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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

Advances in Materials Technology: MONITOR

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Compiled by Development and Transfer of Technology Division, Department for Industrial Promotion, Consultations and Technology, UNIDO, P.O. Box 300, A-1400 Vienna, Austria.

Dear Reader,

This is the tenth issue of UNIDO's state-of-the-art series in the field of materials entitled Advances in Materials Technology: Monitor. This issue is devoted to space-related materials and is addressed to a select target audience of policy-makers, scientists, technologists and industrialists in developing and developed countries.

In each issue of this series, a selected material or group of materials is featured and an expert assessment made on the technological trends in those fields. In addition, other relevant information of interest to developing countries is provided. In this manner, over a cycle of several issues, materials relevant to developing countries could be covered and a state-of-the-art assessment made.

In this issue Mr. Mir Akbar ALI has written the main article for UNIDO. The issue covers materials for space exploration as well as materials processing in space. The current awareness section includes information on new products, new processes and applications.

The tenth Monitor presents itself to the reader in a new "face" as well as with a new addition, namely an advertisement. Aiming at meeting the costs for preparing the Monitor, publishing and mailing it, UNIDO will start publishing industrial advertisements in the Monitor. This activity is non-profit oriented. If any of our readers are interested in industrial advertisements in the Monitor please do not hesitate to contact the Editor and we shall be happy to send you more information.

At this point we would like to emphasize again our appreciation for all your returned filled-out questionnaires as well as your comments and suggestions. Please continue sending them.

Department for Industrial Promotion,
Consultations and Technology

CONTENTS

1. MATERIALS DEVELOPED THROUGH SPACE-RELATED TECHNOLOGIES

The following article is the core of a study prepared by Mr. Mir Akbar Ali for UNIDO. It discusses (I) Materials processing in space and (II) Materials developed for space applications: (1) Technology of carbon/graphite fibres and (2) Space-related advanced ceramic materials.

Since this paper is a condensed version of the original paper, it has been decided to dispense with the list of bibliographic references.

I. Materials processing in space

The processing of materials is influenced by the earth's environmental characteristics such as gravity and the atmosphere in which the processing occurs. The atmosphere can introduce adverse contamination influences which can be minimized by using artificial atmospheres such as inert gases. Nothing practical can be done on earth about gravitational effects which include phase separation, density segregation, uneven cooling characteristics and container contamination for glass, ceramic and metallic materials. On the other hand materials can be processed in space under conditions of virtual weightlessness with the potential advantages of solar energy and a vacuum sink of unlimited volume.

The forces that have an effect on the composition or shape of solidified glass, metal, and to a lesser extent, for ceramics are volume changes, surface tension and gravity induced segregation and convection.

Various countries, depending on the status of their space technology programmes, have conducted experimental materials processing studies which were both ground-based (on earth under simulated near zero "G" conditions, using acoustic and/or electromagnetic levitators) and on board space flights.

Efforts were also made to exploit the potentials of space industrialization including feasibility studies for the commercial manufacture of electronic materials. The following sections will describe the experimental and commercial manufacturing.

Materials processing in space - experimental studies

As mentioned earlier, various countries have conducted both ground-based and on-board materials processing studies, based on their space technology capabilities.

The US materials processing studies are managed and administered by the National Aeronautics and Space Administration (NASA). Ground-based experimental studies were also conducted by selected industrialized and developing countries. In the US, such studies were performed during the Apollo, Spacelab and Space Shuttle Missions; Salyut and Syrena in the USSR; TEXUS in the FRG; and the European Space Programme, to name a few.

The purpose of ground-based studies was to conduct materials-related experiments on earth in a near zero "G" environment and to establish the potential improvements or a specific characteristic which could not be achieved otherwise.

NASA has long had an interest in materials, particularly those of value for the industry, aeronautics and space flights. NASA has carried out extensive studies on materials in its own laboratories and sponsored research in academic and industrial laboratories.

For example, glass melts are highly reactive materials. They react with virtually any container, even platinum. This includes chalcogenide glass for transmitting in the infrared region and laser glasses. In this context NASA sponsored ground-based studies in an acoustic levitator to process chalcogenide and laser host glasses.

Among the advantages claimed for growing semiconductor electronic materials in space are improved homogeneity, greater purity, reduction of physical defects and the ability to grow large diameter crystals. Experiments on Skylab by Wiedemeier, Witt and Gatos have been cited for evidence that crystals grown in a low "G" environment are superior to those grown under the influence of the earth's gravity.

Likewise, the USSR also conducted a variety of space-related materials processing studies which include the directional crystallization of germanium under the influence of the space environment, the space processing of CdHgTe, CdHgSe and PbSeTe, and the structural studies on the Te-Se solid solutions on board SALYUT-6.

These and similar space-related materials processing studies were conducted by other countries either independently or in collaboration with the USA or USSR space programmes. Furthermore, there were several USA-USSR joint studies under the Apollo-Soyuz programme.

Materials related studies were also conducted in the Skylab orbiting space station. The Skylab materials science and technology studies were mainly concerned with metallic materials. The materials studied include the familiar steel, aluminium, copper, nickel and silver and the less familiar gallium, germanium, indium and tellurium. The objective of these studies was to evaluate the space environment for single crystal growth, immiscible alloy compositions, microsegregation in germanium, whisker reinforced composites and so on.

The Space Shuttle programme is also being utilized for the development of low-cost transportation to and from the earth. The system itself is composed of the Orbiter with the Spacelab to do research and develop techniques on a variety of subjects including materials related technologies. The Spacelab is an international programme developed by the European Space Research Organization (ESRO). The Spacelab provides an extension of the ground-based studies with the advantages which only space flight can provide, such as a long-term gravity-free environment. Ten members of the European Space Community consisting of the FRG, France, the United Kingdom, Belgium, Spain, the Netherlands, Denmark, Switzerland and Austria have pooled their resources and combined with the USA to conduct scientific and technological application and studies which includes materials development and processing. For example, germanium selenide (GeSe) was grown aboard Skylab and was about the size and shape of that used in the electronic devices. The study indicated that this type of production is feasible and provided data on the conditions under which products of this kind can be manufactured in space.

As can be seen all these ground-based and on-board test flights are stepping stones for the eventual industrialization of space. The next section describes the details of space industrialization.

Space industrialization studies

The potentials of industrializing outer space is one of the most exciting concepts of the space programme. The word itself - industrialization -

denotes a new vista of thinking. One must use terms such as the production of goods and services, manufacturing equipment, labour-force, return on investment, products, markets and risks.

Among the suggested space industries are unique materials for earth and earth resource surveys. Besides permitting the manufacture of better products, space processing facilities will also enhance our technical knowledge of materials behaviour. The actual properties of many of our materials are far below their theoretical limit; and space-based materials research promises to help us come much closer to these fundamental limits than efforts here on earth. Space processing allows investigators to eliminate the gravity-induced effects on materials, allowing better fundamental studies on solidification, phase transformation, the kinetics of vaporization and condensation and the dynamics of froths and diffusion in fluids in a temperature gradient.

The new and cheaper products manufactured in space will be those that benefit from lack of gravity. With the exception of weightlessness all other characteristics of the space environment such as high vacuum and radiation can be achieved on earth.

One major benefit of such low-gravity processing would be that materials to be processed could be 'levitated' - suspended in space without touching the container. Since there would be no need for containers in space factories, there would be no danger of impurity contamination from the container - a major problem on earth - during the manufacture of highly reactive and high melting materials. For example, crucible contamination is probably the most serious limitation in the production of high purity glasses for lasers and laser system optics and has seriously hindered the ability to grow pure crystals for semiconductors.

A second major advantage of low-gravity processing is the elimination of a container's surface irregularities which come into contact with the melted material. These irregularities provide sites for undesirable crystal growth in the solidifying liquid which spoil the perfection of the solid.

Furthermore, in weightless space, molecular forces such as cohesion and adhesion will replace gravity as the strongest environmental force and become significant factors in control processes. There could be drastic changes in the casting and drawing processes such as those encountered in crystal growth and fibre and ribbon drawing.

In this context NASA conducted an extensive techno-economic feasibility study for the manufacture of single crystal silicon and silicon ribbon in space.

The first task was to evaluate the most common earth-based crystal growing processes in relation to processing in space. Figure I presents the details of the earth-based crystal growing processes which includes:

(a) Melt growth;

(b) Solution growth;

(c) Vapour phase growth.

Each of the three processes has its own particular advantage for use in space. As such, each method was evaluated on the basis of its adaptability to the production of single crystal silicon ribbon on space. The technical criteria for selection was that the process must be continuous, the shape of the end product be ribbon, and, in order to be economically attractive, the process must be capable of a high crystal growth rate.

The selected process had the combination of the best features of melt growth and zone refining crystal growing process together with some unique space techniques. The process was called Ribbon from Melt Growth in Space or simply RMGS process. Figure II provides a block diagram and conceptual sketch of the RMGS process. In the model process the growth of single crystal ribbon was made from a levitated, spherical melt heated by a solar collector. There are two major advantages of this process - direct conversion of the polycrystalline silicon into the desired single crystal planar form and the elimination of contamination by the contact of molten silicon with its surroundings.

The single crystal silicon currently grown on earth is not in the desired planar form but is in the form of large cylindrical boules. The boules are sliced into wafers and mechanical and chemical polishing is required to remove the damaged surfaces. This amounts to a 50 per cent loss of the starting material. However in a space manufacturing operation, the direct conversion of polycrystalline silicon into ribbon form is optimum because it eliminates the processing loss. Also, microgravity makes levitation of the melt possible. Levitation of the melt eliminates both material loss and transportation costs for the lost (waste) material.

In addition, silicon ribbon suitable for IC's have been mechanically shaped using high purity quartz but, for space processing, die erosion and frequent die replacement would have resulted in higher production costs. The process uses alternating current which in the coils results in a radio frequency force field that forces the molten material into rectangular cross sections. Radio frequency force field shaping has been largely unsuccessful on earth, but the microgravity of space should facilitate its application.

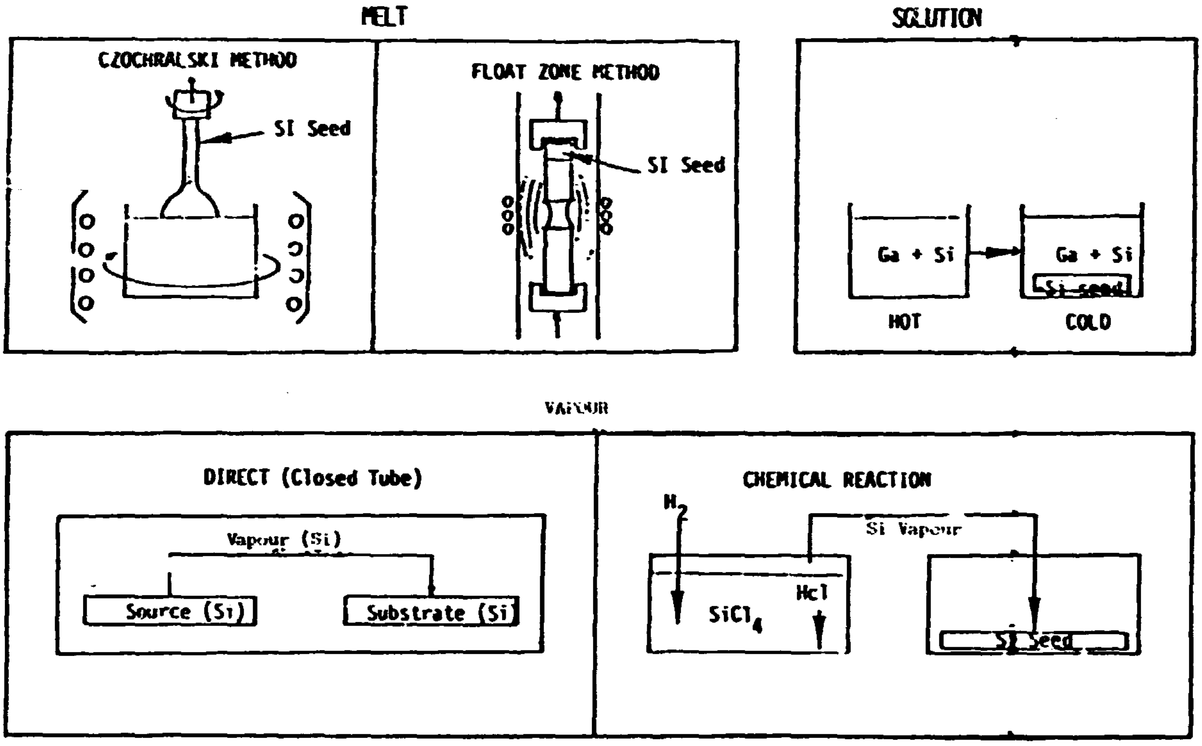
The advantage of microgravity is that surface tension becomes a dominant force and shaping can be effected over a much longer meniscus height, as is shown in figure III below. This longer meniscus height allows the use of multiple coils of a larger cross section, thus minimizing resistance losses. The decreased power density in the ribbon for the longer shaped height space allows a better balance to be achieved between the shaping force and heating of the molten silicon.

The postulated silicon ribbon process was incorporated into the space manufacturing plant design as shown in the following figure IV. One ground rule was that the plant would be an automated free flying spacecraft providing good operating economics. The production rate was based on a 7.6 cm ribbon width and a pull rate (190 cm/hr) of that already achieved on the ground using mechanical dies.

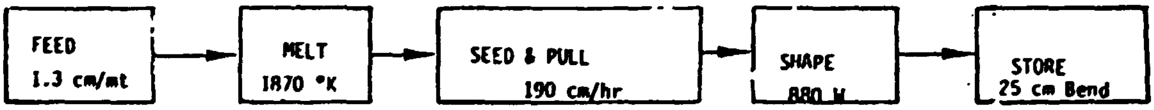
In order to determine the economic feasibility of space manufacture, cost comparisons were made with earth manufacture. Property improvements, extrapolated from Skylab experiment results were postulated for the space-grown crystals and evaluated in terms of integrated circuit processing yield. The yield improvements for the two principal device technologies, bipolar and metal oxide semiconductor (MOS) are shown in figure V for a 0.38 cm x 0.38 cm baseline large-scale integrated (LSI) circuit or chip. The approach used was to calculate the LSI manufacturing cost using earth material cost yield.

Integrated circuit manufacturing consists of three major steps: diffusion, assembly and test. In diffusion the transistors and interconnections are formed by selectively implanting the substrate in a multistep process. The circuits are probed and separated into individual chips. The good chips are then assembled into packages and the final step is to test the assembled integrated circuits.

FIGURE I. SINGLE CRYSTAL SILICON GROWTH METHODS



RIBBON FROM MELT GROWTH IN SPACE (RMGS) PROCESS



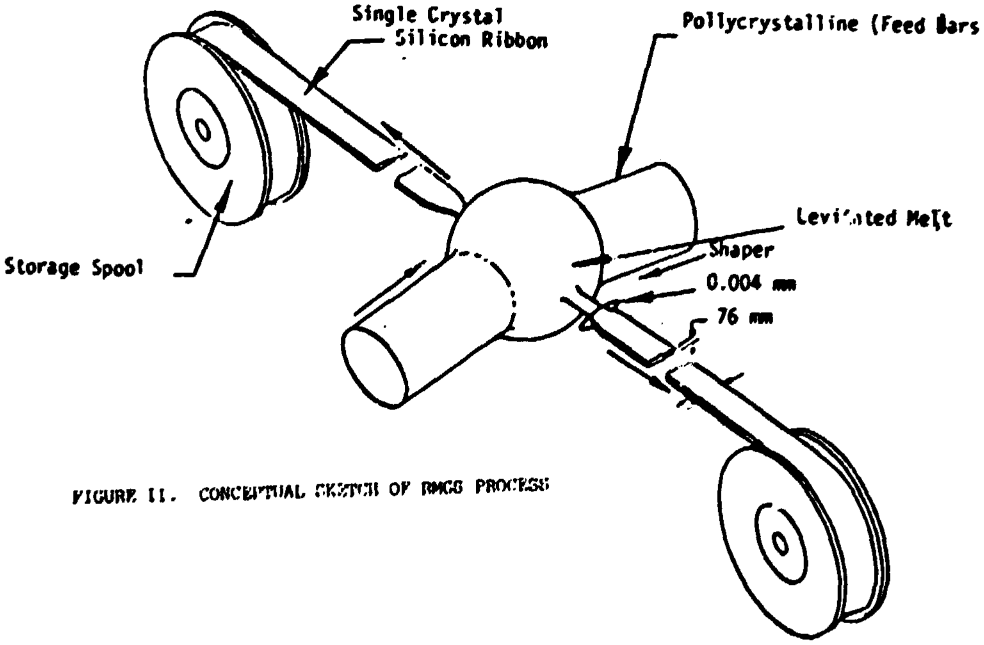
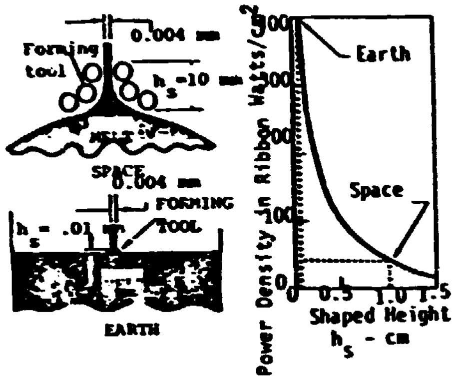


FIGURE II. CONCEPTUAL SKETCH OF RMGS PROCESS

Figure I.I. ADVANTAGES OF FORMING IN MICROGRAVITY ENVIRONMENT



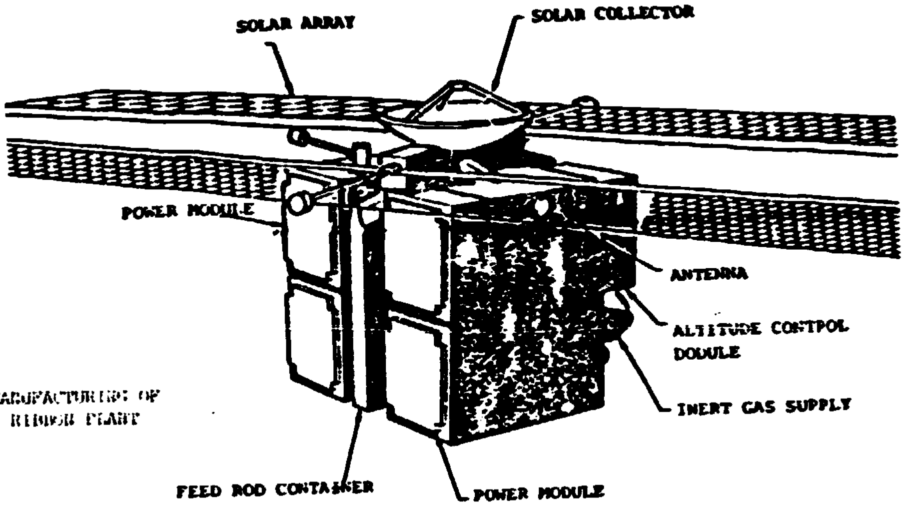


FIGURE IV. SPACE MANUFACTURING OF SILICON RIBBON PLANT

	OVERALL YIELD	
	SPACE	EARTH
BIPOLAR	13.5%	6.3%
MOS	29.2%	16.8%

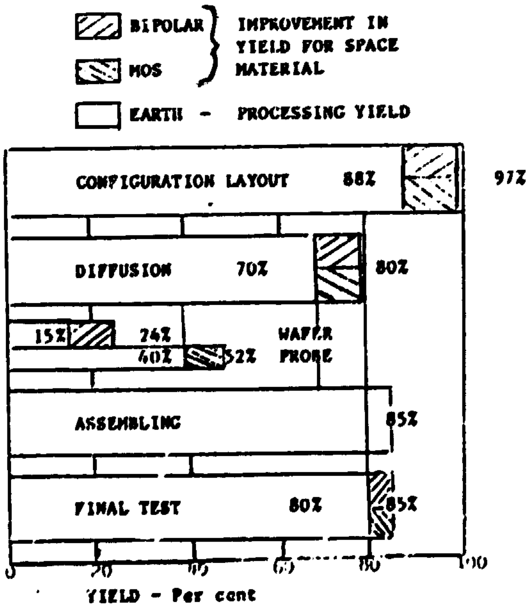


Figure V. INTEGRATED CIRCUIT PROCESSING YIELD

The effects of the increased yields projected for space-processed integrated circuit material costs are shown in figure VI.

The largest effect of space processing is the decrease in diffusion cost per kilogram which is inversely proportional to the overall yield. There is also a small decrease in assembly and test cost due to the small improvement in final test yield.

II. Materials developed for space applications

1. Technology of carbon/graphite fibres

The significance of fibrous materials and products became identified with structural developments in the aerospace industry. The urgency of structural requirements for space-related industries led to the development of carbon/graphite fibre composites.

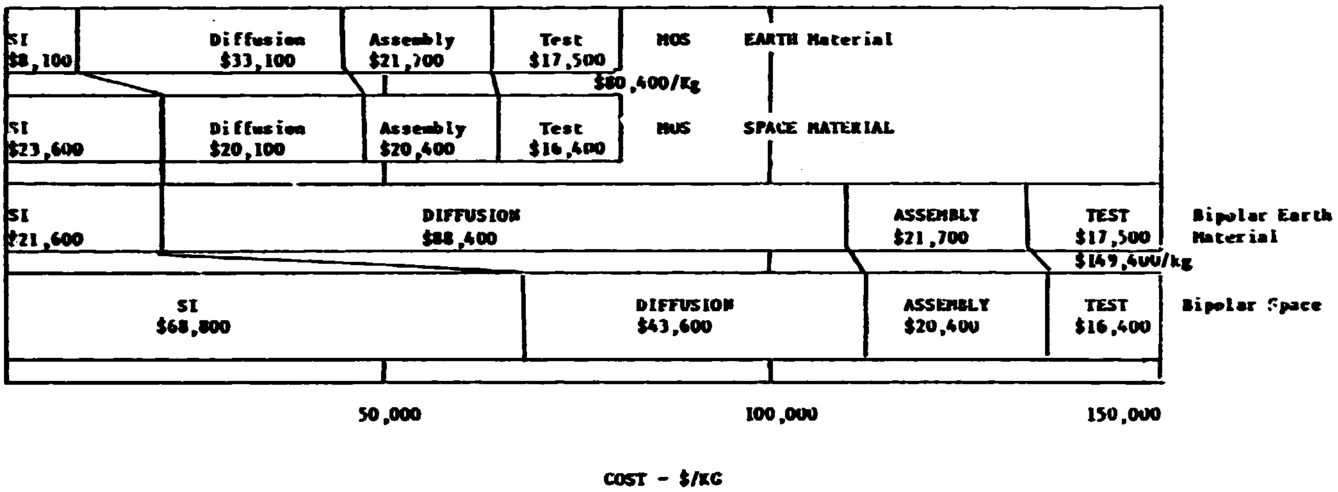


Figure VI. EARTH & SPACE PROCESSING COST BREAKDOWN FOR INTEGRATED CIRCUIT (IC)

Finally, in order to determine the value and market for space produced silicon, a market analysis was conducted to identify market characteristics and is illustrated in figure VII below.

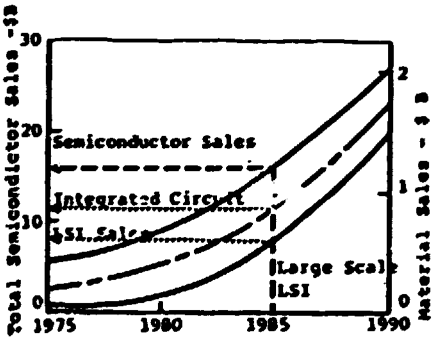


Figure VII. PROJECTED WORLD SEMICONDUCTOR MARKET

The semiconductor market is composed of discrete devices and ICs and is currently around $US 20 billion and is growing at an annual rate of 11 per cent. Single crystal silicon for use in ICs requires extremely high-quality material in terms of purity and structure. The damaging effect of defects increases with circuit size and is greatest for large-scale integrated circuits (LSI). These LSIs would be suitable candidates for space processed silicon if the Skylab and Shuttle studies could be realized in developing a manufacturing process in space with the eventual objective of industrialising space.

Carbon is an abundant element on earth and elemental carbon is sixth in the periodic table with an atomic weight of 12.011 and consisting of 98.9 per cent C_{12} and 1.1 per cent of C_{13}.

The high strength and high modulus carbon fibres are about 7 to 8 microns in diameter and consist of small crystallites of "turbostatic" graphite, one of the allotropic forms of carbon. In a graphite single crystal the carbon atoms are arranged in hexagonal arrays, and are stacked on top of each other in a regular ABAB sequence.

The atoms in the layer or basal planes are held together by very strong covalent bonds and there are weak Van der Waal forces between the layers. This means that the basic crystal units are highly anisotropic - the in-plane Young's modulus parallel to the A-axis is 910 Gn^{-2} m and the Young's modulus parallel to C-axis (normal to the basal planes) is 30 GN cm^{-2}. The spacing between the layers is 0.335 microns. The "turbostatic" graphite resembles graphite single crystal except that the layer planes have no regular packing in the C-axis and the average spacing between the layer planes is about 0.34 nm.

The technique used in obtaining high modulus and high strength is to have the layer planes of graphite alligned parallel to the axis of the fibre.

The basic process in manufacturing graphite fibres is to utilize an organic base precursor with a high percentage of carbon atoms, and through heat and tension drive off all volatile fractions to leave only the carbon atoms. The three most popular precursors are polyacrylonitrile (PAN), staple rayon fibres and pitch fibres. All the three precursors can be carbonized to various degrees with varying difficulty and properties.

(a) Polyacrylonitrile (PAN): Base graphite fibres are made from a long chain linear polymer consisting of a carbon backbone with attached carbonitrile groups. The first step involved in producing a graphite fibre from this polymer is to cyclize the linear structure into a "ladder" type structure. The cyclization reaction is accomplished by holding the prestretched polymer under tension temperatures of 205-240°C for up to 24 hours in an oxidizing atmosphere.

After the completion of cyclization the resulting infusible fibre is heat treated in an inert atmosphere to temperatures ranging from 1,400-3,000°C. The final processing temperature signficantly influences the degree of graphitization that is achieved and the resultant properties of the fibre.

In the preparation of high strength high modulus fibres, Toray oxidized the PAN precursor by contacting the fibres (for less than one second) intermittently at a surface temperature range of 200-400°C. British patents granted to Union Carbide describe a process for the continuous graphitization of textile fibres by stretching at a temperature of around 2,200°C.

The Royal Aircraft Establishment (RAE), UK, have developed a process for the conversion of PAN fibres into high modulus carbon fibres. This required an initial oxidation of PAN fibres in air at between 200-300°C followed by carbonization and then graphitization in an inert atmosphere up to 3,000°C.

(b) Staple rayon precursors: The use of cellulose fibres as precursors for carbon fibres was an important advancement for the carbon/graphite fibre technology. Such commercial fibres from Union Carbide under the trade name of Thornel-50 and Thornel-75 are made by heat-treating rayon filaments in an inert atmosphere in a series of steps to temperatures to the order of 2,700-2,800°C. At these elevated temperatures the filaments are subjected to tensile loads and are stretched or elongated in order to allign the graphite layer planes in a direction parallel to the axis of the filaments.

It should be said that carbon fibres made from a rayon precursor are irregular in shape and the fibre size may range from 5 to 50 microns in diameter.

(c) Pitch precursors: The newest carbon fibre processing technique being used involves the spinning and thermal decomposition of an intermediate liquid pseudocrystalline phase of a coal tar pitch known as mesophase. The mesophase structure forms in the pitch after heating at a temperature range of between 400 and 500°C for up to 40 hours. At this stage the pitch is in the form of a viscous liquid and the carbon molecules are plate-like in shape.

After the conversion of the pitch to the mesophase state it is spun through a small orifice (bushing) into a filament form. The spinning process forms fibres with a high degree of axial orientation. These ordered fibres are made infusible by thermosetting at a relatively low temperature.

(i) Properties of carbon/graphite fibres

Carbon/graphite fibres offer a combination of low weight, high strength, high modulus and stiffness properties superior to similar properties of conventional non-metallic and metallic aerospace-related fibrous material. Further, for the carbon/graphite fibres, their properties vary with the precursor material and this point is well illustrated in tables 1 and 2.

Even within the specific precursor material, the properties of the final product (graphite fibre) varies and depends on the processing parameters such as the carbonization and graphitization temperature. Table 2 illustrates this aspect of graphite fibres made from mesophase pitch.

As indicated earlier, the carbon/graphite fibres were developed for a variety of space-related applications where the superior mechanical and strength properties of these fibres played a vital role in providing the unmet need. The next section describes the strength-related properties of graphite fibres based on the precursor materials.

Table 1. Comparative properties of carbon/graphite fibres (Based on precursor materials)

Property	Precursor material		
	PAN	Pitch	Rayon
Tensile strength (10^3 PSI)	360-450	225	300-400
Tensile modulus (10^6 PSI)	30-50	55	60-80
Short beam shear (10^3 PSI)			
Untreated	10-4	6	4
Treated	18-8	10	8
Specific gravity	1-8	2	1.7
Elongation, %	1.2-0.6	1	-
Fibre diameter, m	-	7.5	6.5

Table 2. Properties of graphite fibres made from misophase pitch

	After carbonization (1,500-1,700°C)	After carbonization (2,800° C)
1. Spacing of carbon crystallites	3.40 - 3.43 A	3.36 - 3.37 A
2. Density (gr/cm^3)	2.1 - 2.2	2.1 - 2.2
3. Tensile strength	140-160 ksi	250-350 ksi
4. Young's modulus	25-35 msi	75-120 msi
5. Electrical resistivity	800-1,200x10^6 ohm-cm	150-200x10^6 ohm-cm

(ii) Strength properties of carbon/graphite fibres

Carbon/graphite fibres are the preferred material due to their low weight and high modulus strength properties. Their properties are also related to the precursor material and are described as follows:

PAN-based graphite fibres: The governing factor of the tensile strength of PAN-based fibres in relation to heat treatment temperature is that the strength gradually increases together with temperature to a maximum of 1,200°C, gradually drops, and levels at 2,800°C at which point the tensile strength is around 200 psi. This figure clearly indicates that the tensile strength does not rise parallel with the increase in heat treatment temperature. The tensile strength reaches a maximum strength of about 450 ksi for fibres processed around 1,200-1,400°C. It drops off significantly for fibres processed at higher heat treatment temperatures. According to Watt and Johnson, the tensile strength of fibres is controlled by the presence of discreet flaws both within and on the surface of the fibres. Barnet and Morr published a summary of strength limiting factors for PAN-based carbon fibres. Many of the internal flaws can be classified into three categories: inorganic and organic inclusions, longitudinal voids due to dissolved gases and irregular voids. During heat treatment these defects change into imperfections and can be seen in the final product. Basal plane flaws are important because they affect the tensile strength of PAN-based carbon fibres.

