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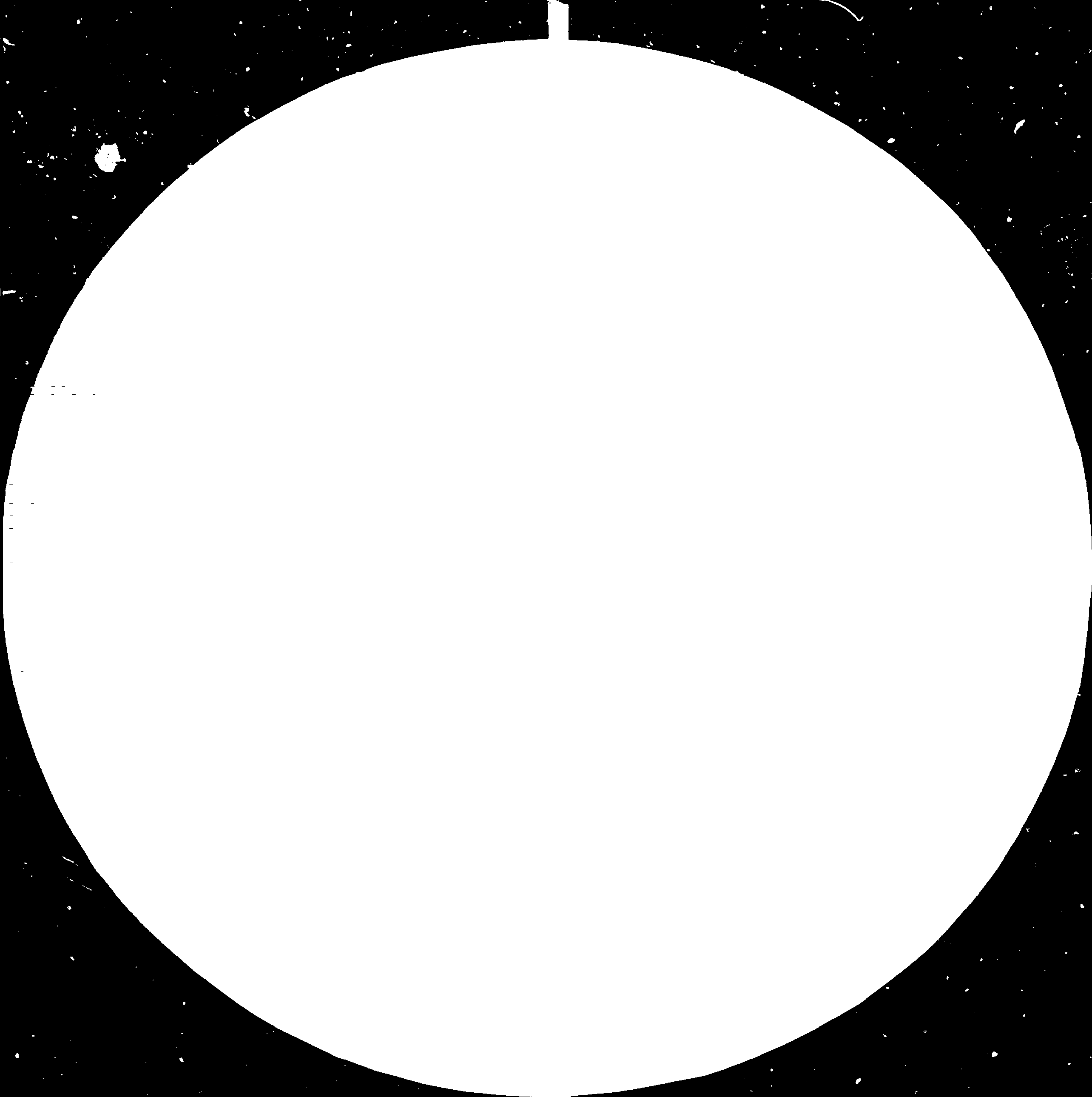

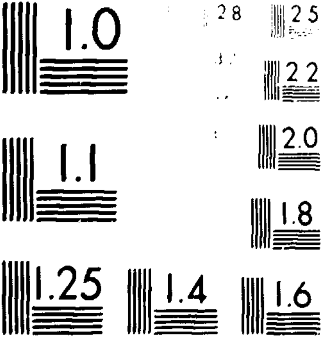
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SOME SIGNIFICANT ADVANCES IN MATERIALS TECHNOLOGY*

prepared by

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Introduction

The role of materials in contemporary society is obvious as we look about at our homes, cities, farms, offices, and factories. Clearly the degree of success in working with materials has an important bearing on our economic and social well being and economists have often shown the correlation between the consumption of materials and the standard of living. Perhaps, therefore, it is almost axiomatic that the economic growth of the developing countries requires a positive materials development and utilization activity.

