for the transmission and diffusion of new styles of production. In these terms their evolution can be considered strategic.

The concept of advanced materials includes new metallic materials, advanced ceramics, new polymers and advanced composites.

Figure 1 shows different types of materials, within these four groups. It also shows the different functions that such materials can assume and gives examples of their main applications.

Among other features, should be pointed out the great diversity of functions (mechanical, thermal, electrical, magnetic, optical, chemical, biological and other special functions) displayed by the different types of materials.

As one result of the recent advances, nowadays, new polymers and composites with sophisticated mechanical functions are competing more and more with metals in structural applications. Advanced ceramics and new polymers can also compete with metals in terms of different applications which require thermal, magnetic, electrical and electronic functions.

---

[3] Lastres et al (1988 a)

Figure 1.1: Functions and Applications of Fine Ceramics

Functions	**Examples of Materials**	**Examples of Applications**
Mechanical Functions		
High temp. strength	Silicon nitride, silicon carbide	Gas turbine, diesel engine,
Cuttability	Titanium carbide, tit. nitride, tungsten carbide, boron carbide	Cutting tools
Lubricity	Boron nitride, molybd. disulfide	Solid lubricant
Wearproof property	Alumina, boron carbide	Bearing, mechanical seal boring drill
Thermal Functions		
Heat resistance	Alumina, silicon nitride, silicon carbide, magnesium oxide	Electrode for MHD generator heat resistant bearing
Thermal insulation	Potassium oxide-titanium oxide, aluminium nitride, zirconia	Heat insulators for high temp furnace, nuclear reactor
Heat transfer chars.	Boron oxide, silicon nitride, aluminium nitride, alumina	Electrical and electronics parts, radiator
Optical Functions		
Light transmitting	Alumina, yttrium oxide, barium oxide	Sodium vapour lamp, high temperature optical lens
Light inducing	Silicon oxide	Optical communication fibre, gastro-camera, photo sensor
Light deflecting	(Zirconium, titanium) acid (lead, lanthanum)	Photo-memory device (reversible)
Fluorescence	GaAs-rare earth ceramics, neodymium-yttrium series glass	Semiconductor laser, light emitting diode
Photo sensitivity	Silver halide containing glass	Sunglasses, image memory materials, window glass
Electrical Functions		
Superconductivity	Yttrium-barium-copper oxide, bismuth- strontium-calcium-copper oxide	Power generator, magnet, supercomputer, maglev train, linear motor car
Semiconductivity	Zinc oxide, barium titanate	Varistor, heater, solar cell, gas sensor
Piezoelectricity	Quartz crystal, lead zirconate titanate, lithium niobate	Ignition device, piezoelectric oscillator
Insulation chars.	Alumina, silicon carbide, beryllium oxide	Multilayer wiring board, IC package, IC printed board
Inducivity	Barium titanate, strontium titanate	IC microcondenser, high voltage service condenser
Ion/ionic conductivity	Zirconia, β alumina	Enzyme sensor, solid electrolyte
Electron radiation	Lanthanum bromate	Cathode material for electron gun
Magnetic Function		
Magnetism	Iron oxide-manganese, iron oxide-barium oxide	Ferrite magnet, magnetic tape, memory device
Biological Function		
Histocompability	Alumina, apatite	Artificial teeth, artificial bone
Chemical Function		
Absorbing property	Porous silica, alumina, porous glass	Absorbent, catalyst carrier, bioreactor
Catalysing property	Zeolite	Catalyst for environment protection
Corrosion resistance	Zirconia, silicon oxide, alumina	Electrode for MHD generator high temp. reactor materials

Figure 1.2: Functions and Applications of New Polymers

Functions	Examples of Materials	Examples of Applications
<u>Mechanical Functions</u>		
High strength and durability	Polyester, polyamide	Various structural materials
Elasticity	Synthetic rubber, foamed plastics	Various structural materials
Shock and sound absorbing	Foamed plastics	Various structural materials
Surface protection	Coating films, electron beam hardened plastics	Coating materials, various paints
Adhesiveness	Polychloroprene	Various adhesives
<u>Thermal Functions</u>		
Heat resistance	Polyimide, silicone resin	Heat resistant structural mat
Low temperature resistance	Silicone rubber, fluororubber	Low temp. resistant rubber
Thermal insulation	Foamed plastics	Heat insulation materials
<u>Electrical Functions</u>		
Electric conductivity	Polyacetylene	Battery, electric wire
Insulation characteristics	Polyimide, polyethylene, terephthalate	Printed circuit board, condenser conductor
Energy convertibility	Polyvinylidene fluoride, doped polyacetylene	Sensor, eletroacoustic transducer device
<u>Optical Functions</u>		
Light transmitting	Polymethyl methacrylate acid polycarbonate	Optical fibre, plastic lens
Photo-active property	Photo-setting plastics	Copying materials, photo mask
Double refraction property	Liquid crystal	Display device
<u>Biological Function</u>		
Compatibility to blood	Polyethylene terephthalate	Artificial blood vessel, artificial heart
Histocompability	Silicone polymer	Artificial organ, artificial bone
<u>Seperating Function</u>		
Ion exchangeability	Styrene group, acryl group	Ion exchange resins
Separation of mixtures	Cellulose acetate group, aromatics, polyamide group	Reverse osmosis membranes, air/gas separation and biological separation membranes
<u>Chemical Function</u>		
Corrosion resistance	Polybutane-1, polyamide, neoprene	Roofing materials, offshore Structural materials
Chemical resistence	Polychloroprene, butadien acrylonitrile	Flexible structure storage tank, fertilizer tank

Figure 1.3: Functions and Applications of New Metal Materials

Functions	**Examples of Materials**	**Examples of Applications**
Mechanical Functions		
High strength	Fine crystal alloy, single crystal alloy	Aircraft and space equipment
Superplasticity	Superplastic aluminium alloy	Aircraft
Vibration absorption	Magnesium series, manganese-copper series	Equipment members (vibration proof materials)
Thermal Functions		
Thermal resistance	Nickel base alloy, cobalt base alloy	Gas turbine, heat pipe
Electrical Functions		
Superconductivity	Niobium-titanium, niobium--3 tin,vanadium-3 gallium	Nuclear fusion reactor linear motor car
Semiconductivity	Amorphous silicon	Solar cell, sensor
Magnetic functions		
High magnetism	Samarium, cobalt	Magnetic recording, motor
High mag. permeability	Amorphous alloys	Transformer core, magnetic head
Others		
Hydrogen absorbing	Fe-titanium series, magnesium-nickel series	Transfer of hydrogen, hydrogen car, heat media
Super-high-speed electron mobility	Gallium arsenide	Super-high -speed IC (Josephson devices)
Shape-memory	Nickel-titanium series, copper-zinc series	Pipe joint, artificial joint artificial muscle

Figure 1.4: Functions and Applications of New Composites

Functions	**Examples of Materials**	**Examples of Applications**
Mechanical Functions		
High strength + light weight	Polymer based composite (Matrices: epoxy resins, fluorocarbon, engineering and superengineering plastics. Reinforcements: carbon fibre, boron fibre, aramid fibre, ceramic fibre)	Aircraft and space equipment automobile and railway cars, ships, leisure and sports goods
Thermal Functions		
Heat resistance + high strength	Metal based composite (Matrices: aluminium, copper, magnesium, titanium, nickel. Reinforcements: ceramic fibre, boron fibre, metal fibre)	Nuclear power equipment, gas turbine, aircraft and space equipment, heat exchanger
	Ceramic based composite (Matrices: alumina, silicon nitride, silicon carbide. Reinforcements: ceramic fibre, metal fibre)	Nuclear power equipment, gas turbine, aircraft and space equipment, rockets

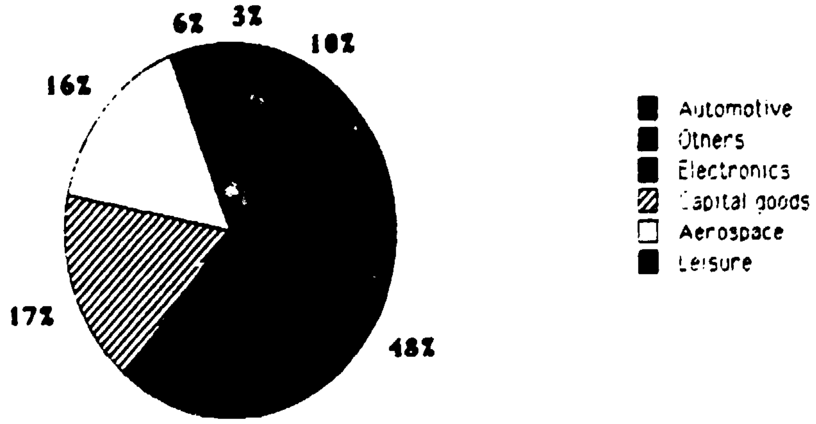
Source: JETRO (1986), Lastres (1988 a)

Regarding their different sectors of application, it should be pointed out, in Figure 1, those which are currently the most consumed AMs:

- electronics and information technology - silicon, compound semiconductors (such as gallium arsenide and indium phosphide), advanced ceramic substrates, photoresists, amorphous alloys and optical fibres;
- space and transport in general - superalloys, special light alloys, new polymers and composites for aircraft, space equipment, rockets, ships, automobile and railway cars;
- capital goods - advanced ceramics and special alloys (for drills, cutting tools, seals and sensors);
- leisure - composites (for fishing rods, tennis rackets and golf clubs);
- defence - composites and special alloys;
- biomedical - advanced ceramics, new metals and composites (for artificial teeth and bones) and new polymers (for artificial organs, blood vessels and skin).

Figure 2 shows the world consumption structure for advanced materials in 1986. From it, we can see that more than 80% of the total sales of AMs in that year (US$ 8.4 billion) refer to three sectors: electronics, capital goods and aerospace, the first being responsible for almost half of the consumption of advanced materials.

Figure 2: World Market for Advanced Materials by Industry
1986 Total Sales = US$ 8.4 billion



Source: Fasth et al. (1988)

3 - Discontinuity in Materials Evolution

The development and introduction of advanced materials and the gradual substitution of them for so-called traditional materials consist in a process the consequences of which are being considered by many authors as a real "materials revolution". In this section, will be discussed the idea that a major discontinuity in materials evolution is taking place.

The main hypothesis behind this idea is that the advent of AMs constitutes a major discontinuity and that the establishment of a new pattern of production and consumption of materials is playing an important role in the process of industrial restructuring (affecting patterns of investment, organization, employment and trade) and is expected to lead to a major change in terms of the patterns of economic and technological leadership.

The four main arguments for such a hypothesis are discussed below.

3.1 - The recent changes are not incremental and originate from strategies adopted outside the traditional materials sector.

The analysis of AMs shows that the development and introduction of these materials have nothing to do with any strategy defined by the so-called traditional materials sector. On the contrary, the very development of the most important AMs seems to be a result of the attempts made to avoid the main constraints produced in and by the "traditional materials" sector mainly in the 70s and 80s.

The rapid increase in the price of raw materials, after the so-called oil crisis, the deregulated increase of production (with the strong entrance of very competitive developing country producers), the oversupplied markets and consequent losses experienced by this sector are the most discussed components of such a constraint.[4] Such a difficult situation contributed to an increase in the rigidity of the industries in this "mature" sector. The lack of new investment and the very low rate of R & D expenditure could probably be considered to be crucially important in terms of the low modernization that this sector experienced during this period. The exceptions were few.

The main innovations in AMs were, then, produced outside the traditional materials sector. In the same way, the appropriation of such development was mainly pursued by consumers of those materials, rather than by producers of traditional materials.

As shown in Table 1, there is indeed a large number of advanced materials consumers attempting a diversification into AMs. Such big Japanese, North-American and European firms belong to sectors such as:

- information technology and electric-electronics (AT&T, IBM, ITT, Texas Instruments, GE, Westinghouse, NTT, Toshiba, NEC, Matsushita, Mitsubishi, TDK, Sanyo, Sony, Sumitomo, British Telecom, Thompson, Philips, Ericsson, ASEA - Brown Boveri and Siemens, among others);

---

[4] See for instance: Souza (1988), US Bureau of Mines (1985), Gonzalez-Vigil (1985)

- aerospace and aeronautics (Boeing, Mac Donnei Aircraft, Aérospatiale); automobile (Isuzu, Honda, Nissan, Toyota, Ford, GM, Renault, Scania, Volvo and Fiat); and
- capital goods (Hertel, Krupps-Widia).

They are interested in all kinds of AMs and particularly, as indicated by Table 1, in the development of advanced ceramics.

Table1: Consumers of Advanced Materials - Diversification into Production

Firms	Advanced Materials
Fuji (JP)	adv. ceramics
Fujitsu (JP)	superconductors and adv. ceramics
Furukawa (JP)	optical fibres, new metals, superconductors and adv. ceramics
Hiteshi (JP)	opt. fibres, semiconds., superconds., adv. ceramics and new metals
Honda (JP)	adv. ceramics
Ishikawajima (JP)	adv. ceramics and new metals
Isuzu (JP)	adv. ceramics
Nissan (JP)	adv. ceramics and composites
NEC (JP)	semiconductors, superconductors, adv. ceramics and new metals
NTT (JP)	semiconductors, superconductors and adv. ceramics
Matsushita (JP)	new polymers, new metals, adv. ceramics and superconductors
Mitsubishi (JP)	opt. fibres, semiconds., superconds., adv. ceramics and new metals
Sanyo (JP)	adv. ceramics and amorphous silicon
Sony (JP)	adv. ceramics
Sumitomo (JP)	semiconds., superconds., adv. ceramics, opt. fibres and n. polymers
TDK (JP)	adv. ceramics
Toshiba (JP)	semiconductors, superconductors, adv. ceramics and new metals
Toyota (JP)	adv. ceramics and composites
AT & T (US)	adv. ceramics, new metals, semiconductors and superconductors
Bechtel (US)	composites and superconductors
Boeing (US)	composites
Energy C. D. (US)	superconductors
Ford (US)	adv. ceramics, composites and superconductors
Gen. Dynamics (US)	composites and superconductors
GE (US)	optical fibres, semiconductors, superconductors and adv. ceramics
GM (US)	composites, adv. ceramics and superconductors
Goodyear (US)	composites and adv. ceramics
J& J (US)	adv. ceramics
IBM (US)	adv. ceramics, new metals, semiconductors and superconductors
ITT (US)	adv. ceramics
Kaiser Aerosp (US)	adv. ceramics, new polymers and superconductors
Mac Donnel Air.(US)	composites
Motorola (US)	adv. ceramics
Texas Ins. (US)	adv. ceramics and semiconductors
Westinghouse (US)	superconductors and adv. ceramics

Table1: Consumers of Advanced Materials - Diversification into Production (cont.)

Firms	Advanced Materials
CGE (FR)	adv. ceramics
Renault (FR)	composites
Aérospatiale (FR)	composites
Stettner (FR)	adv. ceramics
Thomson (FR)	adv. ceramics and optical fibres
British Telecom (UK)	adv. ceramics, superconductors and optical fibres
Oxford Instruments (UK)	semiconductors and superconductors
Plessey (UK)	semiconductors adv. ceramics and superconductors
Hertel (FRG)	adv. ceramics
Krupps-Vidia (FRG)	adv. ceramics
Siemens (FRG)	optical fibres, adv. ceramics and superconductors
Philips (NL)	optical fibres, adv. ceramics
ASEA-Brown Boveri (CH)	semiconductors and superconductors
Ericson (SW)	adv. ceramics
SAAB-Scania (SW)	adv. ceramics
Volvo (SW)	adv. ceramics
Fiat (IT)	adv. ceramics

Source: Yano Research Institute (1984), Long Term Credit Bank of Japan (1984), Cohendet et al. (1988), High Technology Business (1988), Sá (1989) and Lastres et al. (1988).

In fact, we have to consider that there are also some traditional metal producers who have entered the AMs sector. Table 2 shows some examples. Nevertheless, very few metal producers in the US and Europe have shown the interest or capability of entering such a new and high-tech sector.[5]

Only in Japan (where the development of AMs has been one of the main national priorities and where a government policy of restructuring took place) did metal producers display a marked diversification into AMs, as can be seen from Table 2.

---

[5] Cohendet et al. (1988), for instance, regarding the mas producers, argue that the **European situation is marked by a relatively poor mobility of industrial structures, and the failure to switch to functional materials which in overall terms, after a period of adaptation, have taken over** ... (There is a) **manifest strategic sluggishness on the part of a considerable proportion of European companies when it comes to identifying future opportunities and to diversifying, the archetypal example being the steel industry.**' (p. 346)

Table 2: Metal Industries Diversification into Advanced Materials

Metal Industries	Advanced Materials
Daido Steel (JP)	new metals
Hitashi Metals (JP)	adv. ceramics, semiconductors and new metals
Kawasaki Steel (JP)	silicon wafers, adv. ceramics, carbon fibre, supercs., n. metals
Kobe Steel (JP)	adv. ceramics, superconductors, composites and new metals
Mitsubishi Metals (JP)	semiconductors, adv. ceramics and new metals
Nippon Kokan (JP)	silicon, n. metals, n. polymers, carbon fibre and adv. ceramics
Nippon Steel (JP)	new metals and adv. ceramics
Nippon Tungsten (JP)	silicon wafer, carbon fibre, n. metals, supercs., adv. ceramics
Sumitomo Metals (JP)	carbon fibre, semiconductors, new metals and adv. ceramics
Korean Steel (KO)	carbon fibre
Alcoa (US)	n. polymers, adv. ceramics, opt. fibres, composites and n. metals
Teledyne (US)	new metals and superconductors
Pechiney (FR)	ceramics, carbon fibre and new metals

Source: Yano Research Institute (1984), Long Term Credit Bank of Japan (1984), Cohendet et al. (1988), High Technology Business (1988), JETRO (1986), Sá (1989) and Lastres et al. (1988)

One important feature that should be stressed here is the fact that the diversification pursued by metal firms concerns also the production of substitutes for metals. These firms are pursuing the production of materials which are very different from their traditional productive and technological basis. The target seems to be the maintenance of their market share, threatened by the development of such advanced substitutes. As shown in Table 2, the Japanese steel companies are entering not only the field of production of new metals, but also that of advanced ceramics, new polymers and composites. The same is happening in the case of the French (Pechiney) and the North-American (Alcoa) aluminium companies and in the case of the Canadian (Noranda) copper company.

