ROLE OF MATERIALS IN DEVELOPING COUNTRIES

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ABSTRACT

The success or failure of any technology depends, for the major part, on materials. Their right selection, utilization, performance and reliability of use bring the necessary credibility to a given product. Traditional materials, such as stones, wood, common metals and various sorts of cements constituted the basis of economic activities from the beginning of man's activities. As industrialization progressed novel material developments came in to play new roles in industrial processes, metal alloys and plastics increasing their share on the world's materials scenario.

However, within the last two decades worldwide developments in materials technology have been producing an increasingly large number of the so-called new materials. New materials, in a broad sense, can be viewed as substances, or a combination of these, known or developed from the incorporation of first principles to the preparation, fabrication and utilization of new or old applications, however, always presenting new criteria in their fabrication. As such, there is an explicit utilization of innovative processes and manufacturing driven by quality and reliability of use.

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 current average availability of manufactured materials and energy per capita in the developing world is often one hundred times less than the advanced countries. 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 elite in these countries leaving the poor even more impoverished in terms of availability of materials.

While scientifically-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

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the poor in advanced countries, did not receive the necessary attention either from the developed or from the developing world.

MATERIALS IN THE CONTEXT OF DEVELOPING COUNTRIES

THE QUESTION OF RAW MATERIALS

It has been assessed that the amount of natural resources consumed after World War II equals the amount of raw materials and energy used since the start of history up to 1945. However, in the 1970s the pattern of constant growth of raw material consumption rapidly changed.

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<tr>
<td>Crude oil</td>
<td>70%</td>
<td>7%</td>
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<tr>
<td>Industrial minerals</td>
<td>29%</td>
<td>16%</td>
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<tr>
<td>Metallic minerals</td>
<td>54%</td>
<td>7%</td>
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The reasons for this conspicuous development are various:
- replacement of metals by plastics, ceramics and composites
- better utilization of used materials
- environmental pressures
- recycling.

The development also shows the interesting aspect of the growing share of industrial minerals in the overall extraction activity.

The relative share of industrial minerals grows also in line with industrialization. The more developed a country, the higher the share of industrial minerals in that country’s extraction activity.

As for the future demands for non-metals there are some indications of important developments:
- the crude oil shortage is expected to return in the 1990s. That will stimulate drilling activities and the demand for bentonites and barytes;
• it is expected that the use of low grade coal to generate electric energy will increase; desulphurization processes will be applied, consuming limestones and gypsum;
• the demand for plastics will go up, especially for new grades which will use mineral fillers as functional components; it will result in the demand for processed kaolins, e.g., of defined properties;
• the importance of zeolites is growing, they can be produced synthetically from kaolins, perlites;
• the growing consumption of paper generates the demand for mineral fillers;
• the developments in advanced ceramics will lead to the increased demand for smaller quantities of very pure minerals extracted from industrial minerals such as monazite, kaolin, silica, talc, wollastonite, bauxite, etc.

As for the demand of metallics, world economic forecasts for the consumption of metals over the next few decades indicate relatively modest but nevertheless positive rates for metals such as iron, copper, tin and lead. These rates will vary between 1 and 3 percent. On the other hand, consumption of metals such as aluminium, chromium and nickel, as well as those used in the manufacture of special steels, is likely to increase at rates above 3 or 4 percent, particularly in the case of certain metals which are widely used in areas of high technology, such as columbium, titanium and gallium, where the rates will be in excess of 5 percent.

The industrialization of developing countries will further support the consumption of traditional materials, although the spread of new technologies will probably reduce the extent of these benefits in comparison with the benefits gained by the industrialized countries at similar stages of development. This will depend on the ease with which technology is transferred.

UPGRADING, SUBSTITUTION AND RECYCLING

The declining growth of demand for materials in general has been due to: (a) substitution of one material for another, slowing down the growth of demand for particular materials, (b) economy in the use of materials, design and process improvements and reduction of per unit energy cost, (c) the saturation of markets, and (d) the emergence of knowledge-intensive and service industries and the substitution of electronics for earlier electromechanical functions.

Though the growth of demand in developing countries for basic materials such as steel, cement, paper, aluminium, ammonia, chlorine and ethylene is levelling off, such materials will continue to be important. The increasing cost of production of basic materials in some developed countries has also led on the one hand to offshore manufacturing and on the other to production of specialty products and to secondary processes, such as recycling and use of scrap.