In keeping with the objectives of this preparatory meeting, the purpose of this paper is to identify some significant advances in materials technology, comment on the implications of these advances for the developing countries, and suggest some activities to foster the adoption of these technologies as a basis for discussion by the meeting participants.

Because the materials field is so broad and there are so many advances that could be discussed, it is essential to use some criteria for the selection of topics for inclusion in this review. The following were adopted:

1. The technical advance is clearly established and is not a matter of hope or mere promise.
2. The topic is one of broad scope rather than a narrow product or process.
3. The new development should represent an industrial opportunity for the developing countries.
4. The choice should be limited to an important few.

As a result of this screening process, three topics were selected: high strength low alloy steels, fiber reinforced structural composites, and powder metallurgy. A fourth subject, which will not be covered in this paper, is materials for communications and information processing. This rapidly developing field includes fiber optics for communication transmission, light-emiting diodes and liquid crystals for electronic displays, silicon-base components for integrated circuits, and special garnets for computer memories. Perhaps UNIDO will examine this subject as part of the assessment of the microelectronics field.

High Strength Low Alloy Steels

In the not too distant past when strengths beyond those offered by plain carbon steels were needed, metallurgists used rather substantial additions of alloying elements which provided solid solution strengthening and hardenability in steels produced by conventional melting and hot rolling practices. Recently, however, a family of high strength low alloy (HSLA) steels have been developed and put into commerce which provide superior combinations of strength, ductility, toughness, formability, and weldability. This has been accomplished with minor alloy additions. Inreased strength translates to a decrease in the quantity of material needed to carry a given mechanical load, and the assessment of the cost/weight ratio for HSLA and plain carbon steels has resulted in world wide applications of these materials, particularly in the automotive industry. As is well known, the latter is striving to reduce vehicle weight to improve fuel efficiency and some industry experts predict the use of approximately 500 pounds of HSLA steels per car by the end of the decade.

In addition to use in automotive wheels, body and structural parts, HSLA steels have application in trucks and bus frames, cranes, heavy equipment, off-highway vehicles, appliances, prefabricated buildings, shipbuilding, pressure vessels, off shore platforms, bridges, railroad freight cars, and line pipe.

These steels are the result of an improved understanding of the relationships between alloying elements, microstructures of the steel, production processes, and mechanical properties. Further, they involve careful control of production processes including clean steelmaking by using ladle degassing and protection during casting of ingots, maintaining sulfur at low levels, controlling sulfide inclusion shape to minimize anisotropy, and closely monitoring the thermal and mechanical treatments of the mill products.

HSLA steels may be classified in two groups as follows:

1. Conventional

These steels derive their strength from a combination of fine grain structure, solid solution strengthening, and precipitation hardening. The fine grain structure is achieved by hot rolling at temperatures where austenite (the high temperature phase in steel) does not recrystallize and by alloy additions which suppress recrystallization between rolling passes; as little as 0.02 % niobium is effective for this purpose. Solid solution strengthening is typically obtained by micro additions of phosphorus, manganese, and silicon. The highest strengths are attained by increasing amounts of precipitation hardening created by the carbo-nitrides of vanadium, niobium, and titanium. Typically 0.03 % niobium or 0.1 % vanadium is added, and often a combination is used.

2. Dual Phase

These steels derive their name and mechanical properties from a two phase microstructure consisting of a ferrite matrix with a dispersion of martensite. This structure is created by heating a low-carbon HSLA steel to a temperature where high-carbon austenite is in equilibrium with ferrite that is almost carbon free. Upon cooling, the high-carbon austenite transforms to martensite, a very hard strong constituent which is dispersed in a relatively soft ductile matrix of ferrite. The result is a unique combination of properties: the strength of a conventional HSLA steel and the formability of a low-carbon steel. Since the properties are dependent on the formation of martensite, these steels require a proper recognition of the interrelationships of cooling rate, composition, and the production facilities in which the material is processed. Dual-phase steel can be produced as hot rolled or annealed; the latter step can performed in facilities normally used for batch or continuous annealing, or hot dip galvanizing. Typical compositions for the annealed grades include 0.04 % V, or 0.05 % Cr , or 0.12 % Mo; the as hot-rolled steels typically contain 0.04 % Mo and 0.60 % Cr if used in combination, or somewhat more if used alone.