The metal industry's attempt to diversify into AMs faces strong competition from other traditional sectors which are also trying to restructure and diversify their activities. Among them the most important sectors are: cement, textiles, traditional ceramics, chemicals and petrochemicals. The petrochemical and chemical sector is, without doubt, the one which is most heavily investing in AMs and which has the best financial and technical conditions for doing so.[6]

In fact, the biggest petrochemical and chemical firms in the world (such as Du Pont, Dow Chemical, Exxon, Monsanto, Union Carbide, 3M, Basf, Bayer, Hoechst, Elf, Rhône-Poulenc, British Petroleum, ICI, Shell and Ciba Geigy) now include AMs in their strategy of diversification.

---

[6] Ibid

Table 3: Petrochemical and Chemical Industries Diversification into Advanced Materials

Industries	Advanced Materials
Asahi Chemical (JP)	optical fibres, adv. ceramics, composites and new polymers
Idemitsu (JP)	new polymers and carbon fibre
Kureha Chemical (JP)	new polymers and carbon fibre
Mitsubishi Chemicals (JP)	adv. ceramics, semiconductors and new polymers
Mitsui Toatsu Chemicals (JP)	new metals and new polymers
Showa Denko (JP)	adv. ceramics, n. metals, carbon fibre, semics., n.polymers
Sumitomo Chemical (JP)	adv. ceramics, carbon fibre and new polymers
Toho - Rayon (JP)	composites and new polymers
UBE Chemical (JP)	adv. ceramics and new polymers
Allied Chemicals (US)	new polymers, composites, semiconductors and new metals
Dow Chemical (US)	adv. ceramics and new polymers
Du Pont (US)	new polymers, composites, adv. ceramics and supercs.
Eastman Kodak (US)	new polymers and adv. ceramics
Exxon Chem. (US)	new polymers
Hercules (US)	new polymers and composites
Monsanto (US)	new polymers
Union Carbide (US)	silicon, composites, adv. ceramics and new polymers
3M (US)	adv. ceramics, composites, and new polymers
Basf (FRG)	carbon fibre, composites and new polymers
Beyer (FRG)	adv. ceramics and new polymers
Feldmule (FRG)	adv. ceramics and new polymers
Hoechst (FRG)	adv. ceramics and new polymers
Elf (FR)	adv. ceramics and new polymers
Rhône-Poulenc (FR)	adv. ceramics and new polymers
BP (UK)	composites
ICI (UK)	composites, adv. ceramics, supercs. and new polymers
Shell (UK+NL)	carbon fibre and new polymers
AKZO (NL)	carbon fibre and new polymers
Ciba Geigy (CH)	composites and new polymers

Source: Yano Research Institute (1984), Long Term Credit Bank of Japan (1984), Cohendet et al. (1988), High Technology Business (1988), JETRO (1986), Sá (1989) and Lastres et al. (1988).

As Table 3 shows, these firms are mainly pursuing the production of new polymers, composites (and/or carbon fibre) and advanced ceramics. Elsewhere I emphasize that the Japanese efforts in this direction (even if recognized as relatively weak for the time being) cannot be ignored.[7]

---

[7] See for instance the recent attempts in Japan to strengthen this sector and to establish the concept of "New Chemistry" (linking the development of chemistry with, for instance, electronics). Lastres (1989 c)

3.2 - The development of AMs offers the possibility for an inversion in the logic of production.

This second argument refers to the fact that nowadays a major advance in the means of analysing and understanding the structure and properties of matter has been obtained. The cross-fertilized effects and fusion of materials science with other disciplines such as chemistry, metallurgy, physics, electronics, biology, computer science and engineering, etc have led to significant improvements and developments in materials analysis, design, processing and testing (such as powder technology, hot isostatic pressing, rapid solidification process, coating and surface modification, bonding techniques and non-destructive testing methods).

It is possible now to intervene at the molecular and atomic level of matter and rearrange the microstructure of materials in order to obtain the required properties and performance. This has been considered a crucial development that set the basis for the beginning of an inversion in the logic of production. The focus of the new production systems tends to concentrate more and more on specifications to be met and capabilities to be realized, instead of type of materials (or mineral input) to be used. In other words, a given product no longer relies on a given material or on a given input, instead, several materials compete to assume a given function (concept of "hyperchoix des matériaux").[8]

Another important aspect related to this second argument and which is characteristic of this new production system is that the linkages between research, design, production, marketing and consumption were strengthened in order to permit the development of "tailored" materials for specific applications and environments.

3.3 - The development, design and production of advanced materials rely on the use of information-intensive techniques and require new patterns of work organization and industrial organization.

It is important to stress, not only the recent changes in terms of the use of inputs, but also the agility and flexibility brought about by the use of information-intensive techniques in the new materials production systems. The use of computational methods in the research, development, design, production, testing and commercialization of AMs permits a systemic approach, speeding up and augmenting the efficiency of the whole process. A significant example here relates to the utilization of CAD/CAM in order to obtain a "first best" mix among various materials and calculate systemic relations between shape and structure.[9]

It also seems important to emphasize that the use of these information-intensive techniques has been accompanied by new patterns of work organization and industrial organization. Inflexible mass production which characterizes traditional materials production systems has become

---

[8] Cohendet et al. (1988).

[9] See Lastres & Cassiolato (1989)

increasingly unsuitable in conditions of product differentiation, consumer sophistication and fast technological changes. The new plants designed to produce AMs are supposed to be flexible enough to allow the production of "tailor-made" and use-specific materials. Such plants are operated by "multiskilled" labour forces and are frequently designed to produce "multimaterials".

3.4 - This materials revolution is leading to a long term structural change that can be characterized, on the one hand, as a "transmaterialization" of production and, on the other hand, by a "dematerialization" of production.

The concept of transmaterialization of production refers to the recurring industrial transformation in the way that societies use materials, which is a regular and cyclical process. Dematerialization of production, in its turn, refers to a constant decline in the use of materials as a percentage of total production. This latter concept relates to three main aspects. Firstly, the bold degree of miniaturization achieved by industrial production is seen as an important factor in decreasing the requirements of materials needed by industrial processes. Secondly, the increasing use of information technology in the production of materials and products has also been responsible for a considerable saving of materials. Thirdly, there is the fact that the material itself is visibly tending to gain in complexity by "integrating" several functions.

Data showing the declining trend of the consumption and production of traditional materials has been produced in order to support the idea of transmaterialization and dematerialization of production. Such a trend is already clear especially in advanced countries' markets. Figure 3, for instance, shows the declining trend in intensity of basic metals consumption (Kg per unit of GNP) in Japan, which started 16 years ago, just after the oil crisis. Accordingly to this figure, such an inversion is most marked in the cases of steel, zinc and aluminium.[10]

Figure 4 shows the declining trend in the intensity of metal usage (metric tons per million US$ of GDP) in the US and in the world. The data, produced by the US Bureau of Mines, refer to the cases of steel, aluminium and copper. In the same way, the inversion of the consumption trend seems to be associated with the oil crisis.

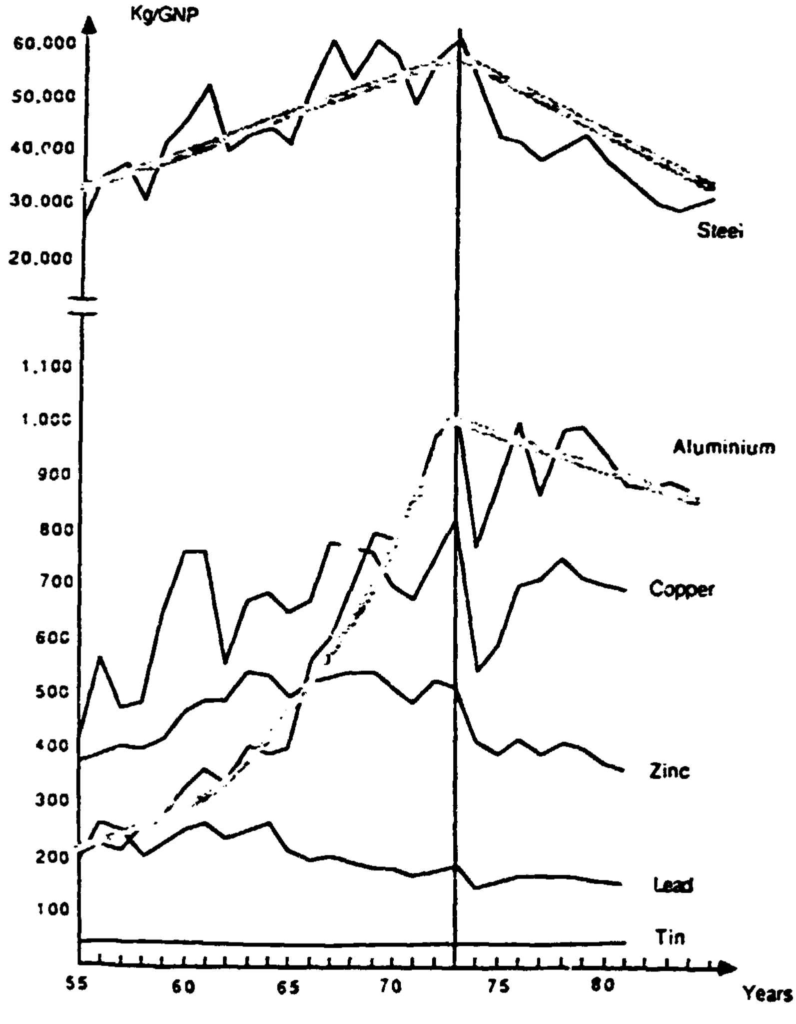
Data relating to metals production in the US show that this declining trend in consumption reinforced the same trend in the production of the five major basic metals (Figure 5).

One strong argument produced by some analysts of such movements refers to the link of these trends to the generalized and temporary difficulties the US economy faced at the beginning of the 80s. However, as Figure 6

---

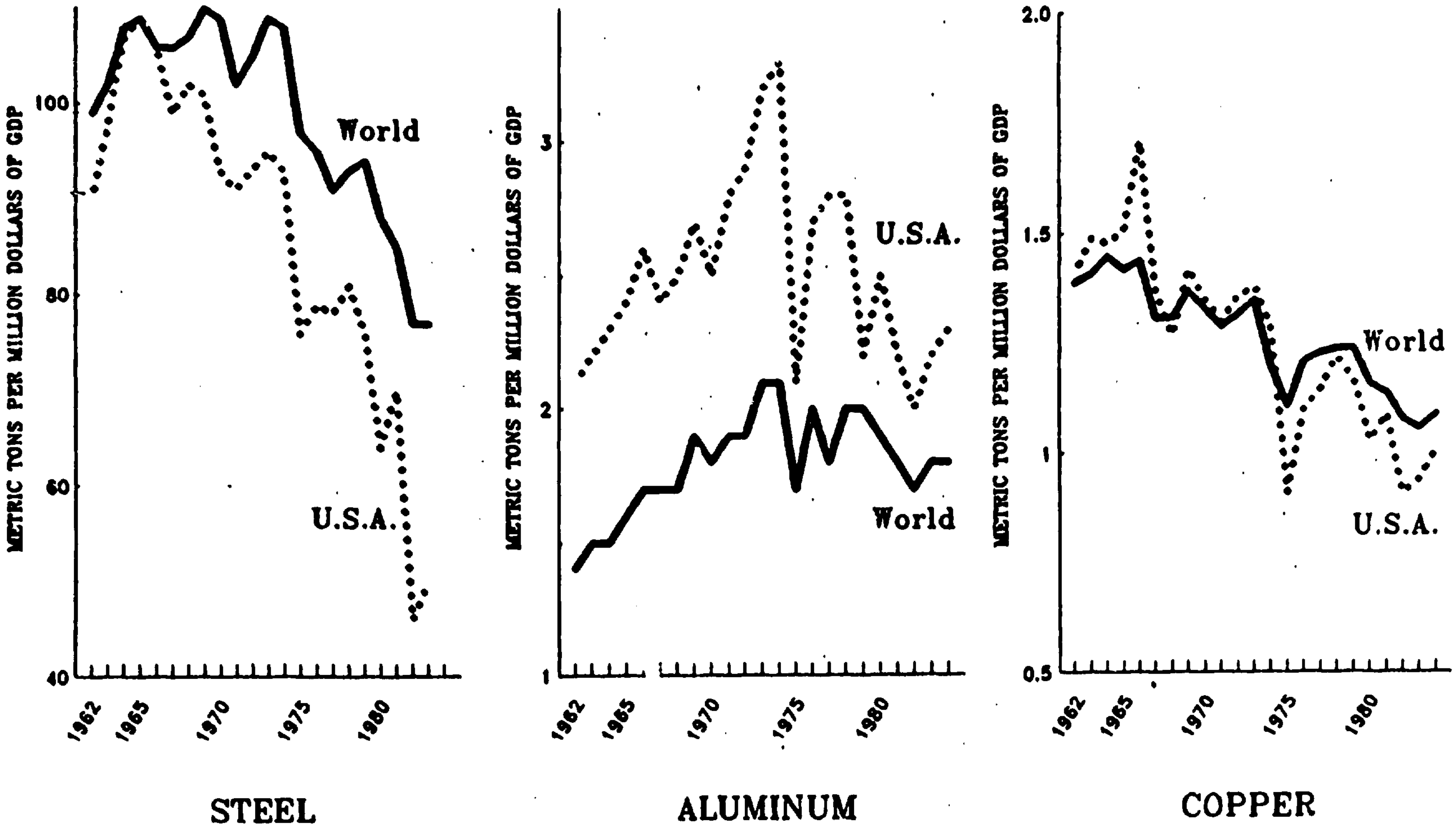
[10] Different sources show the same trend. The originality of those data used in Figure 3 refers to the fact that its primary source is the big French producer of aluminium, Pechiney

FIGURE 3: Metals Consumption per unit of GNP in Japan (1955/84)



Source Cohendet et al (1988)

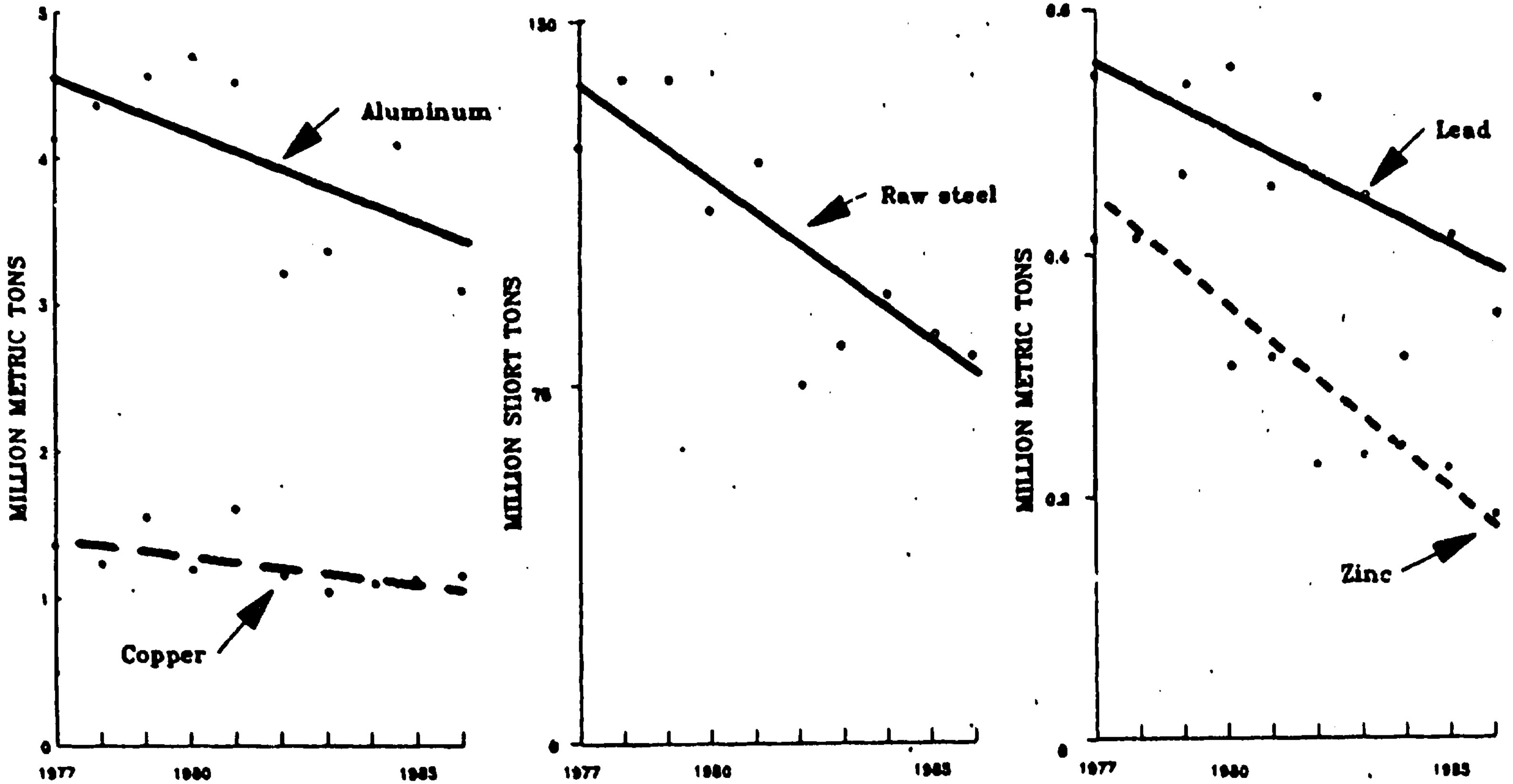
FIGURE 4: TRENDS IN THE INTENSITY OF METAL USAGE



Source: Souza (1988).