Surface flaws introduced during the spinning of the polymeric fibre retain their shape even after carbonization. According to Tokarsky and Diefendorf, the tensile strength of graphite fibres is a function of not only internal and surface flaws but also of the radial and axial flaws. All of these flaws can be removed by careful processing, resulting in a significant improvement in the tensile strength.

The electrical properties of PAN-based carbon/graphite fibres were also studied and indicated major changes in the electronic structure of the fibre at the heat-treatment temperature of 1,750°C. This has been attributed to the release of nitrogen. Marchand and Zanchetta have shown that the release of nitrogen affects the graphitization process.

<u>Properties of pitch based and rayon based fibres:</u> The tensile strength of pitch based graphite fibres is directly related to their processing or heat-treatment temperature. The ultimate tensile strength increases relative to the processing temperature, ranging from an average of 200 ksi for fibres heat-treated at 1,700°C to 320 ksi for fibres processed at 3,000°C. The ultimate tensile strength values of pitch based fibres are relatively low and the primary source of failure is due to porosity.

The electrical properties of pitch based graphite fibres have been discussed in detail by Bright and Singer. The electrical resistivity of pitch based graphite fibres drops with an increasing processing temperature (from 10 ohm-cm processed at 1,700°C to 2 x 10 ohm-cm processed at 3,000°C). As such, the pitch-based fibres are excellent conductors and their electrical conductivity is significantly better than PAN-based fibres.

The rayon based fibres possess a high degree of crystallinity ranging from 25-50 per cent. During processing the structure breaks down around 300°C and a re-orientation of the structure occurs around 1,000°C resulting in voids due to the precursor and consequently lower density (1.3 gr/cm^3). As such, the tensile properties of rayon-based fibres are dependent on several processing parameters.

Carbon/graphite fibres are basically strong fibres; however their strength increases almost by an order of magnitude when they are used as fibre composites.

Composite materials offer a combination of strength and stiffness properties superior to non-reinforced fibres. Graphite fibre reinforcements are essentially graphitic due to the fact that the fibres primarily consist of carbon which is amorphous and a lesser amount of graphite which has a hexagonal crystalline structure. The percentage of graphite in the fibre depends on the final processing temperature and rises with the increase in the final temperature.

The form of graphite fibre plays a significant effect on the fabrication of a selected composite structure. The composite product form is determined both by the structural requirements of the end product and the manufacturing process. Table 3 provides the data on the mechanical properties of graphite fibre

Table 3. <u>Mechanical properties of composites (60 per cent fibre volume)</u>*

Reinforcements	Ultimate tensile strength (ksi) 0°	90°	Ultimate compressive strength (ksi) 0°	90°	Initial tensile modulus (msi) 0°	90°	Ultimate tensile strain (%) 0°	90°	Composite density (lb/in^3)
A-graphite fibre	220	7-12	220	40	18	1.5	1.2	0.5-0.9	0.056
HT-graphite fibre	220	6-12	200	35	22	1.3	0.8	0.5-0.9	0.057
HM-graphite fibre	130	5-10	130	30	27	1.3	0.5	0.3-0.8	0.058
VHM-graphite fibre	200	2-3	97	27	45	0.9	0.5	0.2-0.3	0.058
Aramid 49	220	3-6	45	15	13	0.8	1.5	0.2-0.3	0.050
S-glass	260	5-9	100	23	6-8	2.0	3.0	0.3-0.6	0.072
Boron fibre	230	9-13	400	30	30	3.0	0.7	0.3-0.6	0.075

* W.T. Freeman and G.C. Kuebler "Mechanical and physical properties of advanced composites", <u>Composite Materials, Testing and Design ASTM-STP</u>, Vol. 546, page 205, 1974.

composites and compares it with Aramid 49, 'S' glass and boron fibre composites. The table clearly indicates the overall superiority of graphite fibre composites except when compared with boron fibre composites which are very expensive.

(iii) Applications of carbon/graphite fibre composites

A very large and broad technology and information data base has evolved during the past 25 years for advanced graphite fibre composite materials. This data base has been established primarily by work sponsored by the US federal agencies and aerospace companies. As part of the programme to develop confidence in graphite composites, information is available indicating the progress that has been made in this material for a variety of aerospace and industrial applications.

In a programme sponsored by NASA at Lockheed Corporation, advanced carbon/graphite fibre composites technology has been developed for vertical fins (ACVF) used in L1001 transport aircraft. The experience of several commercial aircraft manufacturers continues to show promise in the application of the advanced graphite fibre composites. Graphite fibre epoxy composites were studied at Douglas for the NASA-Langley Research Center where in Thornel 300 graphite fibre composites were used in the vertical stabilizer of DC-10 jets.

Carbon/graphite composites have also been used in the design of the Space Orbiter and Space Shuttle and in many noteworthy space-related advanced components which involve the use of carbon/graphite composites, such as a space stable support system for the secondary mirror of an optical telescope, structural components in the design for X-ray observation of galactic and extra-galactic X-ray sources.

Advanced carbon/graphite fibre composites are also used in the automotive industry. One of the most effective ways of improving the mileage per gallon performance of passenger cars is through a drastic reduction of the weight of the car. The Ford Motor Company is working in this area and weight reduction for heavy trucks has also been reported.

There are several industrial and commercial applications of carbon/graphite fibres which have been in operation in the industrialized countries, including bicycle frames, carbon fibre reinforced concrete (as a building material), corrosion resistant valves, and medical prosthetic devices.

Bushman has updated the role of carbon/graphite fibres as a source of heating in non-metallic tooling. Among the tools that benefited from integral heating elements are bonding fixtures, tools for thermal forming of thermoplastic sheets and tools for the curing of thermosetting matrix prepreg into finished components.

Carbon/graphite fibres have found many applications in radiological equipment. Advantage was taken of these fibres' transparency to X-rays thereby making it possible to monitor a patient's vital signs during some X-ray diagnoses. In another application carbon/graphite fibres were used to make light-weight and X-ray transparent tables for use during patient examination.

All these applications clearly indicate the significance of this space-related technology in industrial development. This is a growing industry, and apart from the key markets which have been identified there are many small segments which are difficult to locate because available data is both limited and restricted.

2. Space-related advanced ceramic materials

The space environment demands a variety of unique characteristics which can only be satisfied by ceramics. This assessment concerns a number of new ceramic materials and products that have been developed over the past quarter of a century to fulfil the unmet need of the space environment and for its unique application. At the same time, the spin-off of these materials and technologies are:

(a) Technical ceramics or fine ceramics;

(b) Materials for integrated optics; and

(c) Industrial sensor materials.

There are other materials and technologies, but due to the scope of this report the selected technologies are considered as mature enough for transfer and significant enough for potential industrial progress.

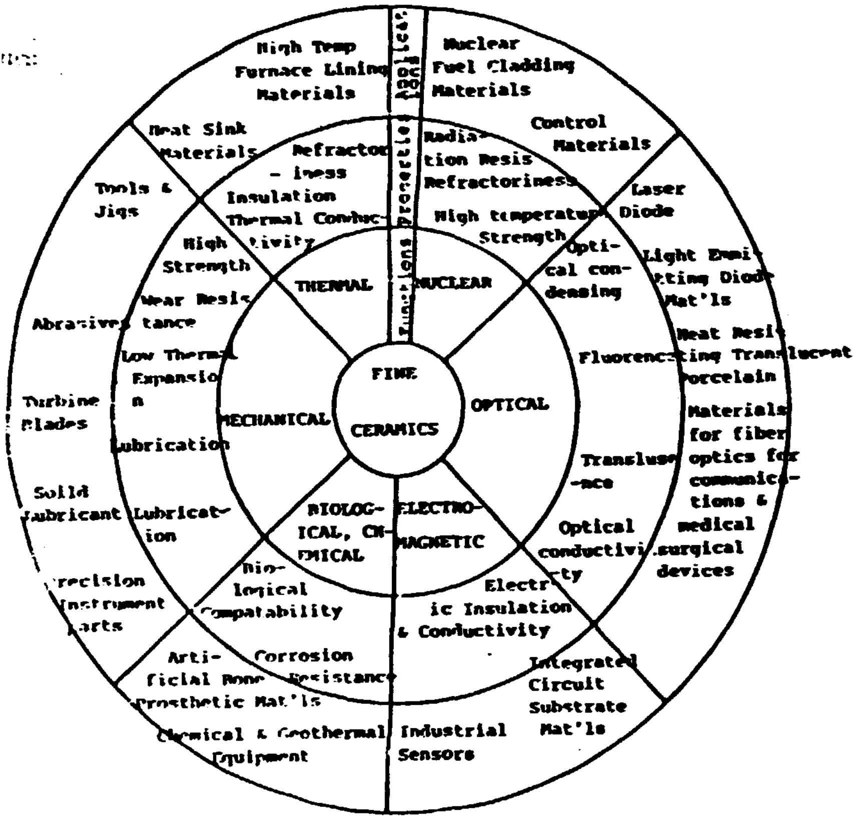
(a) High-temperature ceramics - fine ceramics

The application of heat to ceramic raw materials is one of the earliest of materials technologies. Ancient man discovered that heated wet clay could be moulded into a variety of shapes before baking or firing. By the time the ancient Greeks coined the term "Keromos", mankind had been shaping and firing common clay.

The space-age era is now using this ancient material under sophisticated names for a variety of industrial applications, including automobile engines. There is little doubt that advanced ceramics and/or structural ceramics is a significant "emerging technology" worldwide, affecting such diverse areas as automobile engines, power generation, cutting tools, microelectronics and industrial sensors.

In the United States, these high-temperature ceramic materials are known as advanced or technical ceramics. These high-tech ceramics, referred to in Japan as "fine ceramics", are made from extremely pure, composition-controlled, ultra-fine particles formed, sintered and treated under highly controlled conditions. Their properties give the ceramics superior performance characteristics. The great diversity of practical applications of these fine ceramics as identified by the Fine Ceramic Office, MITI, Japan, is presented in figure VIII.

Figure VIII. EXAMPLES OF FUNCTIONS AND APPLICATIONS OF FINE CERAMICS



Source: Fine Ceramics Office, Ministry of International Trade and Industry - MITI, Tokyo, Japan

What are these so-called advanced ceramics, high-tech ceramics or fine ceramics and how do they differ from the traditional ceramics?

Unlike the traditional ceramic materials which are based primarily on silicates, advanced ceramics include nitrides, carbides, oxides, carbonates, etc. These materials possess specialized properties including high heat, wear and corrosion resistance as well as specialized electrical and optical properties which allow these new ceramics to perform well in a number of high value-added applications. Figure IX provides an overview of these materials. The following are selected high-temperature materials.

Sailon: The acronym "Sailon" was originally given to new ceramic compounds derived from silicon nitride and oxynitride by simultaneous replacement of silicon and nitrogen by aluminium and oxygen. Similar replacements are possible with other structures and other metals such as lithium, beryllium and magnesium. Sailons are made of one, two and three dimensional arrangements of (Si,Al), (O,N) and (M,Si) (O,N) tetrahedra in the same way as the structural silicate tetrahedrons are in the (SiO_4). Aluminium plays a special role because the AlO_4 tetrahedron with five negative charges is about the same size as SiO_4 and can be replaced in the rings, chains and networks, provided valency compensation is made elsewhere in the structure. Jack reported the first of these new materials - "Sailon", and about the same time Oyama and Kamingato and Tsuge reported similar achievements in Japan.

Sailon-type materials can also be prepared from naturally occurring minerals. Dense, sintered solids with compositions in the Si_3N_4-Al_2O_3-AlN systems were obtained by hot pressing a mixture of naturally occurring silica sand and aluminium powder in a nitrogen atmosphere. Hot pressing was carried out at a pressure of 200 kg/cm^2 and temperatures ranging from 1,600 to 2,000°C for one hour in a nitrogen atmosphere.

Hot pressing, as a fabrication process, has found increased use in the ceramics processing industry, with particular emphasis on the preparation of materials with improved properties through composition, microstructure and density control. A general description of ranges used in hot pressing fabrication is included here, but there are no sharp distinctions in the pressure ranges employed, as may be seen in table 4.

Table 4. Ranges in hot pressing fabrication

Press range and application	Mould materials	Size limits for fabricated parts
1. 1,000-5,000 psi Uniaxial	Graphite	Up to 2 ft in diameter
2. 5,000-20,000 psi Uniaxial	Special graphites	
3. 10,000-50,000 psi Isostatic	Al_2O_3, SiC TiB_2, ZrB_2	Increased lengths up to 20 inches
4. 50,000-300,000 psi Uniaxial	High strength steel and cemented tungsten carbide	1 to 3 inch diameter
5. 300,000-750,000 psi	Cemented tungsten carbide	1/4-1/2 inch diameter

Figure IX. Classification of high tech ceramics by functions*

Electric functions	Insulation materials (Al_2O_3 BeO, MgO)	IC circuit substrate, package, wiring substrate, resistor substrate, electronics interconnection substrate	
	Ferroelectrics materials ($BaTiO_3$, $SrTiO_3$)	Ceramic capacitor	
	Piezoelectric materials (PZT)	Vibrator, oscillator, filter, etc.	
		Transducer, ultrasonic humidifier, piezoelectric spark generator, etc.	
	Semiconductor materials ($BaTiO_3$, SiC, ZnO-Bi_2O_3, V_2O_5 and other transition metal oxides)	NTC thermistor:	temperature sensor, temperature compensation, etc.
		PTC thermistor:	heater element, switch, temperature compensation, etc.
		CTR thermistor:	heat sensor element
		Thick film thermistor:	infrared sensor
		Varistor:	noise elimination, surge current absorber, lighting arrestor, etc.
		Sintered CdS material	solar cell
		SiC heater:	electric furnace heater, miniature heater, etc.
		Solid electrolyte for	sodium battery
	Ion conducting materials ([illegible]-Al_2O_3, ZrO_2)	ZrO_2 ceramics:	oxygen sensor, pH meter fuel cells
Magnetic functions	Soft ferrite	Magnetic recording head, temperature sensor, etc.	
	Hard ferrite	Ferrite magnet, fractional horse power motors, etc.	
Optical functions	Translucent alumina	High pressure sodium vapour lamp	
	Translucent magnesium, mullite, etc.	For a lighting tube, special purpose lamp, infrared transmission window materials	
	Translucent Y_2O_3-ThO_2 ceramics	Laser material	
	PLZT ceramics	Light memory element, video display & storage system, light modulation element, light shutter, light valve	
Chemical functions	Gas sensor (ZnO, Fe_2O_3, SnO_2)	Gas leakage alarm, automatic ventilation fan, hydrocarbon, fluorocarbon detectors, etc.	
	Humidity sensor ($MgCr_2O_4$-TiO_2)	Cooking control element in microwave oven, etc.	
	Catalyst carrier (cordierite)	Catalyst carrier for emission control	
	Organic catalyst	Enzyme carrier, zeolites	
	Electrodes (titanates, sulfides, borides)	Electrowinning aluminium, photochemical processes, chlorine production	
Thermal functions (ZrO_2, TiO_2 ceramics)		Infrared radiator	
Mechanical functions	Cutting tools (Al_2O_3, TiC, TiN, others)	Ceramic tool, sintered SBN Cermet tool, artificial diamond Nitride tool	
	Wear resistant materials (Al_2O_3, ZiO_2)	Mechanical seal, ceramic liner, bearings, thread guide, pressure sensors	
	Heat resistant materials (SiC, Al_2O_3, Si_3N_4, others)	Ceramic engine, turbine blade, heat exchangers, welding burner nozzle, high frequency combustion crucibles	
Biological functions	Alumina ceramics implantation Hydroxyapatite bioglass	Artificial tooth root, bone, and joint	
Nuclear functions	Nuclear fuels (UO_2, UO_2-PuO_2)		
	Cladding material (C, SiC, B_4C)		
	Shielding material (SiC, Al_2O_3, C, B_4C)		

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* George B. Kenney et al., "High Tech Ceramics in Japan Current and Future Markets" Am. Cer Svc. Bill, 62 (5) 590 May 1983

In view of their potentials, the application of advanced ceramics to a variety of products is increasing and includes gas turbine engines and cutting tools, to name but a few. Perhaps the most difficult engine component imaginable for ceramic applications are turbine blades in terms of thermal and mechanical stress. Typical values of blade specific stress for small engines are of the order of 100,000 psi. Allowing a safety factor of three for ceramic turbine blades, the desired specific strength exceeds 300,000 psi. For this reason alone, materials technology in the field of Si_3N_4 and SiC has been directed towards further improvements in the processing and fabrication of these materials. Specifically, such trends have also been concisely identified by Kelly.

These high temperature ceramic materials, because of their thermal and hardness properties, have found near-term applications in vehicular parts such as turbo-charger rotors, piston rings and pistons, cylinder liners and small stationary engine parts. Furthermore, due to their hardness, the largest single use of these advanced ceramics is for metalcutting tools and wear parts.

(b) Material for integrated optics

Integrated optic (IO) circuits are optically guided wave devices that perform a variety of processing functions on the light beams which they guide. The largest end use for IOs is in fibre optic communication systems which include both military and commercial communications.

IO devices can be manufactured using single crystal ceramic materials such as lithium niobate as the substrate because of its desirable electro-optical properties. Another such material is gallium arsenide. These IO devices offer the potential for significant performance and cost-saving benefits, in particular for fibre optic systems.

IO devices are fabricated by diffusing waveguides or substrates made of materials that have large electro-optic effects. The waveguides or channels have higher indices of refraction than the underlying substrate material and allow them to contain and transmit light. Due to the large electro-optic effect, the index of refraction of the substrate material changes as voltage is applied. This change in the refractive index of the substance along with the geometry of the waveguide is what determines the function of the device.

Most optical glass and high-tech ceramic materials for use in integrated optics are evaluated for their desirable characteristics, large electro-optic effect and ease of fabrication. The change in the refractive index in a particular crystallographic direction is related to the applied stresses by the electro-optic co-efficient in that direction. The desired material must have a high value for the electro-optic co-efficient "r" to induce a substantial effect that is close to being equal in various crystallographic directions.

Other preferred materials are from the family of single crystals, i.e. lithium niobate and lithium tantalate.

Lithium niobate is the preferred material due to the fact that it has relatively the same values of "r" in different crystallographic directions thus making it insensitive to the plane of polarization of incoming light waves, and to the ease in fabrication. Other candidate materials include strontium barium niobate. Lithium niobate is a relatively mature material. It is used in single crystal form and is grown from melt by the standard Czochralski method, whereby lithium carbonate, a relatively cheap material and niobium pentoxide, which is expensive, are mixed and melted in a crucible and a single crystal is pulled out from the molten melt. The final crystal is generally three inches in diameter and two feet in length. The crystal is cut into one millimetre wafers to produce waveguides. The waveguides are made by channels which are a few microns in diameter. Different kinds of devices - from couplers to switches and modulators are formed by changing the design of the channel patterns and electrode configurations.

(c) Industrial sensor materials

An important spin-off of space-related technologies are sensor materials and technologies which could be effectively utilized. The sensors are useful in electrical and mechanical equipment and a huge variety of new industries and technologies offer hope and promise of new approaches to sensing. These include solid state sensors, biosensors, fibre optic sensors, robot sensors and smart sensors.

What are these industrial sensors? Simply speaking, a sensor is a small device that detects and/or measures conductance, capacitance and resistance or self-generating effects into electrical signals. It is a device which senses and quantifies a relative or absolute value of a physical or chemical phenomenon such as temperature, pressure, pH, flow rate or the intensity of radio, sound, light or air waves and converts these into a useful signal.

Solid state sensing devices are made from a variety of materials including single crystals, semiconducting and polycrystalline materials. Silicon, due to a number of its sensitive characteristics, is a useful sensing material. The material can be combined with other materials such as piezoelectric materials, which make it sensitive to acceleration, mechanical vibration and direct measure of electronic potentials.

One of the important applications of silicon sensors utilizes the near perfect characteristics of silicon, i.e. its elasticity for sensing pressure. Other applications include micro-electronics and sensing the magnetic field. Other similar magneto-sensitive devices include a CMOS magnetic field sensor and a carrier-domain magneto-meter.

One barrier to full industrial automation has been the lack of instrumentation for use in the industrial environment. Space-related technologies solved the problem by developing non-invasive and non-instrusive instruments. Another term used to describe these instruments is by the technique of non-destructive testing or NDT. For space applications a piece of equipment is often allowed to retire after a given number of hours, miles or similar unit of measure, even though the spacecraft or equipment may be in perfectly good order. This is done by NDT in order to find incipient failures. In this context a device was developed using a small yttrium iron garnet (yig) sphere of about 30 mil diameter looped around with a single turn of wire. The device becomes a resonant element in an oscillator circuit. The frequency and amplitude of the oscillator provides the information relating to the condition of the resonator which is affected by cracks, flaws, etc.

Solid state imaging devices are used in robot sensors or robot vision where information is obtained without disturbing the environment, such as in charged-coupled devices - ccd. Currently ccds are of the size of postage stamps, have low voltage requirements, generate direct digital output and register good images.

Robotic sensors are also used in welding where a major application is in seam tracking and robotic seam welding.

The greatest impact of the space related sensor technology for industrial applications has been in the area of optical fibre sensor technology. Development of fibre optic sensors started around the late seventies. Fibre optic sensors offer a number of advantages over existing techniques and include geometric versatility, rotation and their use in corrosive, high voltage, electrically noisy and other stressing environments such as arc welding.

2. MATERIALS FOR SPACE EXPLORATION

Materials for aerospace

The development of materials, together with advances in the technology of fabricating parts, will play a key role in aerospace systems of the future. Among the materials developments projected for the year 2000 are new composites and alloys for structural members; superalloys, ceramics and glass composites for propulsion systems, and carbon-carbon composites (carbon fibres in a carbon matrix) for high-temperature applications in places where resistance to heat and ablation is critical.

In fabricating parts and structures the main goal is to save weight, thereby increasing fuel efficiency and the distance travelled per dollar spent for fuel. (In 1980 fuel accounted for 55 per cent of the direct cost of operating an airline.) Much progress has been made toward fabricating secondary structural parts of advanced composite materials, with demonstrated weight savings of from 25 to 30 per cent. Much remains to be done in finding advanced materials that are tougher and at the same time easier to process, so that the cost of fabrication can be reduced. It will also be necessary to evolve new structural design concepts that are specifically adapted to exploiting the major current development in materials science: the increasing capability to tailor materials in order to achieve specific properties. Only in this way will the potential weight and cost benefits promised by the new materials be fully realized.

A good start toward meeting the materials requirements of all these goals of the Office of Science & Technology (USA) has been made over the past few years. Those years have seen noteworthy advances in two fields: synthesizing new materials and employing new composite materials in aerospace structures.

A major new process is the preparation of novel alloys by what is called rapid-solidification technology (RST to materials engineers). The key is extremely fast cooling of the material from a liquid starting phase to a solid phase that is a powder. The rate of cooling can be upward of one million degrees per second. The process gives aluminium alloys higher specific stiffness and strength and alloys based on aluminium or nickel improved temperature resistance. Subsequent machining does not affect the desired properties, and as a result the materials can be made into structural parts by conventional techniques.

Several other new or emerging concepts in processing and assembly are contributing to the improvement of materials. They include superplastic forming, diffusion bonding and "net shape" fabrication. In superplastic forming large changes in the shape of a material are achieved under conditions of high temperature and low pressure. In diffusion bonding the parts are joined at high temperature and pressure. Joining results because atoms diffuse across the solid surfaces being joined; it does not entail the melting that takes place in welding. In net-shape fabrication a powder-based material is formed into a finished shape without the need for further machining. The technique is to compress the powder in a glass, ceramic or steel container shaped like the part.

The new composite materials consist of a matrix, which can be either an organic resin or a metal, and fibres of high strength that are embedded in the matrix. The commonest fibre is graphite, but fibres are also made of glass, boron, silicon carbide, Kevlar (an organic fibre) and filamentary metals. The matrix holds the composite together and allows the material to be formed into various shapes. Because of the matrix it is also possible to tailor the material to obtain desired properties such as strength and stiffness. Composite materials are stronger than steel, stiffer than titanium and lighter than aluminium. In addition they offer unique mechanical properties, such as resistance to corrosion and to high temperature. For these reasons they are particularly effective in advanced aerospace structures that must be both strong and light.

Other recently developed materials are aluminium alloys that resist high temperature, aluminium alloys low in density and therefore low in weight, improved ceramics and high-strength steels. Compounds of titanium and aluminium offer low density and resistance to high temperature. Rigid-rod polymers are also new; small rods made of a polymer demonstrating high strength and stiffness are embedded in a tough polymer matrix.

An indication of what materials technology has already achieved in improving aerospace vehicles can be seen in its application to jet engines. Over the past 30 years the thrust delivered by a big jet engine for transport and cargo aircraft has increased almost sixfold, until it now approaches 66,000 pounds. During the same period the weight of the engine has increased by a factor of only two or three. The thrust-to-weight ratio of the jet engines being developed for the next generation of military aircraft will exceed 10:1; by the year 2000 it may approach 15:1.

An example of what has been done is seen in the blades of jet turbines. They were once made of wrought nickel. Now advanced metal alloys shaped by casting are favoured. Moreover, they can be made with complex internal passages that provide cooling by air, thereby extending the service life of the blade. The key to this achievement is "investment casting". A wax pattern of the component is coated with a ceramic slurry, which is then dried. Under heat the wax is melted out, leaving a ceramic mold for the part, which is then made by pouring molten metal into the shell.

A major recent development is directional solidification during the investment-casting process. In this process a temperature gradient and a controlled rate of cooling give the blade columnar crystal grains aligned along its major axis. Directional solidification yields major gains in blade life, inasmuch as failure usually starts at transverse grain boundaries (perpendicular to the axis of the blade) and directionally solidified crystals do not have such boundaries.

Another improvement has taken place in blade coatings, which protect the structure from oxidation, corrosion and sulphation from the jet fuel. The new coatings consist of chromium, aluminium and yttrium alloyed with iron, cobalt or nickel. They offer protection at temperatures as high as 2,100° F.

With these improvements and similar ones affecting other aspects of aircraft propulsion, a typical propulsion system today consists of 38 per cent nickel, 28 per cent steel, 22 per cent titanium and 8.5 per cent aluminium, along with small amounts of composites, cobalt and ceramics. The improvements can be expected to continue, so that by the year 2000 a typical propulsion system will be likely to contain about 20 per cent each of composites, steel, nickel and aluminium, 15 per cent titanium, 2 per cent ordered alloys (aluminides, meaning titanium-aluminium or nickel-aluminium of a specific composition) and 1 per cent ceramics.

Progress in much more than propulsion will be needed to reach the aerospace goals specified by the Office of Science & Technology. Further advances in finding new materials and in processing existing ones are crucial. The new generation of subsonic aircraft will need advanced materials for both the airframe and the engines if they are to achieve the desired level of fuel efficiency. These materials will have to be much stronger, stiffer and lighter than the ones they replace. The materials will also have to offer considerably improved resistance to fracture, corrosion and high temperature.

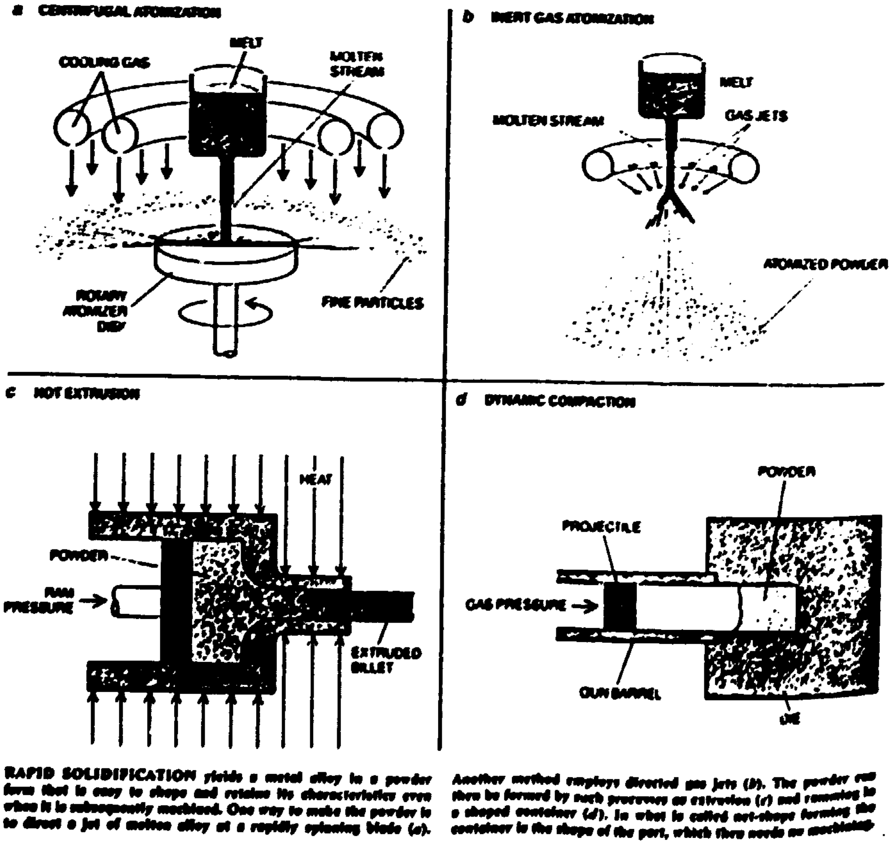
Aluminium, steel and titanium will probably continue to be the principal materials in subsonic airframes. All these materials, however, will have to be improved. Aluminium alloys with enhanced strength and stability at high temperature are on the horizon. Work is being done to improve the ability of aluminium alloys to resist corrosion and fracture.

One of the alloys of major interest is aluminium-lithium. Its improved properties are based on its lower density. Other aluminium alloys (such as aluminium-iron-molybdenum-zirconium) function well enough at high temperature to be competitive with titanium up to 600° F.