Another feature of high quality HSLA steels is the addition of minor amounts of alloying agents to control the shape of sulfide inclusions and minimize anisotropy. If untreated, sulfide inclusions deform during the rolling process into long thin stringers oriented along the rolling direction which greatly reduce the ductility in the transverse direction. The addition of elements such as rare earth metals, zirconium, calcium, and titanium creates spherical inclusions which are dispersed but not deformed during the rolling process. In this treated condition, the steels exhibit good ductility and fracture toughness under multiaxial stresses.

The tensile strength and elongation to fracture of conventional and dual-phase HSLA steels are shown in Figure 1. Included for comparison are the high strength steels which derive much of their strength from retained cold work. These materials consist of low carbon and low alloy steels which are heavily cold rolled and given a controlled recovery anneal treatment; also included are quenched and tempered low carbon steels. Unlike the HSLA steels, these steels are only available in thin sheet (0.05") form. The superiority of HSLA steels is clearly shown in Figure 1.

Implications of HSLA steels for the developing countries:

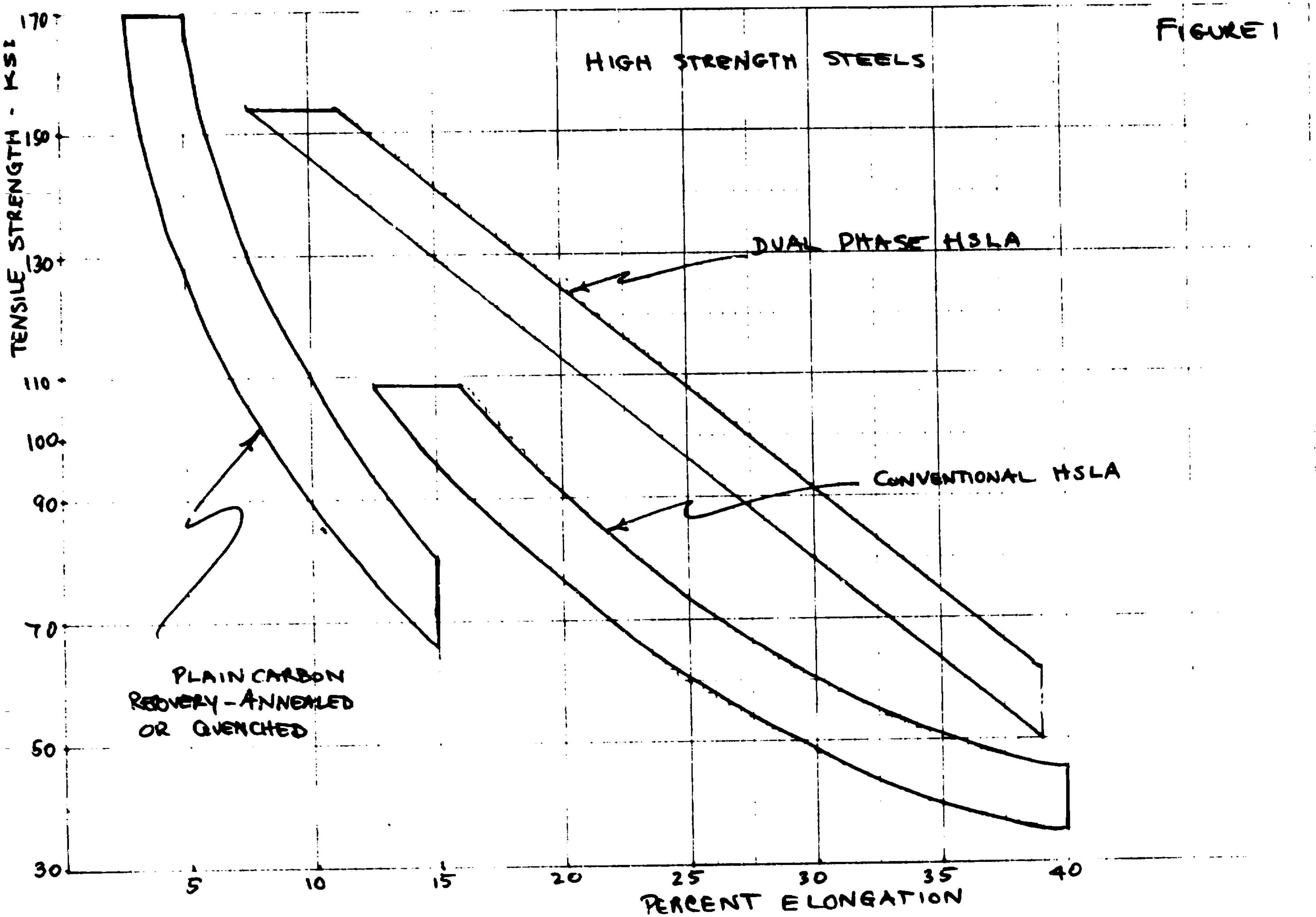
1. A new segment of the steel industry with high potential for growth.
2. A class of products which have higher value than the plain carbon grades they replace, but at the same time, more cost effective in service.
3. HSLA steels are consistent with materials conservation; service is performed in applications using less material.
4. HSLA steels are consistent with energy conservation.