FIGURE: 5

THE DECLINING TRENDS IN COMMODITY METALS PRODUCTION IN THE UNITED STATES



ALUMINUM AND COPPER

RAW STEEL

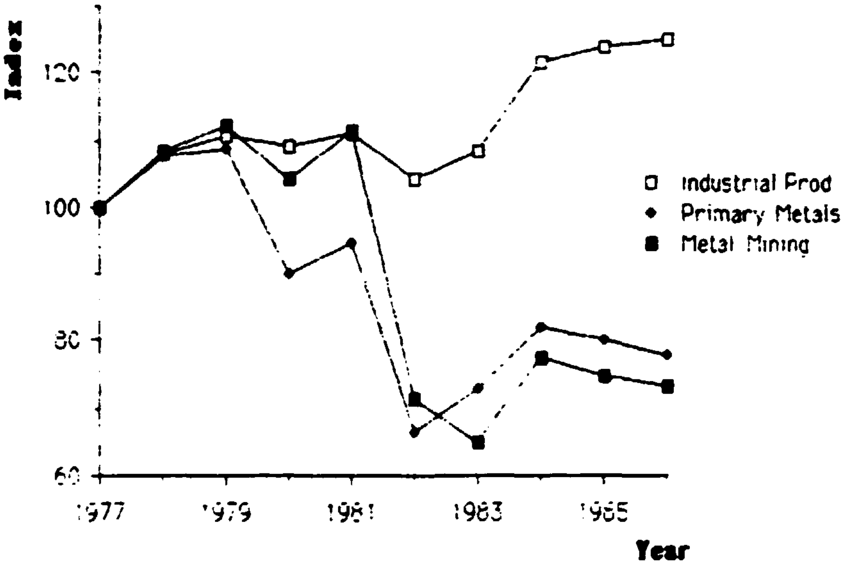
LEAD AND ZINC

Source: Souza (1988).

One strong argument produced by some analysts of such movements refers to the link of these trends to the generalized and temporary difficulties the US economy faced at the beginning of the 80s. However, as Figure 6 indicates, such trends, at least in the case of the US, cannot any more be considered simply as a conjunctural shift.

As Figure 6 shows that the general recovery experienced by the US economy after 1982 was not followed in the primary metals sector and the metal mining sector, suggesting that the possibility of a structural change should be further investigated.

Figure 6: Industrial Versus Metal Production Index



Source: Souza (1988)

There is indeed a well defined tendency towards the process of AMs being substituted for basic metals, as is mainly the case with some polymers and composites displacing steel in the car industry or optical fibres displacing copper wires in telecommunications. Another aspect that relates to the fourth argument is that the advent of AMs goes beyond the process of materials competition and substitution. Opportunities are open for the development of entirely new materials displaying new properties.

As I have already mentioned, most of these AMs have been developed to fulfil completely new and sophisticated functions and applications, especially those associated with the advance in the high-tech areas. In this sense, they do not have to compete with existing materials in order to get into the market. Examples in this case include the development of semiconductor materials, photoresists and memory shape alloys, among others. The decrease in cost and price of such new materials will then be crucial in terms of permitting and accelerating their rate of diffusion throughout the economy as well as making possible the consolidation of these high-tech areas.

Therefore, perhaps the most important aspect relating to the development of these AMs is the fact that they have been seen as a necessary and strategic issue in terms of opening new paths of growth and strengthening future industrial competitiveness. Probably the best example of such a situation is the intense Japanese effort in respect of advanced ceramics. The long term policies adopted in that country towards the development of these materials seem to reflect the aim of building up capabilities aiming at establishing of a new pattern of production and consumption of materials.

So the development and introduction of AMs indeed seems to constitute a discontinuity in terms of materials evolution. Not only are the producers of traditional and advanced materials completely different, but also their inputs, technological processes, industrial structures, work organization, product characteristics (and frequently even their markets) are entirely distinct. The very group of materials which will form the basis for future industrial development is now being defined. A new sector is taking shape. In this sense, the current time presents an opportunity to establish a new technological and economic leadership in such a pervasive area.

4- National and Regional Policies on Advanced Materials

The major advances in materials science until the mid-seventies were mostly as the result of a spin-off from the huge US programmes in the areas of defence, aerospace and energy technology.

The decade of the 80s is marked by the generalized increase in R & D expenditure and, particularly in the case of AMs, by the formulation of private and national R & D projects concentrating attention on specific improvement of those materials.

4.1 - Japan

In Japan, the long term R & D policies on advanced materials have been coordinated by MITI and STA. Having started almost 20 years ago, from a rather modest basis and within the programmes on the conservation and the development of new sources of energy, materials projects have had the support of several industries.

Much more than in other countries, in Japan the development of advanced materials seems to have been pursued within a national framework of objectives. Firstly (and just after the oil crisis), the central target was related to the possibility of attenuating the impact of the increase in the price of oil and other raw materials on the Japanese economy. Nowadays, the hope of taking advantage of a promising structural change seems to be getting stronger in that country. The general idea is to establish a new pattern of materials production and consumption more adequate to the Japanese perspectives of growth. One attempt in this direction is the intention of changing the basis of future industrial development from metals to advanced ceramics. Such a possibility has been pursued by exploring the advantages created by the sound Japanese microelectronics sector, linking the development of AMs with the requirements of this sector.

Table 4 shows the Japanese R & D programmes on AMs in 1988 and 1989. In 1988, ¥ 16,070 million were deployed in this area, within the three main important governmental programmes in terms of materials (BFTI - Basic Technology for Future Industries, Large-Scale Project and Multi-Core Project[11]). From this total, 70% referred to R & D in superconductors.

In terms of the nature of AMs, the Japanese efforts in R & D concentrated on advanced ceramics. This family of materials in 1988 was responsible for almost 70% of that total, mostly because of the high priority given to R & D in high temperature ceramic superconductors (HTSCs).[12]

Table 4: R & D on Advanced Materials in Japan 1988/89 (million ¥)

Targets	Period (FY)	Budget (FY88)	Budget (FY89)
MITI (BTFI)			
Superconductors	1988/97	1061	1872
Advanced Ceramics	1981/92	1099	1149
New Polymers	1981/90	532	530
Synthetic Membranes	1981/90	357	356
New Metals	1981/86	380	-
Composites	1981/88	548	-
Photoactive Materials	1985/93	234	318
Large-Scale			
AMs Proc. Systems	1986/93	1679	2329
Fine Chemicals	1988/95	20	275
Subtotal		5960	
STA (Multi-Core)		11171	
(-BFTI)		(-1061)	
Total		16070	

Note: AMs are also developed within other MITI and STA projects, such as Human Frontier Program, Moonlight (Superconducting Generator), Sunshine, Large-Scale (High-Speed Computing System-GaAs), and also other ministries programmes Education, Post and Telec., Health etc).

Source: AIST/MITI (1988 and 1989) and STA (1988 a and 1988 b)

---

[11] The latter includes R & D projects coordinated by STA, MITI, Min. of Education, Min. of Transport and Min. of Post and Telecommunications

[12] Considering that only 8% of the superconductors programmes refer to metallic materials and also considering the efforts towards the development of structural ceramics (6%)

It is worthwhile mentioning that until 1987 (i.e. before the discovery of the HTSCs), the attention of the Japanese government was concentrated on the development of structural advanced ceramics. MITI, for instance, dedicated 20% of its BFTI total budget for 1987 (which in addition to AMs, included also electronics and biotechnology R & D) to these materials.[13] MITI budget regarding the research in structural ceramics (aiming at the development of gas turbine components) continues to increase year by year. From 1988 to 1989 it increased by 4.5%. Nevertheless, superconductors funding increased by 76% in the same period.

The most important result of these long term Japanese efforts is the leadership achieved by its industry in terms of the world hierarchy in the production of advanced ceramics (both electronic and structural), carbon fibre and semiconductors. In addition, Japanese capability in compound semiconductors (such as gallium arsenide), integrated optical materials, superconductors and biomaterials are being recognized as the most promising in the world.[14]

4.2 - United States of America

In the US, the emphasis on the development of AMs has concentrated on composites and new polymers (and, recently, also on superconductors). Currently, government sponsored R & D is diffused throughout the multitude of government programmes and there is no single agency having the sole mandate for materials R & D. This has been criticized by the US Congress and the scientific community, who attribute the recent Japanese leadership in strategic advanced materials to the US' lack of planning and coordination.

In fact, a recent survey on advanced materials produced under the auspices of the US National Research Council reinforces such conclusions.[15] The study comprises an analysis of advanced materials commitments in countries such as the US, UK, FRG, France, Spain, Canada, Japan and South Korea. The main conclusions are that:

- materials research and development seems to be less coordinated in the US than in other advanced countries. In the US no major agency is in charge of planning, setting priorities or evaluating materials (or industrial) policy and there is low cooperation (or no relationship at all) between various agencies and various sectors (especially between the generation of new knowledge and its utilization);
- most other nations support the development of materials science through carefully targeted government programmes;
- between 1976/87, the Federal government reduced materials funding by 11% and by 23% for nondefence spending;

---

[13] See Lastres (1989 b)

[14] See Morse (1989).

[15] Cohen (1989) and High-Tech Materials Alert (Dec. 1989)

- while the government gives defence and energy research that same type of national push, it leaves materials development for electronics, telecommunications, nonmilitary aerospace, and other fields in the hands of individual corporations.

- such a tendency has dangerous consequences for US competitiveness. The recent negative performance of 7 major industries, in terms of the balance of trade, has been attributed to the lack of sufficient progress in advanced materials.

The final recommendation of the report is that advanced materials offer a special opportunity to start urgent coordination in science and technology in general, which is lacking in the US nowadays. But, probably, the strongest argument used to attract better support for this area relates to the possible threat in terms of national security that the underdevelopment of these materials and their corresponding technologies could imply[16].

As one result of such pressures a recent change in the US is taking place. AMs are now seen as "an enabling technology inextricably linked to technological advancement and competitiveness as well as to national security".[17]

The North-American expenditure in AMs are estimated to be over tenfold the Japanese funding. The US has had the capacity to advance on a wide materials research front, which indeed requires a large budget. Then, and despite all criticism, the US still holds a comfortable international position in composites, new metals and new polymers and also in infrastructure and human resources capabilities in general.

Figure 7 shows that the Federal government spends US$ 1 billion every year in materials science and engineering in the US. This total includes AMs.[18]

As we have already seen, R & D responsibility in materials R & D programmes fall under the ambit of a number of agencies with specific mission targets. These include: Department of Energy, Department of Defence, National Aeronautics and Space Administration, Department of Commerce (National Bureau of Standards), Department of Interior (Bureau of Mines) and the National Science Foundation.

According to this Figure 7, DOE has been the most important promoter of materials R & D, responsible for almost 60% of the total expenditure in 1985.

---

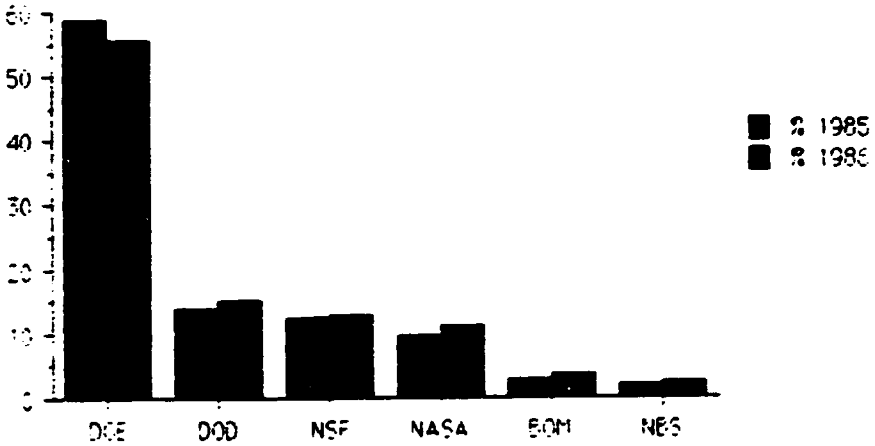
[16] See, for instance, Morse (1989): **'When Japan was identified recently to be significantly ahead of the US in six of 22 critical technologies (microelectronics, compound semiconductors, machine intelligence, integrated optics, superconductivity and biotechnology materials) all critical to long term qualitative superiority in weapons systems, Americans saw this as a threat.'**

[17] OECD (1988).

[18] Reliable data for this area are not routinely available and, as OECD (1988) reports, probably are not separately tabulated. See note 8.

In 1986, DOE budget decreased from US$ 647 million to US$ 609 million. In the same year, all the other agencies increased their funding. DOD (from US$ 155 million to US$ 164 million), NSF (from US$ 135 million to US$ 137 million), NASA (from US$ 107 million to US$ 121 million), BOM (from US$ 33 million to US$ 41 million), NBS (from US$ 23 million to US$ 25 million).

Figure 7: R & D Materials Science and Engineering in the US by Agency FY 85 - FY 86 - US$ 1.1B*



* It is estimated that private investment represents an equivalent amount.

Source: OECD (1988)

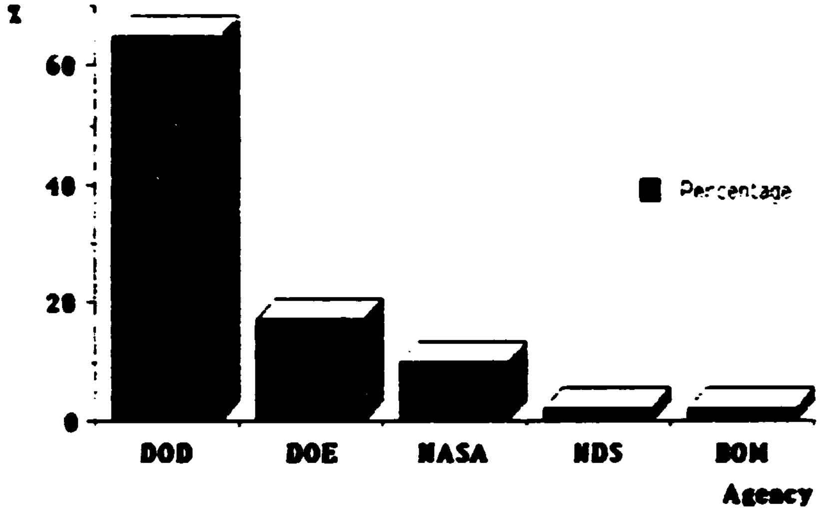
It is estimated that, in the US, private investment represents an amount at least equivalent to the government investment. Among the main firms investing in AMs are: IBM, A T & T, Du Pont, Exxon, 3M, GE, Boeing and GM.

Specific data about R & D programmes on AMs in the US, shows a different picture. As Figure 8, indicates, in 1983, DOD was responsible for 65% of the total government funding. DOE for 17%, NASA for 10% , NSF for 4% and both NBS and BOM for 2%.[19]

---

[19] Data here refer to the survey the General Accounting Office made for FY 1983, based on data provided by the six main agencies in charge with AMs programmes, which totalled almost US$ 200 million. See OECD (1986 b)

Figure 8: R & D in Advanced Materials in the US by Agency (1983)



Source: OECD (1988)

Table 5 shows the R & D priorities in the US for materials in 1986. The most outstanding difference from other national policies relates to the emphasis on composites. Such an emphasis has been very strong there, where materials science has been much improved mainly because of the huge R & D programmes in defence technology.

Table 5: Government R & D Priorities in the US (1988)

Materials	**Goals**
Advanced Ceramics	
High-Perfomance Structural Ceramics	Dev. of mats. for heat components, turbine blades and heat shields for automotive and aircraft engines
Electronic and Superconducting Ceramics	Dev. of mats. for electronic and electrical components and for integrated optics for use in electrical transmission, transport and medical industries
Composites	
Fibre Reinforced Plastic Resin	Dev. of structural components for aerospace, automotive and ind. construction
Metal Matrix Composites	Dev. of mats. for structural and superconducting components
New Metals	
Amorphous Metals	Dev. of mats. for electromagnetic equipment

Source: OECD (1988 a and 1988 b)

As we can see from Table 6, in 1983, composites were responsible for more than half the government funding for AMs. Such a fact reflects the importance of DOD and NASA funding and their priorities for the development of such a family of materials.

Advanced ceramics with 23% of the total funding in that year, was the first priority in DOE, BOM, NBS and NSF programmes.

New polymers, second priority for DOE, NSF and NBS, were considered at the time (as they are still considered nowadays) the most important area in terms of private capabilities. Governmental support in this area (expected to be supplementary to private investment) concentrated on new polymers with optical functions (mainly liquid crystal) and separation membranes.

Table 6: R & D on Advanced Materials in the US by Agencies (1983)

	DOD	**DOE**	**NASA**	**NSF**	**NBS**	**BOM**	**TOTAL**
composites	68%	7%	75%	1%	6%	-	53%
adv. ceramics	13%	6%	1%	34%	49%	53%	23%
amorphous alloys	15%	9%	13%	31%	21%	47%	15%
new polymers	4%	24%	2%	33%	24%	-	9%

Source: OECD (1988 a and 1988 b)

4.3 - Europe

Since the early 80s the EEC has included the development of AMs in strategic research programmes such as Sprit (VLSI integrated circuits), Race (optical fibres), Biotechnologie (biomaterials), Brite (separation membranes, new polymers, composites and amorphous alloys) and Eureka.

Eureka includes, among others (see Table 7) the project "Car Structure Using New Materials - CARMAT 2000). This project has a 5-year budget of 60 million ECUs and European firms such as Basf, Bayer, Elf, ICI, Pechiney, Peugeot and Saint Gobain participate in it.

Table 7: Materials in the Eureka Programme.