Future steel alloys will be more tolerant to stress and damage without compromising strength or ease of fabrication. Metal-matrix composites also show promise. A material consisting of fibres embedded in, say, aluminium can achieve large benefits in the design of aircraft because of its lower weight, improved strength and greater resistance to high temperature. Such composites are likely to get better with improvements in the quality of the raw materials and in the manufacturing process. Today's titanium alloys usually have to be fabricated at high temperature. Future alloys will be workable at room temperature because of improvements in microstructural composition. That will reduce the cost of making parts from them.

Another development that is having a major effect on aircraft design is the rapidly growing number of parts made of organic-matrix composites, such as graphite fibres embedded in an epoxy matrix. Some 40 per cent of the parts of the subsonic aircraft of the immediate future may be made of such advanced composite materials. A new trend is toward thermoplastic composites: fibres embedded in a plastic that can be rendered malleable by heat and that becomes strong and tough after cooling. The composites work well in compression and at high temperature. They also resist damage in manufacture and in service and are simpler to repair than other composites.

The aim of all this work is to have a replacement for the present large subsonic aircraft, such as the Boeing 747, by the year 2000. Indeed, the project has the formal name Transcentury Subsonic Transport. Taking into account the recent and prospective improvements in materials and processing techniques, one can foresee that the new subsonic craft will achieve weight reductions of some 40 per cent, leading to significant gains in fuel efficiency. Some of the weight reduction will result because an aircraft



RAPID SOLIDIFICATION *yields a metal alloy in a powder form that is easy to shape and retains its characteristics even when it is subsequently machined. One way to make the powder is to direct a jet of molten alloy at a rapidly spinning blade (a). Another method employs directed gas jets (b). The powder can then be formed by such processes as extrusion (c) and ramming in a shaped container (d). In what is called net-shape forming the container is the shape of the part, which then needs no machining.*

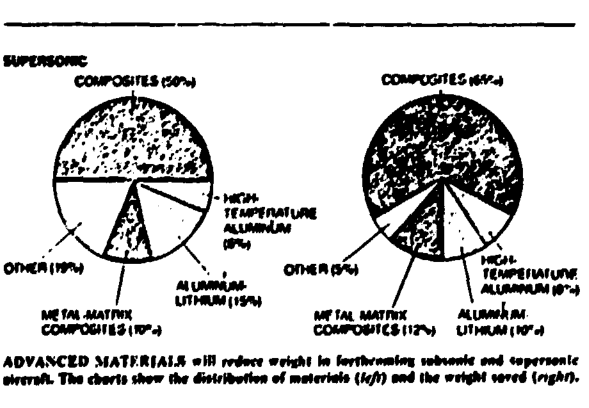
designed to take full advantage of the improved properties of advanced materials can be smaller than today's airplanes, in which parts made of such materials often merely substitute for parts made of heavier material.

Saving fuel will be even more important in future supersonic aircraft. A pound of fuel saved in such a craft has twice the payoff of a pound saved in a subsonic one. Many other improvements will have to be made to meet the Office of Science & Technology goal for supersonic vehicles. They entail advances in aerodynamics and propulsion, all of which will depend on improved materials.

The requirements in aerodynamics arise mainly from the fact that temperatures on the surface of an aircraft flying at Mach 3.5 (3.5 times the speed of sound) can reach 1,000° F. The air inlets, the outlet nozzles of the engines and the leading and trailing edges of the wings will be critical areas. Advanced metal alloys and advanced composites will be needed to cope with such temperatures. Indeed, most of the primary structure of the airframe will be made of such materials in order to achieve good temperature resistance, light weight and a high ratio of strength to density. A sandwich structure consisting of two thin skins of titanium and a honeycomb titanium filler is a likely candidate.

In propulsion the new supersonic aircraft will need reductions in the weight of the engines and improvements in their performance. The compressors and combusters of the engines will have to run at higher temperatures than is now the case. They will therefore call for such materials as refractory metals, intermetallic compounds (titanium-aluminium and nickel-aluminium among them) and structural ceramics (silicon carbide, silicon nitride and carbon-carbon composites).

The transatmospheric airplane will require further quantum advances in the technologies of propulsion, aerodynamics, avionics (electronic control systems) and long-life materials for both low- and high-temperature applications. Propulsion technology is the biggest challenge, followed closely by materials technology for both the propulsion system and the airframe.



ADVANCED MATERIALS *will reduce weight in forthcoming subsonic and supersonic aircraft. The charts show the distribution of materials (left) and the weight saved (right).*

In all likelihood the craft will incorporate a dual propulsion system: ramjets for flight in the atmosphere and scramjets for space flight. A ramjet does away with the heavy air compressor needed in a turbojet; at supersonic speeds the air entering the engine compresses itself by ramming into a barrier. The compressed air is thereupon mixed with a hydrocarbon fuel for combustion. A scramjet (the word comes from supersonic combusion ramjet) works much the same way but burns hydrogen. The hydrogen is stored in the craft as an extremely cold liquid. The liquid hydrogen cools the engine. In the process, it is warmed enough to become a gas, which serves as the fuel. Materials of interest are the nickel- and cobalt-based alloys, suitably coated, that resist high temperatures, and coated refractory alloys of niobium and molybdenum.

The airframe of the hypersonic transatmospheric craft will have to be made of strong, light, heat-resistant materials. A prospectus drawn up by Richard N. Hadcock of Grumman Aircraft Systems, Inc., envisions a fuselage made of heat-resistant metal alloys; wings and fins made of a carbon-carbon composite; engine inlets, ducts and nozzles made of ceramic-matrix composites; landing gear made of metal-matrix composites; internal parts made of organic-matrix composites, and fittings made of titanium.

The materials technology for the airframe builds on the application of a number of materials concepts that have already been put into practice in the space shuttle. For example, the new aerospace craft will have to withstand high external temperatures. Calculations have been made of the temperature at various places on the outer surface when the plane is in sustained flight at a speed of Mach 8 and an altitude of 88,000 feet. They range from 1,400° F along the top of the fuselage to 3,260° at the nose.

The space shuttle's solution to similar conditions, carbon-carbon composite materials for the nose and leading-edge structures, can be applied to the transatmospheric craft. Such a material consists of a laminated structure made of layers of graphite-fibre cloth with a carbon matrix or binder and a silicon carbide coating. The fibres provide high strength and stability at high temperatures; the binder provides the same qualities plus rigidity and low porosity, and the coating provides resistance to oxidation. As a result the material is reusable because it is not ablated and continues to be effective in successive flights. (Engineers often refer to the material as RCC, for reusable carbon-carbon.) In addition the leading-edge structures of a transatmospheric craft will probably need an active cooling system. It would consist of pipes circulating a liquid-metal coolant.

The outside shell of the vehicle will probably be a three-part structure. From the exterior inward the components will be a layer of a heat-resistant metal alloy, a layer of insulating material and a strong but light layer made of an organic-composite material.

Another important component of the structure will be cryogenic tankage: an insulated storage system to maintain the liquid-hydrogen fuel at a low temperature. One can envision a tank consisting of a metal-matrix composite and a surrounding layer of insulation made of a foam material that is virtually impervious to the transfer of heat.

Spacecraft in the past have incorporated such structural materials as aluminium, stainless steel, titanium, magnesium, berylium and Invar (an iron-nickel alloy noted for low thermal expansion). Today the tendency is toward incorporating materials that yield still better performance because they are high in stiffness, low in mass and stable in dimension. Metal-matrix composites are notable for these properties. Among them graphite-aluminium and graphite-magnesium show the greatest promise.

For the projected space station the National Aeronautics and Space Administration has proposed that the inhabited modules be made of aluminium. One reason is that composite materials can give off gases that might be toxic. Moreover, aluminium offers more protection against radiation. For other parts of the space station, such as large beams and trusses, composite materials are likely to be ideal because of their stiffness, low density and resistance to expansion. (Excerpted and reprinted with permission. Copyright (c) 1986, Scientific American, Inc. All rights reserved. Article written by Morris A. Steinberg)

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Success in space

Over the past 15 years or so, several thousand composite parts have been successfully used on spacecraft. The main reason for most of the early applications was weight reduction. Now, however, the trend towards high-performance communications satellites and precision space science instruments is changing the technology of spacecraft materials in general. As a result composites are now the leading candidates not just for saving weight but also for increasing systems' performance. Their high specific strengths and stiffnesses, together with their low coefficients of thermal expansion make them very attractive for high-precision space structures.

Until recently, the design lifetime of most spacecraft was a mere five to seven years, so material changes in the space environment have not been considered very important. The current trend, however, is towards lifetimes of 10 to 15 years, and ultimately this is likely to become 20 to 25 years. The long-term durability of composites in the space environment is therefore arousing much interest.

The basis of design in most composite spacecraft structures is stiffness. The carbon fibres used are high modulus or ultra-high modulus types, whereas those used in aircraft are high modulus or high strength fibres. Ultra-high modulus fibres are an order of magnitude more expensive than aircraft fibres. Even so, the high launch costs of satellites make each kilogram of mass saved well worth the extra cost.

The increasing use of composites in recent years has been strongly influenced by the continuing development of high and ultra-high modulus fibres. These have resulted in lighter and more dimensionally stable structures.

One of the problems arising from these ultra-high modulus carbon fibres, however, concerns testing of some material specimens. They are more brittle than aircraft carbon fibre composites and for space use tests need to be carried out at cryogenic temperatures, which exacerbates the problem. Tests therefore have to be modified to reduce the difficulties arising from this.

Carbon fibre composites are more brittle and more variable in their properties than some conventional materials and both the brittleness and the variability increase as the modulus increases. When dealing with ultra-high modulus fibres, therefore, extra care is needed when interpreting materials tests results.

Few users of advanced composites seem to have the knowledge to carry out such analyses and not all of the methods used are appropriate for these materials. However, suitable techniques are available. A comprehensive suite of software has been developed at Marconi Space Systems for the statistical analysis of test data and this derives design-allowable data from test data directly and quickly. Such formal analysis carried out on the results of an extensive materials test programme has resulted in design-allowable properties which designers can have great confidence in.

Care needs to be taken when designing joints for any composite structure. It is particularly difficult to make efficient structural connections to honeycomb panels. This is not a problem which is peculiar to composites but is a function of the mode of panel construction. Metal inserts are common in composite sandwich panels but leave much to be desired from both the mass and reliability points of view. Other options, such as moulded short carbon fibre/epoxy inserts for bolting through the panels, are available but need more development. More straightforward edge attachments can be made by chamfering the honeycomb core and running the panels out to solid edges. The edges are stiffened by extra plies of composite and a syntactic foam core.

Bonded joints also present problems, due at least in part to the lack of reliable design data and limited design tools. Such data is obtainable, however, and the reliability statistics for composite joints are the same as for composite materials. It is a matter of carrying out sufficient tests and the necessary analyses. Attachments to lightweight structures are difficult to make without reducing structural efficiency. Care is therefore required in producing designs to minimize this loss.

Fatigue is not a problem with single-use spacecraft but the design of re-usable spacecraft will have to take it into account. Carbon fibre composites are less susceptible to fatigue than conventional materials, but the question of fatigue still has to be considered. Fortunately, evidence suggests that composite fatigue performance is linked to static strength, so for those with an understanding of this area of composites technology the problems should be somewhat reduced.

Carbon fibre/epoxy has the capacity for higher damping than aluminium alloy, at least in principle, but cross-plying reduces its effectiveness in this respect. If this property could be used effectively it would lead to higher damping in structures formed from composite materials. The advantages of such structures would include greater protection for sensitive electronics devices such as point contact diodes.

Composites can also have advantages over other materials in the thermal design of spacecraft. Glass fibre/epoxy has a low thermal conductivity and can be used for insulation. Carbon fibre/epoxy on the other hand, has a higher thermal conductivity and can be more effective as a radiator. Carbon/carbon (carbon fibres in a carbon matrix) can be used where even higher thermal conductivity is required. This material however is expensive and difficult to manufacture. The process is quite protracted and components therefore have long lead times.

The most commonly used resin matrices in these materials are the epoxies and the temperatures these can withstand are limited. The performance of epoxies at elevated temperatures is determined by their chemistry and curing schedule. They are limited to operating conditions below their glass transition temperature (Tg). Moisture in the atmosphere will be absorbed by epoxy resins and this has the effect of reducing the initial Tg.

But the primary concern for spacecraft is how the material will respond in the unique operating environment of space. Vacuum can result in outgassing of materials and this is particularly so with polymeric materials. Outgassing is a problem because it can lead to the contamination of sensitive instruments as well as altering the properties of the material.

At very low temperatures, say 90 K, resins stiffen and become more brittle. Although this is not significant in terms of overall mechanical properties there are microscopic effects. Thermal cycling leads to microcracking and a consequent reduction in matrix dominated properties. Crack densities after a given number of cycles vary between materials and this is attributed to different coefficients of thermal expansion and stiffness of fibres and matrices, which in turn control the internal stress states of the materials. Tensile and flexural stiffness are not significantly affected by microcracks as these properties are dominated by the fibres, not the matrix.

Long-term exposure to radiation can lead to in-depth radiation dose levels that exceed the damage threshold for many polymers. Property degradation may therefore be expected during the service life of composites. In matrix dominated (transverse) tensile properties, differences have been found between irradiated and non-irradiated materials showing that space radiation will degrade most polymer matrices. Radiation induced degradation of the matrix also affects the thermal expansion properties of these materials and reduces the glass transition temperature.

For long-term use polymer matrix composites may well have to be coated to protect the resin from ultra-violet degradation and atomic oxygen erosion in low earth orbit, and from low energy electron and proton degradation in geostationary orbit. Experimental coatings are currently being developed such as the vapour deposited of metals and metal oxides, and wrapping with metal foils. These may protect the matrix.

An important spacecraft application for CFRP (carbon fibre reinforced plastics) is in the construction of antennae. The more gain that is required at a given frequency the larger an antenna needs to be. It also needs to be dimensionally stable.

The electrical properties of CFRP have been investigated but most of the knowledge gained has been in relation to aircraft structures and applies to direct or low frequency currents. Little is known of properties in the gigahertz range, especially above 30 GHz.

The reflection of electromagnetic radiation by the surface of a CFRP antenna which does not have a conductive coating will take place at the fibres closest to the surface. The reflective properties of such an antenna depend on whether the fibres are unidirectional or woven, and if woven, on the form of the weave. The orientation of the fibres affects the polarization of reflected signals and this needs to be considered during design.

These polarization effects may not be of any great importance for communications antennae, but for antennae in instruments such as radiometers, polarization is very important and any problems arising from fibre orientation would affect them. This can be overcome by metallizing the active surface of the antenna.

It has to be borne in mind that carbon fibre composites, at least in their present form, can provide only limited electrical shielding. Also they cannot provide an adequate electrical bond path. If a composite material with much better electromagnetic shielding is required, carbon/carbon or a metal matrix composite would have to be used.

It is possible to improve the electrical properties of carbon fibres, by intercalation. This is claimed to increase the electrical conductivity of ultra-high modulus fibres, for example, by an order of magnitude with little or no reduction in mechanical properties. All these features are complicated by the need for joints.

Joints can be a problem from the electrical point of view in that carbon fibres, which are themselves electrically conductive, are contained in an insulating matrix. The shielding properties of a CFRP structure also depend on the geometry of the joint, the size of the gaps and the frequency of the incident radiation. Joints can be designed to be more conductive and less prone to radiation leakage but the price is additional complication. (Source: Advanced Composites Engineering, March 1987)

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3. MATERIALS PROCESSING IN SPACE

Space: beginnings of a new competitive industry

by Patrick Dubarle

Space provides a unique set of conditions which are difficult to reconstitute on Earth - the absence of convection currents or vibrations, a sterile environment, an almost perfect vacuum and of course very low gravity. These conditions are very advantageous for materials processing, especially the production of ultra pure crystals, the separation of substances and the homogenization of compounds.

Although the idea of using near weightlessness to conduct experiments on materials was thought of long ago, most of the projects now under way are still in the very early stages. The most advanced is an experiment in electrophoresis (a technique for separating organic substances in an electric field for the production of medicines) performed on board the Space Shuttle. This project, which was started in 1977, is being conducted by McDonell Douglas in conjunction with Johnson and Johnson, both US firms.

Pharmaceuticals, glass products and semi-conductors are the areas in which MPS might be the most promising. The most optimistic forecasts are for a market of several billion dollars in the 1990s. However, so far, only one space product has been marketed - tiny latex spheres manufactured on behalf of the United States National Bureau of Standards.

How profitable space production will be depends on the value added which might be contributed by space technology, the comparative performance of space and Earth techniques and the cost of launching.

Further research is necessary in this uncertain area. Goverments are increasing their R and D budgets but are above all trying to stimulate private sector initiatives. In the United States, Joint Endeavor Agreements (JEA) and Technology Exchange Agreements have been developed to encourage production in a space environment. Companies signing the agreements are then entitled to cut-rates for shuttle flights and use of NASA's expertise. They keep the industrial property rights concerning the data and results, provided that the Agency is given access to them. The JEAs signed so far include the agreements on electrophoresis (with McDonell Douglas), on organic crystals (with 3 M) and on gallium arsenide crystals (with Microgravity Research Associates). NASA has also extended the range of its agreements by concluding a JEA with Fairchild Industries for the development of the LEASECRAFT, a retrievable multi-mission platform. The Agency is also offering a canister service for 500 kg loads (gross weight) for low-cost small-scale experiments.

In Europe, action is centred on developing the equipment required for experimental activities in space. The Federal Republic of Germany has built the free-flying SPAS platform which made its first flight on the shuttle in 1983. ESA started space microgravity experiments on the first SPACELAB mission. It is at present financing the development of a EURECA platform. Finally, the Japanese programme for the use of microgravity should materialize at the end of the decade with experiments in orbit.
(Extracted from The OECD Observer, No. 134, May 1985)

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In search of the perfect crystal

Manufacturing in space is an expensive proposition. Economics dictate that the products with the highest value per unit volume are the best candidates for space processing. Electronic materials fit this requirement nicely and the unique advantages inherent in the orbital environment may add enough value to the manufactured crystals to make the effort feasible, perhaps even necessary in the competitive electronic components business. Several materials have been identified as good prospects for future programmes, and the ranks include detector materials as well as those suited to computer chips.

Electronic materials are likely to have the most stringent processing requirements of any of the candidate materials now being considered for space manufacuring operations. An extremely clean, low gravity environment is a must for good production yields of dislocation-free semi-insulating crystals of compounds such as gallium arsenide and indium phosphide.

Stellar opportunities for GaAs

GaAs is a well-known high-efficiency chip material with many potential applications in electronics and electro-optics. The difficulty in producing acceptable crystals at reasonable yields also is well known. Prof. Harry Gatos at M.I.T. has developed an electroepitaxial crystal grower in a co-operative effort with Microgravity Research Associates Inc., Coral Gables, Florida, that could set the stage for an improvement in GaAs yields from the less than 17 per cent seen on Earth to 97 per cent in space. The M.I.T. laboratory has grown crystals 2 to 4 mm thick, 1/2 in. (13 mm) diameter, with zero dislocations and carrier mobilities of 7,000 to 8,000 volt-seconds - near the theoretical limit of 8,500 volt-seconds.

Electroepitaxy is M.I.T.'s patented process - it involves passing an electric current through a solution to encourage the migration of atoms to the crystal growth interface. The process is less energy intensive than other common methods because the solution temperature required is below the melting point of the crystal. A suitable furnace design is under development for a series of shuttle flights that will take the programme from proof of concept through proof runs of full-scale production hardware. During this series, the researchers will look at other III-V materials including indium phosphide and even more complex crystals involving three or four component compounds. Commercial quantities of electroexpitaxial GaAs itself may be on the market by 1990 as a result of this programme.

General Electric recently completed a study for NASA that assessed the automation technology required for two future Space Station manufacturing facilities: a GaAs electroepitaxial wafer factory, and a facility for fabricating microelectronic VLSI chips. Linked together, these two factories could take raw gallium arsenide in one end and serve up ready-to-dice microprocessors on wafers at the other.

Although a complete analysis of cost effectivess was not part of this study, researchers H.R. Mallet and D.A. Kugath of GE feel that an integrated factory capable of producing up to 80,000 3-in. wafers per year by the year 2000 is feasible, given continued progress on robotics that would allow largely autonomous operation of the facility.

Free fall: gravity in a new guise

Convection currents are the biggest drawback in Earth-bound crystal growing operations. Of the two forces that drive convection, buoyancy is the one eliminated in zero gravity. Surface tension driven forces (such as Marangoni convection) remain, but to some extent these can be harnessed to sweep impurities away from the developing crystal.

The major, electronically significant growth defects found in crystals are growth bands, growth sector boundaries, inclusions and dislocations. The origin of these defects can be attributed largely to the influence of gravity. Gravity acts on temperature gradient regions in a selective manner, making disruptive mass transfers during crystal growth inevitable. On Earth, that is.

In free-fall conditions, in Earth orbit, objects apparently experience zero gravity. The absence of gravitational effects is an illusion, however, since a spacecraft in orbit is not out of reach of the Earth's influence at all. According to Earth-bound visionaries Newton and Kepler, objects in different orbits require different velocities to attain free fall. Since a spacecraft is not just a point in space but a 3-dimensional structure, its frame is subtly twisted by "tidal" forces from Earth that pull on the outward edge and push against the closest. These accelerations are felt by objects within the structure, as well. To cargo being carried (or a process being conducted) at any location other than the spacecraft's centre of mass, tidal accelerations look exactly like gravity; microgravity, perhaps, but the source of convective perturbations in crystal growth just the same.

Movements of the crew within the spacecraft and pulses from the attitude control thrusters both add accelerations to the processing environment. A quiet microgravity level of 0.00001 g was expected for the crystal growing experiments on Spacelab 3 flown in 1985. The crystal apparatus was carefully installed near the centre of mass. The shuttle was placed in a gravity-gradient orientation that made use of the orbital forces to lock the attitude of the craft relative to the Earth in a manner similar to the way the Moon is constrained to always point the same face toward us. Thruster firings were reduced by this strategy, but actual measurements of the microgravity experienced by the processes conducted on this flight indicated a level 100 times higher, 0.001 g, than that hoped for. This is some indication of the difficulty in satisfying the desire expressed by one materials scientist for an environment one million times quieter.

Processing without walls

Elimination of contaminating influences is very difficult to do on Earth. The processing container alone can be the source of many problems. In microelectronics, where significant electrical effects can be produced by the addition of dopants in the minutest quantities, we would like to be able to ignore the possibility of trace materials contributed by the container. In space, we can do that by leaving the container out of the process entirely. In place of confining walls, we can restrain the motion of the solutions by acoustical levitation, a gentle magnetic field, or, as in the case of float zone processing, by a delicate surface tension connection to a supporting rod of the same material. A bonus of containerless processing is the elimination of physical effects on the growing crystal caused by contact with the walls of the chamber.

The high-grade vacuum of space is one of the intriguing advantages to orbital processing. Maintaining a clean, extremely low-pressure environment is both expensive and necessary to modern electronic materials fabrication. One proposal, put forward by Robert J. Naumann of the Marshall Space Flight Center, would take a molecular beam epitaxy (MBE) device outside of the spacecraft entirely. Protected from low-orbit atomic oxygen by its position behind the orbiter's wake shield, the wafer processing apparatus can go about its work under an equivalent pressure of 10^{-14} torr. This exceeds practical Earth vacuum chamber limitations of 10^{-11} to 10^{-12} torr. In addition, out in the open there are no chamber walls to contribute contaminants, and the "pumping speed" of such an arrangement is infinite - molecules released from the operation continue moving right on out of the neighbourhood.

Naumann's outdoors concept for semiconductor fabrication even makes use of the scouring effect atomic oxygen and unfiltered solar energy have on unprotected surfaces. The shield is cleaned before processing begins by turning it around to face the orbital oxygen flux and bake in the sun.

Special materials needed

Space processing is a solution to the problems encountered in growing sufficiently large crystals of the "ideal" IR focal plane materials: HgCdTe and triglycine sulfate.

Because the solvent solution in HgCdTe crystal growing is more dense than the bulk melt, density-driven convection interferes with stable growth and a flawed crystal results. The opposite density problem occurs with PbSnTe, another important semiconductor, but the effect is the same; perfect crystals of sufficient size for the intended applications are impossible to grow on Earth.

Convective flows are a problem with triglycine sulfate (TGS), also. TGS is valuable as an infrared detector because it can theoretically attain high sensitivity without the extreme cooling required by other high-performance materials. TGS is one of the few electronic materials being grown in space in moderate temperature solutions ($< 100°C$). The bulk of orbital crystal research is concentrated on melt growth or vapour growth processes.

Another detector material of high interest is HgI_2. A space-grown perfect HgI_2 crystal could serve as a highly sensitive X-ray and gamma radiation sensor that does not require the cryogenic operating temperatures needed by other comparable detectors. HgI_2 has a high density and is extremely weak at its crystal growth temperature. Gravity deformation of its layered structure is inevitable during Earth-based processing. EG&G is currently studying the characteristics of a substantial crystal of the material formed by the vapour growth method aboard Spacelab 3.

Vapour deposition excells in space

Vapour growth, while apparently successful in the EG&G experiment, does not perform well on Earth when asked to produce crystals large enough for electronic applications. A hot polycrystalline source provides the vapour pressure needed as the cold seed provides a nucleating surface for condensation. Gravity plays havoc with the process by disrupting transport mechanisms. Even the heat of sublimation released as vapour deposition occurs at the crystal surface adds to the convective maelstrom within the chamber - with nonuniform growing conditions always the result. The vapour growth studies conducted in space, however, have the longest history of success of any crystallization approach used in microgravity.

Although the working materials used, GeSe and GeTe, are not valuable semiconductors themselves, their behaviour during a long-running vapour growth programme (a series of 11 experiments) has told us a great deal about what to expect in space production operations. Researchers D.W. Yoel, R.S. Holmes, and H.J. Willenberg of Boeing Aerospace Co. and H. Wiedmeier of Rensselaer Polytechnic Institute have recently reported on what they have learned about chemical and physical vapour transport in space as a result of Skylab, Apollo-Soyuz, and shuttle flights of their apparatus. The findings centre around the following key points:

- Vapour transport crystal growth in space has demonstrated improved chemical and physical microhomogeneity in the product compared to Earth-based processing.

Chemical and physical vapour transport
space flight history

Flight	Material	Transport agent	Results
Skylab 3 (CVT)	GeTe	GeI_4	Improved crystal morphology
	GeSe	GeI_4	Higher mass transport than predicted
	GeSe	GeI_4	
Skylab 4 (CVT)	GeTe	GeI_4	Improved crystal morphology
	GeSe	GeI_4	Higher mass transport rates than predicted (different temperatures, pressures)
	GeSe	GeI_4	
Apollo-Soyuz (CVT)	GeS	$GeCl_4$ + AR	Improved crystal morphology
	$GeS_{0.98}Se_{0.02}$	GeI_4	Higher mass transport rates than predicted
	$GeSe_{0.99}Te_{0.01}$	GeI_4	
STS-7 (PVT)	GeSe	Xe	Transport rates agree with diffusion
	GeSe	Xe	Largest crystal 100 X larger than on Earth. Largest crystal without direct wall contact

Courtesy, Boeing Aerospace Co.

Electronic materials planned for space processing research

Research area	Thrust
Vapour growth	Flow modelling, Rosenberger/University of Utah Mass transport, Weidemeier/RPI GeSe (model mat.), Weidemeier/RPI HgCdTe, Weidemeier/RPI HgI_2, Schnepple/EG&G CVD, Stinespring/Aerodyne/Spear/Penn State
Melt growth	Flow modelling, Brown/M.I.T. GaAs, Gatos/M.I.T. Thermal model, Lehoczky/MSFC HgCdTe, Lehoczky/MSFC PbSnTe, Crouch/LARC Interface stability, Coriell/NBS Interface control, Witt/M.I.T. GeSe, CdTe, Witt/M.I.T. GaAl KAs, Bachman/NC State
Solution growth	TGS, LAL/Alabama A&M Protein growth, Feigelson/Stanford Organic conductors, Heeger/UCSB
Float zone	Techniques and analysis, Kern/Westec Properties of Si, Hardy/NBS Oxide skin formation, Verhoeven/Iowa State

NASA Office of Space Science and Applications
Microgravity Science and Applications Div.

- The crystals formed in space can be much larger than those obtainable on Earth using this process.

The experiment on shuttle flight STS-7 provided dramatic proof of the improved size of space-grown crystals. The largest vapour process germanium selenide crystal obtained on Earth measures 1 mm^2, while that grown aboard STS-7 was 10 X 4 mm.

Application of the knowledge obtained in well-co-ordinated programmes such as this one is certain to make the transition from scientific model materials on small vehicles to commercially valuable products in large space station factories a smooth and evolutionary one. When the space station arrives, the electronic materials community is certain to be ready and waiting. (Source: Advanced Materials & Processes, April 1986)

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Unlocking nature's metallurgical secrets

Research metallurgists throughout the world are excited, and rightly so. Processing metals and alloys in near-zero gravity will greatly increase our understanding of physical metallurgy principles - old theories will be verified or refuted and new ones developed. This research will most certainly provide the basis for successful development of sophisticated new alloys and for optimising properties of long-established workhorse alloys.

How do small alloy additions affect a metal's structure and properties? What are the limits of undercooling metals and alloys? How do gravity-driven convection currents affect segregation and dendritic growth? These are just some of the questions scientists are asking and hoping to answer through experiments in microgravity, both on Earth and in low orbital space.

Solidification basics

During alloy solidification, interdendritic microsegregation causes density differences between entrapped liquid and bulk liquid. Also, dendrites break away and are carried to other locations due to density differences and convective flows. These processes create micro- and macrosegregation with concomitant property variations. Modelling dendritic growth, and determining the role of gravity-driven phenomena, such as convection and sedimentation, during solidification are some major objectives of experiments in reduced gravity.

A simple model, developed by Dr. Laxmanan (CWRU), describes many known features of dendritic growth in a binary alloy melt. Among its capabilities are the prediction of both the transition from a dendritic to planar (no segregation) interface and the elimination of eutectic composition (representing severe segregation) at small and large growth rates.