The characteristics of the materials scene in developed countries do not necessarily apply to the situation in the developing countries. In many of those countries industrial development is in relatively initial stages and the consumption of materials is expected to grow significantly. At the same time energy efficiency has not necessarily been a strong point in many developing countries nor have design improvements or efforts to save on the use of materials. In regard to substitution of materials, developing countries as producers of certain materials, such as copper or
sugar, have been affected by such substitution processes in regard to their exports. Only a limited amount of substitution of imported materials has taken place. In regard to new technologies and new materials their implications for the industrialization of the developing countries have not by and large been understood. Overall, it appears premature to talk of "dematerialization" of economies of developing countries.

The economies of several developing countries are very heavily linked to the export of a given mineral. For instance, economies of several countries in Africa are based upon the export of copper. In view of the development of glass communication cables it is necessary that materials science and technology are 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 counterproductive in terms of development.

The experience in recent years has shown that there is increasing progress in recycling. This has implications on the use of resources. New strategies will be required for design of all kinds of technical products. The structure of the materials mix in these products should be such that they can be easily separated after the termination of use into the different materials classes of the pertinent components.

ISSUES AND OPTIONS FOR DEVELOPING COUNTRIES

HOUSING Housing remains 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 alumina 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 construction materials include bamboo, Ipoemea carnea, fibres from plants, such as coconut, sisal, banana, sun hemp, grasses and large agricultural wastes, such as paddy straw and wheat straw.

A shortage of cement and its high price are great barriers to 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 to bring down the cost of new high tech cements like zero defect cement, rapid setting cement, chemically-bonded cement, and fibre-reinforced cement, the prices of which are 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 an 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.
STRATEGIC MATERIALS Many developing countries do not have resources for strategic metals, such as nickel, cobalt, tungsten and chromium and it is necessary to synthesize high performance materials with abundant elements, such as aluminium, silicon, oxygen, nitrogen and carbon. The synthesis of structural ceramics, such as silicon carbide and silicon nitride, and composites, such as 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 cost 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 materials, and it should leap frog into the world of advanced ceramics and composites without necessarily going through the cycle of high performance alloys which will eventually be replaced anyway.

On the other hand, some of the developing countries have lateritic soil that needs to be deeply investigated since this soil may be a good source of metals that were concentrated through geological processes that were in effect. Thus, Cu, Co, Ni, V, Si and Nb are metals of primary interest.

RECYCLING In the context of development, advances in materials science and technology relate to recyclable materials, 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; the generation 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 less stringent 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.

ENERGY Materials for energy generation 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. Science and technology may be put to produce conventional materials with low energy inputs in small plants with low capital, high labour inputs as important imperatives for development. Materials with high temperature superconducting properties which have been discovered recently could have large implications on the developing world.

There are large resources of materials which are located solely in developing countries and have not received much attention in the developed world. Therefore, research and development in developing countries would centre on 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 have to be generated in the developing-world countries. A good example is the
Brazilian development of anatase, previously known as a museum curiosity, into a world ore resource of titanium.

**NEW MATERIALS IN THE CONTEXT OF DEVELOPING COUNTRIES**

New materials development efforts are primarily tailored to: (a) promote substitution towards a more rigorous specification of materials application, and (b) promote substitution of vulnerable or critical ores or metals.

As for promoting substitution towards a more stringent material specification, either for a novel or old application, several research and industrial facilities are engaged all over the world in market searching and opening of opportunities related to the high technology fields, such as aeronautics, informatics, microelectronics, etc.

As for promoting substitution of vulnerable or critical ores and/or metals, government efforts of the industrialized countries are envisaging changing the profile of dependability of the central economies from traditional sources of supply.

In both cases the underdeveloped economies do tend to suffer. In the first case due to the fact that either they have to rely upon an industrial basis of "second hand" materials or to import processes or product technology to advanced materials, since their research and development infrastructures in the materials area lag far behind that of the industrialized countries. In the second case the situation is such that very often a metal or ore that is being substituted is a good export item of an industrializing country.

Hence the problems that are faced by the developing countries do at least partially match such a situation and are not of a trivial nature. They have to secure a position that is vital to their balance of payments in foreign currency from the exporting commodities and also to prepare themselves to deal with the introduction of new materials in their own domestic economies.

Thus, such new materials developments, viewed as an amelioration of the raw materials crisis of the industrialized countries, may cause a deepening economic crisis for the third world if no corrective actions are taken.