Nature of project	Projects approved end 1986 (Stockholm)	Cost (M ECU)	Duration (years)
	(nb D = Germany, CH = Switzerland, E = Spain, S = Sweden, F = France, N = Norway, Netherlands, A = Austria, I = Italy, GB = GB)		
EU 3 Amorphous silicon	Solems (F) - MBB (D)	53	5
EU 5 Filtration membranes	Lyonnaise des Eaux (F) - Dégrémont (F) - De Danske Sukker Fabriken (DK)	56	6
EU 13 CARMAT 2000 Development of solid automobile structures, ultra-light fibres	Peugeot (F) - BASF (D) - Battenfeld Extension Technic (D) - Bayer A.G. (D) - Cristaleria Esp. (E) - Ecole des Mines (F) - CIT (F) - Péchiney Alu (F) - Saint-Gobain Vitrage (F) - Usinor (F) - Vetrotex (F) - DSM (NL) - ICI (GB)	60	5
EU 25 Aluminium in place of chromium in treatment of leather	(Spain) - (Germany) (GB)	25	3
EU 29 Development of new ceramics for car engines	Desmarquet (F) - Péchiney Alu (F) - Peugeot (F) - Fiat Holding (I)	15	5
EU 33 Ceramics in gas turbines	SEP (F) - Hispano Suiza (F) - Snecma (F) - Alfa Romeo (I) Volvo Flygmotor (S)	16	5
EU 40 Construction technologies (infrastructures and networks for major building developments)	Giblin (D) - SAE (F) - Società Costruzioni Generalisti (I) Bovis Construction LTD (GB) - Charcon Tunnel (GB)	9.2	5
EU 42 Light-weight materials for transport systems	VAW (D) - Institut für Angewandte Stahlentechnik (D) ESA (D) - Péchiney Alu (F)	15	4
EU 47 Ceramics for diesel engines	Mann (D) - SEP (F)	14	5
EU 52 Disposable sensors for the medical field	(Netherlands) - (Switzerland) - (Belgium) (Germany)	4	5
EU 96 Super-conducting coils	Université de Genève (CH) - Société Elin-Union (A) - Metall-Werke Plansee (A) - Technische Universität Wien (A) Spectro A.G. (CH)	8	3
EU 102 [illegible] (Integrated Circuit Non-Volatile Memory) Memories with a capacity of 16 M bits	(France) - (Italy)	400	5
EU 111 Development of lasers (solid state included)	(France) - (GB)	180	6
EU 117 Fibre-reinforced plastics, glass fibre composites	(Finland) - (Belgium)	2 to 3	2
EU 127 JESSI (Joint European Sub-micron Silicon) Sub-micron technology	(Germany) - (GB) - (France) - (Netherlands) (Italy)	2.4 to 2.8	10
EU 132 Transmission by optical fibre systems	(GB) - (Sweden) - (Portugal)	8 to 16	2 to 7.5
EU 138 Coatings for advanced technologies	Coat A.B. (S) - Leybold Heraeus (D) - Florit (S) - Volvo (S) - Imcol (GB) Pilkington (GB)	4.5	4
EU 139 Methods of forecasting properties of (injection moulded thermoplastic articles	Royal Technology Institute (N) - Centre for Industrial Research (S)	1.6	5
EU 155 International co-operative research for laser applications	(Germany) -	7.5	3
EU 159 EUROTUR (Programme demonstrating technology of gas turbine engine)	(France) - (Netherlands)	33.8	4
EU 160 Development of mineral membranes and procedures for separating fermentation products (antibiotics)	(France) - (Italy)	14.7	4
EU 162 Electron beam treatment : applications in processing industry (micro emulsions, polymer granules)	(Sweden) - (Finland)	1.1	3
EU 163 EUROVISI (display systems)	(Ireland) - (GB)	1.6	3.5
EU 164 Microencapsulation, development of new sensors, pharmaceutical industries	(Finland) - (GB)	0.5	-
Projects pending			
Thin films and deposit on materials (EU 66) (electronic, lubrification)	Lausanne Ecole Polytechnique and other Swiss bodies	3.3	7
New process for polymer production (EU 74) (fermentation, lactic acid)	Spanish companies	-	-
Production line for mass-market integrated sensors	Metravibe (F) - CSEM (CH)	-	-
Flexible automated microlithograph line, for integrated circuits	MATRA (F) - CNET (F) - Cambridge Instruments (GB) Frauenhofer Institut (D) SGS (I), etc.	-	-
Inspection and automatic testing of integrated circuits	Electronique Serge Dassault (F) - CSEM (CH) BATELLE (CH)	5	3
Advanced microprocessors, GaAs integrated circuits, microwave components, high-density memories, flat screens, sensors)	Thomson (F) - GEC (GB) - Philips (Netherlands) - Siemens (D)	-	-
Flexible automated factory for manufacture of electronic equipment	Eurosoft (F) - CSEA (I) - Insiel (I)	28.8	5
Non-invasive medical diagnosis equipment (biosensors and IA)	(France) - (DK) (Spain)	-	-
Custom-built integrated circuits (ES2)	(Luxembourg) - (Germany) - (GB) - (Belgium) - (Finland) (Sweden) - (Switzerland) (Austria)	105	3
Materials and new assembly technologies for transport	Péchiney (F) - VAW (D)	-	4
New materials for semi-trailers	Berlin (F) - Vetrotex (F) - Solvay (B) GKN (GB) - Fruehauf (D), etc.	-	-
Medium-power ceramized gas turbines	SEP (F) - Hispano Suiza (F) - Volvo (S) - Alfa Romeo (I)	16	5
Materials and computer-assisted design and manufacture	Aérospatiale (F) MBB (D)	-	-
Broad-band telecommunications	CIT-Alcatel (F) - Italtel (I) Plessey (GB) etc.	-	-
Full automation of chip assembly	Matra (F) - SGS (I)	-	-
Computer-assisted design and manufacture of GaAs integrated circuits	Thomson (F) GEC (GB)	58.5	3
Thyristors for high-power application in rail traction	Thomson (F) - GEC (GB)	18.5	2

Source: Cohendet et al (1988).

In 1986, a special programme on AMs was established - the European Research for Advanced Materials (EURAM). The basic document of this programme explicitly recognizes the significant results achieved by Japanese and North-American firms as an outcome of R & D expenditure in AMs and the consequent inferiority of European firms in facing such increasingly difficult competition.[20]

This is a four-year programme with a budget of 30 million ECUs. Its main target is the development of those AMs in which Europe is relatively less competitive: advanced ceramics, new metals and composites (see Table 8). It aims at the improvement of materials, linking basic research with engineering work and it is designed to create, develop and apply new materials and to secure the evolution of existing materials to a higher level of improvement and to be competitive in terms of costs.

Table 8: European Research for Advanced Materials - EURAM Programme

Priorities	**Goals**
Development of Metallic Materials:	aluminium alloys (especially for aerosp. and aut.)
	magnesium alloys
	titanium alloy
	electrical contact materials
	magnetic materials
	mats. for surface coating (dev. of new steel alloys)
	development of improved thin-walled casting
Development of Advanced Ceramics:	optimization of SiC, Sialon for use in engines
	mats for surface coating (substitutes for metals)
	basic study of the high-temperature behaviour
	study of ceramic composites
Development of Composites:	organic-matrix composites (for aerosp. and aut.)
	metallic-matrix composites (using aluminium and magnesium matrices)
Other AMs for Specific Applications:	memory shape alloy, alloys with high energy absorption, highly corrosion resistant marine materials, composites with amorphous matrices, composites with vitreous matrices and composites with elastic matrices for energy-shock-noise absorption

Source: **EURAM (1986)**

---

[20] **Pour sortir de ce cercle vicieux de vulnérabilité et de dependance, et aussi pour regagner sa compétitivité sur le plan mondial, l'industrie européenne doit investir massivement dans l'innovation technologique des matériaux. Le project EURAM, en regroupant les entreprises matériaux de la CEE en un ensemble cohérent, peut jouer le rôle de catalyseur pour promouvoir une véritable science et un génie des matériaux européens.** CEE, Programme d'Action de Recherche - Materiaux 1986/89 (Brussels, 1986) p IV-9.

Concomitantly with these regional efforts, national programmes (mainly those in FRG and France) have been strengthened, aiming at modernizing industrial structures and creating capabilities in advanced materials R & D.

In general, the European posture regarding AMs then has been defensive and aimed at "making up for lost time". Cohendet et al, recognizing such a need and trying to analyse the reasons, conclude: **"For a very long time Europe played a leading role in materials research...It would be going too far to say today that Europe has been overtaken, but there is no doubt that it has allowed the US and Japan to steal a march on it in research into most of the materials with the highest expected growth rates between now and the end of the century...There are perhaps many reasons why Europe lags behind (such as dispersion of activities, lack of foresight, divide between research and industry etc), but it is clear that inertia due to tradition is one that merits emphasis"**.[21]

In terms of AMs the European industrial strategy concentrates mainly on the development of polymers and new light metals and alloys.[22] It recognizes the need to link research, production and consumption, aiming at taking advantage of the strongest capabilities of the region. In this sense, the European formula to stimulate this area seems to concentrate on the strategy of linking the most promising European family of AMs (new polymers, given the competitive strength of its chemical industry and its research capabilities) with one of the most promising European industrial consumers of AMs (automobile industry)

4.4 - Other Countries

Other measures and countermeasures regarding the development and introduction of AMs, have been adopted by countries such as Canada, Australia, China, Brazil, South Korea and some other developing countries. Such policies were developed mainly after the second half of the 80s. Most of them are related to the need for a protective policy (mainly in the case of big traditional materials producers who feel threatened by the new advances) or to the perspective of taking advantages of an important transition period.

4 - Japanese Strategy Towards the Development of Advanced Materials

Since Japanese industry can be considered as more vulnerable than others to potential energy and materials supply curtailments and more sensitive to economies with these inputs (because of its almost total reliance on imports), the development of advanced materials has been among its highest R & D priorities, mainly from the 1970s onwards. In the 80s the development of AMs has become one of the three cornerstones of the Japanese industrial strategy, along with microelectronics and biotechnology.

---

[21] Cohendet et al (1988) p 371

[22] Lastres et al (1988 b)

The most important feature of the Japanese policy towards the development of AMs seems to be that the measures adopted in that country are geared towards radically changing the patterns of production and consumption of materials. In other words, Japan is pursuing policies concentrating on discontinuity of traditional production of materials and emphasizing the linkages between materials production and new sectors such as information technology.

As we have seen, one of the major characteristics of Japanese strategy on AMs has been the national concern with the development of these materials and the promotion and improvement of technological strengths through long-term R & D programmes with very high rates of industrial participation. The long term policies adopted in Japan for the development of these materials and their precocious commercialization (with the purpose of changing traditional consumption habits and aiming at acquiring leadership in the area) reflect calculated objectives such as to build up capabilities regarding the establishment of a new pattern of international competition.

The main targets of the policies regarding the development of advanced materials in Japan have been:

. the inauguration of a new pattern of production and consumption of materials, minimizing national disadvantages (innovative activities to substitute for high-priced factor inputs) and, at the same time, maximizing internal advantages (innovative activities to explore capabilities built up in electronics, for instance);

. the aim of building completely synthetic materials, controlled at molecular and atomic level, to cater for a more and more specific and sophisticated demand (utilization-oriented research);

. the strong emphasis on fusion of materials science with other disciplines such as physics, electronics, chemistry and, mainly, biology;

. the objective of developing advanced materials related to IT sectors;

. the promotion of internal and international interactions;

. the attention to R & D, production, marketing and consumption of advanced materials within a conception of a system.

In general terms, the Japanese policy for the development of AMs can be divided into 2 phases. The first (adopted in the 70s), when advanced ceramics were chosen to be the basis of future industries. This choice was made according to two related factors. Firstly, the development of advanced ceramics, in the way it has been pursued, represents a major attempt to considerably reduce mineral and energy inputs (in terms of volume and price) in both production and utilization of materials. Secondly, it represents a very technology-intensive production and a more flexible production organization in a completely new area.

Many advanced ceramics are superior to traditional materials in various industrial applications, resulting in economies in materials and energy (such as applications in automotive engines, meaning lighter and more fuel efficient motor vehicles) as well as in products that cannot be made of conventional materials.

Ceramic materials are also generally more abundant and evenly distributed throughout the earth's crust than conventional metals. Alumina and silicon ceramic materials are plentiful even in Japan. Their refinement and downstream fabrication processes tend to require relatively less energy than metals, need not be located in congested areas and are more pollution-free.

On the other hand, one has to consider that the selection of ceramics to be the core of AMs plays an important role in terms of producing a discontinuity in materials production and consumption. The emphasis on new plastics, for instance, (and as pursued in the US and Europe) could be seen in Japan as a desired but much more difficult target, because of the strong international competition in chemical industry.

As we have seen, Japan has been emphasizing the improvement of advanced ceramics since the mid-70s. This issue did not lose priority within the main national targets, despite the expected technical/economic results in terms of structural ceramics until the mid-80s not having been entirely fulfilled. Due to this patient and long term public policy, Japan can now count on a large base of skill and experience in the field of ceramics, which is fundamental for the development of the programmes on high temperature ceramic superconductors. Such experience relates to previous activities in research, development, production, commercialization and use of ceramic materials.

Regarding this issue concerning superconductivity it has also to be mentioned the Japanese long term investments in the field of metallic superconductors. After the discovery of the new ceramic superconductors, in 1986/87, Japan had the advantage of having placed ceramics and superconductivity among the top priorities in its R & D programmes years before. Then, rapidly, these two priorities were linked to form a new programme oriented to exploit and augment the capabilities built up in both areas. In fact, one the most impressive Japanese features seems to be the agility with which public policy can be reoriented to the new discoveries and new perspectives of growth. Now, the concrete possibility of Japanese supremacy in the field of ceramic superconductors is so high that US measures under Reagan's administration concerning this subject have been considered as a response to this situation.[23]

The second phase is consistent with the new strategy, conceived in the late 80s, of creating new paths for the development of science and technology (and which relies on "Japanese creativity" and the development of international programmes for basic and fundamental research, such as the Human Frontier Programme).

In this new phase the intention emerges of developing advanced materials beyond the traditional concept of materials. For example, intelligent materials (a new substance or material which surpasses single-function

---

[23] See, for instance, Committee on Science, Engineering and Public Policy (1988) and UNIDO (1987).

materials and those which change function in response to changes in environmental conditions), which possess key functions such as self-recovery, self-adjustment or control, self-diagnosis, stand-by capabilities, self-reproducibility and ability to be externally tuned.[24]

6 - Impact of Advanced Materials

We saw in the previous sections that with the development and introduction of advanced materials, some important changes are expected to influence the way science and technology are developed and materials are produced and consumed. The policies adopted by different countries and firms (be they the most aggressive or the most complacent ones) reflect the intention to build up capabilities conforming to a new international pattern.

In the later two sections, I briefly discussed the advanced countries' posture toward AMs, for such countries are the ones which have better conditions for influencing and shaping this new pattern. Despite recognizing the importance of discussing the foreseen global impacts of the introduction of these materials in the international scenario, in this section I will focus on the impacts for the so-called Third World countries, for they seem to be the most dramatic. I will also use some examples from the Brazilian experience on advanced materials which I believe to be very interesting and which is the situation I know best.

As we saw, the introduction of AMs in the market has been accompanied by a decreasing trend in terms of the advanced countries consumption of raw and traditional materials. In global terms, the same sort of declining trend can be identified. The analysis of the world consumption of the seven major metals shows that their yearly rate of growth turned negative after 1979 (see Figure 9). The crisis that started in the early 70s put an end to the high rates of demand growth experienced by most major metals during the period of the 50s and 60s. This **slowdown** was further deepened by the recession which took place in the early 80s.

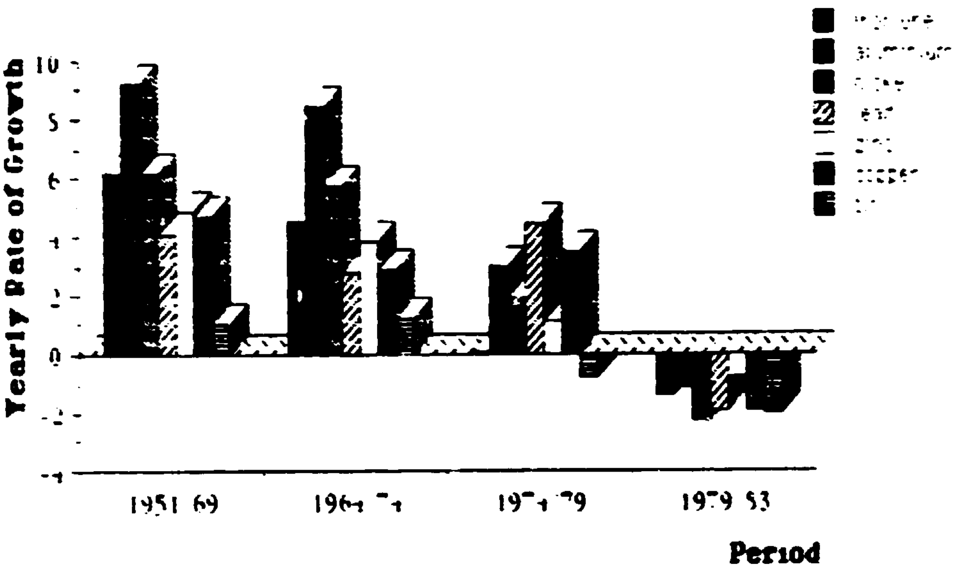
Such a change has various consequences for the less developed countries (LDCs), especially those which are important producers of traditional materials and ores. The most visible one refers to the expected negative impact on the balance of trade of these countries. According to Gonzalez-Vigil (1985): **'The significance of this fall is paramount indeed, as the seven metals** (analysed in Figure 9) **represent around three quarters of more or the value of all metals minerals in the world economy and, in particular, they accounted for three quarters of developing countries' exports of all non-fuel minerals in the mid-70s and together with manganese ore, for 53% of the total non-fuel mineral export earnings received by developing countries in 1980.'**[25]

---

[24] Yanagida (1987) and Saito (1989)

[25] Gonzalez-Vigil (1985), p. 12

Figure 9: Declining Trend in World Consumption of Major Metals



Source: Gonzalez-Vigil (1985)

It is worth mentioning that such a declining trend does not necessarily imply an absolute decline in the volume of raw material and metals exports from developing countries. But it does mean that the consumption of such products is no longer increasing at the same rate as it used to in the past. On the other hand, it is expected not to increase as much as the total increase in manufacturing output in the future.[26]

It is also expected that the metals industry's current international division of labour will continue for some time, but not for long. Developing countries are expected to be the fastest growing market for the major metal raw materials produced by themselves. Then, while in the past a greater rate of consumption of major metals used to express a greater level of industrial development within the different countries, today it has turned to be the opposite. Low consumption growth of metals is now considered a characteristic of mature developed economies.