5. Production requires a deeper understanding of metallurgical principles and tighter control of production practices.
6. As a higher value product, HSLA steels represent a better use of the investment in steelmaking facilities than plain carbon grades.
7. Some plants may require additional equipment for producing HSLA steels.
8. Full and proper use of HSLA steels in industrial applications requires that designers be well informed about the properties and characteristics of these steels.

Some possible activities to foster the production and use of HSLA steels in developing countries:

1. Workshops on the theory and practice of HSLA steels for steel production engineers and metallurgists.
2. Preparation of data books and manuals on the use of HSLA steels for designers.
3. Visits to plants where HSLA steels are produced.
4. Working fellowships for professionals to spend an extended period of time at plants where HSLA steels are produced.
5. Stimulate or possibly subsidize attendance at professional society conferences on HSLA steels. For example, the International Conference on HSLA Steels sponsored by the American Society for Metals to be held in Philadephia, PA in October 1983.
6. Loans to assist in the necessary modifications of steelmaking equipment.

FIGURE 1


HIGH STRENGTH STEELS
DUAL PHASE HSLA
CONVENTIONAL HSLA
PLAIN CARBON RECOVERY - ANNEALED OR QUENCHED
TENSILE STRENGTH - KSI
170
150
130
110
100
90
70
50
30
5
10
15
20
25
30
35
40
PERCENT ELONGATION

Fiber Reinforced Structural Composites

Another significant technological advance is the development of fiber reinforced structural composites. New fibers such as carbon, boron, and polyanide have been created with high tensile strength, high modulus of elasticity, and low density which when imbedded in a resin matrix provide composite structural materials with strength-to-weight and modulus-to-weight ratios far above all previously established levels.

This class of materials can appropriately be called " engineered materials" in that it is possible to make selections from a range of options in designing the material and the structural component. The following outlines some of these options:

1. Selection of the fiber material.
2. Selection of the fiber form (continuous or chopped fiber, textiles, etc).
3. Selection of the resin for the matrix.
4. Selection of the volume percentages of the fiber and matrix.
5. Decisions concerning the orientation of the fibers relative to the stress field in the component, and the number of plies to be used.
6. Selection of the production process (hand lay up, press molding, filament winding, pressure bagging, autoclaving, injection molding, etc).

Thus, unlike conventional materials which are usually fabricated into components from mill product sheet,rod, and plate stock, composites are fabricated directly into the desired shape from the basic constituents. This difference has some important consequences. Working with composites requires a high degree of integration of materials design, mechanics, structural design, fabrication, and non-destructive testing as an iterative process. Success is dependent on the combined abilities of the designer, structural analyst, materials specialist, and fabrication engineer to a greater extent than in working with metals. Non-destructive testing takes on a special importance since some flaws can only be detected during processing.

Figure 2 provides a comparison of the weight-compensated elastic modulus and tensile strength for several fiber materials.* Fiber glass is included to put the new materials into perspective. The dominant position of carbon with respect to properties will be noted as well as the interesting properties of polyamides for high strength applications which do not require high specific modulus. Fiber glass is seen to be a material with reasonably good specific strength but low stiffness-to-weight ratio.

The reason for the range of properties in Figure 2 is that changes in processing variables produce fibers of different densities and mechanical properties. In the case of glass, fibers are spun from the melt and selected compositions provide grades intended for different applications. The aromatic polyamide fibers, known by the generic name aramid, are spun by a technology similar to that used to produce nylon. Boron fibers are made in continuous form by reducing boron trichloride with hydrogen and depositing the elemental boron formed on an electrically heated, continuously moving tungsten wire substrate. The relatively narrow range of properties shown for boron in Figure 2 reflects the fact that there is not much latitude in the characteristics of an elemental material.