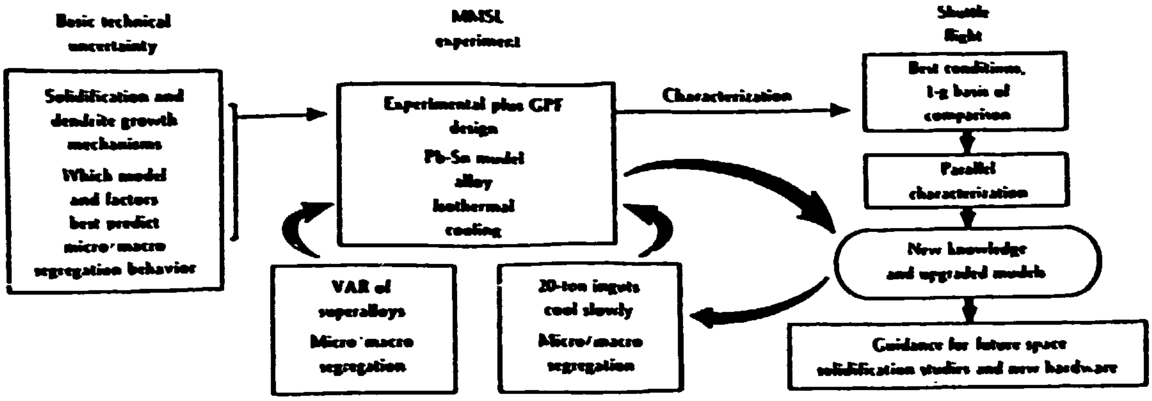
Studies of casting solidification in low gravity, where inhomogeneities are eliminated, are expected to lead to improved process controls for application on Earth. Several proposed shuttle experiments will simulate the macrosegregation that occurs in large ingots on Earth. In original ground-based experiments, slowly cooled, small Pb-Sn ingots had more severe segregation than massive industrial ingots. Removal of convective disruption at low gravity will verify the gravity influence theory.

Directional solidification uses a unidirectional thermal gradient and controlled growth rate to produce castings with highly directional properties, and can produce natural composites as well. Microstructural features are dependent on growth rate; higher growth rates yield finer structure but require very high thermal gradients. Also, convection in the melt causes some microsegregation. Microgravity provides the advantages of reduced melt convection, which in turn, lowers the total heat transfer, and allows the use of very thin, low-heat sink moulds. Under these conditions, complicated shapes like turbine blades can be melted and directionally solidified using only a thin oxide skin to maintain the shape.

A shuttle experiment based on these considerations will provide data on the feasibility of producing turbine engine blades in space and can help improve production techniques on Earth. Developed by MAN Neue Technologie, Federal Republic of Germany and Netherland's Delft University of Technology, the experiment consisted of directionally casting a simple gray cast iron in a 75-μm thick ceramic skin. Directional solidification of the 0.3 in. (8 mm) diameter by 5.5 in. (140 mm) long sample produced a fibre structure in a superalloy matrix.

Going in the right direction

There is high interest in low-gravity, directionally aligned magnetic composites based on results of experiments sponsored by Grumman Corp. Finer, more regular microstructures in manganese-bismuth-bismuth (Mn-Bi/Bi) composites are obtained under microgravity than with identical processing on Earth. The finer pattern of aligned rods in the composite as a result of convection damping yields very high magnetic coercivity.



Micro/macrosegregation in large industrial ingots is responsible for nonuniform properties and high scrap, which lead to higher costs. In this microgravity experiment, NASA LeRC scientists hope to verify the influence of gravity-driven convection on severe segregation by simulating very slow cooling of industrial ingots in small, 180-g Pb-Sn samples.

Where we stand on solidification fundamentals

Phenomenon of interest	Current level of understanding	Current "0-G" activities	Potential for contribution	Potential time-frame for industrial implementation
Macroscale				
Macrosegregation	Fair/well	Few	High	Long term
Pore formation	Poor	None	High	
Bulk undercooling	Some	Limited	High	Medium to short term
Columnar-equiaxed transition	Well	Few	Medium	
Microscale				
Microsegregation	Very well	Lot	Medium	
Controlled undercooling	Some	Some	High	Short term

Courtesy, NASA Lewis Research Center.

As a follow-up to these experiments, there is additional interest in producing samarium-cobalt ($SmCo_5$) composites to investigate the potential of approaching the material's theoretical maximum magnetic strength. Presently, the magnetic strength of $SmCo_5$ magnets produced on Earth is said to be only 10 per cent of theoretical maximum.

Directional solidification of cast iron in microgravity also is an area of interest. At normal gravity, lower density carbon particles in molten iron float to the top of the melt as a result of buoyant forces and convection. Deere and Co. anticipates that its sponsored research of low-gravity, directional solidification of flake- and spheroidal-graphite cast iron will provide information for improving process controls on Earth.

In microgravity, the absence of flotation allows incorporation of primary graphite into the solidification front producing coarse graphite in low-phosphorous, flake-graphite iron. Also, larger eutectic cells are produced in high-phosphorous, flake-graphite iron than those produced under normal gravity, which suggests that convective flow promotes increased nucleation.

Researchers believe that the percentage by weight of carbon that can be retained in the melt under low gravity could go as high as 10 per cent. At this level, the volume fraction of carbon would be over 50 per cent making an iron/carbon composite with a greatly reduced density. Furthermore, with directional solidification, these materials would have a highly oriented structure and properties if the graphite structures were solidified. For example, thermal conductivity could be very high along the solidification axis and very low across this axis.

Some metals don't mix

Everyone knows that oil and water don't mix. What is probably less well known is that there are reportedly over 500 alloys that could have useful engineering properties if they could be processed. However, the components are immiscible; during solidification, the two components rapidly separate due to density differences resulting in nearly complete stratification.

For example, the Pb-Zn binary system has an extended solubility gap in the liquid state; this has placed limitations on forming Pb-Zn alloys. Because of the great density differences of the two melts above the monotectic temperature, it is virtually impossible to obtain Pb-Zn alloys between the limits of 0.9 and 99.5 per cent Pb. It should be possible to generate the entire spectrum of Pb-Zn alloys in microgravity.

Dr. R.B. Pond, Johns Hopkins University, will determine the diffusion constants of liquid lead and liquid zinc above the monotectic and consolute temperatures, in his proposed shuttle experiments. He expects that the results of this research will allow the production of any Pb-Zn alloy composition in microgravity. The technique would consist of putting the necessary ratio of Pb and Zn into a container and heating above the consolute temperature for that alloy. After a time long enough to allow homogenization by diffusion, the temperature is lowered to solidify the alloy.

In similar work, finely dispersed, homogeneous mixtures of Ga-Bi, Al-In-Sn, Cu-Pb-Al, and Cd-Ga-Al have been produced in low gravity. Studies of these and transparent model materials will help identify nongravity segregation phenomena and help to establish production methods. Applications may be speculated from theoretical considerations. However, bulk samples produced in low gravity are required to verify expectations.

Joint research by Gelles Associates and Battelle Columbus Laboratories is aimed at determining the way microstructural features of liquid-phase miscibility gap alloys develop. Studies of ground-based and shuttle experiments in Al-In, Cu-Pb, and Te-Tl alloys have provided information on the effects of cooling rate, composition, and interfacial energies on phase separation and solidification processes that influence microstructural development.

Processing goes untouched

Now that relatively long periods of microgravity are available on the shuttle, there is renewed interest in the ability to process samples without physical contact with a container. There are several advantages to containerless processing including the ability to: measure thermophysical properties of high temperature and corrosive metals and alloys (materials which might destroy a container); produce ultrapure samples; study nucleation and associated time-temperature-transition relations; and study solidification of deeply undercooled samples.

Terrestrial containerless processing is accomplished by free-fall or levitation techniques. Only a few seconds of true containerless and near-zero gravity conditions are provided by free fall. Levitation, on the other hand, can support a sample for an indefinite period by means of an external force, such as electrostatic, electromagnetic, or acoustic, without solid contact.

Unfortunately, very high power is required to levitate heavy samples. In addition, applied forces are external, which can cause unwanted heating or stirring, and the sample still is subject to gravity-influenced convection and sedimentation. Although containerless processing in space provides essentially free-fall conditions, some external levitation forces are needed to keep the sample in place. However, the effects of these low-level forces are negligible.

Collaborative work between NBS, Rice University, and GE's Space Systems Division will provide heats of fusion, heat capacities, and enthalpy increment functions for third-row transition metals and other refractory metals with melting points above 4,123°F (2,270°C). Tungsten has been given priority because of its importance as the highest melting element. In a similar programme at Midwest Research Institute, high temperature property measurements are being made by laser induced fluorescence (LIF). Space experiments allow application of this method to a broader range of materials.

Studying solidification in a containerless, microgravity environment eliminates possible nucleation and solid phase growth on a container surface and promotes deep undercooling. Drop-tube cooling rates are generally lower than cooling rates of atomization and splat quenching. Thus, effects of undercooling and recalescence on alloy morphologies can be observed at large undercooling without the interference of a fast quench.

Vanderbilt University researchers studied the effects of undercooling on niobium and its alloys in a number of drop-tube experiments. Very deep undercooling in excess of 932 °F (500°C) was observed on small droplets. Many Nb alloys also form metastable phases when solidified at the highly undercooled state. Of particular interest is the possibility of forming bulk samples of a high-temperature superconducting metastable phase (Nb_3Ge) in the Nb-Ge alloy system. So far, results show that recalescence largely causes transformation to equilibrium although some of the metastable phases remain in small quantities. The relationship between the perfection of the crystalline structures and superconductance can be determined if large enough samples of this material can be produced. Other alloy systems of interest are niobium-silicon, niobium-tin, and niobium-aluminium.

Some unexpected results

Battelle scientists believe that containerless undercooling may provide another powerful approach to rapid quenching. Four representative, fcc, nonmagnetic, austenitic stainless steels (AISI 310S and 316, and Nitronic 40 and 40W), were evaluated in drop-tube experiments. When these alloys are rapidly solidified, they retain some ferromagnetic delta ferrite, which provides a qualitative measurement of quench severity.

Current and proposed microgravity research (metals, alloys, and composites)

Area of interest	Principle investigator/ affiliation	Metal/alloy systems	Objectives
Containerless controlled/bulk undercooling	Dr. R.J. Bayuzick Vanderbilt University	Nb and Nb-base alloys	Determine limits of undercooling Determine metastable phase formation
	Dr. E.W. Collings Battelle Columbus Labs	AISI 310S & 316 Nitronic 40, Nitronic 40W	Quantify quench rates Determine relationships between microstructures and micromagnetic properties
	Prof. M.C. Flemings Dr. Y. Shiohara M.I.T.	Fe- and Ni-base alloys	Study solidification and remelting phenomena due to recalescence
	Dr. M.E. Glicksman RPI	Pure succinonitrile (SCN)	Determine influence of gravity, and corrective and diffusive transport on dendrite growth at low undercooling
	Dr. M. Kelly/ E.I. Du Pont Dr. E. Ethridge/MSFC	Ni-Al alloy	Obtain 100% peritectic $NiAl_3$ phase
	Prof. J.H. Perepezko Univ. Wisconsin-Madison	Fe- and Ni-base alloys	Extend understanding of physical mechanisms of undercooling
	E.A. Winsa	Ni-Sn alloy	Clarify rapid solidification process
Containerless processing	Dr. W.E. King/ANL Dr. E. Ethridge/MSFC	Fe-Cr-Y alloys	Determine how yttrium improves high-temperature oxidation resistance
Containerless high-temperature property measurements	Dr. D.W. Bonnell/NBS Prof. J.L. Margrave Rice Univ.	Third-row transition metals; Extremely refractory metals	Determine heat capacities, heats of fusion, and enthalpy increment functions
	Dr. P.C. Nordine	W, Mo	Measure high temperature properties by laser induced fluorescence (LIF)
Solidification kinetics	Dr. Angus Hellawell Michigan Inst. of Technology		Determine origination, spacing, and diameter of segregation channels
	Dr. V. Laxmann Prof. J.F. Wallace Case Western Reserve	Pb-Sn	Study fundamental solidification phenomena; Develop simple dendritic growth model
Directional solidification	Drs. S.R. Coriell, R.J. Schaefer, G.B. McFadden/NBS	Pure succinonitrile (SCN) w/wo ethanol	Study effects of gravity and μg on fluid flow and segregation
	Drs. J.J. Favier and Y. Malmejac/Center for Nuclear Studies at Grenoble	Sn-Bi alloys	Study destabilizing mechanis .t solidification interface
	Dr. D.J. Larson Grumman Aerospace Corp.	Bi-Mn alloys Sm-Co alloys	Study influence of gravitationally driven thermosolutal convection Study μg convection damping
	Dr. R.G. Pirich J.L. DeCarlo Grumman Aerospace Corp.	Bi-Mn alloys Pb-Bi alloys	Reduce or eliminate gravity-influenced convection with applied transverse magnetic field
	Dr. D.M. Stefanescu Univ. of Alabama Dr. P.A. Curreri/MSFC	Cast iron	Study roles of homogeneous nucleation, grain multiplication, and innoculants in forming microstructure
Immiscible alloys	Dr. S.H. Gelles S.H. Gelles Assoc. Dr. A.J. Markworth Battelle Columbus Lab.	Al-In alloys Cu-Pb alloys Te-Tl alloys	Determine how microstructural features of liquid-phase miscibility-gap alloys develop
	Dr. R.B. Pond	Pb-Zn alloy	Measure diffusion coefficients in the immiscible liquid-phase region
Metallic foams	Dr. R.B. Pond John Hopkins Univ.	Cu-graphite	Investigate formation of metal foam
	J. Newall/Fairchild Ind. R. Safman/student	Pb-Bi alloy (cerrolow 136)	Investigate formation of metal foam
Electroplating	Drs. C. Riley and F. Wessling Univ. of Alabama-Huntsville	Various alloys	Evaluate space-produced electroplate to improve plating on Earth

For example, chill cast Nitronic 40 retains only a few per cent of delta ferrite, whereas hammer-anvil melt quenched Nitronic 40 retains 48 per cent delta ferrite; this is estimated to be equivalent to a 10^6K/sec quench rate. Drop-tube solidification of the same alloy produced a structure with 86 per cent retained delta ferrite. This indicates that drop-tube processing can achieve higher quench rates than conventional splat quenching.

Containerless drop-tube processing also was used to obtain solidification of 100 per cent peritectic $NiAl_3$ in the Ni-Al system by undercooling through the liquid plus solid phase region. Nickel alloys rich in aluminium are used as catalysts for a number of important chemical reactions, and the $NiAl_3$ eta phase is the most active catalytically.

Although the joint Du Pont and MSFC effort to produce a single-phase peritectic structure was unsuccessful, the study provided other valuable information. The strong affinity of aluminium for oxygen forms oxides that prevent significant undercooling. This indicates that even without any surface contact, surface heterogeneous nucleation may result from the reaction of some melts with ambient gases. In addition, small droplets solidified with a unique morphology consisting of highly convoluted surfaces and interior porosities. The smallest droplets had bulk densities as low as 20 per cent of normal density.

Ultrapure metals and alloys are possible with containerless processing by eliminating potential crucible contamination. In addition, containerless evapouration can purify melts if impurities have a higher vapour pressure than the main melt, and the vacuum of space would be even more beneficial. Interest is high on producing materials free of oxygen. As one example, oxygen impurities in $SmCo_5$ magnets are thought to limit the material's magnetic strength. (Source: Advanced Materials & Processes, April 1986)

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Superglass from space

New glass compositions

During Earth processing of glasses, heterogeneous nucleation can occur at the melt/container interface. This limits the development of new compositions that are considered reluctant glass formers. For instance, neodymium-doped glass used for lasers can become more efficient by increasing the calcia content. However, the higher calcia content promotes rapid crystallization, so a glass cannot form. Researchers have calculated homogeneous nucleation rates that show containerless processing may extend the range of these glass-forming compositions.

The University of Missouri - Rolla, USA (UMR) is trying to obtain quantitative evidence on several shuttle flights for the suppression of heterogeneous nucleation/crystallization by measuring critical cooling rates (R_c). The critical cooling rate is defined as the slowest rate at which a melt can be cooled and still form a glass. Therefore, determination of the ratio, R_c-earth/R_c- microgravity, permits quantitative measurement of the suppression. This value is assumed to exceed unity and the enhancement of glass formation may even be increased up to 100 X!

The study will use binary calcia-gallia, lead-silicate, and ternary calcia-gallia-silica compositions having different critical cooling rates. Several samples that were processed in an acoustic levitator/furnace on a recent flight are being analyzed. Their physical, optical, thermal, and mechanical properties will be compared with the same properties of Earth-made glasses.

Another important practical task of UMR's experiment is to determine the suitablity of using hot-pressed precursor samples for containerless melting. Hot pressing has the advantage of being a relatively simple way of preparing precursor samples without chemical contamination from a container. The degree of chemical inhomogeneity that can be tolerated in a hot-pressed precursor while still yielding a chemically homogeneous multicomponent melt within a reasonable time in microgravity is being determined.

Levitate it with sound

Though no container is needed to hold the melt, positioning is required to prevent drifting into the furnace wall. Acoustic levitation can be used and Intersonics Inc. (Northbrook, Ill. USA) has developed several designs.

The design uses a nonresonant interference technique that automatically adjusts for these changes; therefore, no tuning is required and higher temperatures up to 2,912°F (1,600°C) are possible. Called a single-axis acoustic levitator (SAAL), the unit also requires no chamber. A single vibrator excites an axial acoustic wave, which is then reflected; the sample is levitated at a node of the resulting standing wave.

Acoustic levitation has been suggested as a possible means of manufacturing optical fibres. When the acoustic waves are reflected, standing waves are produced. These standing waves form high- and low-pressure regions; the low energy wells provide stable points of levitation for supporting the sample. The high-pressure wells provide a strong axial restoring force that acts as a constraining force to resist the pulling.

'Floating' glass

There are several disadvantages with using an acoustic levitator. Because the radial force is small, the sample can oscillate, making it difficult to pull the fibre. The sample also may drift into the wall as the levitation forces decrease with an increase in temperature. In addition, the high velocity field associated with acoustics produces large amounts of energy that could cause nucleation.

Spacey optics

One of the key areas of interest for containerless processing is optical glasses. Fluoride glasses, undergoing research at Rensselaer Polytechnic Institute (RPI), have great promise as infrared optical components, especially fibres, because they are transparent to 8 μm and higher. At this wavelength, scattering is minimized, permitting longer distances between relays. However, many compositions are difficult to form in a container, such as the heavy cation (Zr, Hf, Th) fluoride glasses. Other fluorides include those replacing CaF_2 crystals that control the secondary spectrum in optical systems (called apochromats). On Earth, P_2O_5 has to be introduced to prevent crystallization. Such fibres usually have losses on the order of 2×10^{-1} dB/km; it is hoped to reduce this loss to the theoretical limit of 10^{-3} for fluoride glasses.

The advantages of containerless processing also can be extended to optical lenses. For instance, gallia-calcia compositions only can be produced in small quantities on Earth. These and other compositions containing La_2O_3, Ta_2O_5,

Nb_2O_5, Al_2O_3, Ga_2O_3, Y_2O_3, and rare Earth oxides easily can be made into spherical shapes of useful size for lenses and windows.

Sol gel precursors

Because containerless processing allows no stirring of the melt, starting materials must be compositionally homogeneous. The sol gel technique, where polymerization of alkoxysilane with metal alkoxides or metal salts form a gel at room temperature, is being studied for this purpose. The gel is then heated to form a glass that retains the original purity and homogeneity of the starting materials. Because the components are already mixed in the gel, no further mixing is required.

Exotic composites

Many binary and polynary glass systems show an above-liquidus immiscibility region of two phases. On Earth, gravity-induced segregation prevents the uniform mixing of these two phases. On the other hand, the liquid phases should not segregate under microgravity conditions. Hence, a whole new family of novel microphase-separated materials may be possible. The uniform mixing can be extended to other materials that include glass-matrix compositions reinforced with metal spheres for electronic applications and glass ceramics whose matrices tend to sag in unit gravity.

Suppression of immiscibility regions also can lead to improved properties. Soviet researchers increased the Nd_2O_3 content of a laser glass from 2 to 10 per cent in a microgravity environment. The lasing efficiency was improved. Likewise, the radiation resistance of a phosphate-based optical glass was increased. Other researchers showed that the efficiency of a magnetic-optic borate glass improved due to a more-uniform distribution of the active iron-oxide crystals in the matrix.

In addition, interest in directionally aligned composites is increasing. Based on the high magnetic coercivity measured in space-grown composites of Mn-Bi/Bi, M.I.T. researchers have extended their work to rapid-solidification of magnetic oxides. The first system being studied is $SrO-Fe_2O_3$, which contains the hard magnetic compound strontium hexaferrite. As-quenched ribbons contain high concentrations of super-paramagnetic particles, 80 to 250 Å in diameter, in a glassy matrix. Therefore, it may be possible to produce monodomain (less than 0.8 μm in diameter) strontium hexaferrite during subsequent heat treatment. The coercivity should be greatly increased compared to that of conventional materials.

The trouble with bubbles

One disadvantage of manufacturing glass in space is removing bubbles, otherwise called fining. On Earth, large bubbles rise naturally to the surface where they burst; small bubbles are removed by dissolution. Though dissolution can be used to remove small bubbles in space, this mechanism is too slow for large bubbles. In addition, on Earth, buoyancy helps to achieve uniform mixing of the glass melt.

Researchers at Clarkson University have already determined in ground-based studies that gas bubbles migrate in a thermal gradient in a glass melt under microgravity conditions. The thermal gradient is produced by heating a spot on the surface, resulting in a surface tension on the drop that creates a circulatory motion within the drop. The bubbles tend to move toward the heated spot and can then be removed from the melt.

Another theory predicts that the velocity of an isolated bubble liquid under the action of a uniform thermal gradient is proportional to the diameter of the bubble. Thus, larger bubbles move at higher speeds, requiring some means to make the small bubbles coalesce into the larger ones. If the difference in size is significant, the large bubble will have a strong influence on both the temperature field and flow patterns of the small one. However, the small bubble has little effect on the temperature field and flow patterns of the large one.

The large bubble also affects the velocity of the small one depending on the separation distance. If the large one is close to the small bubble, the latter will increase its speed, no matter which one is leading. On the other hand, the speed of the large bubble is only reduced slightly by the presence of the smaller one. In contrast, two bubbles of equal size have no effect on each other regardless of the separation distance.

However, bubble behaviour of equal size differs significantly under gravitational effects. With buoyant rise, each bubble moves more rapidly than either bubble would if isolated. Hence, the velocity will increase still more as the bubbles are placed closer together. Under thermal gradients, a large bubble trailing a smaller one will catch up with it in time. If the large bubble leads, the separation distance will increase with time.

These theoretical models also can generally be applied to drops of one fluid in another. Another mechanism that can be used to move bubbles and drops in the absence of gravity is concentration gradients. These can occur when a single phase mixture is cooled to a temperature at which a different composition precipitates. Clarkson and others are studying this mechanism in addition to the thermal-gradient work. Several shuttle experiments are planned using the three-axis acoustic leviator. Drops of model fluids containing gas bubbles will be rotated or spot-heated and the behaviour recorded on videotape.

Understanding bubble behaviour also will lead to improved manufacturing of hollow-glass shells used in inertial-confinement fusion research. The shells must be perfectly spherical with a uniform wall thickness; hence, the bubbles must be centred within the molten glass. To understand what mechanism - rotation, oscillation, expansion, or contraction - centers the gas bubble, gravitational buoyancy must be avoided. In addition to the Clarkson experiments, both JPL and Los Alamos are conducting research to determine which mechanisms control the dimensions, sphericity, concentricity, and the surface topology of the shells. (Extracted from Advanced Materials & Processes, April 1986)

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Main results from the first Spacelab mission

The first mission of the European built Spacelab took place during the period 28 November - 8 December 1983 on board the US Shuttle Orbiter Columbia. The mission payload was multi-disciplinary and the two microgravity disciplines "Life Sciences" and "Material Sciences" were two amongst six others.

The preliminary results of the life sciences exepriments have been presented by the investigators in June 1984 at a symposium held in Cologne and were published in "Science" in July 1984. The results of the material sciences experiments were presented at the Elmau Conference, 5-7 November 1984.

Materials sciences

It would go beyond the scope of this summary to describe all 33 materials sciences experiments performed during the Spacelab 1 mission. Two planned experiments could not be performed because of hardware malfunctioning. Several experiments did not obtain the full set of experimental runs/operations.

The basic advantage of the microgravity environment for material processing and fluid physics is the practical absence of thermal (gravity driven) convection, sedimentation and hydrostatic pressure. In the microgravity environment "secondary disturbing factors" like surface tension, capillary forces, intermolecular forces etc. become dominant.

Growth of insoluble crystals by precipitation reaction

The objective of the experiment to grow near-perfect dislocation-free single crystals has been achieved by controlled precipitation reaction. Under terrestrial conditions sedimentation of growing nuclei has to be eliminated by the use of gels, which causes inclusions and other imperfections in the crystals. In the sedimentation-free and convection-free space experiments the gel is not required and free-floating nuclei grow under purely diffusion-controlled conditions. The space experiment was performed with the hydrophosphates $PbHPO_4$ and $CaHPO_4.2H_2$ and resulted in dislocation-free crystals as shown by X-ray topography. These hydrophosphates are representative of insoluble, incongruently melting or thermally decomposing materials. There is a large family of this type of materials which was thus far only accessible by growth in gels.

Floating zone growth of silicon

The objective of this experiment was to grow silicon single crystals without dopant striations (i.e. dopant concentration variations) which always occur on Earth. From the space experiment it can be concluded that - as believed until now - gravity-driven convection is not the only reason for these dopant striations but also surface tension-induced Marangoni convection, which occurs both on Earth and in space. As a consequence of this experimental result one is now considering to eliminate free melt surfaces in float zone geometries by thin oxide layers and first experiments with silicon grown in a slightly oxidizing atmosphere have demonstrated that by eliminating Marangoni convection much more homogeneous crystals could be grown even under terrestrial conditions.

Free convection in low gravity

This is one of the six Fluid Physics Module experiments. Several of these experiments were affected by unexpected behaviour of the anti-spreading barrier, which was less effective in space than expected from tests.

This experiment was conceived to investigate free convection in low gravity for configurations such as liquid bridges and modelling the floating-zone technique used for crystal growth. The experiment confirmed the prediction that thermal Marangoni convection and Marangoni boundary layers exist in large liquid bridges in space. On Earth only 3 mm high liquid bridges with a radius of 3 mm could be obtained whereas in space the height of the liquid column was 68 mm. In the geometry considered there is no detectable influence of the imposed electric fields, when silicon oil is used as fluid.

Capillary surfaces in low gravity

The experiment of Dr. Padday was concerned with the behaviour of fluids in contact with solids. The shape of a floating zone (or bridge) is ideally a catenoid. It was the objective of the investigation to measure the influence of the interface layer on the macroscopic shape of a large liquid bridge. In a large meniscus a very small change of the conditions at the edge region of the bridge, which is due to Van der Waals forces, entails a large deformation of the curvature of the meniscus. By this method it was possible for the first time to measure quantitatively the strength of Van der Waals forces, which are the long-range intermolecular forces between solids and liquids in molecular contact. On Earth very small liquid bridges can be produced, which are too small to perform quantitative measurements of these long-range solid-liquid forces which are of highest interest for surface physics and surface chemistry.

Metallurgy

A number of experiments were conducted dealing with eutectic solidification (i.e. simultaneous formation of two separate solid phases from a homogeneous melt) and the formation of fault structure in fibrous and lamellar eutectics, preparation of composite materials, e.g. dispersion alloys, solidification of metallic binary systems having a miscibility gap in the liquid state and dendritic solidification (cast iron). These systems are inherently rather complex and though experimental conditions in near weightlessness are much better defined than on the ground because of virtual absence of gravity-driven convection, sedimentation and buoyancy in heterogeneous systems, the results are still difficult to analyse in quantitative terms. However, a number of mechanisms causing component separation even under microgravity conditions that are overruled by sedimentation on the ground could be identified and our overall fundamental understanding of the processes involved in composite preparation and metallic solidification has been much advanced by the investigations conducted during the Spacelab 1 mission. (Compiled by G. Seibert, Head, Microgravity Office, ESA. Short Summary of the Main Results from the First Spacelab Mission in the Microgravity Research Disciplines, 17 January 1985)

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4. SPACE PROGRAMMES AND EQUIPMENT DEVELOPMENT

Analysis of new results in space materials science obtained in recent 3-4 years

The review of the experimental studies in the main fields of SMS (Space Material Science) performed in the USSR allowed to make a conclusion that considerable progress has been achieved in obtaining various materials and biological specimens with improved properties under micro-gravity (MG). This is particularly true of materials for electronics. New technologies were developed which might provide economic benefits in manufacturing some specific materials in space.

Physical investigations shed new light on effects which may be used to improve promising technological processes. They are solidification of monocrystals at extremely high rates, solidification of overcooled melts, properties of thermocapillary convection, electromagnetic control of a phase composition of melts and so on. To modify technological equipment to some extent the principles of their functioning were outlined and certain recommendations for their optimization were worked out.

The results of space studies made in the USSR allow for a conclusion that it is time to go further in the development of SMS and to start production of materials of interest in space. The primary aim of this stage is to design on-board facilities for material production in space for manned and unmanned stations.

It was suggested that in the near future the Salyut-type long-term space stations, on board of which cosmonauts work from time to time, will be replaced by a multi-module constantly inhabited orbital complex, i.e. single large-size structures located on orbits (from 200 to 4,000 km) and shuttling passenger-cargo transports. The configuration of such a complex will include special-purpose scientific laboratories, comfortable habitable modules, powerful energy plants, a fuel-transfer station, repair shops, and, perhaps, a site for manufacture and assembly of typical structural elements.

To solve multi-purpose and large-scale problems in interest of national economy a future orbital complex (OC) should possess several technical features which have not been yet provided by applied cosmonautics.

The programmes implemented in the USSR are, to some extent, the preparatory activity for developing such an orbital complex. In particular, they are experiments on welding in space, application of coatings. They proved that in outer space one can successfully repair structural elements and restore thin-film coatings with a quality which meets most severe Earth standards. Together with ground-based testing of structural elements for a future orbital complex it is also planned to test its generalized physical models (small-scale) during orbital flights. The study of their behaviour in outer space during 2-5 years will allow for predicting reliably the state of OC structures for the period of 20 years and more. The generalized physical models are based on multi-layer thin-film composites which have been studied in the USSR for several years. The complicated problems pertaining to normal functioning of orbital complexes are impossible to be solved without further widening and deepening fundamental studies. Undoubtedly, these studies cover weightlessness physics and SMS.