---

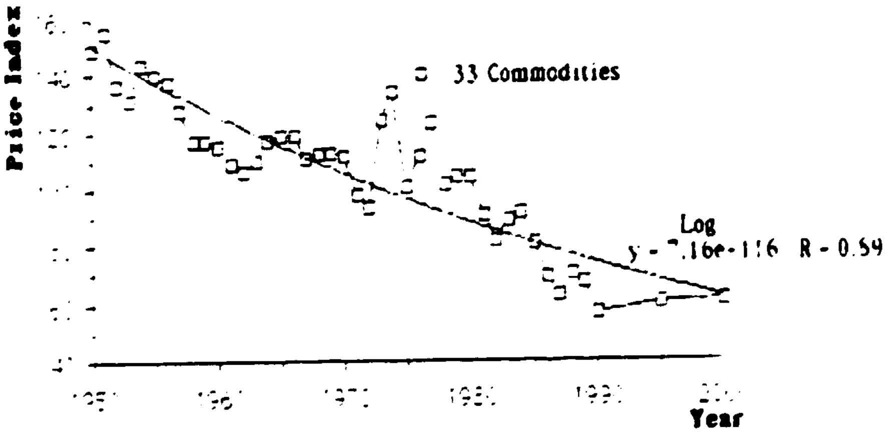
[26] See US Bureau of Mines (1988) and World Bank estimates

At the same time, figures about the estimated world market for AMs are eloquent showing growth rates around 20% per year. And if the traditional materials sector is losing its importance and separating more and more from the dynamic axis of industrial growth, worse than this is the depressing trend experienced by the prices of those traditional materials and raw materials.

In fact, as the World Bank has demonstrated, such a declining trend can be seen as the general tendency of commodity prices (excluding petroleum) in the last decades. Figure 10 shows the weighted index of prices for 33 non-fuel commodities in the period 1950/2000. This group of commodities includes agricultural products (67.7 %), minerals and metals (27.1%) and timber (5.2%).[27] It is clear from the figure that the price index of these commodities is experiencing a remarkable decline in the analysed period. It is worth emphasizing that these data also indicate that, after the 80s, short run price increases were always followed by greater price decreases.

As the price forecast reveals, non-fuel commodity prices are expected to decline even more from their 1988 level over this and the next year and are expected to make only a modest improvement over the 1900/2000 period, increasing only 5% with the price forecast for 2000 representing only 45% of the price at the beginning of the period.

Figure 10: Weighted Index of Commodity Prices
(Constant 1985 US Dollar's)



Source: World Bank (1989)

---

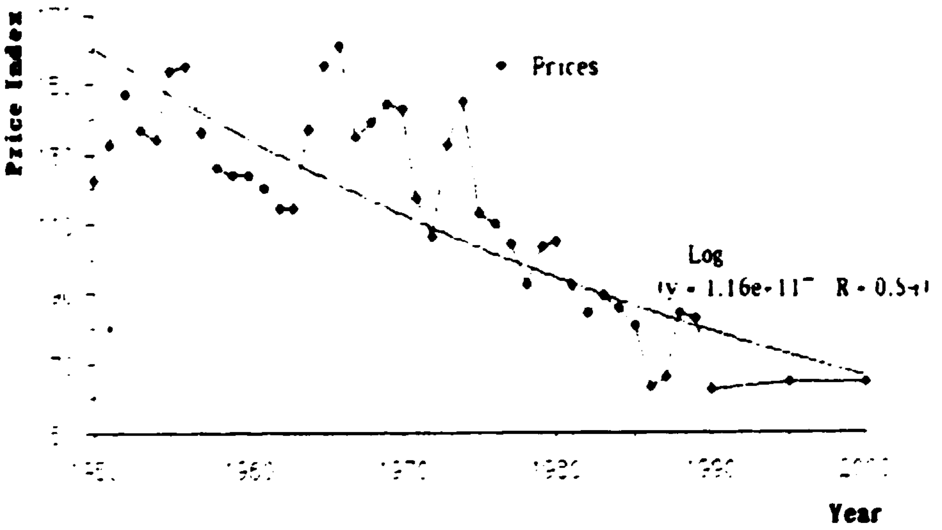
[27] For the methodology used to produce these data see World Bank (1989)

Figure 11 shows the weighted index of metal and mineral prices for the same period. From it we notice the consistent decline in the prices of these products. Such a decline became sharper after the 70s.

The decline in minerals/metals prices expected between 1988 and 1990 is about 16%. An improvement of 10% is expected over the 1990/2000 period. As a result, the average metal and mineral prices index estimated by the World Bank for this decade (1990/2000) is less than half of the 50s and 60s averages.

Figure 11: Weighted Index of Metal and Mineral Prices

(Constant 1985 US Dollars)

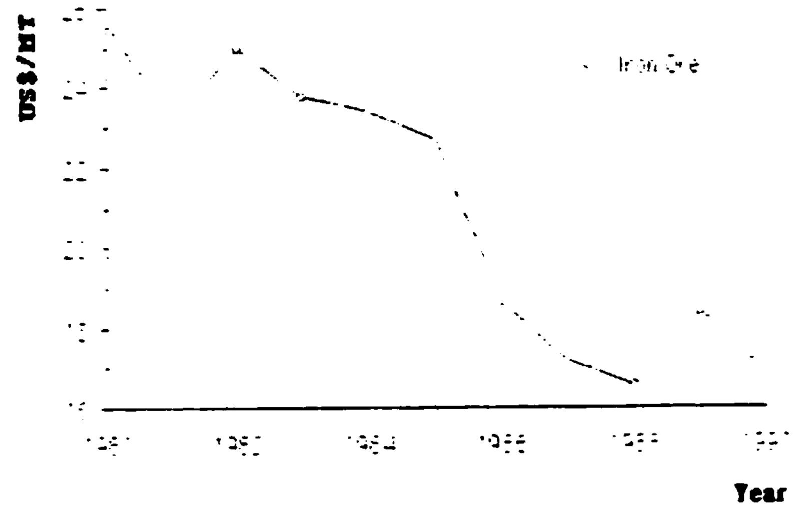


Source: World Bank (1999)

In terms of the analysis of specific price behaviour, the next figures present the trend for 4 selected ores and metals in the last decade.

Figure 12 shows the declining trend in the prices of iron ore. We can see from it that the prices of this ore fell from 25.6 US$/MT in 1980 to 16.6 US$/MT in 1988 and are estimated to reach 16.9 this year. It should be emphasized that in 1970 the price of iron ore was 41.8 US$/MT, i.e. 2,5 times the present price.

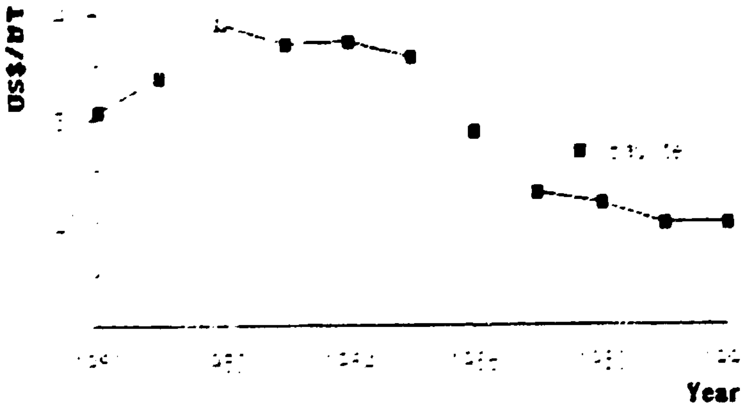
Figure 12: Declining Trend in Iron Ore Prices
(in 1985 constant US dollars)



Source: World Bank (1989)

Figure 13 shows a similar trend for the prices of bauxite in the same period. In this case, the price of bauxite, which reached 39.2 in 1982, experienced a fall of almost 50% during the following 6 years, reaching 21.8 US$/MT in 1988. The estimate of the World Bank shows that a continuing decline is expected this year, with the price falling to 19.8 US$/MT.

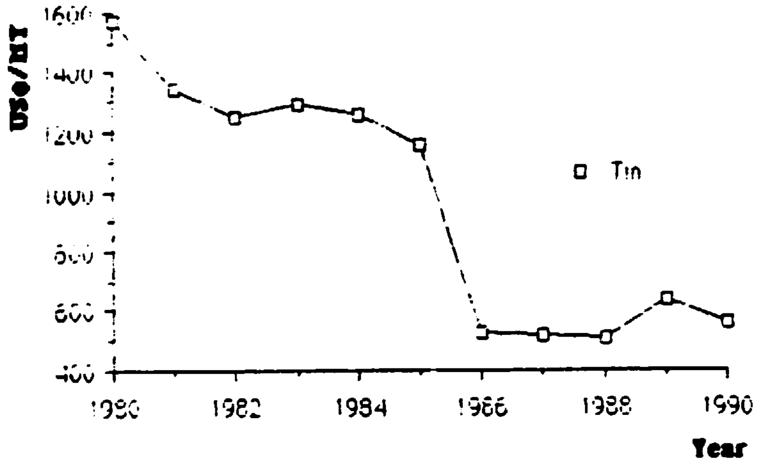
Figure 13: Declining Trend in Bauxite Prices
(in 1985 constant dollars)



Source: World Bank (1989)

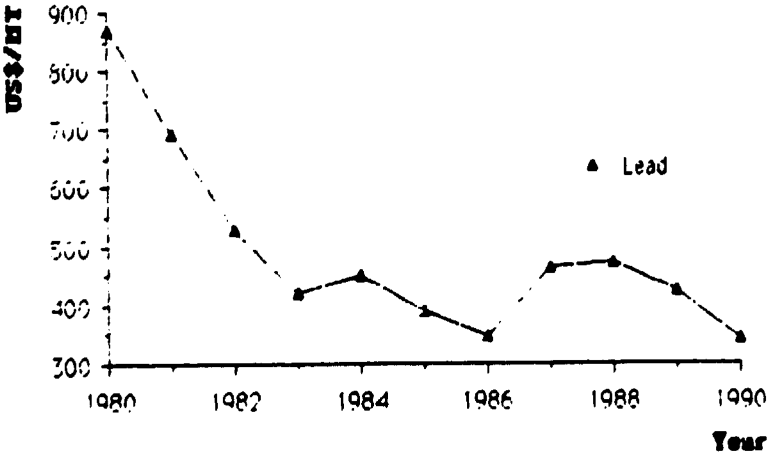
Among the metals, tin and lead were the ones that experienced the most dramatic price fall in the last decade, as Figure 14 and 15 show. From 1980 to 1988 tin price fell more than 300% and lead price almost 200%. In the latter case, a major decline is still expected. The estimated price of lead for this year represents almost one third of the price of 1980.

Figure 14: Declining Trend in Tin Prices
(in 1985 constant US dollars)



Source: Worl Bank (1989)

Figure 15: Declining Trend in Lead Prices
(in 1985 constant US dollars)



Source: World Bank (1989)

The impact of these changes on the metallurgy of developing countries will of course depend on the degree and pace of the dissemination of AMs. For most metal producers, even in advanced countries, their attempts to remain in the market and make profits in such a difficult scenario involve some very difficult options. But the discussion of the foreseen impacts of the introduction of AMs on LDCs, as well as the alternatives which can be open to these countries, transcends the limits of a simple change in the materials basis of the economy. The range of aspects that have to be discussed varies from the difficult financial situation of most the LDCs (and, in specific terms, of the metals producers in these countries [28]) to the specificity of AMs development and production (such as their sophisticated technological requirements and their interaction with and dependence on consumers).

Attempting to discuss some of such aspects, I would stress the fact that with the advent of advanced materials the tendency in materials production seems to be a complete change from production based on physical factors endowments, leading to an increasing dependence on sophisticated processes and resulting in an era of strong savings in energy and natural resources. As one result, the introduction of advanced materials is already changing (and is expected to lead to a dramatic major change) the structure of the so-called traditional comparative advantages and the present international division of labour.

Then, from some developing countries' point of view, these recent changes pose a perhaps unprecedented challenge and render much of the currently practised development strategies obsolete, mainly those based on production geared to exports of ores and basic metals. As we saw, a significant number of developing countries have had exports of minerals and basic metals as the core of their growth strategies. In 1985, among the LDCs which had more than 50% of their exports originating in the mineral sector, the cases of Zambia (94%), Bolivia (82%), Zaire (74%), Peru (70%), Jamaica (67%), Chile (64%), Togo (52%) and Papua New Guinea (51%) should be emphasized[29] Even bigger countries which have implemented more sophisticated economic structures like Brazil and Australia have a significant share of their export revenues derived from mineral production.[30]

In this new situation, the importance of large and high grade national mineral reserves, relatively cheap and abundant energy inputs and non-qualified work (even with extremely low levels of wages) is tending to diminish. The consequences of such changes have to be analysed not only in terms of the threat to developing countries' international market share and export earnings, but also in terms of the loss of attractiveness this new situation exerts on foreign investments.

---

[28] Such a situation is worsened by the lack of agility that government bureaucracy and traditional materials producers may display when facing the challenge of restructuring.

[29] World Bank (1987)

[30] See Lastres & Cassiolato (1989).

The best example in this case is perhaps that which relates to the Carajas Project in Brazil. It was designed in the early eighties to attract foreign capital via exploitation of Latin America's most important mineral province in the Amazon. The Brazilian Government provided the necessary infrastructure for the project, including ports, railroads, energy supplies and various subsidies (ten year exemption of federal and regional taxes, energy prices below cost, etc.). Even with such subsidies the project failed as far as its main objective is concerned. Only the iron subproject led by a State company - CVRD - was implemented with the external participation of the World Bank and other minor foreign partners, leaving aside original subprojects for other minerals. The "failure" was due to lack of interest by foreign investors (both financial and productive firms) in investing in Brazil in minerals and basic metals. It is interesting to point out that the same model had been very successful throughout the sixties and the seventies.

One related implication here is the expected change in the location of materials production. Given the relatively lesser importance of the availability of inputs and the greater importance of the linkages with their consumers, the processing plants of advanced materials tend to be located near the consuming and end-using industrial markets. On the other hand, as most of these AMs are high in value and low in volume and weight, they are mostly economically transported by air. Hence, the emerging geographical pattern of advanced materials production is expected to be centred in those countries with better technological capabilities and strong markets for high-tech products. Given such expectations, some analysts of the area have concluded that the plants located in LDCs will tend to serve local and regional markets only.[31]

Apart from all the other macroeconomic problems faced by the developing countries (high external debt, accelerating inflation and political and institutional instability), and together with the uncertainty surrounding mainly minerals and basic metals (regarding the serious decline in demand, problems of supply overcapacity and depressed prices of ores and primary metals experienced during the 80s), it has to be considered that the traditional means of articulation between LDCs and the advanced countries are experiencing major changes.

Then, the main argument here is that these recent changes have lead to far more complex industrialization processes, where comparative advantages depend increasingly on innovation (both technical and organizational), rather than on purely physical factor endowment.

The high requirements of sophisticated scientific and technological knowledge the production of AMs implies can be seen as a handicap for those LDCs who intend to produce such materials. Brazil, for instance, has (in a very advantageous condition) all the important mineral resources needed to produce advanced ceramics, but, until 1988, there was no production of high purity ceramic oxides in Brazil. Even the most consumed ceramic oxide

---

[31] See Gregory (1988)

in the world, alumina, was not produced in that country with the purity required for its utilization in electronic devices[32] (even despite Brazil being one of the major world producers of alumina and aluminium for years). As a result Brazil exports the ores and oxides which are submitted to further purification and imports back the necessary inputs to produce those advanced ceramic which are processed in the country. The reasons for such a situation relate to the internal lack of sufficient technological capability to produce such pure oxides and the still small Brazilian advanced ceramics market.[33]

On the other hand, it is not only the fact of suddenly finding themselves producing "traditional materials" with "inputs and technology of the past" that matters in the case of LDCs. The shift to the production of AMs would also require a new industrial and sectoral organization, as we saw in section 3. Among all these requirements, I would particularly stress the more flexible and agile style of production and the linkage between research, production and consumption of materials. Many authors have emphasized such characteristics when discussing the new techno-economic paradigm and the new high-tech areas, much have expanded the understanding of the problem.[34] Regarding the latter, I would only repeat that the very genesis of such a new category of materials is a result of those linkages. In other words and as suggested in section 2 and 3, the advent of AMs is a result of the huge research and development programmes, particularly those in high-tech areas, pursued by governments and firms in the most advanced countries.

Having seen this, one could conclude that previous capabilities in traditional materials production has very little contribution to offer to those who aim at starting the production of advanced materials. In fact, as we saw in section 3, the international trend in terms of the production of AMs shows that the research-production-consumption relationship has prevailed over the traditional input-production linkages of the previous paradigm.

In the Brazilian case, which certainly follows the international trend, for instance, traditional materials producers have made very little effort to

---

[32] Lastres (1988 b). See specifically the section on advanced ceramics produced by Maria Thereza Garcia Duarte: "**Assim, apesar de dispormos de recursos minerais no Brasil em situação extremamente vantajosa, ainda não produzimos insumos na pureza e granulometria exigidas _ mesmo o óxido mais amplamente utilizado a nível mundial - a alumina - ainda não é produzida no país na pureza que permite sua utização em componentes eletrônicos**" (p. 49)

[33] The survey produced on the Brazilian advanced materials sector, during 1987/88, showed that some big multinationals firms which were already investing in the country in other areas (and which started to produce advanced materials in their countries of origin) stated that they would wait for the Brazilian advanced materials market to grow before investing in this new area. One interesting discussion here would be that related to the applicability of the traditional concept of economies of scale to define a strategy related to the production of advanced materials.