Henceforth, many of the advances in new materials will reach the developing countries through changes in the pattern of new materials trade and changes in usage of materials in their economies. In addition, developing countries may develop their own new materials and uses, e.g., composites, suitable to their resource and domains. However, the diversity of conditions in developing countries and the endowment of raw materials will require different approaches to be evolved by each country. The question "which material technology is most suitable" cannot be answered through comprehensive catalogues or criteria in a general manner. Instead, this question has to be considered and answered individually in any single case. It appears that the following questions must be answered before and during planning basic materials industries:

- Where is the natural resource located and how is it crucial to the materials development process?
- By what methods can it be extracted?
- How and where will it be processed?
• What are the impacts of natural environment?
• What are the energy implications?
• What is its commercial value at current and likely future prices?
• What are the export possibilities?
• What impact on imports can be expected?
• What socio-economic effects are to be anticipated?

IMPLICATIONS OF MATERIALS TECHNOLOGY

Through research the use of new materials has spread into areas which are different from those for which they were originally intended since their greater efficiency makes up for their higher price.

There exist manufacturing techniques for products of primary importance to developing countries, which are heavily dependent on human resources readily available in developing countries. The skills to deal with composites can be quickly adopted and accelerated by appropriate instruction. Some of the skilled labour force required could be imported in the initial phases mainly for quality control at all stages of production.

There is a need to balance the use of natural products and their synthetic equivalent products and materials because, on the one hand, natural products support developing countries' economies, but on the other hand, the advancing economies require increasingly sophisticated materials with a high knowledge content and specialized efficiency.

The structure of the manufacturing industry has changed as a result of the marriage of advances in materials and processes with developments in production engineering based on computer-aided design, computer-aided manufacturing, flexible manufacturing systems, etc. The marriage of these two large streams of knowledge has opened vast opportunities.

MATERIALS PROCESSING

Materials processing needs to be driven in directions of near netshaped 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, local manpower and efficient technologies which can be maintained and established in the developing world without vast inputs of capital. It will be worthwhile 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 molding of complex shapes could be very important.
ATTITUDE TOWARDS NEW MATERIALS

At the very outset two points are to be clear regarding developing-world attitudes towards new materials: first, the economic growth of developing countries requires positive materials development and utilization activities, and second, the potentials of the new materials for developmental purposes have to be identified and utilized.

However, any concerted action, particularly of a policy nature, is rendered difficult for the following reasons: (a) there are several materials and composites; (b) many of the materials are intermediates and are inputs to a variety of final products; (c) the substitution of materials is a result of techno-economic considerations carried out by different enterprises over a period of time; and (d) different materials may be critical for export or import purposes for different groups of countries.

Against this background, what are the possible actions that can be taken by developing countries? Such activities could include the following:

(a) One of the first tasks of any country should be to monitor and assess the implications to it of the changing scene of the development and use of materials. In addition, the trends in the substitution of materials have to be watched, both to conserve scarce materials and also to study the implications for exports of their own materials.

(b) The developing countries have to be more sensitive to the fact that there is scope for choice of materials to be used in producing several products.

(c) Economy in the use of materials and conservation of material sources have to be achieved.

(d) Increasing efforts have to be made to reduce the energy content in the processing and use of materials.

(e) The technological capabilities for development, testing and use of materials have to be built up, including institutional and human resources.

(f) The process of diffusion of new materials into the economy has to be studied so as to see how such a process could be accelerated or arrested in line with overall socio-economic development objectives.

The interest of research and development institutions in developing countries in the subject of materials should be substantially augmented. Materials science laboratories may have to take a broader orientation and they should be equipped with pilot units, so that prospects and materials substitution are followed up to the stage of manufacture and use. Whether combined with such laboratories or otherwise, design capabilities should be promoted since material saving is ultimately a function of design. Likewise, recycling of materials should be encouraged, recycling being viewed in a broad sense to include use of materials now considered as waste in developing countries.

Alternative building materials and their use are obviously important to improve housing conditions in developing countries.
Advances in plastics as materials need to be systematically monitored in view of their wide substitution possibilities. In addition, apart from their relevance to oil-producing countries, the use of plastics would become particularly relevant to developing countries which have plenty of biomass resources in general provided the whole chain of technologies are developed for production of plastics through the biomass route.