New results in space materials science

Experiments on growing semiconductor crystals in MG both confirm some earlier conclusions and yield some new interesting results which are:

- It is confirmed with GaAs as an example that crystals consisting of two components ($A^{III}B^{V}$, $A^{II}B^{VI}$ and $A^{IV}B^{VI}$) could be grown from melts in MG with improved homogeneous impurity distribution and fewer defects;
- It is shown that suppression of convection streams in the melts decreases stoichiometric inhomogeneities, not only inhomogeneities in impurity distribution;
- It is shown that formation of bubbles can be prevented in growing some materials in MG;
- A number of new results are also obtained in growing three-component crystals in MG; this justifies further endeavors to produce in space more perfect crystals of this complex type than is possible on Earth since they are fairly important for practice.

Among new items is the formulation of some still outstanding and debated problems which should be further studied in future. It should be made clear

- How non-gravitational convection types affect the impurity distribution when doped crystals are grown from the melts, and also the homogeneity of the composition and the deviations from stoichiometry in two- and three-component semiconductors;
- What is typical of the development of non-equilibrium phenomena (in particular, overcooling) in MG which may sometimes degrade rather than improve the homogeneity of the composition of some specimens;
- What details characterize the effect of the melt partially touching the ampoule's walls which occurs when the liquid phase does not moisten the material of these ampoules;
- What questions are still unsolved and debated, which involve all peculiarities of crystal growth from the vapour phase in MG, especially in cases when effects of chemical and physical gas transport should be taken into consideration.

One may feel sure that these and other fundamental problems of SMS, if solved, can be used as a basis for industrial production of some semiconductor materials in space and for improving semiconductor manufacturing on Earth.

The investigation of peculiarities of solidification in metals, alloys of composites in MG was also interesting. New experiments performed in MG made it possible:

- To analyse in detail the mechanism via which immiscible alloys may be obtained and the possibility of decreasing and even eliminating their microscopic separation in MG;
- In studying the melting and crystallization of composites in MG (new experiments which differ from those made earlier) to apply an in-situ method for observing in space drops and bubbles in the melt and to obtain valuable information on the peculiarities in the solidification of composites in space;
- To show while studying, peculiarities of foamed metal formation in space, that microgravity conditions favour a more intense generation of gas inclusions in liquid phase which leads to the smaller size of bubbles, lower energy and higher formation rate. A conclusion is made that in future studies it is necessary to understand still better the regularities of the processes basic to the generation, growth and agglomeration of bubbles and to their removal from the melts;
- To derive different conclusions in studying eutectics crystallization, this might be explained by differences in the impurity composition in the materials employed by different specialists. A series of new experiments is required to derive unambiguous statistically substantiated conclusions;
- To confirm the earlier conclusion that microgravity appreciably affects the structure and physical properties of superconducting and magnetic materials;
- To make a conclusion that experiments in MG are indispensable and promising to further advance fundamental concepts of both dendritic and cellular crystallization of metal alloys;
- To show how a specific role of capillary forces is displayed in MG, in particular, in the shaping of crystals grown by crystallization methods preserving a free surface of the melt, e.g. the Stepanov method;
- To show that experiments in MG provide valuable information on physical constants in such mass transfer processes as diffusion, thermal diffusion and electrical energy transfer. Hardly, if at all, is it possible to obtain such information in terrestrial conditions; hence further use of microgravity seems promising for measuring - in the absence of gravitational convection - thermophysical and physical parameters, also promising in the

checking of the theories of heat and mass transfer;

- To achieve considerable success in further development of space welding and soldering where microgravity conditions were basic in the studies of fundamental peculiarities of these processes. A large number of various samples of unique coatings was obtained by thermal evaporation and condensation methods in MG, their properties were investigated and a conclusion was made that maintenance and reconditioning operations are possible in orbit. Techniques were developed to build special welded thin-walled structures and it was made clear why they get burnt out when welded.

In recent investigations of glass solidification in MG emphasis is being made on studying the solidification of overcooled metal alloys, the processes of nucleation and the conditions of formation of metallized glasses. Microgravity was employed to derive new valuable information on the regularities of these processes, and on the diffusion phenomenon on silicate glasses. Further space experiments seem promising to find proofs to possible difference in critical cooling rates in MG compared to those obtained on Earth; they also show prospects for providing more data on surface and diffusion phenomena when gravity is non-existing. To further advance the studies of glasses in MG new systems should be designed which would permit higher heating temperatures, faster cooling and stable levitation. Important and interesting programmes are currently being planned to help solve essential problems of the science of glass.

Of most interest among the results of new studies in crystal growth from water solutions in MG are the first data on the growth of organic crystals with metallic conductance, when a novel three-chamber reactor with valves equipped with special-purpose filters to prevent harmful convection (the valves being open) is used. Attention should also be drawn to the experiments on growing crystals of "synthetic-metal" type conducted aboard the LDEF, an automated NASA module for long-duration experiments. Successful were also experiments on growing low-solubility crystals in a three-chamber reactor.

Most promising and impressive were the experiments on growth of protein crystals from melts in MG. Crystals grown in space were much larger, more perfect in structure and purer than those obtained on Earth and also were grown at a much higher rate. Thus, all further experiments on growing various protein crystals are rather promising for practical use and will undoubtedly be performed.

Rather interesting could also be fundamental studies to test the hypothesis concerning the fact why protein crystallization becomes drastically accelerated in MG (in other words, the hypothesis concerning clusters). Promise is also shown in the experiments on the in-situ mechanism and kinetics of mass crystallization from melt using direct methods for observing the growth of small crystals, e.g. by way of holography.

So, recent analysis of crystal growth from solutions in MG and their growth from melts of semiconductors and metals yielded interesting and promising results, and posed problems which should be theoretically and experimentally solved in future.

The equipment and methodology used for studies in the field of zero-gravity physics and SMS in MG should be further improved. It is already now that considerations must be given to developing new generations of automatic equipment and methodology for unmanned platforms and new orbital stations, the equipment designed for high power supply and manufacturing some materials in space. In recent years certain advances have been reached and novel results have been obtained in the following aspects:

- Comprehensive studies of high-temperature furnace properties (temperature field), when operating in MG, and design of other types of furnace with improved parameters. A step-by-step implementation of automatic heating systems to operate aboard unmanned spacecraft, as well as of more powerful systems which ensure higher heating temperatures and analysis of specimens of large diameter, almost such as required by industry;

- Further sophistication of equipment and methodology of studies in the field of physics of liquids in MG taking into account that in addition to solving the fundamental problems, the experiments performed with this equipment might be aimed at working out recommendations on optimization of the technological processes of manufacturing new materials in zero-gravity. Sophistication of the equipment for crystal growth from melts (including special thermostats and cryostats to grow protein crystals), development of new types of three-chamber reactors and valves as well as of new methodologies to observe nucleation processes and crystal growth in the melts;

- Sophistication of technological equipment for cutting welding, application of thin-layer coatings in space, design of new generations of this equipment;

- Further creation of both theorerical bases and new experimental equipment to provide levitation in MG using various techniques: electrostatic, electromagnetic, acoustic, ion-plasma, due to ablation, with the help of gas fluxes and so on. In this field a certain progress has been achieved;

- Development of new light small-sized holographic instruments for operation in space. They have already been used to carry out experiments in MG, and the methodology is intended for studies in the field of physics of liquids, the process of crystal growth from melts and in other space experiments;

- Development of sophisticated instruments to measure microaccelerations; they were used for numerous studies of gravity conditions aboard various spacecraft and orbital stations;

- Development of other techniques for studying variations of condensed medium structure and properties: spectroscopic, X-ray topographic, optical using TV systems, as well as space vacuum, skin-technology and so on.

By and large, sophisticated equipment and methodologies used in MG for the development of SMS make it possible to perform many experiments and to prepare some materials for space manufacturing. Some of the space methodologies can also be used to solve "earth problems" and develop advanced technology.

Numerous zero-gravity tower, aircraft and, particularly, rocket experiments were continued in short-term MG. The objectives of these experiments were: (1) to prepare and substantiate the experiments aboard spacecraft, orbital stations and unmanned platforms in long-term MG; (2) to perform experiments for further development of SMS. Recently published results of investigations in short-term MG emphasized the interest to the experiments in the field of zero-gravity physics and vast methodological possibilities of their implementation. Specifically, the advanced equipment has been developed for the MIR and TEXUS rockets, which opens great possibilities for studies in the field of SMS. The tests in short-term MG were essential in the evolution of ideas of zero-gravity physics and greatly contributed to space materials physics, including the development of automatic equipment.

It is hoped that the experiments on short-term MG will be good practice in future even though long-term space experiments are planned to be performed aboard manned and unmanned spacecraft.

Some recent papers described the experiments intended for studying the effect of MG and higher gravity on the alloy solidification processes and crystal growth. These experiments revealed that in higher gravity the effects of convection and alloy interaction with the ampoule walls are enhanced, what yields additional data on the role of gravitational and capillar forces in crystallization processes.

Over the past 2-3 years an advanced methodology was designed to study crystal growth and metal and alloy solidification in higher gravity with bulky and rigid equipment installed in a powerful centrifuge where acceleration reached 30 g. The methodology was tested to perform experiments on crystallization of semiconductor materials PbTe with Ag; Te; Te-Se; Te-Si impurities and on solidification of eutectic alloys Al-Cu at different gravity levels. The investigation of the peculiarities of crystallization and impurity distribution, the overload increasing, gave quite unexpected results which deserve a comprehensive analysis.

Discussion of the results of recent studies and analysis of the opinions the specialists expressed on the promisings of zero-gravity physics and SMS, allow optimistic forecasts about the future of these sciences.

At present the following trends of SMS progress can be outlined:

- Further development of fundamental studies in the field of zero-gravity physics and comprehensive preparation for manufacturing some specific materials;
- Numerous long-term experiments aboard unmanned space platforms along with short-term investigations aboard manned spacecraft, rockets and zero-gravity towers;
- Preparation for the investigations in the field of SMS aboard new orbital stations where high power supply will be ensured for both experimental and industrial facilities;
- Establishment in some countries of the ground-based SMS laboratories both to prepare space experiments and to check whether they are correct, and to carry out ground-based and space experiments. It is strongly recommended that much attention be given (including financial aspect) to ground-based experiments;
- Deeper and comprehensive discussion of expediency of new experiments to be performed in space, involving a great number of specialists from various fields of science, both theorists and experimentors.

All new aspects involved in recent publications and numerous results obtained for 3-4 years allow us to emphasize that zero-gravity physics and SMS will face many challenges in the near future.

The foregoing discussion points to the necessity of intensive studies in the field of zero-gravity physics and SMS which can illustrate peaceful and fruitful use of modern achievements in exploration of space. Joint efforts of the specialists of many countries and establishment of the respective international scientific societies would make a great contribution to the progress of this branch of science.

It is safe to say that SMS will be further advanced both in space and within ground-based laboratories due to the successful studies in the future. (Extracted from Proc. 6th Symposium on Material Sciences under microgravity conditions, Bordeaux, France, 2-5 December 1986, written by L.L. Regel' Space Research Institute, USSR Academy of Sciences, Moscow, USSR)

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Coating developed for space station solar cells

A cost-effective coating process to protect solar cell panels on a future space station is under development by Battelle Columbus Laboratories in Ohio for the National Aeronautics and Space Administration. The cells will power the space station, which is scheduled to be constructed in the 1990s.

The solar panels will consist of silicon cells mounted on thin plastic strips that are connected and folded like an accordion. At launch, the array is folded; in the proper orbit in space, it is extended. The space station will be located in low orbit, flying at 180-650 kilometers from the Earth, Battelle says. Without special protection, at this altitude atomic oxygen would react with the plastic of the panels and degrade it.

Battelle's coating process is intended to help preserve the panels by applying a polymer coating that does not react with oxygen. The coating, which must last for 15 years, is applied through an ionized gas technique known as plasma polymerization, Battelle explains. The process is inexpensive because it does not require a high-vacuum environment to apply and it also is capable of coating large areas in a short period of time. (Extracted from Int. Solar Energy Intelligence Report, 31 March 1987)

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Development of a multizone furnace for the Multi Furnace Assembly (MFA)

The multizone furnace is a specific equipment designed for material science experimental research in space. It constitutes an element of the Multi Furnace Assembly (MFA), a multi-user facility integrated on the retrievable orbital instrument carrier which is being developed in the frame of the EURECA European programme. The platform is scheduled to be launched in early 1991 for a first microgravity-oriented mission.

The furnace features the peculiar capability of achieving and maintaining highly accurate temperature profiles along its axis, for long time periods, to process such sensitive experiments as thermodiffusion or crystal growth in a weightless environment.

Furnace operational characteristics

- Maximum operating temperature	900°C
- Transient time to reach steady state operation at 900°C (including outgassing to $< 10^{-6}$ millibar)	7 hours
- Cool-down time from 900 to 50°C under vacuum	64 hours
- Nb of cartridges/furnace	1
- Cartridge external diameter	22.0 mm
- Cartridge length	375 mm
- Maximum number of thermocouples per experiment	9
- Temperature measurement accuracy	±2°C
- Furnace thermal stability	± 0.05°C
- Maximum power consumption at 28 VDC (transient)	450 watts
- Steady state power consumption (900°C)	< 190 watts

Furnace description

1. Mechanical architecture

The furnace includes three heating blocks each weighing 1.5 kg mounted on an inconel tube.

The tube must be thin walled to reduce thermal losses while the high resonant frequency of the tube calls for thick walls. This optimization was one of the critical points of the project.

The heating assembly is superinsulated and held at cold extremity by a flange bolted on the heat sink while the other extremity is centered by a low thermal conductivity membrane.

When furnace is hot, axial dilatation reaches 4 mm, furnace hot end is allowed to unseat from the centering membrane to avoid thermal stresses.

When the tube is cold, the membrane ensures a 500 N prestress on the tube in order to avoid shocks during vibrations and to ensure proper tube centering.

This membrane does not introduce any relative transversal motion between the tube and the envelope.

The outer envelope is made of 2618 A alloy. It acts as support as well as protective barrier in case of cartridge rupture. It is rib reinforced in its lower part, close to heat sink interface. The very high service temperature of 2618 A allows to guarantee structural integrity even in case of abnormal cooling.

2. Thermal architecture

The furnace may be divided into two parts: the hot zone and the cold zone.

The cold zone includes the furnace heat sink, the stand-off and the core envelope.

The hot zone comprises the furnace tube with its three heating blocks.

Heating blocks are evenly distributed along furnace axis. Each heating block consists of an 80 mm long pure nickel cylinder, the diffuser, thermally bound to the inconel tube. Machined grooves on the outer cylindrical surface receive a hairpin-shaped resistor fixed with stainless steel binding hoops.

Block temperature control is performed at heater level, on the nickel diffuser outer surface, for safety purpose, and at central tube/diffuser interface, to insure an accurate sample temperature profile regulation. Thermocouples are mounted with great care in order to avoid measurement errors; they are individually calibrated.

The two diffusers next to the heat sink are each equipped with nine sodium-filled heat pipes to establish isothermality over the full block length, when Na vaporizes in transient heating, and damp thermal fluctuations.

Conductive thermal fluxes are evacuated through the furnace tube to the heat sink and then through the stand-off to the MFA cold plate regulated around 20°C.

Radiative fluxes are limited by a superinsulation set composed of inconel and titanium foils, 25 to 50 micron thick.

The superinsulation consists of:

- 25 micron thick inconel 600 foils for the inner cylindrical insulation
- 25 micron thick titanium foils for the outer cylindrical insulation
- inconel 600 foils in disc stacks for the axial insulation between diffusers
- titanium foils in disc stacks for the hot end axial insulation (between the last inconel disc stack and the core envelope end cap).

The superinsulation allows to control thermal losses towards the envelope.

The nominal power consumption is thus reduced to only 190 watts at 900°C.

3. Electrical architecture

Each heating block receives a THERMOCOAX 2 mm diameter heater of 200 watts power dissipation capability in transient heating.

Power is delivered by the MFA PCCS (Power Control and Conversion Subsystem): 15 amps max under a 27 ± 4 V voltage.

Heater terminals are brazed on CP 20 connectors located on the heat sink baseplate.

Eight K-type Chromel-Alumel thermocouples are distributed inside the furance:

- Two for each heating block (heater on outer part and tube/diffuser interface)
- One on the tube flange, close to the heat sink
- One on the connector holder between diffuser and heat sink.

These thermocouples are soldered to a set of two 10-pin LEMO connectors located on heat sink baseplate.

Their "hot" junction is electrically insulated from their inconel sheath with magnesia.

All thermocouples are selected, aged and calibrated by hot cycling at 900°C before being integrated in the furnace.

4. Furnace physical characteristics

- Overall furnace weight	13.5 kg
- Outer structure	
. conical stand-off (interface level)	160x160 mm
Height	130 mm
. Cylindrical envelope	
Length	550 mm
External diameter	105 mm
- Inner structure	
. external tube	
average external diameter	27.5 mm
diameter between diffusers	24 mm
length	415 mm

The cartridge

1. Cartridge description

The cartridge is a Z2 CN 18.10 stainless steel cylinder holding the sample to be processed.

It is divided into two main parts:

- The hot part, which is dismountable, and allows loading and unloading of the experiment (thermal diffusion). In the crystal growth alternative, this part is reduced to a simple quartz ampoula held at both ends by appropriate cushions to prevent breakage from dynamical or thermal loads.

For thermodiffusion the hot part may be black oxidized to improve radiative coupling between the cartridge and the furnace tube.

- The cold part, on heat sink baseplate side, receives all instrumentation connections on an isothermal printed circuit board.

It is made of stainless steel and light alloy and presents a conical part mating with the conical silicon seal on heat sink side to ensure thermal transfer to the MFA cold plate.

2. Cartridge instrumentaton

The cartridge is instrumented to a maximum of nine thermocouples normally distributed along its axis.

Electrical connection is realized through an isothermal printed circuit located in the cartridge head (cold end) to a SOCAPEX JT06, 37-pin connecter.

Thermocouples cold junction is located at electronics level.

Experiments

1. EURECA 1 experiment description

Two types of experiments are implemented to be processed by the MTZ furnaces on the EURECA 1 flight.

- Diffusion and thermodiffusion in liquid phase:

(P.I. = Dr. PRAIZEY - CEA/CENG)

. Either diffusion of a doping component in a pure metal (concentration gradient) with particle migration versus time.

For example: doping Co in Sn
or radioactive tracer in a molten metal

. Or thermodiffusion under thermal gradient of a binary alloy, or isotope migration (separation, from an initial homogeneous concentration).

- Vapour phase deposition and/or crystal growth under temperature gradient ("Enforced flux" method)

(P.I. = Dr. LAUNAY (CNRS)

This peculiar experiment uses a quartz ampoula filled at both ends with a tin-lead telluride of the form

$Pb_{1-x} Sn_x Te$

The material is held by optical quartz grids controlling the diffusive flux.

A thermal gradient is established between the source and the sink.

A thin layer deposit (monocrystal) occurrs around an initial nucleus located in the middle of the ampoula.

2. Possible applications

Beyond these two experiments, the multizone furnace could be used for any Physical Vapour Growth or Chemical Vapour Growth process. This is of special interest for the ternary semiconductors like Hg Cd Te.

Another semiconductor growth method is directional solidification under low gradient.

This could be obtained by programming a constant temperature difference between zone 1 and zone 2 while both temperatures decrease versus time: this results in solidification front displacement like in GHF.

The third zone could be used at constant temperature to maintain the vapour pressure of the most volatile component and by such, avoid composition shift during process. The use of heat pipes and the very high temperature stability ensures that the vapour pressure remains constant.

In the stationary gradient mode, it could be used for experiments ranging from thermodiffusion to thermal conductivity measurements.

Qualification testing

The furnace sustained recently environmental and functional qualification tests.

The furnace sustained high level sinus and random vibration tests without any damage despite the rather severe environment (8.9 grms).

The first resonant frequencies of the furnace are well over the 80 Hz specification.

The first transverse mode is above 120 Hz, the first longitudinal mode above 625 Hz.

The furnace sustained thermal vacuum tests in a dedicated facility built by SEP in order to perform also functional tests. Ultimate vacuum can reach 5.10^{-8} mbar with furnace inside vacuum chamber.

Automatic control ensures that pressure never exceeds 10^{-5} mb during heat-up thus avoiding furnace hot parts oxidation during long duration tests. (Extracted from Proc. 6th European Symposium on Material Sciences under microgravity conditions, Bordeaux, France, 2-5 December 1986. Written by J. Terracol, D. Valentian (SEP), G. Cambon (CNES - CERME), MM. Mary, Deleris (SOTEREM))

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Table. Effective Utilization of Space and New Raw Materials Mapped Out in FMPT (First Materials Program for Tests)

Advantages afforded by space Sector of raw materials	Large-size crystals and uniform consistency	Perfect crystals	Homogeneous consistency and uniform shape	High purity
Semiconductors	oLead-tin-tellurium: zone melting method (large area infrared image sensor) oIndium-antimonium compound semiconductor (superhigh speed logical element) oCrystals of organic metals (new type of raw materials with electronic functions) oIndium-GaAs compound semiconductor (superhigh speed electronic element, raw materials for optoelectronics)	oLead-tin-tellurium: unidirectional solidification (infrared sensor of high performance) oSilicon globule (development of technologies for the manufacture of semiconductors	oSilicon-arsenic-tellurium amorphous semiconductor (solar cell of high efficiency)	
Metals and alloys	oAluminum-lead-bismuth alloy (new superconductive alloy) oAluminum-indium alloy (superconductive alloy) oMechanism of the formation of deoxygenated products in steel mass (improvement in steel making technology)		oResearch on the mechanism of liquid phase sintering: tungsten (solid phase)-nickel (liquid phase) oResearch on solidification of eutectic type alloys: aluminum-copper; aluminum-nickel oMutual diffusion of two fused metals: gold-silver, gold-aluminum oResearch on the mechanism of solidification of metals in the gas state: magnesium, chromium, iron, zinc, etc.	
Composite materials			oNickel-based alloys with ceramic particles dispersed (heat-resistant alloy) oComposite material of carbon fiber and aluminum alloy (fiber-reinforced metal of high strength and supersmall weight)	
Glass and ceramics	oSamarskite (electrode material for photochemical reaction)		oBehavior of glass at high temperature (glass of superhigh resistance to heat, materials resistant to heat and shock)	oOptical material for nonvisible regions (optical material for laser)
Fluid physics	oResearch on the Marangoni convection (development of technologies for processing materials for space science)	oBehavior of bubbles, development of theories for crystal defects		oFloating of drops of liquids on second waves (development of technologies for float processing)

Development of plan for utilization of space environments - Japan

In the 1980s and beyond, research on microgravity and, in particular, experiments on raw materials will be the major subject of research in the space development programme. In Japan, the First Materials Programme for Tests (FMPT) project, the first raw materials experiment, has been set up which is slated to be implemented in 1988 in the space shuttle. The project, as shown in the table, involves experiments which are associated with various types of raw materials such as semiconductors, metals, alloys, composite materials, glass, and ceramics. This indicates the high hope Japan has for development of new raw materials using space.

Processing of raw materials in space

Raw materials processing, as exemplified by the production of single silicon crystals from ore, is a technology for making various value-added products, e.g., crystals, chemicals, metals, and ceramics, from common low-priced raw materials.

The most important reason for conducting raw materials experiments in space is to make use of its weightless environment. On the Earth, substances separate from each other according to their difference in temperature and density and because of their gravity, producing changes in shape owing to its weight. In weightless raw material processing, on the other hand, growth of semiconductor single crystals, far more homogeneous and much nearer perfection than on the Earth, is conceivable. This is also true for mixing and solidification, through containerless processing, of metals and ceramics which are of a shape and purity not to be attained on the Earth. Outer space permits manufacture of high-value raw materials both in scientific and commercial terms using weightlessness.

(1) Electronic raw materials

Improvement of the technology for manufacturing semiconductor crystals has played an extremely important role in the development of computers, lasers, and a variety of sensors. Crystalline structures and purity are vital factors in this technology development such that even 1 ppb impurities (one-billionth) can sometimes render a crystal defective, just as structural defects of even the atomic level can produce fatal effects on some occasions. On the Earth, these problems can be surmounted only partially by complex and uneconomical means. However, in weightlessness, large, near perfect single crystals can be grown with comparative ease because of the lack of natural convection that produces uneven growth surfaces and distorted growth zones.

(2) Metals

Weightlessness is important in directional solidification, a major technology for raw materials processing. By imparting directional features to metal at the time of its solidification, some characteristics of the metal can be strengthened. A unidirectionally solidified metal should be an essential raw material for such products as turbine engines, where heavy stress is applied in one single direction and where a large strain is produced in that direction.

Another important promising process in space is rapid quenching. In this process, a metal is solidified at such a rapid rate that its constituent atoms cannot settle themselves in their unique structural arrangement. Consequently, a random structure is produced like that of glass with unusual properties. Such research of technologies in space is expected to advance metal casting technologies developed on the Earth. The manufacture of new types of superconductive alloys, for which assessment of special properties is not possible on Earth because differences in specific gravity of component metals prevent the metals from mixing properly, is also one research theme uniquely adapted to space.

(3) Glass and ceramics

Where ceramics are used in turbine blades, jet engines, etc., which are subjected to high temperatures and heavy stress, a matter of concern is the destruction of the material. One method for dealing with this problem involves improvement of the performance of the ceramic by the addition of some specific metal to the material. This controls its microscopic structure. In such a case, weightlessness again provides an important means of research. Nongravity in space permits one to prepare a microscopic structure which is unavailable on Earth because of the absence in space of up and down movement of the component materials based on the differences of specific gravities, among other things. That is, it provides important knowledge for the development of high-function raw materials.

Another important field of application for processing raw materials in space is that of development of optical fibres for use in optical communications. The manufacture of optical fibre with a low attenuation coefficient for light, which is required for sending signals over long distances, should be made possible by containerless treatment in space. This permits fusion and solidification of crystals under conditions that preclude any contamination by impurities derived from a container and makes it possible to produce highly pure glass with high transmittance.

Future prospects

According to NASA, microgravity science and appropriate application programmes are aimed at the application of the weightless environment in space with a view to obtaining a deeper understanding of its physical implications and also to develop further technologies for the manufacture of raw materials. In this series of projects NASA has mapped out a plan starting with experiments using fall tubes and fall towers on the ground, advanced to airplanes and sounding rockets in semiorbits, and is presently using the space shuttle in orbit, to be followed by a space station, also in orbit.

Utilization of space environments must include efforts to develop applications of that environment in industrial technology, made simultaneously with efforts to put in order the yet unknown physical phenomena under weightless conditions as part of science. In this sense, progress in the science of weightlessness may require a system of research in which the government, industry, and academic circles have to co-operate more intimately than ever before. We may see in the future new S&T prospering in space. (Extracted from Tokyo PUROMETEUSU, September-October 1985. Article by Nobiyuki Tsujiuchi, deputy director, Social Systems Division, Mitsubishi General Research Institute.)

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5. MARKETING

Marketing outlooks

Orbiting factories: fact or science fiction?

Is space the final frontier for materials processing? With the space station, perhaps the research performed both on the ground and on the space shuttle will finally become a commercial reality. The New York Times predicts that materials processing in space will generate $1 billion per year by 1990; in the next five years, pharmaceutical materials will be a $5 billion business, electronic materials, $2 billion. Another forecast by the Congressional Space Caucus has projected a $300 billion Gross National Product from space business by the year 2000 - which also will generate 10 million jobs. The Centre for Space Policy is a little more

Centres for the commercial development of space

	Research topics	University/corporate members
Battelle Columbus Laboratories (will use NASA Lewis Research Centre's Microgravity Materials Science Laboratory)	Catalysts for hydrocarbon polymerization; polymer blends; electronic crystals (piezoelectricity); glass materials for digital electronics and fibre optics (controlled porosity)	Amoco Chemical Corp., GE, Goodyear, PPG, Rockwell, Hercules Inc., Akron University, CWRU, Cleveland State, Ohio State, Edison Welding Institute, Washington State, Clarkson U., Edison Polymer Institute
Consortium for Materials Development in Space, University of Alabama Huntsville (most experiments were to be flown on GAS and other payloads in 1986). Future: Centre for Applied Optics	Optical crystals; organic crystal growth via vapour transport; purification of biological materials by phase partitioning; surface coatings; catalyst production by electrodeposition; oxygen interaction with materials exposed in space	Boeing Aerospace, Celanese Research, Deere & Co., GTE Labs., Martin Marietta Aerospace, McDonnell Douglas, Teledyne Brown, Union Carbide, Wyle Labs., University of Alabama-Tuscaloosa
University of Alabama-Birmingham, Centre for Macromolecular Crystallography	Crystalline structure of enzymes; protein crystal growth (were to be flown aboard a fall 1986 space lab mission)	McDonnell Douglas, Schering, Smith Kline, French Labs., Merc, Upjohn, Du Pont, Georgia Tech, Southern Research Institute, University of Alabama-Huntsville
Vanderbilt University	Directional solidification; casting of aluminium alloys, platinum group alloys, and immiscible alloys; containerless processing of Ti alloys, refractory alloys, and steels; μg processing of superalloys and composites	Twelve companies, University of Florida, University of Alabama-Tuscaloosa

Industrial space facilities, entrepreneurs

Company	Facility	Objective
Wyle Laboratories	Attached laboratory module	Requires fee for service - wants private sector to contribute both technically and materially
Space Industries Inc. (has agreement with NASA)	Industrial Space Facility (ISF) - expandable attached laboratory for research and production, mainly MPS, up to 6 identical modules, permanent with in-orbit servicing	Operating on a lease-for-service basis by 1990; compatible orbit with space station; fully operational with a single module and one launch; accelerate commercialization of MPS
Teledyne Brown Engineering	Small Payload Flight System (SPFS) spans orbiter cargo bay, 4,300 lb of payload, some power and controls, data recording	Materials Science Lab was first payload (12/84); low cost, quick turnaround; provides frequent flight opportunities
	Commercial Materials Processing Support Facility (COMPS) for space station	Includes laboratory, pilot production test equipment, and production support capability; users would share support costs and pay fees based on these costs
Boeing Aerospace	Modular experiment platform for science and applications (MESA)	Low cost, reliable, adaptable to either Ariane or shuttle launch systems
Fairchild Space Operations (has JEA with NASA to receive a free shuttle flight and retrieval mission in 1987)	Leasecraft - unmanned space platform retrievable free flyer Primary payloads: 32,000 lb, $4 to 7 million/month; secondary: 2,200 lb, $0.5 to 1 million/month	Lease space for commercial materials processing, government projects; in-orbit payload exchange; reconfiguration capability; payload integration support for both platform and shuttle interface
Centre for Space Policy, Spacelab Inc. (has MOU with NASA) Aeritalia, Italy	Three "mid-deck augmentation modules", fit in shuttle payload bay, available 1987	Increase mid-deck space by 50 per cent; advanced module will contain independent power and thermal systems; reduce back-log of experiments; support space station
Instrumentation Technology Associates	Provides services, hardware for flying small payloads (GAS and larger)	Offers basic experiment support equipment, designs and assembles equipment, handles interaction with NASA; reduce "upfront" technical and financial risk; expand to space station
Space Test Inc.	Provides engineering services for shuttle flight experiments	Provides payload integration at fixed pricing, documentation services

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conservative: $17 to 51 billion. Out of this total they have reduced their materials processing prediction from $25 billion to a maximum of $18 billion as a result of the three-year delay in establishing the space station. Originally scheduled to be operational by the early 1990s, there probably - and unfortunately - will be even more delays due to the recent shuttle disaster. When the space station will finally be operating, the advantages will compensate for the delays. (Extracted from Advanced Materials & Processes, 4/86)

High profits expected from space material

Yearly profits of neary ¥60 billion ($242 million) are expected through production of advanced materials in space in the year 2000, Japan's National Space Development Agency (NASDA) has reported.