Carbon fibers can be obtained in many combinations of strength and modulus because of the nature of the process by which they are produced. In simple outline, carbon fibers are produced by the pyrolysis of an organic fiber precursor at progressively higher temperatures until an all-carbon replica is achieved. A widely used precursor is polyacrylonitrile (PAN) which breaks down structurally with increasing temperature to form a "carbon polymer" and then upon heating to temperatures in the 2000 - 3000^{0} C range, forms a graphite structure with the graphite layer planes oriented along the fiber axis. The theoretical modulus of elasticity for a graphite single crystal is 140 million psi and values of 100 million have been obtained experimentally in graphite whiskers grown from

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* The units in Figures 2 and 3 are unorthodox; psi divided by g/cc. Comparison, however, is not affected.

the boule, thereby defining the potential for carbon fibers. By manipulating the raw material, time and temperature treatment, and other variables, different densities and mechanical properties are obtained. In general, the higher the final processing temperature, the higher the density and elastic modulus; also generally, the tensile strength of carbon fibers decreases as the modulus increases.

Carbon fibers are also made from petroleum and coal tar pitch which are less expensive than organic fiber precursors.

Figure 3 shows the properties for these fibers in the form of unidirectional composites with an epoxy matrix. Data are also included for steels, aluminum alloys, and titanium alloys showing the superiority of composites on a weight compensated basis.

Glass fiber reinforced plastic is a mature commercial material which is well known for its applications in boat hulls, auto and truck bodies, appliance and equipment parts, storage tanks and electrical equipment components. Its cost/performance characteristics have led to extensive use which now amounts to more tha one million metric tons per year in the USA.

Carbon fibers, on the other hand, are better suited for high performance applications, are at an earlier stage of technical and commercial development, and are more costly. Thus, use has been in those applications where weight savings and performance are critical such as aircraft, automobiles, and sports equipment.

Aramid fiber reinforced composites are now established commercially and are finding increased use in aircraft, boat, and marine applications. A related polymer fiber is being used for tire cord and for reinforcement of belts and hoses.

In aggregate, the fiber reinforced composites field is assured steady growth and industrial expansion. Considerations of weight reduction for energy conservation and the substitution of materials for functional advantages or supply considerations, favor increased use of this class of materials.

Implications of fiber reinforced composites for developing countries:

1. A new class of materials with strong industrial growth prospects.
2. Compatible with the development of a plastics industry which has been a UNIDO program with the developing countries for the past decade.
3. The possibility exists for an industrial strategy using fiber glass reinforced plastics as an industrial base, with advanced fiber reinforced composites as an outgrowth.
4. Composite fabrication tend to be labor intensive which could be an advantage to the developing countries. The industrialized countries are working on automated fabrication techniques to reduce labor costs.
5. Special knowledge is needed in design, analysis, and fabrication of composites.
6. Production of fibers involves very sophisticated technology and much of it is covered by patents.
7. Fabricated composites have good added value.
8. The simplicity of hand lay up and press molding lend themselves to small and moderate size markets.
9. Composites represent a relatively low capital investment route to the manufacture of components as compared with conventional means using metals.

Some possible activities to foster composites in the developing countries:

1. While this field is an attractive industrial opportunity, it is not obvious as to which countries would find it suitable for their needs and interests. Perhaps what is needed is some assistance in assessing the field relative to the strengths and interests of individual countries and, if positive, some further assistance in developing the necessary strategic industrial planning.