The advances in the use of steel and the technology for its manufacture need to be carefully considered, since about 65 developing countries are involved in the production of steel. The advances in powder metallurgy will be of particular interest since the technologies involved in rerolling may be redundant.

The substitution of aluminium by other materials has to be kept under watch in view of the energy-intensity of aluminium production.

Silicon technologies, in general, have to be carefully watched since they are important, both for production of solar cells and for semiconductors.

Development in composites which are relevant to the natural resources and conditions of developing countries and are of key interest in sectors, such as housing, water and sewage as well as transportation, should be watched and capability built up selectively.

The potentialities of new materials for development of developing countries need to be studied systematically. For instance, some materials developed for space-related activities are also found to have scope for developing-country applications.

**CONSTRAINTS FOR THE USE OF NEW MATERIALS**

There are several constraints imposed on any development of efforts in advanced materials technology.

Besides those of a more strategic position there are also those of:

**TRAINING AND EDUCATION** The now-a-day demand for scientists, researchers and engineers well trained in advanced materials technology and utilization is exceeding any supply. This holds true for the industrialized countries, and in a most prominent way in the third world countries. It is recognized that education may show the most effective approach towards accelerating the development and utilization of new materials. Undergraduate courses are to be offered in a systematic basis to engineering, physics and chemistry bachelors; post-graduate courses aiming to create the research and development capabilities on new materials are a must; special emphasis is to be put on faculty members training programmes.

**INTERDISCIPLINARY APPROACH** The combined efforts of specialists from several fields of knowledge play a decisive role in project, manufacture and utilization of new materials. Synergy, so common in nature, but seldom appreciated in scientific thinking, is the key role to understand and interpret new material design. No distinctive ways to carry out a given project on the product and the material from which it is made are allowed in new materials developments. Such an approach,
however, although needed for advanced materials proper designs, is very much against the third world countries capabilities, due to their lack of qualified personnel.

**INTEGRATED DESIGN** Advanced materials development and utilization required an extensive database on materials properties and capabilities to permit sophisticated software for computer modelling and simulation analysis, to understand the properties of the microscopic constituents, acting in a given synergetic environment, which determine the overall behaviour of the desired product. This constraint, again, acts against third world countries, due to their lack in qualified personnel and computing tools.

**SYSTEMS APPROACH TO COSTS** One of the characteristics of advanced materials is their high cost and it is unlikely that such a characteristic is going to change in a near to medium foreseeable future. The "system costs" approach, including primary materials manufacturing, utilization properties and life cycle of the product, tries to diminish the cost disadvantage of the new materials: the idea being the cost decrease from US$300 per pound to less than US$20 per pound (that actually occurred to the standard high strength carbon fibre), repeating and decreasing further to the US$5 per pound range to compete satisfactorily with common metallic products (that actually is far from happening).

Two very important costs in favour of the economical use of some advanced materials, as composites, ceramics and engineering polymers, are the reductions in energy and labour costs.

**ATTITUDE TOWARDS RESEARCH AND DEVELOPMENT** Research and development activities are officially spoken of as being very necessary and of utmost importance in almost any government official and businessman speech all over the world.

In the industrialized countries, research and development is an integrated part of the running enterprises and is responsible for maintaining the competitiveness of a given company and/or for improving a given country's supremacy, even if these countries R&D expenditures are heavily financed by the government.

In the third world countries, however, R&D expenditures either from government or from local industry are extremely poor, thus widening the distance from the central economies. Why is this so? Answers to this question are normally given in terms of socio-economic priorities: transportation, basic health, production, etc.

Such answers do show a remarkable lack of real meaning and understanding of the role of science and technology. They are not an end *per se*; they are the way to overcome and reach the ultimate goals imposed by the country.

In any country and especially those of the third world a coupling of resources is a must: there are not enough facilities to be utilized for R&D purposes; there are not enough conventional and specialized equipment to deal with; and there is creditability from the industry (and government) towards local R&D groups.

What to do then? Firstly, government has to review R&D programmes not as perfunctory actions to which some illuminated people dedicate themselves for their own satisfaction. Secondly, local industrial business, eager to go around and bring
any "expert" they can find available, has to promote R&D projects that fit their own needs. Thirdly, R&D personnel have to understand that they are not divinely inspired and need to sweat in order to have credibility.

Therefore, from a national standpoint, a consortium of actions and activities, coupling available scientific capabilities with engineering skills, laboratory and scale-up facilities as well as testing operations, is to be carried out if any chance of success is to be assured.