According to the report, materials produced in small quantities at high cost - like semiconductor materials and pharmaceuticals - will be best produced in space around the turn of the century and total profits of about ¥58 billion ($234 million) could be derived from the expected combined market value of ¥151.8 billion ($612 million) after covering manufacturing costs.

Space-produced semiconductor materials and pharmaceuticals have a good chance of becoming ¥100 billion ($403 million) industries, the report noted.

The materials currently envisaged include indium, gallium and arsenide used for high-speed semiconductor elements and urokinase, an antithrombolitic agent.

The NASDA report showed pharmaceuticals and semiconductor materials will be produced at 40 per cent and 60 per cent, respectively, of their costs of production on Earth.

While NASDA officials admit there are still many unknown factors involved in space manufacturing of these products, they are confident the market value estimates will not be far off the mark. (Source: Tokyo Daily Yomiuri, 16 December 1984)

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Aerospace sciences

It is profitable to develop space materials

Investigation has been carried out for the following two purposes: (1) to prepare basic data for studying the Japanese space station project, and (2) to study whether or not Japan's participation in the US space station project will be cost-effective with consideration to future projects developing from the present project.

As a result of the investigation, the following items can be considered to be the main materials which will be used in the most promising space manufacturing field.

(1) Semiconductor materials and electronic materials compound semiconductors (optoelectronics, solid laser material, and high-speed operating semiconductors)

Amorphous electronic material (optoelectronic material)

Superconductive material (ferromagnetic field generating superconductive magnet)

High-performance magnetic material (compact, accurate, and high-performance magnet)

Super-perfect crystal (standard single crystal for researching physical properties)

(2) Biomaterials

Protein such as enzymes, hormones, etc., (pharmaceuticals and research reagent)

Biological cells (pharmaceutical manufacturing cell and research cell)

(3) Optical materials

Optical laser glass (large output laser and infrared wave guide)

High-strength ceramics (corrosion-resistant and high-strength material, wear-resistant and high-strength material, and heat-resistant and high-strength material)

Lamellar ceramics (precise processing tool and ultra LSI - large-scale integrated circuit - substrate)

(4) High-function alloy and metal composite material

Directionally solidified alloy (high-temperature and high-strength alloy material)

Unmixed alloy (vibration absorbing alloy material, bearing material and superconductive material)

Metal composite material (high-temperature and high-strength material and aircraft material)

(5) Polymeric organic material

High-strength organic composite material (automobile lightweight material and medical organic material)

Environment-resistant high polymer molecule (space structural material, high-heat resistant resin, and radiation protection resin)

Precise shaped high polymer molecule (latex sphere with a uniform diameter)

Space is a world controlled by weightlessness, vacuum close to perfection, extremely high temperature, cryogenic temperature, a large amount of cosmic rays, and nearly boundless solar energy. In any case, special conditions can be simultaneously obtained in space, although these conditions cannot be realized on Earth except at enormous cost.

For example, lead and tin tellurium (PbSnTe) single crystal, mercury cadmium tellurium (HgCdTe) single crystal, aluminium gallium arsenide (AlGaAs) single crystal, indium gallium arsenide (InGaAs) single crystal, silicon arsenic tellurium (SiAsTe) amorphous, etc., can be cited as semiconductor materials. It is expected under the above-mentioned environment that these materials can be relatively easily mass-produced because they are mainly advantageous in a weightless state.

These projects require a large amount of investments at the initial stage, have many ambiguous points concerning expected effectiveness at present, and have many problems which must be solved in the future. For these reasons, it would be necessary to consider that the space station project and the space manufacturing field as a part of the project should be promoted as a key technology in the future development of space activities, aside from the "profitability".

Example of new semiconductor materials expected to be manufactured in space

Materials	Use	Present status	Effectiveness expected by manufacturing materials in space
Lead and tin tellurium (PbSnTe) single crystal	High-speed operation semiconductor element (High-speed computer) Laser element in far-infrared region (Optical communication system) Sensor element in far-infrared region (Remote sensing, gas sensor element, etc.)	Although laser elements in the far-infrared region have good reproducibility and their movements are stable, the development plan for them has not been determined.	It is said to be difficult to manufacture large-sized, high-quality single crystals on Earth because of heat convection in melted liquid, specific gravity difference between mixed substances, etc., but it is expected that such single crystals can be manufactured by making the most of a characteristic, i.e., weightlessness.
Mercury cadmium tellurium (HgCdTe) single crystal	Sensor element in infrared region (Artificial satellite, optical communication system, etc.)	It is expected that the mercury cadmium tellurium single crystal will bring about elements with higher sensitivity and reliability and longer life as a material of sensor elements in the far-infrared region than any other substance.	
Aluminium gallium arsenide (AlGaAs) single crystal	Laser element in visible region (Optical communication system and laser disk light source)	It is believed for the time being that InP is used in the same way as AlGaAs, but it is expected that this material - i.e., the AlGaAs single crystal - will bring about higher quality elements.	
Indium gallium arsenide (InGaAs) single crystal	High-speed operation semiconductor element (High-speed computer) High-sensitive magnetic sensor element (Computer memory device)	It is believed for the time being that GaAs is used as a semiconductor element which replaces silicon IC (integrated circuit), but it is expected that this material - i.e., the InGaAs single crystal - will bring about higher quality elements.	
Silicon arsenide tellurium (SiAsTe) amorphous	High-effective solar battery Sensor element in visible infrared region (Optical communication system)	The SiAsTe has come into the limelight, because the ratio of components or organic elements can be changed, etc., but the best of this characteristic cannot be made, because this material is liable to be uneven when it is manufactured on Earth.	Although it is difficult to manufacture the large-sized, high-quality amorphous on Earth, it is expected that such amorphous can be manufactured in space.

(Extracted from Nikko Materials in Japanese, March 1985)

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Space-made product sales

Space-made product sales will reach $18 billion in the year 2000, according to the Centre for Space Policy. Weightlessness enormously simplifies the manufacture of some drugs. Gravity makes the molecules of proteins, enzymes, and hormones stick together. In the absence of gravity, rearranging molecules to make new drug compounds is easy. It is also possible to make materials whose crystalline structures are free of defects and to mix metals to form perfectly blended alloys. It may be possible to automate most space manufacturing, reducing the costs and hazards of manned flights. (Extracted from Fortune, 3 March 1986)

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Persevering in space research

When NASA began providing laboratory quarters for corporate research aboard the Space Shuttle, only one major US corporation responded with enthusiasm: 3M of St. Paul, Minn. The first non-aerospace company to establish a space research laboratory, 3M has already conducted three experiments aboard the shuttle and remains committed to its programme of materials research in microgravity despite the fleet's temporary grounding. (Extracted from High Technology, July 1986)

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In Chemical Marketing Reporter of 15 December 1986, 3M talks about its future plans in conducting further tests in space:

"3M Company and the National Aeronautics & Space Administration plan to conduct 62 materials processing experiments over a 10-year period aboard the space shuttle. The experiments will be in the areas of organic and polymer science.

Under an agreement, any material produced or process developed will be for research and development purposes, with NASA and 3M as co-equal, 'co-operative participants'.

The agreement further states that it is the intent of both parties that any promising results arising from this joint endeavour will result in commercial production and sales.

NASA says it will schedule the 3M experiment flights on a 'space available' basis. Assignment of specific experiment flights will be contingent upon negotiation of individual task agreements.

The agreement calls for two experiments each year in the shuttle orbiter mid-deck over a 10-year period, two experiments a year in the cargo bay during the first three years of the agreement, and six experiments a year in the cargo bay from the fourth through the ninth year of the agreement."

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NASA and Boeing sign materials processing agreement

NASA and Boeing Aerospace Company, Seattle, Washington, USA, have entered into an agreement to fly a series of materials processing experiments on the Space Shuttle.

Objective of the experiments is to prove that crystals of a size and quality impossible to create on Earth can be produced in space. These crystals are expected to be of a type valuable in the commercial production of semiconductor and electro-optic devices.

The experiments involve the manned operation of a chemical vapour transport crystal growth furnace which will be installed in the galley area of the Shuttle orbiter mid-deck compartment.

Boeing expects to fly a total of three separate furnaces on each of the three flights. The University of Alabama, Huntsville, USA, with which Boeing is affiliated under the NASA programme of Centres for the Development of Space, also will perform experiments in the Boeing furnaces during the flight programme. There is an option for two additional flights for prototype production experiments if the programme yields promising results.

Under the agreement, Boeing will fund the experiments, provide the crystal growth furnace and other needed equipment. Boeing also will process some NASA samples in its furnace on each flight. NASA agrees to integrate the experiment packages into the Space Shuttle, provide available off-the-shelf support equipment where applicable and provide room and crew support on Shuttle flights.

NASA's involvement in this agreement and others underscores the agency's commitment to the development of commercial endeavours in space, particularly in relation to the Space Station, which NASA plans to have operational in the 1990s. (Source: NASA News, 15 May 1986)

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Boeing Aerospace wins $95,000 research contract

Boeing Aerospace has further won a $95,000 research contract to build graphite epoxy composite tubes to be used for space station truss structure studies at NASA. Boeing's Parts, Materials & Processes Technology division will fabricate 21 high stiffness composite tubes, varying from 12-120" long, to be submitted to NASA for a test program to determine the durability of the materials in low-Earth orbit. The tubular truss is a grid-like structure that will form the space station's body. (Source: Am Mtl Mkt, 8 April 1986)

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Products made in space

Space beads

The National Bureau of Standards is selling "space beads" as an educational tool, measurement standard. The first commercial product made in space is now being sold by NBS on a microscope slide as an educational tool for teachers and students and as a standard to calibrate microscopes for small particle measurements. The new product contains material produced aboard a NASA space shuttle using a chemical process developed by Lehigh University. The first space-made reference material put on sale by NBS in July 1985 contained about 30 million microscopic spheres packaged in a vial; the new material contains only a few thousand spheres which are sealed in a slide. The spheres are arranged so that students in high schools and colleges can carry out a series of laboratory experiments that are included in the package.

NBS is selling the new reference material - SRM 1965, priced at $77 - as a way to offer a lower-cost version of the space-made material, to permit wider distribution of the material, and to extend the Bureau's limited supplies. NBS has sold more than 300 of the initial reference materials (SRM 1960), which cost $386 each, to industrial, medical, university, and government users. (Source: Journal of Research of the National Bureau of Standards, January-February 1987)

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Work found for space-made product

The second commercial space-made product is now a new-size, small-particle measurement standard. It is Standard Reference Material 1961, 30-μm polystyrene spheres, developed for industry by the National Bureau of Standards. The reference material is said to be an important quality-control tool for chemists using powders for the manufacture of industrial compounds and other products requiring particle sizing near 30-μm. (Source: Machine Design, 25 June 1987)

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Space-borne solar-power electrical generator

AEG (Federal Republic of Germany) is developing a space-borne solar-power electrical generator, which will be used on the European Space Agency's Eureca, a reusable payload carrier that will be launched by the US Space Shuttle. The Eureca carrier will require a total of 2.3 kW of continuous solar-generated power, a need that has to be met during full sun phases and eclipse phases of its flight. If factors such as power losses in the power system itself and the efficiency of the energy storage system are taken into account, the total power demand on the solar generator could be as much as 5.2 kW. To meet power needs during eclipse phases, Eureca needs four battery modules switched in parallel. Each battery module comprises 30 NiCD cells, each with a capacity of 40 Ah. During a mission, each battery goes through 4,000 charge/ discharge cycles with a discharge of approximately 30 per cent. The voltage emanating from the solar generator is monitored by sequentially switched voltage limiters to maintain a regulated 28 V main bus. (Source: Elec Eng T, 6 August 1987)

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Single-crystal blades

Several firms and the Foundry Institute at the technical university in Aachen, FRG, have begun a joint project to research how microgravity can be used by industry to optimize the material properties of components. The OSIRIS (oxide-dispersed single crystals improved by resolidification in space) project is initially expected to run for three years.

The project is a new idea in the area of materials research in microgravity. It encompasses several problem areas which are being researched by means of individual experiments in an Earthbound laboratory, such as have already been performed in Spacelab, and over the long term links them with a common, technically feasible objective. The crux of the matter is the stability of a suspension of oxide particles within molten metal, the interaction of the particles with the advancing solid-liquid interface, the directional single-crystal solidification of super alloys and the directional solidification of preformed parts with complex geometries. In addition to solving scientific and technological problems, the project should also allow estimates of how to utilize the results. As an applications-related example, turbine blades are to be investigated. They are of enormous economic importance because they are used in steady-state and non-steady-state turbines to provide energy. The super alloys employed to date represent the current state of the art with respect to desirable properties such as high-temperature resistance. (Extracted from Chemische Rundschau in German, 6 March 1987, p. 1)

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Space-oriented programmes, companies

Materials Processing Laboratory

Space Industries (Houston) will jointly design, develop, build and market an industrial space facility (ISF) with Westinghouse Electric for NASA. The man-tended, space shuttle-launched privately-owned facility will initially serve as a materials processing laboratory, and eventually be used for the purification of pharmaceutical and biological products, growth of large protein crystals essential to advanced drug research, and growth of ultra-pure semiconductor crystals for use in high-speed computers. The modular ISF will have a pressurized 2,500 cu. ft. cabin and will operate in a circular, 28.5 degree orbit at 200 mi. ISF's facility module will remain permanently in space and its supply module will be carried to and from space by the shuttle and transport raw materials, and resupply equipment and products produced in space. (Source: Satel News, 10 June 1986)

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Space Acquisition

Saab Space AB of Goteborg, Sweden, a part of Saab-Scania's Combitech, has become a part-owner of Intospace. This is a newly formed European company, the goal of which is the commercial utilization of space technology for research and development under conditions of weightlessness. The production of new types of pharmaceuticals and new materials will be a significant part of activities on board the space stations of the 1990s. (Source: Stockholm Svenska Dagbladet, 27 August 1986)

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New company for space experiments

Six Japanese companies including Ishikawajima-Harima Heavy Industries and Hitachi, Ltd., will set up a new company for outer space experiments, with subsidies from the Basic Technology Research Promotion Centre. The new company will make preparations for participating in the "D2" plan scheduled by the Federal Republic of Germany for autumn of 1988. (Source: Chemical Economy & Engineering Review, July/August 1986)

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6. CURRENT AWARENESS

Composites

Advanced composite material

A lightweight, strong, and high-performance composite material is called "ACM (advanced composite material)". The ACM is reinforced with carbon fibre, aramid fibre, boron fibre, etc. A typical ACM is CFRP (carbon fibre reinforced plastic). The CFRP has widely been used in sports equipment such as tennis rackets and fishing rods, in Japan. It has also attracted attention in the West, particularly the United States, and has been developed as a material for space equipment and aircraft. Worldwide use of carbon fibres in 1984 was 2,800 tons. Thirty-seven per cent of the 2,800 tons were used as a material for space equipment and aircraft. Sixty-two per cent of the carbon fibres used in the United States is used in space equipment and aircraft. Importance is attached to performance rather than cost of military aircraft and space equipment. There is a strong possibility of particularly ACM being used in such military aircraft and space equipment. CFRP is used in nose cone, storehouse doors, fuselage of booster rockets, of the space shuttle. One and a half of tons of ACM mainly, CFRP is used in the rudder, etc., of civil aircraft such as the Boeing 767, the newest jet passenger airplane. As mentioned up to now, the ACM contributes to reduction in weight and rise in fuel efficiency.

Epoxy resin has been used a thermosetting resin called "Matrix Resin" combined with fibre reinforced materials, because it is a well-balanced resin with respect to moldability, cost, and mechanical and physical properties. However, a rise in resin characteristics, particularly heat resistance and toughness has been required in proportion to the increase in range of applications of resins in the space and aircraft industries.

There are two tendencies for new resins. One is a modification or improvement of epoxy resin, and the other is a polyimide type thermosetting resin. New resins are being developed so that they can have the heat resistance and mechanical strength much higher than those of resins used in sports equipment. But, of the new resins, those based on epoxy have the limit in the rise of heat resistance, and the most sensational topic at present is the development of resins based on thermosetting imide. The US National Aeronautics and Space Administration is developing the polyimide of norbornane end and acethylene end, and is studying the resin based on (bismaleimide), which is excellent in moldability. Comparing the ALCN resin which is a resin based on (bismaleimide) and the present heat resistant epoxy resin for aircraft with each other, the ALCN resin is excellent in moldability, and the heat resistance of the ALCN resin is about 100°C higher than that of the epoxy resin.

In the future, ACM's employing new resins will be adopted as materials for space, military aircraft, and civil aircraft, and the main structural material for aircraft will probably be changed from metal to ACM in the 1990s. In addition, it is anticipated that light weight and tough aircraft will be flying worldwide. Also, these aircraft will be excellent in reliability and fuel efficiency. (Extracted from Tokyo NIKKO MATERIALS, May 1986, "Future Materials" written by Teruho Adachi)

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A necessity for the space effort

The contribution of composite materials to the strategic and space systems of Aerospatiale certainly need not be demonstrated any longer. Their advantages reside in their light weight, their reliability during storage, and their operation in a vacuum (satellites), performance (best possible dimensioning), reproductivity and quality guarantee (automation and control), integration of functions (mass and room gain).

The processing methods used by the Strategic and Space Systems Division for the most part are similar to the processes already mentioned; however wide use is being made of filament winding. The latter is used to make nonpressurized tanks, originally using glass fibre and then switching to aramide fibre or Kevlar and now very-high-strength carbon fibres. The helium tanks are also made by filament winding of aramide or carbon on a titanium liner. The mass gains are considerable: 15 per cent on the Ariane V boosters, 30 per cent on the helium tanks, compared to the all-titanium tanks.

When it comes to improving the specific rigidity, carbon sandwich structures are used. A specific technology was developed for the rigid solar generators; it uses very-high-carbon fibre fabrics, module GY 70 SE with 65 g/m^2 and glue films with a gram content of as much as 15 g/m^2.

However, the Strategic and Space Systems Division is distinguished from the other divisions in the field of materials that can resist very high temperatures. These materials had to be developed to take the stresses connected with re-entry into the atmosphere; the stoppage temperatures can go beyond 6,000°C and the pressure can exceed 100 bar. This led to the adoption of ablative materials with base substances consisting of resin, carbon, or ceramics, reinforced by carbon fibres or ceramics woven in three dimensions.

Heat protection feasibility studies for Hermes are under way. As of now, only carbon fibre makes it possible to guarantee mechanical resistance at high temperature (1,800°C in the area of the attack edges and the nose). A carbon-carbon material was created to get satisfactory mechanical resistance at 1,800°C, good resistance to oxidation, cycling, and heat shock.

In the field of materials for Hermes, Aerospatiale was designated to conduct the material tests. In this connection, the CNES [National Centre for Space Studies] ordered the SIMOUN test unit which will be installed at the Aquitaine heat testing establishment. (Extracted from Air et Cosmos, 20 December 1986, "R&D, Application of Composites at France's Aerospatiale")

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Space station composites from lunar regolith

Since lifting one pound of material from the moon costs 1/20th of boosting the same payload from Earth, it makes sense to look to the lunar regolith for materials for the space station. Given the expense of mining and refining, high quality lunar alloys cannot compete with metals made on Earth, but perhaps lunar glass-glass composites can.

Experiments confirm that glass-reinforcing fibres can be made using feldspar, a readily available lunar ore that contains alumina and little contaminating iron. Glass or porcelain-enamel technology could supply the matrix. The alumina-based fibres melt at 980°C, and the ideal matrix would be fritlike materials that melt at 315°-375°C. As a bonus, pyrolytic production of fibre, frit and oxygen for the lunar colony could be made part of one continuous operation. They could be processed like thermoplastic/glass composites, and conversion from prepreg to end product could be easier.

Process heat would be supplied by a light-weight solar furnace, and the fibres could be made right on the lunar surface. The initial melt would coat the ground and insulate the production melt from contamination. This eliminates contamination from melt tank walls, and the higher purity should minimize fibre breakage during pulling and yield properties not found in Earth-made fibres.

The final composite could be made either by dipping the fibre into molten frit before forming, or depositing powdered frit onto the fibre, sintering into a prepreg and converting. The second method seems more controllable and degrades the fibre less. Rough composite structures could be made by bending, forming and glass-glass welding, while more refined objects are compression molded, filament wound, pultruded or tape laid. (Goldworthy Engineering, Inc., 23930 Madison St., Torrance, CA 90505-6085.) (Source: High-Tech Materials Alert, Vol. 2, No. 11, November 1985, p. 6)

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Stability of graphite composites in space

Perhaps now is the time to turn your attention to developing metal, polymer and glass-based composites that can stand up to the harsh environment of space - high vacuum, radiation, atomic oxygen and thermal cycling.

Thermal cycling is caused when an object passes in and out of the Earth's shadow. It causes microcracking, which affects both the coefficient of thermal expansion (CTE) and stiffness of the composite. The CTE of a flat polyimide/PAN based graphite fibre system fell 50 per cent after cycling 250 times between -156°C and +121°C. The part did not reach equilibrium crack density even after 500 cycles, so further drop-offs in CTE were expected.

Graphite/epoxy (Gr/Ep) tubes, considered for high-stiffness trusses in space systems, showed a 35 per cent degradation of torsional stiffness at a crack density of 10 cracks/cm after 500 cycles. But the reinforcing fibres held up well; extensional and flexural stiffness were not significantly affected.

Radiation is another hazard. Over 20-30 years, a satellite in geosynchronous orbit will be belted with about 10,000 Mrads of high-energy electrons and protons. Radiation tends to degrade matrix properties while leaving reinforcing fibres alone. In Gr/Ep systems, it lowers the epoxy's softening point, which generates greater free volume and volatiles that embrittle and stiffen the matrix below room temperature. Elastomer-toughened 121°C cured epoxy composites are more sensitive to radiation than 177°C cured epoxy composites.

Sequential radiation and thermal cycling causes embrittlement, which leads to more microcracking. (NASA Langley Research Center, Hampton, VA 23662). (Source: High-Tech Materials Alert, Vol. 2, No. 11, November 1985, p.7)

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Graphite epoxy

A composite material made of graphite epoxy is ideal for use in space because it is stronger than steel yet lighter than aluminium. Unlike metal, it does not expand from exposure to heat or cold, and its reduced weight translates into lower costs and larger payloads. For example, saving just one pound in a space vehicle means a reduced launch cost of several thousand dollars or added fuel for longer operations. Until now, however, graphite composites have proved difficult to mold to shapes more complex than a simple cylinder. But research and development by Hughes Aircraft Company has opened the way for the fabrication of a variety of new forms, including tubes with integrated end fittings in a one-piece design, support beams, and ring structures up to seven feet in diameter. (Source: Economist, 25-31 July 1987)

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Glass

Space glass gains Queen's Award

Pilkington Space Technology (UK), jointly with the Space Department of the Royal Aircraft Establishment (RAE), Farnborough, has been awarded a Queen's Award for Technological Achievement for the development of a new solar cell coverglass used in satellites. Pilkington coverslips have been used on more than 100 satellites and the new technology coverslips were used on the Giotto satellite aimed at Halley's comet.

Satellites in orbit are usually powered by large wings of solar cells converting the sun's rays into energy. Special ultra-thin glass is required to cover the cells to reradiate heat into space because solar cells lose efficiency at high temperatures. The glass shields the cells against radiation and micrometeorites and protects the cement attaching the cells together from the effects of intense ultraviolet radiation.

The specially coated microsheet glass used until recently for cell coverslips had several disadvantages, particularly when subjected to space radiation. Sponsored by RAE, Pilkington developed a new glass composition, new glass drawing techniques, and cleaning and coating operations and now manufactures the new product, CMX, for space use. The new CMX glass can be used in coverslips or optical surface reflectors, mirror-like glass which is fixed to the skin of spacecraft to control the inside temperature. The glass can be as thin as a human hair. This helps reduce the weight of the solar array which can measure several square metres, as the launch cost of a space shot is approximately $50,000 for every pound weight launched.

The glass has improved flatness and can be made up to 10 cm square, giving substantial assembly cost savings to the customer and increasing the power to weight ratio. Also, a new coating extends the operating life of a solar cell in orbit and because the surface is inert, it is not affected by atmospheric corrosion while on Earth, so eliminating storage and handling problems.

October 1986 saw the introduction of Pilkington's first new patterned glass for over four years, and Prisma is not just another pattern. It features a strong geometric design conceived to appeal beyond the established acceptance of patterned glass, and it also heralds a major new initiative to revitalise the use of the material in domestic and commercial interiors. (Source: Glass Technology, Vol. 28, No. 2, April 1987)

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Ceramics

National Aerospace Laboratory develops heat-resistant material

The National Aerospace Laboratory (NAL) of the Science and Technology Agency (Japan) is proceeding in the joint development of a heat-resistant material made of ceramic composite material using "chirano fibre" jointly developed by Ube Industries and Shikishima Canvas (headquarters, Osaka). This agreement on joint development has been made by the three entities and trial manufacture/evaluation of the heat-resistant material is scheduled to be conducted by March 1988. The aim is to develop a heat shield material for use in the Japanese version of the space shuttle.

Chirano fibre is a fibre developed by Ube Industries. It has a high strength of 300 kgf/mm^2 (2,900 MPa) at a high temperature of 1,300 to 1,350°C. NAL is making the most of these properties of chirano fibre with a three-dimensional weave and is developing a material which can be fastened mechanically, not with adhesive, due to its high strength compared to the heat-resistant materials used up to now in the space shuttle. By this, the heat-resistant material will not fall off and maintenance after landing can be greatly simplified compared to the shuttle.

The material currently under study has changed the parent material to ceramics and impregnated and baked the vanguard material polytitanocarbosilane used in the chirano fibre structure into a three- dimensional weave chirano fibre. The aim of this is to develop a heat-resistant material with a heat- resistance strength of over 1,350°C, a specific gravity of 0.1 g/cm^3, a heat conductivity of 0.05 W/M°C, and a strength of 1.0 kgf/mm^2 (9.8 MPa).

On the other hand, the strength of this material can be changed over a wide range by changing the volume content of chirano fibre. For this reason, it can also be used for turbines and furnace walls. The immediate objective of NAL lies in developing a heat-resistant material for a winged flight body, but it also plans to proceed with a study of other uses. (Source: Tokyo NIKKEI AEROSPACE, 15 September 1986)

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Concrete

Joint development for moon concrete

The Shimizu Construction Co. Ltd. will begin joint research with the Construction Technology Laboratory (CTL) of the US Concrete Association on concrete for use in space. Research will centre around the use of moon rock in the production of concrete.

CTL is using moon material obtained from NASA to conduct research into the production of concrete. So far, CTL has succeeded in demonstrating that moon rock can be used to produce concrete with a strength of 740 MPa, much stronger than standard concrete (280 to 350 MPa).

Shimizu Construction wants to be in a position to compete for concrete orders in the event of US construction of a moon base. In addition, the firm wants to explore Earth applications of any technology which might emerge from the research. Thus, the joint research will not only investigate new materials but will also seek to develop concrete production technology. The research is also attractive to Shimizu as a further entry into the field of high technology. (Source: Tokyo NIKKEI AEROSPACE, 23 June 1986)

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Alloys

A 45 m ultrahigh vaccum tube for studying alloy solidification under microgravity

Starting in mid-1988, French researchers will be able to use a 47-m-high ultrahigh vacuum tube in Grenoble on the campus of the Grenoble Nuclear Studies Research Centre (CENG). This will be one of the most powerful devices in the world, over a specific range of parameters, for the study of the solidification of metal alloys under simulated microgravity conditions.

The uniqueness of this vacuum tube is its high vacuum tube (10^8 torr) in addition to the free fall period (3 seconds) exceeded only by the large towers in the United States (100 m and 5 seconds of free fall). The new device will benefit from all the expertise acquired by AEC in the vacuum area with its construction of large accelerators.

The tower will allow extremely short experiments to be carried out on metal alloys of interest in basic research and possibly the preparation of experiments to actually be carried out in space. (Extracted from AFP Sciences, in French, 5 February 1987)

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Swedish space alloys produced

A successful experiment in the field of materials research has been conducted in a probe rocket from Esrange in Kiruna. Twelve different experiments were conducted. Most involved the fusing of metals that are incompatible on Earth, but can be joined together under weightless conditions. Silver and zinc are two such metals. The weightless condition lasted 7 minutes and 15 seconds. One possible result of the experiment is that industrial companies from around the world could order rare alloys that are in great demand from Esrange. Three more probe rockets will be sent up for additional experiments. (Source: Stockholm NY TEKNIK in Swedish, 14 April 1987, p. 10)

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Low density aluminium-beryllium-lithium alloys

Aluminium-lithium alloys (which also include copper, magnesium, and zirconium) combine high stiffness and low density. For structural applications, though, they need to be stiffer, more ductile, tougher, and still less dense.
An interesting variation on this theme goes a long way toward meeting those goals. It contains 0.5-4.3 per cent lithium (Li), 0.02-10.0 per cent beryllium (Be), and the balance aluminium (Al). The result is unusually low density, greater stiffness, and high strength. The addition of beryllium, like that of zirconium, helps refine aluminium alloy microstructure and disperse slip. Be also lowers alloy density and increases stiffness and strength. Properties are optimized by such dispersoid strengtheners as magnesium, silicon, and manganese. A typical alloy (3.6 wt. per cent Li, 9.8 wt. per cent Be) has an elastic modulus of 96.4 GPA, yield strength of 483.4 MPa, ultimate tensile strength of 510.0 MPa, and 2.3 per cent elongation. Al-Li-Be ingots are made by rapid solidification, cold compaction to 30-50 per cent density, vacuum hot pressing at 480° C and 69 MPa to full density, and extrusion. (Lockheed Missiles and Space Co.) (Source: Aerospace America, July 1986)

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Equipment

The MEPHISTO scientific space instrument

A sophisticated scientific space instrument, called MEPHISTO, is under development at CNES, the French National Space Centre, for the CEA/CNES/NASA Co-operative programme on the Fundamental and Applied Study of Material Solidification from the liquid phase. MEPHISTO is the acronym for Matériel pour l'Etude des PHénomènes Intéressant la Solidification sur Terre et en Orbite.