[34] Among them see various works by Freeman, Perez and Kaplinsky. On the importance of user/producer relations in shaping technical developments of new technologies see Lundvall (1985) and specifically in a developing country context, see Cassiolato (1990).

produce AMs. The most successful attempts to produce AMs refer to the cases of those firms which had the support of and have strong linkages with high-tech consumers (especially those in the information technology , aeronautics and defense sectors). It should also be emphasized that most of these cases relate to the constitution of a new firm formed by researchers and professors, mainly from physics and electronics institutes.[35]

A great commitment to the production of traditional materials by big firms and governments of LDCs can even retard the restructuring that the recent changes are forcing. In this sense, I would emphasize the necessity of a deep understanding of the present changes and the importance of sufficient agility and creativity by the public and private sectors to make the best of the opportunities that the beginning phase of a new paradigm presents.

In this aspect I fully agree with Perez, who argues that much of the knowledge required to enter a technology system in its early phase is in fact public knowledge available in universities, and that many of the skills required do not yet exist. Her conclusion is that, given the availability of well-qualified university personnel, a window of opportunity opens for the relatively autonomous entry of lagging countries into new products in a new technology system in these early phases."[36]

One example which shows the empirical validity of such theoretical contributions refers to the case of optical fibres in Brazil. The project was designed by the state company in charge of telecommunications - Telebrás - and matured into one the strongest university institutes which, since 1975, has been developing a research program on optical fibres together with Telebrás' research centre. In 1984 the technology developed earlier was transferred to a private national firm instituted to produce the fibres required for the development and renewal of the Brazilian telecommunications network. At that time an agreement was signed granting a 5-year market reserve by Telebrás (90% of the Brazilian market for optical fibre).[37]

One result of such measures is that Brazil is today one of the few countries in the world that holds an autonomous research program on optical fibres. In this case, I note that a modern and agile governmental institution could take the opportunity to articulate internal political interest in designing a strategic planning, promoting research-production-utilization linkages and making effective use of its active market procurement policy to build up capabilities in a high-tech area, which was new even in advanced countries.

Without any doubt the existence of a political and institutional framework was then (and continues to be) fundamental for the accomplishment of such a strategy. That seems to be of particular importance

---

[35] Lastres (1988 b)

[36] Perez (p 92) Small countries

[37] Lastres (1988 a), see especially the section on quartz and silicon by Cristina Lemos.

especially in moments when a new technological trajectory is taking place. Freeman (1988) has strongly emphasized this aspect and has developed the idea of pervasive changes in technology associated with 'national systems of innovation' (the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies).[38]

Regarding the importance of designing specific policies which could exploit the temporary opportunities opened up by the new technologies, the Ministry of Science and Technology was created in Brazil in 1985. One of the main objectives of this Ministry was precisely to define and implement policies for high-tech areas.

In the specific case of advanced materials, a National Commission, a Centre for Studies and Planning and a Secretary were established in 1986 and 1987.[39]

As the main political and institutional alliances of the new government which took over in 1985 were not sustained, the measures regarding high-tech areas were gradually cast off. The friction with more conservative areas was so great that in 5 years the area had 4 ministers and in early 1989 the Ministry was dissolved and reestablished at the end of the year.

It should be recognized that the implementation of such policies (which require agility and deal with the renovation of the whole concept of national development) is a very difficult task, especially for LDCs that are facing great macroeconomic problems associated with political and institutional instability. But a definition of a new form of development can be considered fundamental, particularly for these LDCs, as they are now facing a crucial challenge related to their future chances of growth. Entering this new paradigm in its early phase and defining a national strategy to exploit the opportunities opened by the development of the new areas seems to present the best conditions for doing so.

In this sense, I emphasize again the primary importance of a better understanding of the specific characteristics of the development and introduction of AMs, particularly by the policy makers of LDCs. Some of the AMs. which are being introduced in these countries (mainly in sectors led by big multinational companies) contrast sharply with traditional policies pursued, particularly those which only emphasize the export of minerals and

---

[38] "One of the most notable features of the Japanese system has been the speed with which Japanese firms and Japanese policy-makers _ identified the importance of information and communication technology (ICT) and embarked on measures to diffuse the new technology very rapidly to more traditional industries, such as machinery and vehicles. The Japanese system of technological forecasting is particularly well-suited to the identification, promotion and diffusion of major changes in 'technological paradigm' - pervasive technologies which can be applied throughout the economy." (pg 4/5)

[39] For a review of the Brazilian policy for advanced materials see article by J. E. Cassiolato, former Planning Secretary of the Ministry of Science and Technology and President of the National Commission for New Materials, published in the ATAS Bulletin (1988)

metals which, as we have seen, are experiencing a world-wide decrease in their consumption levels.

There is a strong tendency in these countries to follow the same steps as the most developed countries and accept high-tech advances as neutral and, in any circumstance, progressive ones. As a result, some of the LDCs are promoting the use of imported new materials which are displacing traditional materials they can produce (and for which they have inputs and technologies) In most cases this kind of behaviour consists in isolated attempts to reproduce some of the successful steps made abroad. There is no consideration of which kind of material would provide better results, regarding national conditions, and rarely is there any connection with policies adopted in other industrial sectors or those related to R & D.

Then, each country will have to use its best powers of creativity to define the most suitable policy and group of materials to which to give priority This should be done regarding national conditions and constraints and selecting the most important policy tools and markets niches. Obviously the degree of agility and efficiency with which such measures are taken will eventually determine the level of success obtained.

Bibliography

The Association for the Progress of New Chemistry - Aspronc, Second International Symposium on New Chemistry: Expanding Frontier of Advanced Technologies - Action for the Age of New Chemistry, preprints (Tokyo, 24-25 Oct. 1989)

Brazil, 'O desafio dos Novos Materiais - Programa Brasileiro', Série Brasil Ciência nº2, MCT, Brasilia, 1987. .

Cassiolato, J. E., 'Policies in Newly Industrialized Countries: the Case of Brazil' in Advanced Technologies Alert System Bulletin (5), UNO, 1988.

Cassiolato, J. E., 'Interaction User-Producer: Case-study of Banking Automation in Brazil', in H. Schmitz and J. Cassiolato (eds): High-Tech for Industrial Development, Institute of Development Studies, University Of Sussex, 1990, (forthcoming)

Cohendet et al. New Advanced Materials: Economic Dynamics and European Strategy, English version edited by M. Ledoux, 1988

Commission of the European Communities, Les Materiaux Nouveaux - Dynamique Economique et Stratégie Européenne, FAST Programme - FOP nº 146, Brussels, 1987.

Commission of the European Communities, Programme d'Action de Recherche - Materiaux 1986/89, Brussels, 1986.

Dosi, G. 'Technological Paradigms and Technological Trajectories' in Research Policy, 1982 11 (3).

Dosi, G., Technical Change and Industrial Transformation , Macmillan, London, 1984.

Duarte, M. T., 'Cerâmicas Avançadas - Diagnóstico do Segmento' in Lastres, H., Diagnóstico dos Novos Materiais, NMAT/INT/MCT, Rio de Janeiro, 1988.

Fasth, R. et al., 'Advanced Materials Markets' in Chemtech, July, 1988.

Forney, R. C., 'Advanced Materials and Technological Innovation' in Chemtech, March, 1988.

Freeman, C. Long Waves in the World Economy, (London 1984)

Freeman, C., Design, Innovation and Long Cycles in Economic Development (London 1986)

Freeman, C. Technology Policy and Economic Performance: Lessons from Japan. (University of Sussex, SPRU, 1988)

Freeman, C. and Lundvall, B., Small Countries Facing the Technological Revolution (London, 1988)

Forester, T. (ed.) The Materials Revolution: Superconductors, New Materials, and the Japanese Challenge (Oxford, 1988)

Gonzales-Vigil, F., 'New Technologies, Industrial Restructuring and Changing Patterns of Metal Consumption', Raw Materials Report 3(3), 1985.

Herrera, A., 'The New Technology and the Developing Countries: Problems and Options', in MacLeod, R. M., Technology and the Human Prospect: Essays in Honour of Christopher Freeman, Frances Pinter, London, 1986.

The International Technology Forum and The Engineering Academy of Japan, International Symposium on Advanced Materials and Issues of Science and Technology Policy (Tokyo, Oct. 1989)

Japan, Science and Technology Agency - STA, Promotion for Material Science and Technology Research and Development in STA (Tokyo, 1988)

Japan, Science and Technology Agency - STA, Research and Development Plan of the New Superconductors (Tokyo, 1988)

Japan, Science and Technology Agency - STA, Multi-Core Research Project on Superconductivity (Tokyo, 1988)

Japan, Science and Technology Agency - STA, Research Development Corporation of Japan Exploratory Research for Advanced Technology (Tokyo, 1988)

Japan, Science and Technology Agency - STA, White Paper on Science and Technology-1988 (Summary), Towards the Establishment of a New Creative Research Environment (Tokyo, 1988)

Japan, Science and Technology Agency - STA, STA, Its Role and Activities-1988 (Tokyo, 1989)

Japan, Science and Technology Agency - STA and Agency of Industrial Science and Technology - AIST/MITI, Human Frontier Science Program, Report of the International Scientific Committee (Tokyo, Jun. 1989)

Japan, Science and Technology Agency - STA and Agency of Industrial Science and Technology - AIST/MITI, Human Frontier Science Program, Report of the International Scientific Committee (Abstract) (Tokyo, Jul. 1989)

Japan, Ministry of International Trade and Industry - MITI, Agency of Industrial Science and Technology - AIST, 1988 Report - New Directions for Industrial Technology Policy (Tokyo 1988)

Japan External Trade Organization - JETRO,
JETRO News
The Japan Industrial and Technological Bulletin, special issue No 15, 1983 - 'The Development of Structural Fine Ceramics in Japan'.
The Japan Industrial and Technological Bulletin, special issue No 19, 1984 - 'New Metal Materials in Japan'
The Japan Industrial and Technological Bulletin, special issue No 19, 1984 - 'Special Polymer Materials in Japan'
Your Market in Japan, No 41, Mar. 1986 'New Materials'

Junne, G. et al. 'Dematerialization of Production: Impact on Raw Material Exports of Developing Countries' in Third World Quaterly, vol. 11, No 2, 1989.

Kaplinsky, R., Industrial Restructuring in LDCs: the Role of Information Technology, Stanford University, Stanford, 1988.

Lastres, H., Programa Grande Carajás: Aspectos Políticos e Institucionais, Rio de Janeiro, 1982.

Lastres, H., Novos Materiais: Capacitação e Potencialidades Nacionais em P&D , NMAT/INT/MCT, Rio de Janeiro, 1988.

Lastres, H., Diagnóstico dos Novos Materiais, NMAT/INT/MCT, Rio de Janeiro, 1988

Lastres, H., Report on the II International Symposium on New Chemistry: Expanding Frontier of Advanced Technologies - Action for the Age of New Chemistry, University of Sussex, 1989

Lastres, H. & Cassiolato, J., 'High Technology Sectors and Developing Countries: the Case of Advanced Materials', Materials and Society, 1990 (forthcoming).

Lemos, C., 'Quartzo e Silício - Diagnóstico do Segmento' in Lastres, H., Diagnóstico dos Novos Materiais, NMAT/INT/MCT, Rio de Janeiro, 1988.

The Long-Term Credit Bank of Japan -LTCB
'Japan's High Technology Industries' in LTCB Research Special Issue, 3, Dec. 1984.

'Japanese Business Enterprises Diversification Strategies for the 1990s - Its Impacts on Corporate Profitability' in Monthly Economic Review, No 89 Nov. 1986.

Lundvall, B-Å, 'Product innovation and User-Producer Interaction', Industrial Development Research Series, n°31, Aalborg University Press, Denmark, 1985.

Morse, Research. A., International Competition and Cooperation on High Technology - the Critical Issues (Tokyo, Oct. 1989).

Neto, H. L. and Soares, M. C., 'Novos Materiais Metálicos - Diagnóstico do Segmento' in Lastres, H., Diagnóstico dos Novos Materiais, NMAT/INT/MCT, Rio de Janeiro, 1988.

Organization for Economic Development - OECD, New Materials (Countries Annexes), Paris, October 1988.

Organization for Economic Development - OECD, Le Politiques Nationales en Matiere de Materiaux Avances, Paris, October 1988.

Peiter, C. C. and Maldonado, J. 'Novos Polímeros - Diagnóstico do Segmento' in Lastres, H., Diagnóstico dos Novos Materiais, NMAT/INT/MCT, Rio de Janeiro, 1988

Perez, C., 'Structural Change and the Assimilation of New Technologies' in The Economic and Social Systems, Futures, 1983, Vol. 15, n°5.

Perez, C., 'New Technologies and Development' in C. Freeman and B. Lundvall (eds.), Small Countries Facing the Technological Revolution , Pinter Publishers, London, 1983, p.92.

Perez, C. & Soete, L., 'Catching up technology: entry barriers and windows of opportunity' in G. Dosi et al. (eds.) Technical Change and Economic Theory, Pinter Publishers, London, 1988.

Perez, C., 'New Technologies and Development' in Freeman, C. and Lundvall, B., Small Countries Facing the Technological Revolution (London, 1988)

Pinhão, C. M., 'Materiais Compósitos - Diagnóstico do Segmento' in Lastres, H., Diagnóstico dos Novos Materiais, NMAT/INT/MCT, Rio de Janeiro, 1988.

Ray, G. 'Innovation in Materials' in R. MacLeod (ed.) Technology and the Human Prospect - Essays in Honour of Christopher Freeman, Frances Pinter, London, 1986.

The Royal Society Technology in the 1990s: The Promise of Advanced Materials, Cambridge 1987(includes Hondros, Marcum, Simenz, Barnes, Malpas, Chichos, Kröckel & Westbrook, Ashby, Kelly, Gilman, Schwattz, Phillips, Beldin & Staniland, Suzuki, Tan & Howard & Birchall).

Sá, P. C., Estratégias dos Grandes Grupos Internacionais no Domínio dos Novos Materiais, MCT, 1989.

Souza, Problems and Opportunities in Metals and Materials - an Integrated Perspective, U.S. Bureau of Mines, Washington, 1988.

UNIDO, 'High Temperature Superconductive Materials' in Advances in Materials Technology: Monitor, issue number 11(1987/4).

U.S. Congress, Office of Technology Assessment - OTA, New Structural Materials Technologies - Opportunities for the Use of Advanced Ceramics and Composites, a Technical Memorandum, Washington, 1986.

U.S. Congress, Office of Technology Assessment - OTA, Commercializing High-Temperature Superconductivity, OTA-ITE-388 Washington, June 1988.

U.S. National Research Council, Materials Science and Engineering for the 1990s - Maintaining Competitiveness in the Age of Materials (National Academy Press, 1989).

World Bank, Price Prospects for Major Commodities, 1988-2000, vol 1, Washington, 1989.

Yano Research Institute Ltd, Japan's Innovative Industrial Materials Tokyo, January, 1984.

Yano Research Institute Ltd, New Ceramics Market in Japan Tokyo, August 1982.

8. PUBLICATIONS

Silicon nitride and the sialons is a comprehensive state-of-the-art reference work covering the different forms of the materials, methods of production of powders, components, coatings, fibres and various composites, world production, world consumption and the numerous end uses - both current and potential - not only of components but also of the many composites, films and coatings.

Prices are also given together with silicon nitride and sialon activities of some 400 companies and organizations in 32 countries.

Silicon nitride and the sialons was published in September 1989 and is now available at 600.00 pounds sterling or $US 1,050.00 from:

Mitchel Market Reports on Advanced Materials
(MMR), 24 Donnington Road, Harrow,
Middlesex HA3 ONA, England
Phone: 01-907 8423 Fax: 01-908 5083
Telex: 297761

* * * * *

High-temperature materials

Four-page reference guide from Cotronics Corp., Brocklyn, N.Y., USA, lists melting point, temperature limit, hardness, density, specific heat, thermal expansion, thermal conductivity, and electrical resistivity of high-temperature alloys, ceramic materials, and intermetallic compounds. A list of metric to English conversion factors and a nomograph for rapidly calculating heat loss and insulation thickness also are included.

* * * * *

Plastic coatings

Series of four data sheets from Panelgraphic Corp., W. Caldwell, N.J., USA, detail performance characteristics of proprietary coatings for engineering plastics. Coating formulations for resistance to wear, abrasion, and chemical attack are among those described.

* * * * *

Composite materials

Brochure details specifications of new thermoplastic powder prepregs and commingled yarns from Thermoplastic Composites Div., BASF Structural Materials Corp., Charlotte, N.C., USA. The document also gives an overview of thermoplastic powder prepreg technology, and gives complete specifications for several commercially available products.

* * * * *

Engineering thermoplastics

A 12-page selection guide from Engineering Plastics Div., Hoechst Celanese Corp., Chatham, N.J., USA, includes comparative mechanical and physical property data on nine families of 30 per cent glass-reinforced and unreinforced engineering thermoplastics.

* * * * *

Polymer characterization

Rheometrics Inc., Piscatavay, N.J., USA, has published a bulletin describing the use of dynamic mechanical spectroscopy to characterize interpenetrating polymer network (IPN) materials. IPNs are mixed crosslinked polymers partially or completely combined in their monomeric stages and polymerized in-situ.

* * * * *

Composites design

A video tape that gives technical details on designing with composite materials is available from PPG Industries Glass Group, Pittsburg, PA, USA. Produced by PPG and the Society of the Plastics Industry Composites Institute, the 20-minute tape looks at computer-aided design techniques for composite structures. Available on a loan basis from PPG Industries, One PPG Place, Pittsburg, PA 15272, USA.