FIGURE 2

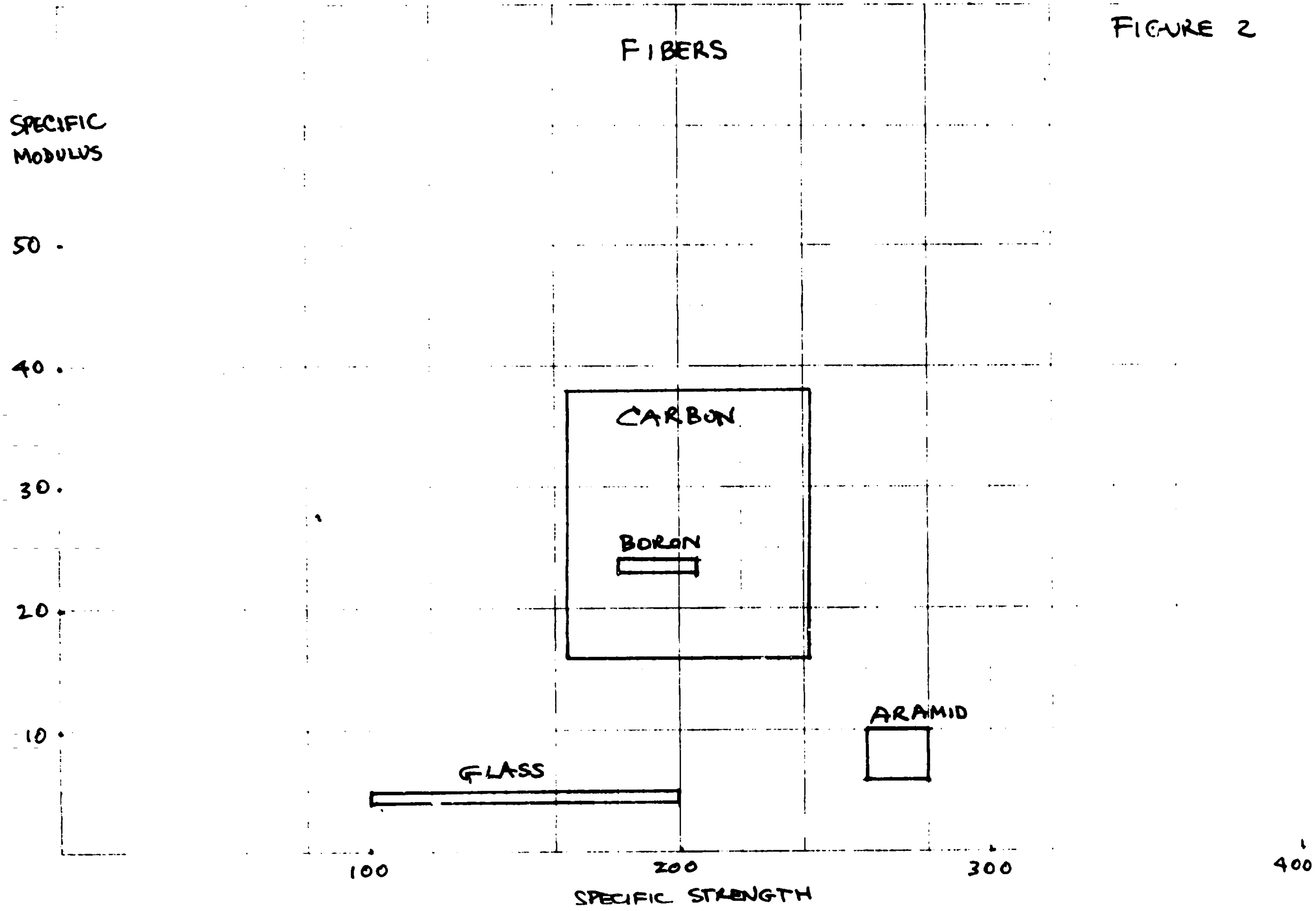
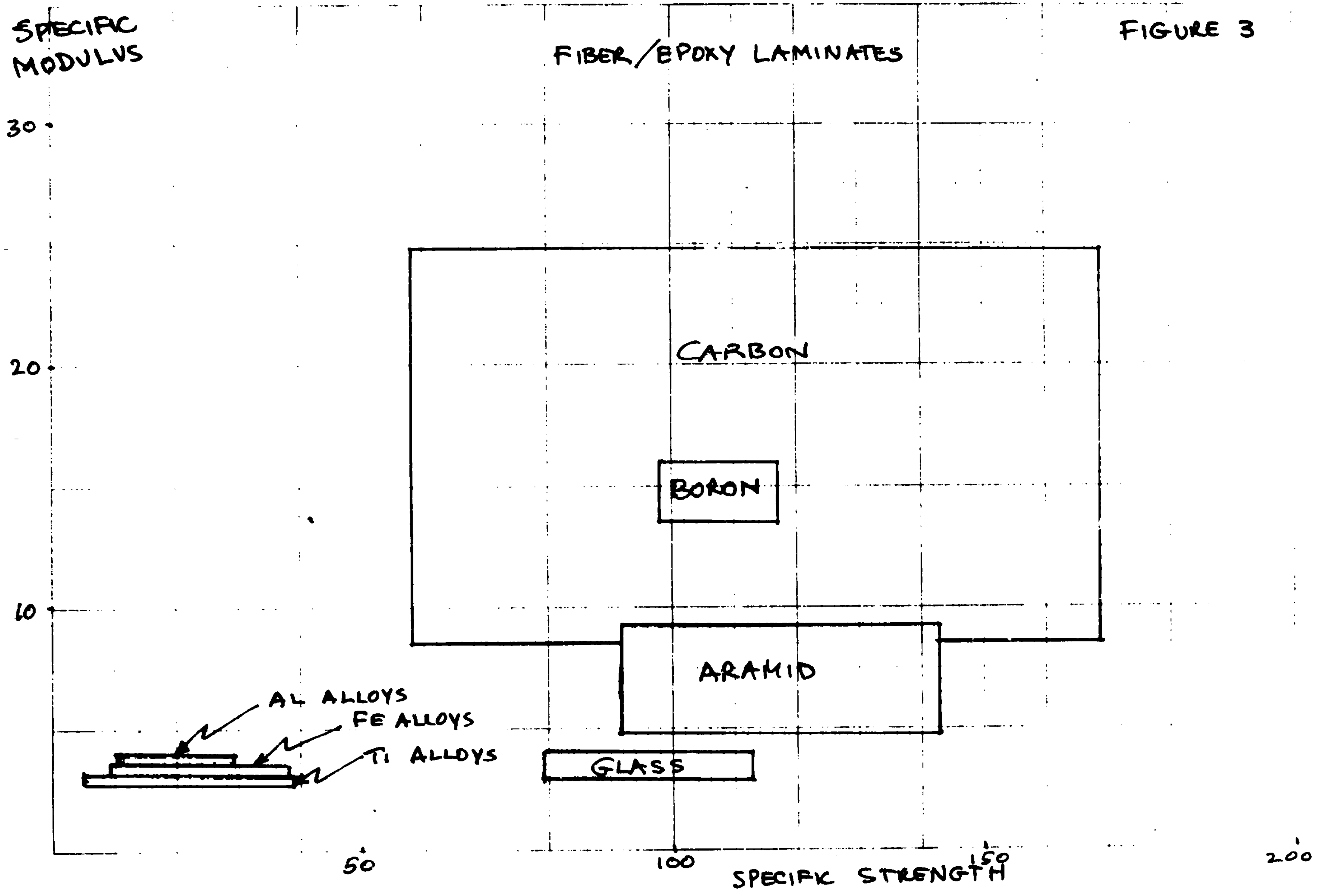