The purpose of the MEPHISTO apparatus is to perform fundamental studies on the influence of different parameters influencing the growth, such as the thermal gradient G_{th}, the solidification rate R, in comparison with the growth mechanisms and the characteristics of the solidified sample under microgravity. All these studies are made with different classes of materials with different concentration of doping. The phenomena to be observed are:

- The solutal microsegregation in the experiment sample during solidification,
- The solid/liquid interface stability thresholds,
- The growth perturbations,
- The interface morphology.

The originality and particularity of the MEPHISTO instrument are that it is designed for in-situ experiment measurements in real-time with possibilities for the scientist of real-time analysis and reaction from the ground. The experiment flight data will be correlated with other flight parameters, such as microgravity level, perturbations, available resources, mission elapsed time, etc. ... and also with post-flight analysis of obtained sample microstructures.

The main physical parameters measured are:

- Temperature field along the sample, deduced from thermocouples plunged in the molten bath or in the solid sample material.
- Solid/liquid interface temperature fluctuation measurement deduced from the SEEBECK effect.
- Solidification rate deduced either by PELTIER pulse marking or by electrical resistance variation measurement.
- Solid/liquid interface MORPHOLOGY by electrical pulse marking during the last solidification.
- Solid/liquid interface concentration profile blocked by local QUENCHING at the end of the experiment.

Conclusion

The MEPHISTO Instrument developed for the achievement of a very large and fundamental scientific programme on the Material Solidification study, is today the most sophisticated apparatus for space research under Microgravity conditions.

A programme of six flights on board of the US Shuttle is scheduled from September 1989 with a mean period of one year between each flight. The modular conception of the scientific instrument will permit a possible evolution function of the results from flights. (Extracted from Proc. 6th European Symposium on Material Sciences under Microgravity Conditions, Bordeaux, France, 2-5 December 1986. Written by G. Cambon, G. Cadet, Centre National d'Etudes Spatiales, G.E.R.M.E., 18, Avenue Edouard Belin, 31 055 Toulouse CEDEX FRANCE, J.J. Favier, Commissariat à l'Energie Atomique/CENG, Département de Métallurgie de Grenoble, Laboratoire d'Etudes de la Solidification, 38 043 Grenoble CEDEX FRANCE)

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Thermal coating developed

Mitsubishi Heavy Industries and Sumitomo Chemical Company have jointly developed a thermal insulating material for rockets. It is intended for use in insulation of the engine cover of rockets like the H-II.

The jointly developed material is a mixture of glass microballoons, which provide the insulating properties, a base of epoxyamide resin, and fibres of potassium titanate to strengthen the surface of the paint. It will protect various parts from heat that is radiated due to the abrasion cooling effect. Its thermal conductivity, which expresses insulating performance, is 0.23 W/m°C, and its density is about 0.8 g/cm^3. It can be sprayed or otherwise applied to parts which require insulation. To make that possible, consideration was given to ease of use, including viscosity and hardening time of the insulating material.

This insulating material will be used to prevent damage to the structural parts of rockets or missiles from rocket flames during launching or air friction during rapid flight. Because large quantities would be used on a large rocket like the H-II, it is composed of inexpensive and easily obtained ingredients. It is said that as a result, thermal protection of structural components of rockets can be accomplished at a lower cost than for the H-I, which used an expensive quartz fabric.

MHI has conducted vacuum heating experiments and plasma arc heating experiments, and has confirmed that the material's performance as an insulator is in no way inferior to that of rockets in the US. After further testing of workability hypothesized in actual use and testing of thermal insulating characteristics, MHI hopes to use it on an H-II rocket. (Source: NIKKEI AEROSPACE, in Japanese, 2 March 1987)

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Recent development of material processing studies under microgravity and future outlook in Japan

NASDA launched six TT-500A rockets for material processing experiment under low gravity between 1980-1983. Experimental results are summarized below:

FLT No.	Launch date	On board experiments (number of furnace)	Flight results
1	14 Sept. 1980	Ni-TiC Composite Alloy (2) Si-As-Te Amorphous Semiconductor (1)	Expected result was obtained including recovery system.
2	15 Jan. 1981	Ni-TiC Composite Alloy (3) Si-As-Te Amorphous Semiconductor (1)	Heating and cooling were normal, under 10^{-4}G. Payload recovery unsuccessful.
3	2 Aug. 1981	Si-As-Te Amorphous Semiconductor (3) Pb-Sn-Te Single Crystal Growth (1)	Heating and cooling were normal, under 10^{-4}G. Payload recovery unsuccessful.
4	16 Aug. 1982	Ni-TiC Composite Alloy (1) Si-As-Te Amorphous Semiconductor (1)	One furnace temperature control malfunctioned. Other performances were normal under 10^{-4}G. Payload recovery successful.
5	27 Jan. 1983	Si-As-Te Amorphous Semiconductor Pb-Sn-Te Single Crystal Halogen Lamp (1)	Heating and cooling were normal, under 10^{-4}G. Payload recovery successful.
6	19 Aug. 1983	C-fibre/Al Composite Al/In Acoustic Mixing $PbO-B_2O_3$/Diamond Composite	One electric furnace temperature control malfunctioned. Other performances were normal, under 10^{-4}G. Payload recovery successful.

Aircraft experiments

Five preliminary flight tests for FMPT/SL-J (FMPT = First Material Processing Test. It is the first national microgravity experimental project. SL-J is a joint flight shared by FMPT and NASA's project) have been conducted in March 1986 by using jet aircraft MU-300. Duration of low gravity is about 20 s. Acoustic levitation furnace (ALF), gas evaporation experiment facility (GEF), liquid drop experiment facility (LDF) and fluid physics experiment facility (FPF) which consisted of two units (bubble behaviour experiment unit (BBU) and Marangoni convection experiment unit (MCU)) were tested.

Melting and levitation of glass consisted of 65 CaO, 25 Ga(2)O(3) and 10 GeO(2) were confirmed in this experiment.

During low gravity condition, a heater in the bulbe was lighted and the growing smoke ball observed in case of experiment with drop capsule, was found to be suppressed by controlling the pressure of the filled gas and heating temperature.

Texus experiments

Unidirectional solidification test of Al - 6.8 wt% Pb - 6.8 wt% Bi alloy has been conducted by the TEXUS - 13 in May 1986. This experiment is performed by the National Research Institute for Metals.

The alloy in a BN crucible preheated to 1,200°C before lift-off of the rocket, was solidified under microgravity environment during the flight. It appears that the flight processed sample has much more homogeneous distribution of Pb-Bi alloy particles in Al matrix, although a small difference in size distribution exists which has been probably caused by the presence of temperature gradient.

FMPT project

FMPT is the first national microgravity experimental project. After a feasibility study by NASDA, nine facilities were selected as candidates of common facilities for materials processing test in 1980. NASDA's policy for FMPT was basically development of experimental facilities by domestic technology. As a result using preliminary breadboard model test, it was concluded that development of four facilities among the above nine were difficult within limited schedule and budget, which were very high temperature heating furnace, electric induction furnace, electromagnetic levitation facility and electron-beam melting facility.

FMPT/SL-J will be conducted in 1990. FMPT consists of 22 material processing and 12 life science experiments. For the material processing test, 10 equipments were developed. Two separation experiments by electrophoresis concerning biogenic materials and animal cellular organella, and one crystal growth experiment of enzymes were classified into life science experiments in the FMPT project. Themes of 22 material processing are summarized in the following table.

List of experiment themes in FMPT/SL-J excepting life science themes

EQUIPMENT	EXP. NO.	EXPERIMENT TITLE	SAMPLE/SPECIMEN
Continuous heating furnace (CHF)	M-4	Casting of Superconducting Filamentary Composite Materials	Al-Pb-Bi
	M-7	Diffusion in Liquid State and Solidification of Binary System	Au/Ag
	M-11	Fabrication of Very-Low Denisty, High-Stiffness Carbon Fibre/Al Hybridized Composites	CFRP/Al
	M-13	Fabrication of Si-As-Te: Ternary Amorphous Semiconductor in the Micro-gravity Environment in Space	Si As Te/Ni
	M-19	Solidification of Eutectic System Alloys in Space	Al-Cu
Large isothermal furnace (LIF)	M-5	Formation Mechanism of Deoxidation Products in Iron Ingot Deoxidized withTwo or Three Elements	Iron ingot
	M-6	Preparation of Ni Base Dispersion Strengthened Alloys	Ni base alloys Al(2)O(3), TiC
	M-12	Study on the Mechanism of Liquid Phase Sintering	Tungsten powder/Ni
Gradient heating furnace (GHF)	M-1	Growth Experiment of Narrow Band-Gap Semiconductor PbSnTe Single Crystal in Space	Pb(1-x)Sn(x)Te
	M-10	Study on Solidification of Immiscible Alloy	Al In
	M-22	Crystal Growth of Compound Semiconductors in a Low-Gravity Environment	In Ga As

(Extracted from ESASP-256, Proc. 6th European Symposium on Material Sciences under Microgravity Conditions, Bordeaux, 2-5 December 1986; article written by A.B. Sawaoka and A. Kanbayashi)

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7. NEWS AND LIST OF SPACE-TECHNOLOGY CENTRES

United States of America

Centres for the commercial development of space power

The US National Aeronautics and Space Administration has selected new teams to research areas promising to the commercial development of space, including space power. Auburn University, Auburn, Ala., and the Texas A&M Research Center, College Station, Texas, were each picked to set up Centres for the Commercial Development of Space Power. The industry/university teams are eligible to receive up to $1 million annually for the next five years to support research which could lead to new technologies commercially exploitable in space. The seven centres - also involving space propulsion, robotic sensing systems, secretion research, bioserve space technologies and materials for space structures - were selected from 28 proposals. (Source: Intl. Solar Energy Intelligence Report, 4 August 1987)

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Centre for crystal growth in space

Clarkson University has announced the formation of a Centre for the Development of Commercial Crystal Growth in Space with funding of over $2 million per year from NASA, industry, and the states of New York, Florida, and Massachusetts. While the primary goal is to grow crystals in space of higher perfection and larger size than it is possible to grow on Earth, the research will also advance the technology of crystal growth on Earth.

The centre is made up of a consortium of eight universities, 11 corporations, and two national laboratories. Clarkson and the University of Florida are concentrating on solidification of cadmium telluride and gallium arsenide. Rensselaer Polytechnic Institute is studying the vapour transport of mercury halides for radiation detectors. Alabama A&M University is growing infrared detector and electro-optic crystals from aqueous solutions. Worcester Polytechnic University is continuing research on the growth of zeolite crystals.

Scientists from the National Bureau of Standards will use the National Synchrotron Light Source at Brookhaven National Laboratory to observe defects during and following crystal growth by X-ray topography in real time. (Source: Ceramic Bulletin, Vol. 66, No. 2, 1987 (c) ACerS)

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Advanced materials research guide

A useful guide to materials techniques and properties under research around the world is available from Technical Insights (P.O. Box 1304, Fort Lee, NJ 07024, USA). More than 350 high tech materials research centres are described in Advanced Materials Research Guide, a technical information source to not-for-profit research organizations in 30 countries. The technical capabilities of the materials research centres, more than half of which are located outside the US, are described. Names and addresses of the centres, their key administrative personnel, research programmes under way, their working relationships with industry, and their patent activities are described.

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Materials manufacturing, a favourite of industry, moves ahead

National Aeronautics and Space Administration's (NASA) new commercial centres, created in 1985, include a microgravity laboratory and five centres for space commercialization that focus on materials processing and crystal growth. The sites are designed to investigate the potential for developing materials and processes of commercial significance.

Even though the shuttles needed for the space portions of the experiments have been grounded, NASA's backing of the new centres means that there will be sustained interest in space manufacturing for the next five years; to this agrees the technical director of the materials science department at Battelle Columbus Laboratories' Centre for the Commercial Development of Space, Battelle, Columbus, Ohio, one of the five centres named by NASA. The research centre will focus on electronic materials, metal alloys, glass, ceramics, polymers and associated process technologies. The work will be of special interest to chemical firms, which may be able to use the low gravity of space to develop new and ultrapure chemicals, and to materials manufacturers, which may be able to process new types of metals, alloys, glasses, ceramics and polymers in space.

A materials-processing and project scientist for the space station at the Marshall Space Flight Centre in Huntsville, Alabama acknowledges the loss of an orbiter is hurting the space-manufacturing programme, but the setback can focus effort on getting the most out of groundside work.

One way to do some space-like work is to go to Cleveland. There, at NASA's Lewis Research Centre, the Microgravity Materials Science Laboratory is offering university and industry researchers a low-cost, low-risk method of testing proposals for materials processing in space without leaving the Earth. Along with such facilities as furnace systems and mockups of flight hardware, the laboratory also offers access to Lewis' two drop towers, which help achieve weightlessness for up to five seconds.

Thus far, only GTE Laboratories of Waltham, Mass., has used the microgravity laboratory to conduct GaAs crystal-growth experiments.

One of the most promising research areas is the production of purer GaAs in space. Microgravity Research Associates, Inc., Coral Gables, Florida, entered a joint-endeavor agreement with NASA in 1983 to demonstrate the superiority of GaAs crystal material produced in space.

Since the early 1970s, NASA has been investigating several methods for processing low-defect semiconductor materials in space. Among the processes under investigation are crystal growth by chemical vapour transport, seeded containerless solidification of materials such as indium antimonide, and steady-state growth and segregation of indium antimonide. A vapour crystal-growth system that was designed for use on the shuttle has also been used to grow single crystals from vapour. NASA has 37 existing or pending joint agreements with industrial partners for space manufacturing; 13 joint agreements are in electronics and electro-optics. That number is surpassed only by the biological experiments. (Extracted from Electronics, 5 May 1986, "A bruised NASA hangs in with space-factory programme" written by George Leopold)

* * * * *

Europe

Microgravity user support centre

The DFVLR (German Research and Experimental Institute for Aeronautics and Astronautics) in Cologne-Porz is constructing a Microgravity User Support Centre (MUSC). The MUSC project will provide support for scientific and industrial space users in planning and carrying out space experiments with the

Spacelab, Eureca, and Columbus vehicles, which are or will be available in terrestrial orbit for days, months, or years. The most important work area will be supporting microgravity experiments in the specific fields of materials sciences, biology, and medicine.

On behalf of the interested parties, the MUSC experts are involved in the efficient preparation of planned experiments, in determining the best use of the precious time in space, and, finally, in the optimal evaluation of the measurement results obtained.

The Microgravity User Support Centre will be organized so that scientific work can be carried out in the space station as in a large research installation comparable to a particle acceleratory facility, a research nuclear reactor, or an astronomical observatory. MUSC installations will be available to interested parties from the FRG and member countries of the European Space Agency (ESA). (Extracted from VDI Nachrichten, 26 September 1986)

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First European Centre in Italy

In 1988 Italy will have the first European centre for the study, preparation and utilization of scientific and industrial experiments in reduced gravity conditions, namely MARS (Microgravity Advanced Research and Users' Support). This announcement was made at the 27th International Space Meeting in Rome. (Extracted from Rome AIRPRESS, 28 March 1987)

* * * * *

Irish prepare for space tests

A small company in the Republic of Ireland is about to take delivery of equipment for testing experiments that are to go into space.

Space Technology Ireland, is the first firm on a new science park at St. Patrick's College.

The equipment to be delivered to Space Technology Ireland reproduces some of the conditions found in space. The test chamber has dimensions of about one cubic metre. The idea is that scientists will send experiments that they want to qualify for space flight to the facility, where the company will put the experiments through their paces at the temperatures and pressures found in space. The space agencies, such as NASA and the European Space Agency, insist that equipment must pass certain tests before they are accepted for a launch.

Besides this environmental testing, the company designs and tests equipment for space and writes software. So far the company has done work for the Technical University of Graz in Austria and the Hungarian Academy of Sciences in Budapest.

The work in Hungary was connected with the Phobos mission. During the mission, a probe from an orbiting spacecraft will land on the surface of Phobos to study the moon's chemical composition.

Space Technology Ireland also checks to ensure that electromagnetic radiation generated by other parts of the spacecraft does not interfere with the electrical circuits on a particular experiment. For example, digital switching circuits on the main spacecraft might generate electromagnetic radiation that effects the operation of, say, charge sensitive amplifiers. (Extracted from New Scientist, 4 June 1987)

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British National Space Centre in co-operative talks with the USSR

An official seven-member delegation of the British National Space Centre (BNSC) visited Moscow from 29 September to 1 October 1986 at the invitation of Soviet officials to discuss new possibilities for space co-operation between the United Kingdom and the USSR. A protocol of agreement was signed at that time by BNSC on one side, and by the Institute for Cosmic Research (IKI) and the Institute for Biomedical Problems on the other, regarding co-operation in materials science, space biology and medicine, high energy astrophysics, sun-earth physics, planetary science, as well as ultraviolet, infrared, submillimeter, and radio astronomies.

The USSR has offered BNSC a participation in the Soviet X-ray telescope project expected to be installed on a specialized module that will be attached to the Mir station for five years. The Soviets will accept to carry five British or Western X-ray astronomy experiments. They also proposed that BNSC participate in the Soviet project for an astronomy satellite in the extreme ultra-violet, as well as in materials science and space biomedicine projects. (Extracted from Paris AIR & COSMOS in French, 18 October 1986, p. 61, article by Pierre Langereux)

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The Space Research & Technology Centre in the Netherlands

The Space Research & Technology Centre has completed the most advanced large space simulator in the world. The 9.5 m diameter simulator is already being used to test the Italian Research Interim platform, which will be used in space to boost craft into higher orbits. Spacecraft are tested under a high vacuum, and high levels of solar and infrared radiation. Optical measurements are taken of mechanical and thermal distortions that occur when the object is irradiated. A sun simulator has an intensity of 1 solar constant, and mirrors allow reflecting the beam at various angles to simulate various positions in orbit. The light is generated by a bank of 20 xenon lamps. Temperatures are controlled by surrounding the simulator with a steel vessel containing gaseous or liquid nitrogen. The vacuum is produced with turbo-molecular and cryo pumps. Pressures of 0.0000001 millibars have been achieved. Spacecraft motion is achieved with a turntable and spinbox. The UK £20 mil simulator will test the ESA Hipparcos, Intelsat and Eureka (the European Recoverable Carrier), which are all too large for existing simulators. Building the new simulator was cheaper than having to modify craft already in space. (Source: New Scientist, 22 January 1987)

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Japan

Space environment utilization centre

A space environment utilization centre was set up in 1986 under the support of the Ministry of International Trade & Industry (MITI) and the Science & Technology Agency for the purpose of developing high technology by utilizing the weightless state in outer space.

The above centre is scheduled to investigate needs from private enterprises concerning primary material experiments, to utilize a space laboratory developed by ESA (European Space Agency), and to develop machinery, equipment and facilities necessary for space environment utilization in co-operation with the private sector. MITI will start the development of a free flyer next year, for which information exchange and co-operation with the private sector will be essential. There is a growing interest in industrial utilization of outer space.

The centre will provide venues for various seminars, workshops, and exchange with Western nations and between domestic enterprises. (Extracted from Chemical Economy and Engineering Review, June 1986, Vol. 18, No. 6)

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List

International

European Space Agency (ESA), 8-10 rue
Mario-Nikis, 75738 Paris Cedex, 15 France

European Space Operations Centre (ESOC),
Robert-Bosch Strasse 5, D-6100 Darmstadt,
Federal Repubic of Germany

European Space Research and Technology Centre
(ESTEC), Keplerlaan 1, Noordwijk aan Zee,
Netherlands

Groupement Européen d'Etudes Spatiales
(Eurospace), [European Space Study Group],
16 bis, avenue Bosquet, 75007 Paris, France

Advisory Group for Aerospace Research and
Development (AGARD), 7 rue Ancelle, 92200 Neuilly
sur Seine, France

Argentina

Centro Espacial San Miguel (CESM), [San Miguel
Space Centre], Avenida Mitre 3100, San Miguel
1663 Buenos Aires

Austria

Osterreichische Gesellschaft für Sonnenenergie
und Weltraumfragen GmbH (ASSA) [Austrian Solar
and Space Agency], Garnisongasse 7/26, A-1090 Wien

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Instituto de Pesquisas Espaciais (INPE)
[Institute for Space Research], P.O. Box 515,
Avenida dos Astronautas 1758, 12200 Sao José dos
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National Research Council of Canada (NRC),
Montreal Road, Ottawa, Ontario K1A 0R6

Canada Centre for Space Science

Czechoslovakia

Aerospace Information Analysis and Dissemination
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Centre National d'Etudes Spatiales (CNES)
[National Centre for Space Studies], 129 rue de
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Guiana Space Centre, BP 6, 97310 Kourou,
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Toulouse Space Centre, 18 avenue Edouard-Belin,
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avenue de l'Observatoire, 25000 Besançon

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Technology], Heinemannstrasse 2, Postfach 200706,
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Templergraben 55, D-5100 Aachen

Air and Space Travel Institute

Astrophysics and Extraterrestrial Research
Institute, Auf dem Hügel 71, D-5300 Bonn 1

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Gujarat

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Spaziali [Space Telecommunications Research
Centre], c/o Instituto Elettronica ed
Elettrotechnica, Politecnico, Piazza Leonardo da
Vinci 32, 20133 Milano

Piano Spaziale Nazionale [National Space Plan],
Viale Regina Margherita 202, 00100 Roma

Instituto per Richerche in Fisica Cosmica e
Tecnologie Relative [Cosmic Physics and Related
Technology Research Institute], c/o Instituto di
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Koganei-shi, 184 Tokyo

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Oslo 3

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Consejo Superior de Investigaciones Cientfficas
(CSIC) [Higher Council for Scientific Research],
Serrano 117, Madrid 6

Sweden

Statens delegation för rymdverksamhet [Swedish
Board for Space Activities], Box 4006,
S-171 04 Solna

Svenska Rymdaktiebolaget [Swedish Space
Corporation - SSC], Tritonvägen 27,
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Switzerland

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(SAFR) [Swiss Association for Work on Space
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St. Mary, Dorking, Surrey RH5 6NT

University of Kent at Canterbury, Canterbury,
Kent CT2 7NZ

Electronics Laboratory

United States of America

Air Force Office of Scientific Research (AFOSR),
Builidng 410, Room A-113, Washington, DC 20332

Ames Research Center (NASA), Moffett Field,
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Jet Propulsion Laboratory (JPL), 4800 Oak Grove
Drive, Pasadena, CA 91103

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Box 400, 4455 Genesee Street, Buffalo, NY 14225

University Attached Institute, Ithaca, NY 14853

Center for Radiophysics and Space Research

Goddard Institute for Space Studies,
2880 Broadway, New York, NY 10025

Goddard Space Flight Center, Greenbelt, MD 20771

Wallops Flight Facility (WFF), Wallops Island,
VA 23337

Johnson Space Center, Houston, TX 77058

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Cambridge, MA 02139

MIT Center for Space Research

National Aeronautics and Space Administration
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United States Department of Agriculture,
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University of Alabama, University, AL 35486

Bureau of Engineering Research (BER),
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University of Texas at Austin, Austin, TX 78712

Center for Space Research and Applications

University of Virginia, Charlottesville, VA 22903

Mechanical and Aerospace Engineering Department

(Extracted from Earth and Astronomical Sciences Research Centres, a World Directory of Organizations and Programmes, ISBN 0-[illegible]-90020-4, 1984)

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8. GALAXY OF ACRONYMS

Out-of-this-world abbreviations

As the space programme continues, new technologies emerge, and with them, new acronyms and abbreviations. The following is a condensed list from NASA dealing mostly with materials processing experiments.

AADSF	Advanced automated directional solidification furnace
ACC	Aft cargo carrier
ACES	Acoustic containerless experiment system
ACPF	Acoustic containerless processing facility
ADSF	Automated directional solidification furnace
ALU	Advanced levitation unit
ARC	Ames Research Center (NASA)
ASCG	Automatic solution crystal growth
AVCG	Automatic vapour crystal growth
CCDS	Centers for the Commercial Development of Space
CFES	Continuous flow electrophoresis system
CFIF	Continuous flow isoelectric focusing
CIEF	Continous isoelectric focusing
CNES	Centre National d'Etudes Spatiales
COMLAB	Commerce Lab
COMM	Commercial missions
DCF	Droplet combustion facility
DFVLR	Deutsche Forshungs- und Versuchsanstalt für Luft- und Raumfahrt (German Aerospace Research Establishment)

DMOS	Diffusive mixing of organic solutions
DSF	Directional solidification furnace
DTA	Development test article, or differential thermal analysis
DT/DT	Drop tube/Drop tower (facility)
EAC	Experiment apparatus container
EBF	Electron bombardment furnace
ECG	Electro-epitaxial crystal growth
ECP	Electromagnetic containerless processing
EEVT	Electrophoresis equipment verification test
EMC	Electromagnetic compatibility
EMI	Electromagnetic interference
EMI	Electromagnetic levitator
EMU	Extravehicular maneuvering unit
EOS	Electrophoresis operations in space
ESA	European Space Agency
ESRO	European Space Research Organization
EURECA	European retrievable carrier
FF	Free flyer
FMPT	First material processing test (Japan)
FZES	Float zone experiment system
GAC	Grumman Aerospace Corporation
GAS	Get-away-special
GAS Can	Get-away-special cannister
GC-MS	Gas chromatograph-mass spectrometer
GEM	Generic experiment module
GERME	Groupe D'Etude et Recherches es, Sur Test Materieux Dans L'Espace
GFP	Glass fibre pulling
GHF	Gradient heating facility
GPRF-G	General-purpose rocket furnace-gradient
GPRF-I	General-purpose rocket furnace-isothermal
GSFC	Goddard Space Flight Centre (NASA)
HH-G	Hitchhiker (Goddard)
HH-M	Hitchhiker (MSFC)
HPF	Heat pipe furnace
HTGPF	High temperature general purpose furnace
IEF	Isoelectric focusing
IFF	Isoelectric focusing facility
IG	Igloo (Spacelab Pallet Missions)
IGI	Industrial guest investigator
IML	International Microgravity Laboratory
IOC	Initial operating capability
IPL	Integrated payload
ISC	International Space Corporation
ISF	Industrial Space Facility
ITA	Instrumentation Technology Associates Inc.
JEA	Joint endeavor agreement
JEM	Japanese experiment module, or Joint endeavor manager
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center (NASA)
KSC	Kennedy Space Center (NASA)
LaRC	Langley Research Center (NASA)
LDEF	Long duration exposure facility
LEO	Low earth orbit
LeRC	Lewis Research Center (NASA)
3M	Minnesota Mining and Manufacturing Co.
MAC	Microgravity Advisory Committee
MASU	Metal alloy separation unit
MAUS	Materialwissenschaftliche Autonomo Experimente Unter Schwerelosigkeit
MDAC	McDonnell Douglas Aerospace Corporation
MEA	Materials experiment assembly
MEPF	Multiple experiment processing furnace
MEPHISTO	Matérial pour l'Etude des PHénomènes Intéressant la Solidification sur Terre et en Orbite
MGM	Mechanics of granular materials
MICG	Mercury iodide crystal growth
MIT	Massachusetts Institute of Technology
MLR	Monodisperse latex reactor
MLRS	Monodisperse latex reactor system
MMPF	Microgravity and Materials Processing Facility
MMLS	Microgravity Materials Science Laboratory
MPS	Materials processing in space
MRA	Microgravity Research Associates
MRI	Midwest Research Institute
MS	Materials science
MSA	Microgravity science and applications
MSDR	Materials science double rack
MSFC	Marshall Space Flight Center (NASA)
MSL	Materials Science Laboratory
MTL	Manufacturing and Technology Laboratory

NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency (Japan)
NBS	National Bureau of Standards
NRL	Naval Research Laboratory
NSTS	National Space Transportation System
OCP	Office of Commercial Programmes (NASA) - Code I
OFPU	Optical fibre production unit
OSF	Office of Space Flight (NASA) - Code M
OSS	Office of Space Station (NASA) - Code S
OSSA	Office of Space Science and Applications (NASA) - Code E
OTA	Office of Technology Assessment
OTV	Orbital transfer vehicle
PACE	Physics and chemistry experiment
PCGS	Protein crystal growth system
PI	Principal investigator
PL	Payload
PS	Payload specialist, or phase separation
PVT	Physical vapour transport
PVTOS	Physical vapour transport of organic solutions
RI	Rockwell International
RIEF	Recirculating isoelectric focusing
RPI	Rensselaer Polytechnic Institute
SAAC	Space Applications Advisory Committee
SAAG	Science and Applications Advocacy Group
SAAL	Single-axis acoustic levitator
SASX	Science and Applications (Mission)
SAB	Space Applications Board
SCG	Solution crystal growth
SCIF	Static column isoelectric focusing
SEM	Scanning electron microscope
SII	Space Industries Inc.
S/L	Spacelab
SPACELAB-D	German Spacelab Mission
SPACELAB-J	Japanese Spacelab Mission
SPAR	Space processing applications rocket
SPAS	German shuttle pallet satellite
SPICE	Spacelab payload integration and co-ordination in Europe
SPPO	Spacelab Payload Project Office (MSFC)
SS	Space station
SSIP	Shuttle student involvement project
SSP	Space station program
STAMPS	Scientific and Technological Aspects of Materials Processing in Space (Committee)
STEP	Space technology experiment platform
STS	Space transportation system
TEA	Technical exchange agreement
TEZG	Tribological experiments in zero gravity
TFCG	Thin film crystal growth
TFDU	Thin film deposition unit
TFSUS	Task Force on the Scientific Uses of Space Station
TGS	Triglycine sulfate
3AAL	Three-axis acoustic levitator
UAB	University of Alabama in Birmingham
UAH	University of Alabama in Huntsville
USRA	Universities Space Research Association
VCG	Vapour crystal growth
VCGS	Vapour crystal growth system

(Source: Advanced Materials and Processes, April 1986)

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9. PUBLICATIONS ON SPACE-RELATED AND OTHER NEW MATERIALS

Space colonization; technology and the liberal arts
Holbrow, C.H., Russell, A.M., Sutton, G.F., American Institute of Physics, New York, N.Y. 1986, 153 p. American Institute of Physics. Conference proceedings 148 Conference on Space Colonization: Technology and the Liberal Arts, Geneva, N.Y., 11-12 October 1985

Space radiation effects on materials sponsored by ASTM Committee E-10 on radioisotopes and radiation effects, Philadelphia, ASTM. 1962, 61 p. American Society for Testing and Materials Special Technical Publication

The future for space technology
Pardoe, G.K.C. London, Pinter. 1984, 206 p. Future for science and technology

Dictionnaire de l'aeronautique et de l'espace
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Coursau, H. Conseil International de la Langue Française, Paris. 1982, 727 p.