* * * * *

Materials Research Society Symposia Proceedings. Volume 31, Electron microscopy of materials

William Krakow, David A. Smith and
Linn. W. Hobbs, ed. New York, N.Y.:
Elsevier Science Publishing Co., Inc., 1984.
xi + 373 pp.

In situ experiments with high voltage electron microscopes. H. Fujita, ed. Osaka, Japan: Research Centre for Ultra-High Voltage Electron Microscopy, Osaka University (Distributed by ISBS, Inc., Portland, OR), 1985. xxvi + 507 pp.

Two proceedings on electron microscopy of materials have recently been published. One is Electron Microscopy of Materials, a collection of papers from a symposium held in November 1983 in Boston, MA, USA, and published as Vol. 31 of the Materials Research Society Symposia Proceedings. The 373-page book is divided into four sections: current trends in electron microscope characterization techniques, semiconducting materials, surfaces and interfaces, and ceramic materials.

The second book, In situ experiments with high voltage electron microscopes, published by the Research Center for Ultra-High Voltage Electron Microscopy, Osaka University, Osaka, Japan, is the proceedings of the International Symposium on "Behavior of Lattice Imperfections in Materials - In situ experiments with HVEM", held in November 1985 at Osaka University.

* * * * *

Environmental technologies

A six-part study, covering waste disposal, materials recovery, water purification, sewage treatment and energy conservation.
Helmut Kaiser Consulting, Philosopherweg 2,
D-7400 Tubingen, Federal Republic of Germany.

* * * * *

Plastics statistics

The 1989 edition of the British Plastics Federation's statistics handbook, containing information on materials, semi-finished products and finished products, is available from the BPF, 5 Belgrave Square, London SW1X 8PD, United Kingdom.

* * * * *

Plastics research & development in Canada: A compendium includes the names of 75 organizations conducting plastics research, more than 200 scientists and other personnel associated with plastics research, 40 research subject areas, 50 institutions that offer courses and training, and 30 testing facilities. 85 pp. Canadian Plastics Institute, 1262 Don Mills Rd., Suite 48, Don Mills, ON, M3B 2W7, Canada.

* * * * *

Advanced materials for severe service applications

K. Lida and A. J. McEvily, ed. New York, N.Y., USA, and London, UK: Elsevier Applied Science, 1987. xii + 416 pp.

Advanced materials for severe service applications is the proceedings of the Japan-US Joint Seminar on Materials for Severe Service Conditions, held in May 1986 in Tokyo, Japan. The seminar was sponsored by the US National Science Foundation and by the Japan[ese] Society for the Promotion of Science.

Four papers in the proceedings are devoted to fracture behaviour of ceramics. One of them is an extensive review by Evans and Dalgleish entitled "Some aspects of high temperature performance of ceramics and ceramic composites", which discusses mechanisms of ceramic failure at high temperatures.

Several papers are devoted to corrosion and stress corrosion of metals at high temperatures, and there is one by Itoh *et al*. on "Corrosion of welds in steels for ice-breaking ships". A significant number of papers in the proceedings deal with fatigue resistance in different environmental conditions at cryogenic and elevated temperatures. Three papers are devoted to lifetime analysis: one, by Miya *et al*., directed to the nuclear industry; the second, "Life-time prediction of power plant components" by T. Endo; and the third, by Kitagawa *et al*., dealing with the material characterization of the high-temperature gas-cooled reactor.

* * * * *

Reference book for composites technology

S. M. Lee (ed.), Vols. 1 and 2; 1989, Lancaster, PA., USA, Technomic Publishing Company. Vol. 1: 334 pp., ISBN 0-87762-564-6; Vol. 2: 206 pp., ISBN 0-87762-565-4.

The first volume contains 11 sections, each of which targets a particular class of composite material; for polymer matrix composites individual sections concentrate on particular resin types (e.g. epoxies, thermoplastics) and fibre types (e.g. aramids and ultra-high modulus polyethylenes), while metal matrix composites and ceramic matrix and glass matrix composites are treated as a complete class.

Volume two is more varied in its range of topics covering technological aspects of composites and downstream properties, together with modelling and predictive techniques and testing methods.

* * * * *

Polymers, laminations, and coatings are covered in TAPPI's 1988 conference proceedings, which are available in bond-volume form. Topics include film extrusion technology and equipment, extrusion coating and flexible packaging, adhesives and coatings technology, high-barrier packaging materials for health care, microwaveable substrates, polymer processing, additives and modifiers, pressure sensitive adhesives and label stock, coextrusion technology, modified or controlled atmosphere packaging, film testing and analysis, both melt technology, and radiation curing. TAPPI Press, Technology Park/Atlanta, P.O. Box 105113, Atlanta, GA 30348-5113, USA.

* * * * *

Recycling directories

Two new volumes are available - one from SPI's Plastic Bottle Institute, the other from the publisher of *Plastics Recycling Update* newsletter.

SPI's 8th annual Plastics Recycling Directory lists 172 companies involved in recycling. Other sections list companies by state and by resins handled and a description of the voluntary container coding system. 36 pp. SPI Literature Sales, 1275 K St. N.W., Suite 400, Washington, DC 20005, USA.

The newsletter's 1989 Directory of US and Canadian Scrap Plastics Buyers and Processors includes nearly 100 North American firms that purchase and process scrap plastics. The directory lists the following for each firm: name, location, contact, phone, fax, telex, company description, grades of scrap purchased, form desired, preferred supply sources, and desired shipping methods. Cross listings are provided according to grades handled and location of processing plants. Resource Recycling, P.O. Box 10540, Portland, OR 97210, USA.

* * * * *

Electronic ceramics: properties, devices and applications

Edited by Lionel M. Levinson, New York: Marcel Dekker Inc., 1988. ISBN 0-8247-7761-1, (vi) + 525 pp., index.

Ceramics have been part of the electronics industry for a long time, starting with their use as insulators and now exploited for their superconducting properties.

* * * * *

The electrical resistivity of metals and alloys

By Paul L. Rossiter. Cambridge: Cambridge University Press, 1987. ISBN 0521-249473, xvi + 434 pp.

* * * * *

Computer applications in applied polymer science II. Automation, modelling, and simulation. Theodore Provder, Editor, The Glidden Company.

This new volume is an extensive guide to the practical applications of computers in today's polymer laboratory.

This book focuses on specific topics such as robotics, mathematical modelling for plastics, modelling for bulk and solution polymerization, simulation for chemical processes, co-polymerization and network formation, and emulsion polymerization.

Developed from a symposium sponsored by the Division of Polymeric Materials: Science and Engineering of the American Chemical Society.

ACS Symposium Series No. 404, 551 pages (1989)
Clothbound, ISBN 0-8412-1662-2 LC 89-17602
American Chemical Society Distribution Office,
Dept. 40, 1155 Sixteenth St., N.W.,
Washington, D.C. 20036, USA.

* * * * *

Advanced materials in the manufacturing revolution

Michael V. Nevitt, Norman D. Peterson, editors. v + 85 pages. National Technical Information Service, NTIS Energy Distribution Center, P.O. Box 1300, Oak Ridge, Tenn. 37831, USA. 1989.

* * * * *

Analysis of polymers: an introduction

T. R. Crompton. viii + 362 pages. Pergamon Press, Maxwell House, Fairview Park, Elmsford, N.Y. 10523, USA. 1989.

* * * * *

9. PAST EVENTS AND FUTURE MEETINGS

<u>1989</u>

6-8 November Houston, Texas	Materials Technology Transfer Course (The transfer of technology from national laboratories to industry, organized by ASM International, Metals Park, OH 44073, USA)
14-16 November	Industrial Sensing, Birmingham. Exhibition devoted to sensors, transducers and associated signal-conditioning systems. Total Solutions, Evan Steadman (Services) Ltd., The Hub, Emson Close, Saffon Walden, Essex CB10 1HL. Tel.: 0799 26699. Telex: 21383 Fax: 01-337-8943
14-19 November Kuala Lumpur, Malaysia	International Fair with special focus on rubber and wood-based industries (Malaysia International Fair. Federation of Malaysian Manufacturers, 17th Floor P.O. Box 12194, 50770 Kuala Lumpur, Malaysia)
22-24 November	Euromat '89, Aachen. First European Conference on Advanced Materials and Processes, organized by the Deutsche Gesellschaft für Metallkunde EV, Adenauerallee 21, D-6370 Oberusel, FRG. Tel.: 06171 4081. Fax: 06171 52554
4-7 December Zürich, Switzerland	SP'89. International conference on speciality plastics, applications and markets, concentrating on the subject of polyolefins in food and technical packaging. (Maack Business Services, CH-8804 Au/near Zürich, Switzerland)
6 December London, UK	7th Seminar "Characterization of High-Temp. Materials". (The Institute of Metals, 1 Carlton House Terrace, London SW1Y 5DB)

* * * * *

<u>1990</u>

10-14 January Bangalor, India	Intl. Conf. on Superconductivity (ICSC, Dept. of Physics, Indian Inst. of Science, Bangalore 560 012, India)
15-18 January Bombay, India	International Conference on Advances in Composite Materials (ASM International India Chapter). Prof. P. Ramakrishnan, Department of Metallurgical Engineering, Indian Institute of Technology, Powai, Bombay 409 076, India
4-7 February San Diego, CA, USA	Third International Conference on Ceramic Powder Processing Science. (Pennsylvania State Univ., University Park, PA 16802, USA)
4-8 February Bendigo Victoria, Australia	18th Australian Polymer Symposium (Bendigo College of Advanced Education, Bendigo, Victoria 3550, Australia)
5-7 February Boston, MA, USA	MOVE Workshop on assessment of plastics processing/conversion technologies, innovations, markets and business activities (Maack Business Services, CH-8804 Au/near Zürich, Switzerland)
7 February London, UK	International High Performance Plastics Conference (PIRA, Packaging Div., Randalls Road, Leatherhead, Surrey KT22 7RV, UK)
12-15 February Washington D.C., USA	45th Annual Conference and Expo. (Composites Institute SPI, 355 Lexington Ave., New York, N.Y. 10017, USA)
19-23 March Ventura, California, USA	Gordon Research Conference on Superconductivity. (Gordon Research Center, University of Rhode Island, Kingston, RI 02881-0801. Phone: (401) 783-4011 or 3372. FAX: (401) 783-7644)
21-22 March Rosemont, Illinois, USA	SPE Thermoset Retec. (Society of Plastics Engineers, Chicago Section, 7761 W. Thorndale, Chicago, IL 60631. Phone: (312) 774-4558)
2-6 April NASA Goddard Space Flight Center, Greenbelt, Maryland, USA	Advances in Material Science and Applications of High Temperature Superconductors (AMSAHTS '90). (Westover Consultants, 6303 Ivy Land, Suite 416, Greenbelt, MD 20770. Phone: (301) 220-0685)
3 April Buffalo, New York, USA	Third Annual Buffalo Materials Symposium and Exhibition. (Wilson Greatbatch Ltd., 10,000 Wehrle Drive, Clarence, NY 14031. Phone: (716) 759-6901)
3-6 April Petten, The Netherlands	Designing with Structural Ceramics. (European Physical Society, Main Secretariat, P.O. Box 69, CH-1213 Petit-Lancy 2, Switzerland)
4-5 April Bristol, England	Advanced Composites, from Inception to inspection Symposium. (British Institute of NDT, 1 Spencer Parade, Northampton, NN1 5AA, UK. Phone: (44) 604 30124. Fax: (44) 604 231489)
4-6 April Palais des Congrès, Paris, France	25e Journées Européennes des Composites. (Le Centre de Promotion des Composites, 65 rue de Prony, 75017 Paris, France. Phone: (33) (1) 47 63 12 59. Fax: (33) (1) 47 63 57 39)
4-6 April Warwick, England	Fine Ceramic Powders: Processes, Properties and Applications. (Institute of Ceramics, Shelton House, Stoke-on-Trent, Staffs., ST4 2DR, UK. Phone: (44) 782-202116. Fax: (44) 782-202421)

9-11 April Sheffield, England	International Conference on Ceramics in Energy Applications: New Opportunities. (Institute of Energy, 18 Devonshire Street, London W1M 2AU, UK. Phone: (44) 1-580-7124)
10-12 April University of Warwick, Warwick, England	New Materials and Their Applications. (The Institute of Physics, 47 Belgrave Square, London SW1X 8QX. Phone: (44) 1-235 6111. Fax: (44) 1-259 6002)
16-20 April San Francisco, California, USA	Materials Research Society Spring Meeting. (Materials Research Society, 9800 McKnight Road, Suite 327, Pittsburgh, PA 15237. Phone: (412) 367-3003. Fax: (412) 367-4373)
22-26 April Dallas, Texas, USA	92nd Annual Meeting of the American Ceramic Society. (American Ceramic Society, 757 Brooksedge Plaza Dr., Westerville, OH 43081-6136. Phone: (614) 890-4700. Fax: (614) 899-6109)
23-25 April Brugge, Belgium	Material Aspects of Machining. (Ingenieurshuis VZW, Desguinlei 214, B-2018, Antwerpen, Belgium. Phone: (32) 03 216 09 96. Fax: (32) 03 216 06 89)
23-26 April Berkeley, California, USA	International Conference on Low-Temperature Electronics: Semiconducting - Superconducting. (Butterworth Scientific Ltd., P.O. Box 63, Westbury House, Bury Street, Guildford, Surrey GU2 5BH, UK. Phone: (44) 483 300966. Fax: (44) 483 301563)
23-27 April Las Vegas, Nevada, USA	Corrosion '90. (National Association of Corrosion Engineers, P.O. Box 218340, Houston, TX 77218. Phone: (713) 492-0535. Fax: (713) 492-8254)
24-27 April Academy of Sciences of the GDR, Dresden, Dem. Rep. of Germany	MASHTEC '90: International Conference on Materials Science for High Technologies. (Academy of Sciences of the GDR, Central Institute of Solid State Physics and Materials Research, Helmholtzstrasse 20, Dresden, DDR-8027 GDR. Phone: 4 65 93 40. Telex: 2131 zfw dd)
30 April - 4 May Denver, Colorado, USA	Conference on the Science and Technology of Thin Film Superconductors. (Solar Energy Research Institute, 1617 Cole Boulevard, Golden, CO 80401-3393. Phone: (303) 231-1158. Fax: (303) 231-1199)
2-5 May Oakridge, TN, USA	Tribology of Composite Materials (ASM International, Metals Park, OH 44073, USA)
6-8 May Montreal, Canada	Symposium on High Tc Superconductor Technologies - 177th Electrochemical Society Meeting (IBM, Research Centre, P.O. Box 218, Yorktown Heights, N.Y. 10598)
9-11 May Garmisch Partenkirchen, FRG	High-Temperature Superconductors - Materials Aspects (Deutsche Gesellschaft für Metallkunde EV, Adenauerallee 21, D-6370 Oberursel, FRG)
16-17 May	Reinforced Plastic Conference, São Paulo, Brazil. (ASPLAR, Avenida Ipiranza No. 318, Bloco A, 11° Andar, 01046 São Paulo, Brazil)
17-18 May Heidelberg, FRG	Nonmetallic Materials and Composites at Low Temperatures (Kernforschungszentrum, Institut für Materials- and Festkörperforschung, PF 3640, D-7500 Karlsruhe, FRG)
21-24 May Long Beach, CA, USA	AeroMat '90 - The Advanced Aerospace Materials/Processes Conf. and Exposition (ASM International, Metals Park, OH 44073, USA)
21-25 May	21st Institute for Electronic and Electrical Engineers Photovoltaic Specialists Conference, Kissimmee, Fla. (Institute for Energy Conversion, University of Delaware, Newark, Del. 19716, USA)
28 May - 1 June	Florence World Energy Research Symposium, Florence, Italy. (American Society of Mechanical Engineers, 345 E. 47th St., New York, NY 10017, USA)
29-31 May	SAMPE Conference and Exhibition, Basel, Switzerland. (European Chapter of the Society for the Advancement of Materials and Process Engineering, P.O. Box 141, 4007 Basel, Switzerland)
5-8 June Lucerne, Switzerland	Conference on Polymer Blends and Alloys. (Institute in Materials Science, State University of New York, New Paltz, N.Y. 12561)
10-16 June Helsinki-Espoo, Finland	MAT TECH '90. 1st European-East-West Symposium on Materials and with High Industrial Potential. (Mr. Pentti Attila, Teknolink Oy, Finland, Hietalahdenkatu 2B, SF-00180 Helsinki, Finland. Fax: 358-0-6901599)
11-16 June Paris, France	Europlast '90, International Plastics Exhibition. (ADSM, 59 rue Boissière, 75116 Paris)
25-27 June Petten, The Netherlands	User aspects of phase diagrams. A conference organized by the Institute of Metals and the Commission of the European Communities, Joint Research Centre, Petten Establishment in collaboration with a number of other international organizations. The meeting will focus on all aspects of the application of phase diagrams in the extraction, production, processing, and the use of materials ranging from advanced ceramics superconductors, composites, and electronic materials to the conventional metallic ferrous and non-ferrous alloys. (The Institute of Metals, 1 Carlton

	House Terrace, London, SW1Y 5DB. Tel.: 01-839-4071; Telex: 8814813; Fax: 01-839-2289)
1-6 July Kyoto, Japan	Third International Conference on Technology of Plasticity. (Japan Society for Technology of Plasticity, Torikatsu Bldg, 5-2-5 Roppongi, Minato-ku, Tokyo 106, Japan)
2-6 July Edinburgh, UK	Minerals, Materials and Industry, Congress of the Council of Mining and Metallurgical Institutions. (Contact: The Secretary, The Institute of Mining and Metallurgy, 44 Portland Place, London W1N 4BR, UK)

PREVIOUS ISSUES:

Issue No. 1	STEEL
Issue No. 2	NEW CERAMICS
Issue No. 3	FIBRE OPTICS
Issue No. 4	POWDER METALLURGY
Issue No. 5	COMPOSITES
Issue No. 6	PLASTICS
Issue No. 7	ALUMINIUM ALLOYS
Issue No. 8	MATERIALS TESTING AND QUALITY CONTROL
Issue No. 9	SOLAR CELLS MATERIALS
Issue No. 10	SPACE-RELATED MATERIALS
Issue No. 11	HIGH TEMPERATURE SUPERCONDUCTIVE MATERIALS
Issue No. 12	MATERIALS FOR CUTTING TOOLS
Issue No. 13	MATERIALS FOR PACKAGING, STORAGE AND TRANSPORTATION
Issue No. 14	INDUSTRIAL SENSORS
Issue No. 15	NON-DESTRUCTIVE MATERIAL TESTING

FOR NEW SUBSCRIBERS:

Request for ADVANCES IN MATERIALS TECHNOLOGY: MONITOR

If you would like to receive issues of the Advances in Materials Technology: Monitor in the future, please complete the form below and return it to:

UNITED NATIONS NATIONS UNIES

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

UNIDO MAILING LIST QUESTIONNAIRE

Advances in Materials Technology: Monitor
(Code: 504)
UNIDO MAILING LIST, INDUSTRIAL INFORMATION SECTION,
P.O. BOX 300, A-1400 VIENNA, AUSTRIA

	Type or print clearly (one letter per box) and leave a space between each word
NAME (underline family name)	
TITLE OR POSITION	
ORGANIZATION	
STREET AND No. (or P.O. Box)	
CITY AND STATE OR PROVINCE	
COUNTRY	

PLEASE DO NOT WRITE IN THESE SPACES

S/A ☐ DISP. CODE ☐ COUNTRY ☐☐☐

CITY ☐☐☐☐☐☐☐☐☐☐☐☐

Readers' comments

We should appreciate it if readers could take the time to tell us in this space what they think of the 16th issue of Advances in Materials Technology: Monitor. Comments on the usefulness of the information and the way it has been organized will help us in preparing future issues of the Monitor. We thank you for your co-operation and look forward to hearing from you.