FIBERS
SPECIFIC MODULUS
50
40
30
20
10
CARBON
BORON
ARAMID
GLASS
100
200
300
400
SPECIFIC STRENGTH

FIGURE 3


SPECIFIC MODULUS
FIBER/EPOXY LAMINATES
30
20
10
CARBON
BORON
ARAMID
GLASS
AL ALLOYS
FE ALLOYS
TI ALLOYS
50
100
150
200
SPECIFIC STRENGTH

Powder Metallurgy

In contrast with the usual processing methods of melting, casting, and working of metals, powder metallurgy involves the production of metal powders, compressing them, sintering the compacts, and performing any necessary finishing operations. The field is old and well established, but is now going through a revival because of a combination of new technical advances and economic considerations.

In general, powder metallurgy is favored over fusion metallurgy when the application falls in one of the following categories:

1. The powder route is the best or only way to process the material. For example, making cemented carbide cutting tools.
2. When powders offer lower processing costs. For example, producing structural and magnetic alloys to final dimensions, or making parts from expensive alloys by producing near-net shapes from powder which are subsequently forged.
3. When powders offer superior properties in the manufactured part.

Before describing the new advances, a brief outline of conventional powder metallurgy might be useful.

Various commercial processes are established for producing spherical metal powders with particle sizes in the range of 50 to 400 microns in diameter by dispersing a stream of molten metal with a jet of liquid or gas to produce frozen droplets. Some processes use an electron beam or a plama arc for melting and vacuum or inert gas in the solidification chamber. Compositionally there are few limitations and a wide variety of metals and alloys are avilable in powder form.

The customary method for producing parts is to cold press powders in a rigid die followed by sintering in a continuous furnace. To obtain the necessary mechanical properties, various alloy compositions and heat treatments have been developed and to gain still greater improvements, several additional process steps have been used: (1) repress and resinter, (2) infiltrate with a liquid metal of lower melting point, or (3) hot forge the sintered compact. Still another conventional approach is to combine the powder compacting and sintering steps in a single hot pressing operation. This technique has had limited use in the powder metallurgy industry until recently when new developments have made hot consolidation one of the important new features of this field, as will be discussed.