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

Price List for Advertisements in the Publication

Advances in Materials Technology: MONITOR

General provisions

1. UNIDO activities in the field of advertising are non-profit-making and are carried out to cover the cost of preparing, publishing and mailing its publications, which are sent to readers all over the world *free of charge*.
2. Requests for placing advertisements in the UNIDO *Advances in Materials Technology: Monitor* should be made in writing. They should be accompanied by a layout, illustrations and a text containing all necessary information.
3. Advertisements are printed in black and white and in English only.
4. UNIDO reserves the right to reject advertisements without giving reasons, to suggest amendments or to hold advertisements if space is not available.
5. UNIDO cannot guarantee to print advertisements on specific pages of the *Monitor*. Page proofs will not be provided to advertisers.
6. Payment of invoices is due immediately after receipt and should be made within 30 days in United States dollars or Austrian schillings to the UNIDO bank account (see below) or to the Treasurer, UNIDO, Vienna International Centre, P.O. Box 300, A-1400 Vienna, Austria (telegrams: UNIDO Vienna Austria: telex: 135612). Upon payment, please advise the Head, Development and Transfer of Technology Division, at the same address.

Bank accounts

For dollar payments:

"UNIDO dollar account" No. 29-05115
Creditanstalt Bankverein
Schottengasse 6, A-1010 Vienna, Austria

"UNIDO general account" No. 949-2-416434
The Chase Manhattan Bank
International Agencies Banking
380 Madison Avenue, New York, New York 10017
United States of America

For schilling payments:

"UNIDO schilling account" No. 29-05107
Creditanstalt Bankverein
Schottengasse 6, A-1010 Vienna, Austria

Prices

Size	*Prices in Austrian schillings (AS) (or equivalent in US$)*
Full page (255 mm × 178 mm)	AS 5,000
½ page (125 mm × 178 mm or 255 mm × 86 mm)	AS 3,700
¼ page (178 mm × 60 mm or 125 mm × 86 mm)	AS 2,500

The price for the publication of announcements of up to five lines under the rubric "Resources available" is AS 1,000. The text is subject to editing.

Resources available

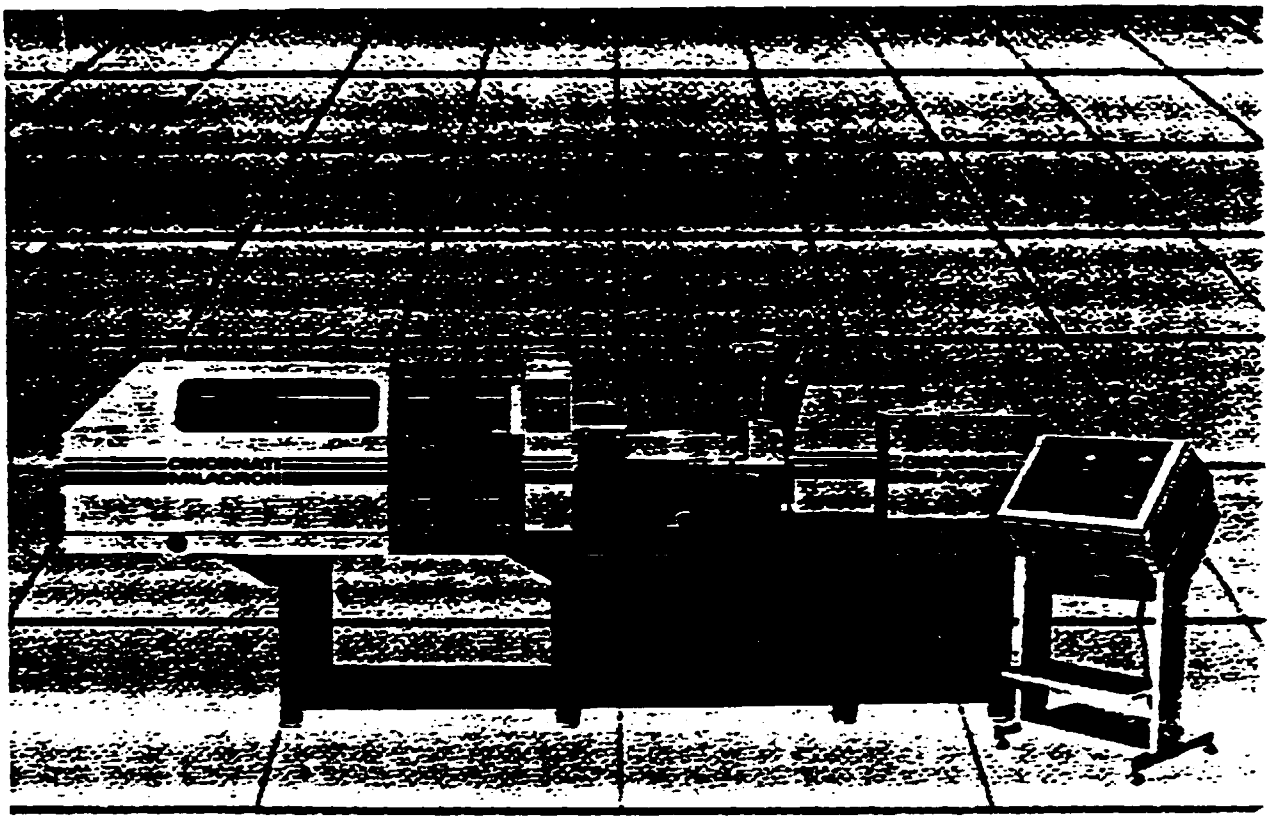
Know-how, designs and licences offered to manufacture drilling machines for water wells of up to 2.5-m diameter and 80-m depth and for concrete-injected piles of up to 2-m diameter and 45-m depth. Claude Bourg, Drill-France, B.P. 15, Le Haillan 33160, France.

Know-how available to manufacture synthetic ceramic from mineral wastes, sand and a binding synthetic resin for use as sanitary ware, material for furniture, decorative items etc. L. Valette, Administrateur Gerant, Science, 98 avenue de Tervueren, 1040 Brussels, Belgium.

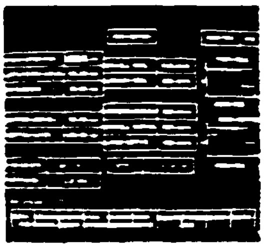
Manufacturers of various metal powders offer know-how for the production of electrolytic copper and iron powder, atomized aluminium powder and synthetic iron oxide. R. Devroy, Radar International, Post box No. 2014, Calcutta 700 001, India.

Technical know-how and complete turnkey plants available for the production of monocrystalline and poly-crystalline solar photovoltaic cells and modules and integration of systems, such as photovoltaic powered pumping, refrigeration, communication and water purification systems. N. R. Jayaraman, Vice-President, TPK International Inc., 36 Bentley Avenue, Nepean, Ontario K2E 6T8, Canada.

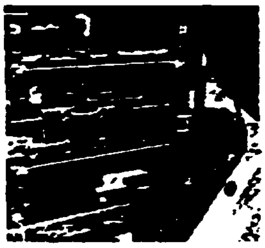
Technology and licensing available for manufacturing polyurethane from saturated polyester polyols, polyether polyols, isocyanate intermediates, one- and two-component polyurethane systems. Capacity tailored to requirements, from 2,000 tonnes upwards. Application: flexible, semi-rigid polyurethane foams, industrial and domestic appliance insulation, shoe soling, coating and sealants. Synthesia Inter AG, Tigerbergstr. 2, CH-9000 St. Gallen, Switzerland.



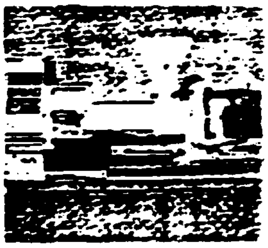
Fully electronic plastic injection molding machines "ACT" provide versatile, high-precision molding.



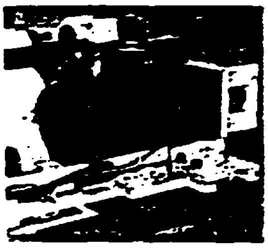
All "ACT"-models come equipped with advanced CNC controllers as well as AC servo motors. Fast, easy setting of parameters using a versatile 14" colour graphic CRT. Without need for setting limit switches, valves and other mechanical adjustment. All molding parameters are recalled within seconds from the built-in memory. With additional external memory, capacity can be expanded up to 240 molds. CNC controllers and AC servo motors provide high precision molding.



The "ACT" clamping unit features a double-toggle design. It ensures high speed and repeatability. An AC servo motor is also used in the ejector mechanism. Programming from CRT number of strokes, length, speed and starting position provides maximum flexibility. Each AC servo motor operates with a precision of 0.01 mm for each movement and also during movement. All AC servo motors are maintenance free and carbon brushes are not required.



The ACT's combined use of powerful AC servo motors and precision ball screws has enabled exact control of injection screw positions and injection speeds. The ACT's extra heavy-duty AC servo motor features advanced phase control technology which maintains powerful torque even in the higher speed range. In addition a pressure sensor is mounted at the base of the screw to provide pressure control accuracy.

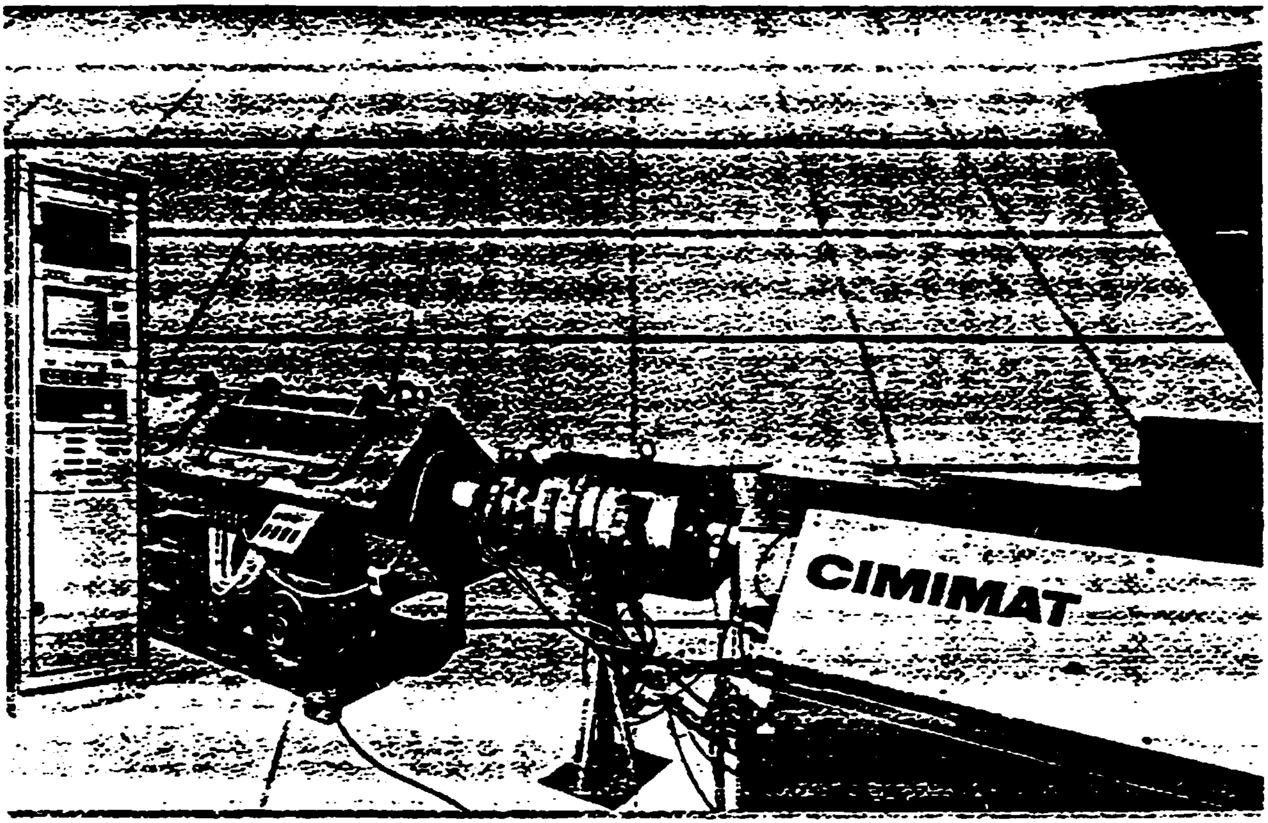


The AC servo motors utilized in the ACT are extremely efficient since they run only when needed and only to the extent needed. They thereby result in a significant saving in energy. Power consumption is reduced by up to 75%. Oilless bushings are used in the toggles and platen guides. As a result, molded products are kept free of oil and the work environment is kept extra clean. All "ACT" models, from 150 kN up to 3000 kN, with direct drive by AC servo motor make for extremely quiet operation and a clean, pleasant work environment, ideal for clean room applications.

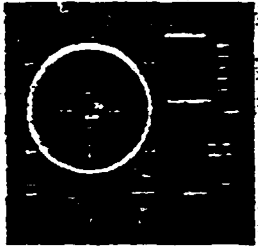
Cincinnati Milacron Austria AG
Laxenburger Straße [illegible]
Postfach [illegible] A-1232 Wien Austria
Tel. (0 22 2) [illegible]
Telex [illegible] cmaw a
Telefax (0 22 2) [illegible]

Deutsche Niederlassung und technisches Zentrum
Sprendlinger Landstraße [illegible] Postfach 414 D-6050 Offenbach (Main)
Tel. (0 69) 83 04-0
Telex 4152862 cmg d
Telefax (069) [illegible]

CINCINNATI
MILACRON

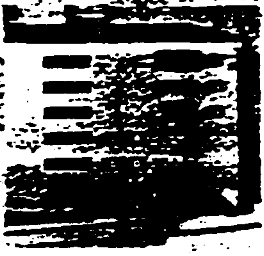


Why should pipe producers consider the new automatic pipe plant "CIMIMAT"?



Because:

You will be able to control wall thickness tolerances not only over the full pipe length but over pipe circumference as well.
This feature yields wall thickness tolerances of below [illegible] of those admitted by DIN standards, and you save expensive raw material.
CIMIMAT® is meant to increase the efficiency of your operation and helps you to reduce raw material costs while at the same time producing better quality pipe products.

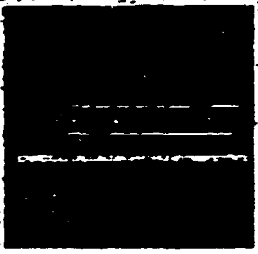


Because:

You will be fully independent of fluctuations in different raw material compounds.
The new weighing system SAVEOMAT controls the precise material consumption of the extruder. When employed in standard pipe plants, the SAVEOMAT system makes for controlling haul-off speed so as to reach contant meter weights. And when employed in a CIMIMAT® pipe line, the data acquired are used for automatic gauging in ultrasonic wall thickness measuring.
In this way you are independent of temperature fluctuations and the wall thickness meter will control haul-off and centering units to minimum wall thickness.

Because:

The automatized pipe extrusion line CIMIMAT® is equipped with the thermal pipe centering system CIMICENT®.
This is replacing a complicated and mechanically sensitive die-head construction.
The thermal pipe centering system CIMICENT® works trouble-free and is able to centralise thin or thick areas by equalising opposing sides.
With CIMIMAT® you'll have an advantage in the very competitive pipe market.



Because:

The automatic pipe plant CIMIMAT® means reliability to you.
Microprocessor control CIMICRON 9/16 guarantees pipe production within closest tolerances and it warrants moreover that once optimized process parameters are reliably reproducible.
Only the automatic pipe plant CIMIMAT® from CINCINNATI MILACRON AUSTRIA offers you the combined advantages of the thermal pipe centering system CIMICENT® and of automatic gauging of the wall thickness measuring.

Cincinnati Milacron Austria AG
Laxenburger Straße 246
Postfach [illegible] Wien, Austria
Tel. [illegible]
Telex [illegible]
Telefax [illegible]

Cincinnati Milacron U.K.
Castle Vale Industrial Estate
Maybrook Road, Minworth
Sutton Coldfield
West Midlands B76 8DS
Tel. (021) 351 67 19
Telex 338943 cimicv g
Telefax (021) 35 14 [illegible]

Finding better ways
to more profit.

AUSTRIA CINCINNATI MILACRON