A very noteworthy advance in powder metallurgy technology are the newly developed rapid solidification techniques using quenching rates up to 10^6 degrees per second to produce very fine particles (less than 50 microns in diameter) which are especially uniform in composition and microstructure. In one such process, a stream of molten metal strikes a ceramic coated disk rotating at 400 revolutions per second; the fine molten particles thrown from the disk are rapidly quenched by a jet of helium gas. These powders after consolidation and heat treatment, provide superior properties as compared with conventional powders or fusion metallurgy.

The basic mechanisms by which rapid solidification imparts improved properties to the material include the following:

1. Creation of a very small grain size and a fine dendrite spacing.
2. Creation of metastable structures including extended solid solubilities.
3. Creation of dispersoids which control recrystallization and grain growth.

It is probably fair to say that the properties of aluminum alloys have nearly reached a plateau insofar as the application of conventional metallurgical techniques are concerned. By the use of rapidly solidified powders, however, new levels of mechanical properties are being achieved. Improvements of 10 to 20 % in room temperature yield strength, fatigue strength, and elastic modulus have been reported for consolidated aluminum alloy powders produced by rapid solidification as compared with the properties of conventional commercial products of the same composition. Even greater improvements are reported in stress rupture and creep strength at elevated temperatures.

As a structural material, aluminum suffers from a rather low elastic modulus (about 1/3 that of steel) and increasing this modulus has been a long standing metallurgical objective. Aluminum-lithium alloys are of interest in this regard since in normal processing they are known to offer the highest specific modulus for a given addition of alloying element of any of the aluminum alloy systems. By conventional processing, aluminum-lithium alloys involve difficulties with regard to segregation in ingots and loss of toughness when processed for high strength. Use of rapidly solidified material solves these problems and provides improved mechanical properties. The following table shows the remarkable increase in modulus of elasticity and in specific modulus achieved by using rapidly solidified material.

Table 1

Material	Modulus of Elasticity 10^6 psi	Density Lbs/in^3	Specific Modulus 10^7 in
Al - 1 % Li Conventional	10.4	0.100	10.4
Al - 1 % Li Rapid Solidification	11.2	0.097	11.5
Al - 3 % Li Rapid Solidification	12.3	0.091	13.5

One of the major incentives for the recent advances in hot consolidation techniques is cost savings in the production of parts from expensiv [illegible] The latter, which include titanium and nickel base alloys, incur very significant loss of material between starting ingot and final product when processed by conventional means. Although much of the scrap generated can be recycled, the expenditure of time and energy in a relatively inefficient manner is considerable. Hot consolidation of powders to produce near-net shape provides overall savings even though the process itself is more expensive than the conventional process it replaces. Another incentive for hot consolidation is achieving properties superior to those obtained by fusion metallurgy. Many alloys based on aluminum, nickel, and steel with a capacity for strengthening by the controlled formation of second phases (dispersions and precipitates) respond to this process.

Producing near-net shape can be accomplished by hot pressing powders in rigid dies, but much greater interest and development has been placed in hot isostatic pressing. The latter imposes pressure uniformly from all directions and has greater latitude in the shapes that can be produced. The general procedure for hot isostatic pressing is that a container of the shape of the final article is filled with metal powder, evacuated, sealed, and placed in a pressure vessel surrounded by a furnace. Under heat and pressure, the container compresses the powder isostatically into the densified shape. Various methods have been developed for encapsulating the powder including metal cans, glass containers, and ceramic molds; other modifications of the technique involve the use of extrusion rather than autoclaving.

Implications of powder metallurgy for the developing countries:

1. Conventional powder metallurgy is favorable for the production of a large number of identical parts.
2. Powder metallurgy is a highly flexible technology and presents a very useful supplement to conventional fusion metallurgy, and in certain instances surpasses it in economics and product performance.
3. Much of the development in the powder metallurgy field has been oriented toward the needs of the industrialized nations, some of which should be useful to the developing countries.
4. The opportunity exists to develop facets of powder metallurgy which are particularly suitable for the developing countries. For example, the rolling of metal powders to produce sheet might be a more versatile process requiring less capital investment than conventional sheet production.
5. Entry in the powder metallurgy industry can be made on an incremental basis starting with a partial activity and subsequently expanding the process and product scope.

Some possible activities to foster powder metallurgy in the developing countries:

1. Powder metallurgy is a specialty and successful practice requires the relevant knowledge and skills. Hence, technology transfer. education and training, investment assistance and other UNIDO activities would be supportive.
2. Because of the broad scope of products and processes in the powder metallurgy industry, the possibility exists for the developing countries in a region to cooperate in the development of an industrial strategy and to collaborate in carrying it out. UNIDO might consider fostering such an approach.