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International space programmes and policies, Jasentuliyana, N., Chipman, R. Amsterdam, North-Holland. 1984, 551 p. United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE), 2nd, Vienna, Austria 1982; proceedings.

Astronautical engineering and science; from Peenemuende to planetary space, Stuhlinger, E. New York, N.Y., McGraw-Hill. 1963, 394 p., illus.

Cospar directory of organization and members 1977, Varna. 1977, 104 p. Space Sciences - Directories/Astronautical Research - Directories.

A summary of extremes of isotopic variations in extra-terrestrial materials, Shima, Masako (National Science Museum, Tokyo, (Japan)). English. Geochim. Cosmochim. Acta. ISSN 0016-7037. CODEN: GCACA. (April 1986). v. 50(4) p. 577-584.

Use of refractory metals. Primenenie tugoplavkikh metallov. Efimov, Yu.V.; Makarov, P.V.; Savitskij, E.M.; Horz G.; Burkhanov, G.S.; Ottenberg, E.V. Russian. Refractory metals and alloys. Tugoplavkie metally i splavy. Burkhanov, G.S.; Efimov, Yu.V. (eds.). 450 refs.; 140 figs.; 51 tabs. Moscow (USSR). Metallurgiya. 1986. p. 293-340.

The European conference on non-destructive testing. Evropejskaya konferentsiya po nerazrushayuschemu kontrolyu. Klyuev, V.V. Russian. Vestn. Akad. Nauk SSSR. ISSN 0002-3442. CODEN: VANSA. (1985). (No. 7) p. 74-77.

International co-operation in highly technological fields, especially in the field of aeronautics and astronautics and nuclear engineering. Internationale Zusammenarbeit in hochtechnologischen Bereichen - unter besonderer Berücksichtigung von Forschung und Entwicklung in der Luft - und Raumfahrt sowie der Kerntechnik. Schunk, C. German. Baden-Baden (Federal Republic of Germany). Nomos. 1982. 305 p. ISBN 3-7890-0760-9. Internationale Kooperation. Aachener Studien zur Internationalen Technisch-Wirtschaftlichen Zusammenarbeit. No. 22).

Engineering testing requirements in FED/INTOR. Abdou, M.A.; Nygren, R.E.; Morgan, G.D.; Trachsel, C.A.; Wire, G.; Oppermann, E.; Puigh, R; Gold, R.E. Argonne National Laboratory, IL (USA); McDonnell Douglas Astronautics Co., St. Louis, MO (USA); Hanford Engineering Development Laboratory, Richland, WA (USA); Westinghouse Research Laboratories, Pittsburgh, PA (USA). English. CONF-830406-6. October 1982, 3 p. Availability: INIS. Available from NTIS, PC A02/MF A01 as DE83009589.

Materials sciences in space; a contribution to the scientific basis of space processing. Edited by B. Feuerbacher, H. Hamacher and R.J. Naumann. NY: Springer-Verlag, 1986, 496 p., ISBN 0-387-163538-1.

Contents: Microgravity materials sciences. Physical phenomena. Experimental hardware. Case studies and results. Index.

Note: This volume was written to introduce readers to the field of microgravity materials science. It provides readers with background information obtained from space experiments to date. This knowledge will be needed for future commercial space utilization. The contributing authors are from organizations such as NASA-Jet Propulsion Laboratory, the European Space Agency, and NASA-Marshall Space Flight Center. The intended audience consists of scientists and engineers whose specialty is not microgravity materials science.

European space directory. A Sevig Press publication sponsored by Eurospace.
SEVIG PRESS Publishing Company,
11, rue Alexandre Cabanel, F-75015 Paris
France.

High technology, space and society. Manuel Castells, ed. 1985. Sage Publications, Beverly Hills, CA. 320 pages. ISBN: 0-8039-2414-3.

This collection of 14 essays explores the relationship between technology and space, with the mediation efforts of the economic, cultural and political processes. Divided into 6 major areas: an overview, the new industrial space, the transformation of services, the communication revolution, theoretical perspectives and alternatives.

Composite materials for aircraft structures. Brian C. Hoskin, and Alan A. Baker, both of the Aeronautical Research Laboratories, Australian Department of Defense.

Contents: Basic Principles of Fibre Composite Materials. Fibre Systems. Resin Systems. Composite Systems. Component Form and Manufacture. Structural Mechanics of Fibre Composites. Joining Advanced Fibre Composites. Environmental Effects and Durability. Damage Tolerance of Fibre Composite Laminates. Nondestructive Inspection (NDI) of Reinforced Composite Materials. Repair of Graphite/Epoxy Composites. Aircraft Applications. Airworthiness Considerations. (American Institute of Aeronautics and Astronautics, 1633 Broadway, New York, N.Y. 10019)

Refractory composite insulation

Brochure and three data sheets explain the concepts, applications, and properties of LI900, LI2200, and FRCI refractory composite insulation materials for the aerospace industry.
Lockheed Missiles & Space Co., Sunnyvale, Calif., USA.

Fluid sciences and material science in space - a European perspective

H.U. Walter (Editor), 1987. Approx. 500 figures, 2000 ref. Approx. 800 pages, Hard cover.
ISBN 3-540-17862-7. Publication date: June 1987 (tentative). Springer-Verlag, Berlin, Heidelberg, New York, Paris, Tokyo.

The volume gives a complete review of the present status of microgravity research. It includes the results of the D-1 Spacelab mission, the last microgravity-dedicated mission before the Challenger disaster. Close to 50 European scientists have co-operated in the book's preparation, and this synergetic approach has greatly enhanced the depth and the scope of the contributions. Each individual chapter first presents the theoretical background to justify microgravity experiments, then follows a review of the experiments performed and a critical discussion of the results obtained. Finally, recommendations for future activities are put forward.

A thesaurus of engineered materials has just been published by Materials Information - a joint service of The Institute of Metals and ASM International (USA). The 132-page first edition is the basis for the terminology used in the recently introduced "Engineered Materials Abstracts". It contains the vocabulary for classification, processing and properties of polymers, ceramics and composites.

Japan Technical Information Service and ASM Intal (Metals Park, OH) will jointly produce 2 publications on Japanese new materials R&D in the US; start-up: June 1987. The publications are Japan Materials News, a monthly report on developing new materials, and Japan Materials Report, initially a bi-monthly report on new trends on new materials R&D. The publications will include such materials as metals, ceramics, polymers, graphites and composites, and manufacturing and processing methods. Japan Technical is a subsid of Nippon Steel, whose large information-gathering network will be used to promote the project.

Publications from Proceedings of Conferences organized by the Institute of Metals, 1 Carlton House Terrace, London, SW1Y 5DB, UK

Materials at their limits. Autumn Meeting, September 1985 at the University of Birmingham.

Contents: Ceramics: applications and limitations, M.H. Levis. Composites - the present and the future, G.D. Scowen. Mechanical alloyin - the development of strong alloys, M.J. Fleetwood. Aluminium alloys for airframes: limitations and developments, C.J. Peel. Aero engine alloy development - the sky's the limit? D. Driver.

(B 392, 280x210mm, 86 pp, ISBN 0 904357 86 4, Paperback, published 1986)

Materials data sources

The guide is simple to use and for each category of material it gives reference to authoritative printed texts, standards, trade and research associations and academic establishments. It also identifies some material selection systems which are in text form or computer based. (Book 405, 210x150mm, 111 pp, ISBN 0 852986, 36 X Paperback, published 1987)

Engineering composite materials by Bryan Harris

Contents: The nature of composite materials. Elastic properties of fibre composites. Strength of composites. Fracture and toughness of composites. Fatigue behaviour of fibre composites. Environmental effects.

(Book 366, 240 x 180 mm, 136 pp, ISBN 0 901462, 28 4, Paperback, Published 1986)

Composites

Engineering composites

Literature package focuses on Fiberloc polymer composites, a glass fibre-reinforced material based on high flow thermoplastic resins. Set of three brochures provide engineering design data, an injection molding processing guide, and an extrusion processing guide. BF Goodrich, Geon Vinyl Div., Cleveland, Ohio. Nos. FL-010, FL-009, FL-011, USA.

Graphite products

Brochure describes Desulco carbon/graphite and the other types of graphite processed by Superior. It also covers standard sizes of graphite and major product applications. Superior Graphite Co., Chicago, Ill., USA, 8 pp.

Engineered materials handbook, volume 1: composites

Chief Editor: Theodore J. Reinhart, Hardcover 9"x11", 960 pages w/illus.; AIAA Marketing Dept. ASM, 1633 Broadway, New York, N.Y. 10019 (AIAA = American Institute of Aeronautics and Astronautics)

Metal matrix composites: developments in the USA

Authors: S. Booth, M. Ball, A. Clegg, N. Hurd, R. Savery. Published: BNF Metals Technology Centre 1987; 200 pages; BNF Metals Technology Centre, Denchworth Rd., Wantage, Oxon OX12 9BJ, UK

Specialty additives

Brochure highlights the physical and chemical properties of the company's broad line of specialty additives and depicts, by way of application grids, many of the effective ways in which these additives may be used. Products featured include: Surfynol surfactants; Ancor acetylenic alcohol and amine-based corrosion inhibitors; Amicure, Imicure, and Metacure amine and tin catalysts; additives for epoxy resin systems; and acetylenic fine chemicals. Air Products and Chemicals Inc., Allentown, Pa., USA

Advanced composites: conference proceedings

American Society for Metals Publications, March 1986, ISBN 087170-223-1; Proceedings of a conference held in Dearborn, Michigan, USA in 1985; organizers mainly ASM and the Engineering Society of Detroit and Advanced composite: The latest developments, Conference in November 1986.

Toughened composites covers current research findings in the effort to develop high performance fibre composites. The papers are multidisciplinary, covering micromechanics, interlaminar fracture, composite toughness, interfacial adhesion, thermoplastic matrices, and thermoset matrices. (ASTM, 1916 Race Street, Philadelphia, PA 19103)

ASTM (American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103, USA) has published Delamination and Debonding of Materials (STP 876), sponsored by committees on fracture and on high-modulus fibres and their composites. The hard-cover anthology (499 pp) contains 25 peer [illegible]wed papers grouped into three categ[illegible]ractography and NDI, stress analysis, and mec[illegible]behaviour.

Polymers

Advances in polymer synthesis

Edited by Bill M. Culbertson and James E. McGrath. NY: Plenum Press, 1986, 553 p. (Polymer Science and Technology Series; Vol. 32) 85-24477. ISBN 0-306-42109-7.

This symposium volume contains 25 papers which summarize recent breakthoughs in basic research on polymer synthesis. The editors expect that this volume will stimulate further research in this field. New polymeric materials are needed for the automotive, aerospace, electronics, and communications industries among many others. For collections supporting academic or industrial research in polymer chemistry.

Encyclopedia of polymer science and engineering

Volume 6, Ed. J.I. Kroschwitz, New York: John Wiley & Sons 1986, pp. xxiv + 839, ISBN 0-471-80050-3.

This new volume extends the value of an important serial work. The subjects covered go from 'Emulsion polymerization' to 'Fibres', both major sections. By the luck of the alphabet, other important topics in polymer science discussed include energy conservation, engineering plastics, enzymes (including immobilized enzymes), epoxide polymers, epoxy resins, ethylene polymers, ethylene-propylene elastomers, extrusion (methods for plastics), coated fabrics, elastomeric and engineering fibres, and fibre manufacture.

Fibres

ISF '85 Society of Fibre Science and Technology, Japan

Elsevier Publishing Co. Inc., P.O. Box 1663, Grand Central Station, New York, N.Y. 10163, 1986, 368 pp.

Presents 50 papers emphasizing three areas of fibre science and technology: structure and function of fibres and fibre composites; novel textile processing, machinery, and testing; and cellulose, pulp, papers, and new utilization of membranes.

Carbon fibres, technology, uses and prospects

The Plastics and Rubber Inst. London, Noyes Publications, USA, 1986, ISBN 0-8155-1079-8; This book, which is divided into four parts, is based on the 3rd Intl. Conference on Carbon Fibres held in October 1985, sponsored by the Plastics and Rubber Institute of London and published in USA.

Ceramics

High-purity ceramics

Company's line of composite reinforcement materials, high purity ceramic powders, nuclear ceramics, and ceramic shapes and components are described and illustrated in eight-page bulletin. American Matrix Inc., Knoxville, Tenn., USA

Defect properties and processing of high technology nonmetallic materials

The proceedings of the second MRS symposium on Defect Properties and Processing of High Technology Nonmetallic Materials features progress in advanced ceramics, particularly in physical properties and ceramic processing. Topics of interest include: synthesis of ceramics through novel chemical routes, thin film ceramic preparation, economic aspects of alternative ceramic processing techniques, and optical mechanical behaviour of nonmetallic materials. Hardcover, 531 pp., 1936, ISBN 0-931837-25-1. (Materials Research Society, 9800 McKnight Rd., Suite 327, Pittsburgh, PA 15237, USA)

Emergent process methods for high-technology ceramics

Materials Science Research Vol. 17. Edited by R.F. Davis, H. Palmour III, R.L. Porter, New York, London 1984, 842 pp., cloth, (English).

The collection of 58 papers offer a wealth of comprehensive and up-to-date information on such topics as colloidal processing, ceramics derived from polymers, laser and ion beam surface modification and deposition, laser preparation of powders, and chemical vapour deposition of ceramics and composites. Other topics covered include microwave and plasma sintering, thermite reactions, hydrothermal preparation of powders, as well as hot isostatic pressing, shock conditioning, and dynamic compaction of powders.

Ceramic materials and components for engines

Proceedings of the 2nd International Symposium, Lübeck 1986. W. Bunk, H. Hausner, Bad Honnef 1986, 1205 pp., (English). This volume contains 134 lectures

High tech ceramics

Author: P. Vincenzini, Published: Elsevier Science Publishers BV 1987 (Elsevier Science Publishers BV, Sara Bargerhartstraat 25, P.O. Box 211, 1000 AE, Amsterdam, The Netherlands), ISBN 0 444 42776 7 (set);

High Tech Ceramics is a new publication containing the proceedings of the 6th Intl. Meeting on Modern Ceramics Technology (6th CIMTEC) held in Milan, Italy, 24-28 June 1986.

Glass-ceramic materials by Z. Strnad

Glass Science and Technology Series, 8, Elsevier Science Publishers, Amsterdam, 1986, ISBN 0-444-99524-2

Clays and ceramic raw materials

Second edition, W.E. Worrall, Elsevier Publishing Co. Inc., P.O. Box 1663, Grand Central Station, New York, N.Y. 10163, 1986, 242 pp.

Incorporates research in the field over the last ten years with highlights of the relevant literature published during this time. Presents the main aspects of clays and ceramic raw materials, including geology, occurrence, structure, physical and chemical properties, and applications. Contains additional chapters on silica, alumina, fluxes, bone, gypsum products, and various refractory oxides. Incorporates advances made in clay minerology and instrumentation during the past decade.

Publications from the American Ceramics Society, 757 Brooks Edge Plaza Drive, Westerville, OH43085-2821, USA

Handbook of properties of technical and engineering ceramics

"Part 2: Data Reviews, Section 1: High Alumina Ceramics", by R. Morrell, comprises a series of data reviews on the properties of ceramics, divided into groups according to composition and/or application. This volume covers high alumina materials, which currently have more than 50 per cent of the total world market for technical ceramics. The materials are divided into 12 groups according to narrow ranges of composition based on total aluminum oxide content.

Each review combines manufacturers' data with data from the scientific literaure and from National Physical Lab tests to provide an authoritative and unbiased view of the reasonable property expectations of commercial products. Hardcover, 270 pp. 1987.

High-technology ceramics past, present and future

This is the third volume of "Ceramics and Civilization" - a continuing series edited by W. David Kingery. Opening with a discussion of the historiography of technology, the book describes specific innovative developments of high technology ceramics. Ceramics made of novel, specially prepared materials and manipulated with imaginative manufacturing methods can achieve new or improved properties not obtainable by traditional ceramic practice. Art ceramics, electronic materials, refractories, glass, and concrete are also presented. The final three chapters discuss the source of innovation in ceramic materials and processes as well as ways of assuring the health of the activity. Hardcover, 404 pp. (Ceramic Materials for Electronics Processing, Properties, and Applications, Edited by Relva C. Buchanan, Marcel Dekker, Inc., New York, 1986, Electrical Engineering and Electronics, No. 31, ISBN-0-8247-7501-5)

Engineering applications of ceramic materials

Source Book, Ed. M.M. Schwartz, American Society for Metals, Ohio, 1986, ISBN 0-87170-207-6

The book is divided into seven sections and contains an Appendix and subject Index. The sections are a compilation of 45 papers and articles being divided into: (I) Introduction; (II) Ceramic Applications: engines, especially turbines; (III) Ceramics: making them - past and future; (IV) Ceramics as cutting tools; (V) Ceramics: applied in electronics and electron tubes, and methods of joining to metals and other materials; (VI) Ceramics: properties, design and use as coatings; (VII) Ceramics: future trends and uses.

High-technology ceramics - past, present and future

The Nature of Innovation and Change in Ceramic Technology, W.D. Kingery and Esther Lense, Eds. American Ceramic Society, Westerville, OH, 1987, x, 388 pp., illus,. + plates. Ceramics and Civilization, vol. 3. From a symposium, Chicago, IL, April 1986.

Derived from a session of an annual meeting of the American Ceramic Society, this volume is concerned both with technological innovation broadly and with its manifestations in the production of ceramics.

Metals

Non-ferrous metals and alloys

Sedlaček, Vladimir. NY: Elsevier, 1986. 475 p. (Materials Science Monographs; 30) 85-13159. ISBN 0-444-1685-4.

Contents: Fundamental properties of metals and alloys. Relationships between structure technology and properties. A brief review of non-ferrous metals and alloys. Physical properties. Mechanical properties. Behaviour of structural materials under load. Technological properties. Surface properties. Chemical properties. Subject index.

Note: This modern translated work sets out from the fact that all the properties of any metallic material are governed by the basic parameters of its lattice and structure and the author deals with individual properties (about 50 of them) rather than individual materials. There are brief explanations of the underlying fundamentals of each property, and the various factors that influence it and then an examination of the fundamentals in its concrete contexts on individual metals and alloys. Many tables are provided, for example, to permit direct comparisons and thus facilitate the choice of a material with the desired combination of properties. This is a key publication for any collection on materials science in both academe and industry where physicists, metallurgists, production engineers, and statisticians can work together in solving the problems of selecting a material for a given application. The author is with Technical University, Prague.

Oak Ridge National Laboratory (USA) has published its Technical Literature Reference Guide and Professional Activities of the Metals and Ceramics Division for January - March 1985. The bibliography (39 pp) includes abstracts of papers on eddy current testing of steam generator tubing, X-ray excitation of argon, and other studies on material properties and behaviour.

Corrosion and material testing

Corrosion, failure analysis, and metallography

Proceedings of the Seventh Annual Technical Meeting of the International Metallographic Society. Edited by Stuart A. Shiels et al. Metals Park, Ohio: American Society for Metals, 1986. 599 p. ISBN 0-87170-215-0.

Contents: Microhardness - technique and application. Metallography, microstructures. Corrosion-induced surface changes. Fractography, failure analysis, and microstructural studies. 1984 International Metallographic Exhibit.

Note: A collection of 39 papers presented in 1984 under the sponsorship of the International Metallographic Society. There is a broad range of microstructural topics such as applications of microhardness testing; physical metallurgy on materials such as aluminium, thoria fuels, and dental amalgams; corrosion problems; and material failures. No subject index. For comprehensive collections on metallurgy.

Materials to resist wear

By A.R. Lansdown & A.L. Price, Pergamon Press, Elmsford, N.Y. 1986. Pp. 125.

The authors explain that this book is intended as a simple guide to the selection of materials for various situations where wear occurs, aimed at the fairly uninitiated reader. The book begins with a comprehensive summary of the types of wear that may be found with an excursion into the basic theory behind the effects. There follows a diagnostic chapter explaining, with the help of useful tables and flow charts, how to identify particular situations and their causes. At this point the authors divide the subject into seven categories, namely sliding wear, fretting, three body abrasion, gouging wear, low stress abrasion, erosion, and corrosive wear, each of which is defined sing examples. The following seven chapters take each of the aforementioned categories and, using the basic theory outlined in chapter one with photographic samples, suggest choices of materials to alleviate the problem. Each of these chapters makes excellent use of photographic examples, flow diagrams, and tables, ending with general guidelines which are especially useful for readers with more unusual engineering problems.

Chapter ten goes on to discuss wear resistant coatings, covering the various coating methods, new coating technologies, and the effect of heat treatment. The next chapter is devoted to the effect, both beneficial and detrimental, of lubricants on wear surfaces. Finally the methods of wear testing using both laboratory and rig testing techniques are discussed, outlining how the results of such tests can be used to predict wear behaviour within the limits of the experiment. An appended section gives the names and addresses of suppliers of the various materials mentioned in the text.

Instrumented impact testing of plastics and composite materials consists of information related to the mechanical and chemical properties of polymeric materials and their composites. The particular area addressed in this book is the characterization of impact performance. Five major categories in the book are: methodology for impact testing, impact testing for end-use applications, impact characterization of selected materials, partial impact testing and fatigue of plastics, and fracture toughness. (ASTM, 1916 Race Street, Philadelphia, PA 19103, USA)

Pitting corrosion of metals

Z. Szklarska-Smialowska, National Association of Corrosion Engineers, P.O. Box 218340, Houston, Texas 77218, 713-492-0535, 1986, 400 pp.

Written for corrosion researchers and practitioners, this book is the first publication devoted solely to the vast problem of pitting corrosion. Discusses the reasons for pit initiation and growth, and explains how to evaluate the pitting susceptibility of various metallic materials. A comprehensive and critical review of all aspects of pitting corrosion on different metals and alloys is presented.

Flow and fracture at elevated temperatures

Ed. Rishi Raj, American Society for Metals, 1985. ISBN 0-87170-201-0.

Flow and Fracture at Elevated Temperatures is a collection of papers from an ASM Materials Seminar held in Philadelphia, USA, 1983. This seminar reviewed the status of our understanding of high temperature flow and fracture of structural materials, and in particular, directs attention to engineering metals and alloys used in high temperature applications.

Composite materials - testing and design proceedings

J.M. Whitney, Baltimore 1986, 457 pp.

The 7th conference on composites in April 1984 in Philadelphia dealt with the fields of testing and design. It was organized by the USA Bureau of Standards.

General Methods and Instrumentation Volume 14.02 - General Test Methods, Nonmetal; Laboratory Apparatus; Statistical Methods; Appearance of Materials; Durability of Nonmetallic Materials contains standard specifications for laboratory apparatus, including glassware and microchemical; practices for statistical analysis; practices for exposure testing; specifications for plates, screens, and sieves used in particle size measurement; guides and test methods for materials used in oxygen services; practices for evaluating testing and inspection agencies; test methods and practices for determining the appearance of materials, the hazard potential of chemicals, and the durability of nonmetallic materials, primarily pipeline coatings. (ASTM, 1916 Race Street, Philadelphia, PA 19103, USA)

Recycling

The Economic Feasibility of Recycling: A Case Study of Plastic Wastes, T. Randall Curlee, 203 pages, Praeger, New York, 1986, ISBN 0-275-92376-2.

This book reviews the current status of plastic waste recycling from the viewpoints of technical issues, economic issues, institutional issues, incentives and barriers. The analyses are detailed with plentiful data.

Post-consumer waste is projected to 1995. The author concludes that recycling of uncontaminated wastes will grow, but segregated wastes will be used largely as refuse derived fuels for the foreseeable future.

10. UNITED NATIONS DOCUMENTS

The Government of Mexico hosted and co-sponsored a United Nations meeting of experts on Space Science and Technology and its Applications within the Framework of Educational Systems in Mexico, D.F. from 13-17 October 1986.

United Nations documents:

A/AC.105/378 (23 December 1986) "Committee on the Peaceful Uses of Outer Space"

Background and objectives of the meeting

Excerpt: The General Assembly, in its resolution 37/90 of 10 December 1982, endorsed the recommendation of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE 82) that the United Nations Programme on Space Applications should promote the growth of indigenous nuclei and autonomous technological bases in space technology. At its twenty-eighth session, in June 1985, the Committee on the Peaceful Uses of Outer Space (COPUOS) endorsed the United Nations Programme on Space Applications for 1986 as proposed by the Expert on Space Applications and recommended by the Scientific and Technical Subcommittee of COPUOS at its twenty-second session. Subsequently, the General Assembly, in its resolution 40/162 of 16 December 1985, endorsed the United Nations Programme on Space Applications for 1986. The United Nations Meeting of Experts on Space Science and Technology and its Applications within the Framework of Educational Systems is part of the 1986 activities of the Space Applications Programme.

The objective of the meeting was to promote the growth of indigenous capabilities in the areas of space science and technology. The meeting provided the participants with the knowledge of the role that space science and technology can play in national development. It also focused on the processes and issues involved in introducing aspects of space science and technology and related disciplines into the existing education curricula, particularly in the developing countries.

A/AC.105/C.1/L.150 (31 December 1986) "Report submitted by the International Astronautical Federation (IAF)"

Excerpt: The generation of electrical power in orbit is of great importance to all space activity. As space is being increasingly recognized as an arena for industrial activities that hold the key to future global economic growth, these broadly based activities are projected to provide opportunities during the next two decades for the development of space infrastructure in low and high Earth orbits.

A key to the evolution of this infrastructure will be the supply of power to various orbital facilities and eventually to facilities in circumlunar space, on the moon and on and near other bodies of the solar system. The specific technological developments of significance in space power which have emerged during the year have been advances in solar power conversion and a free-piston sterling engine with advanced space-radiator technology for a hybrid power supply system for the NASA Space Station. A further example is work on high-efficiency planar and concentrator solar cells with increased resistance to the deleterious effects of the space environment. Further work has been carried out on nuclear reactors in the 100-kW range and also advances in energy-storage systems, for example, based on nickel-hydrogen.

The industrialization of space is associated with technologies and systems such as those for Earth observation and communication. It was noted in various papers presented at the IAF Congress that there should be a realistic awareness of the timing of future commercial benefits which can be derived from space. Technologies such as materials processing in orbit, and spin-offs from a variety of processes, both hardware and software, arising from the development of launch vehicles and spacecraft (including the vital area of ground support equipment), all generate enormous potential value, but the realization of this value requires conscious effort not only by the aerospace community but also by the non-aerospace communities of the world. There is a major need for information programmes to stimulate the take-up of ideas on a sensible and profitable basis. This emerges strongly as an increasing requirement for most activities of the world space community.

<u>A/AC.105/C.1/L.149 (17 December 1986) "Report submitted by the Committee on Space Research</u> (COSPAR) of the Intl. Council of Scientific Unions (ICSU)"

Materials sciences in space

Excerpt:

1. The Western European programme (Please note also the article "Main results from the first Spacelab Mission on page 24)

The major event in the European programme was the D-1 mission of Spacelab flown in November 1985. Below is a list of experiments performed during this flight:

- 4 experiments in Mirror heating facility
- 3 experiments in Isothermal heating facility
- 6 experiments in Gradient heating facility
- 7 experiments in Fluid Physic Module
- 1 experiment in High temperature thermostat
- 1 experiment in Protein crystallization
- 4 experiments in Ellipsoidal mirror furnace
- 1 experiment in High precision thermostat
- 2 experiments in Gradient heating facility with quenching
- 4 experiments in Hollop
- 1 experiment in Salt interdiffusion
- 1 experiment in Marangoni convection with boat geometry

The experiments were carried out very successfully, and numerous results have been reported during scientific meetings, such as: Toulouse (COSPAR - June/July 1986), Noordernay (Federal Ministry for Research & Technology (BMFT) - August 1986), Innsbruck (International Astronautical Federation - October 1986) and Bordeaux (European Space Agency - December 1986).

Even if, according to the latest information, the EURECA (European Retrievable Carrier) flight is to be postponed to April 1991, its preparation is progressing rapidly. Most of the engineering models of the facilities for materials research have already been produced and tested.

The Federal Republic of Germany's sounding rocket programme Texus continues to play an important role in ESA's activity related to Materials Sciences. It is planned to increase the frequency of rocket launchings in this programme from 2 to 3 per year. The Swedish programme of sounding rocket Maser should also be taken into account (the payloads of Texus are compatible with Maser).

In March 1986, ESA also used the NASA KC 135 aircraft to study mainly combustion and Fluid Physics. The participation of ESA in the D-2 mission and the second International Microgravity Laboratory (IML-2) is presently under preparation at the level of payload definition.

2. Activities of the countries participating in the Intercosmos Programmes

Within the period under review, essential attention has been paid by the national working groups on "Materials Sciences" of the Intercosmos countries to the development and testing of new equipment for crystal growth, as well as of devices for in-situ process measurement. This equipment enables a more precise thermal process regime and data recording. The aim of this work consists of the complete utilization of space experiments' information content and of the construction of fully automated aggregates for material research in space.

The thorough scientific evaluation of the past μg experiments indicated that more detailed theoretical work and experiments were required to elucidate the fundamental problems of material transport in fluid phases of crystallization, growth and segregation processes.

To study the hydrodynamic processes and mechanisms of interaction in diffuse transport processes, temperature and concentration fields have been mathematically simulated for the case of practical growth geometries, and their effects on material properties have been derived.

Simultaneously experiments on metals and semiconductors have been carried out regarding the fundamental conditions and mechanisms for kinetic phase transitions between different convection modes. The investigations on monotetic and eutectic systems as well as alloys have been continued under simultaneous application to segregation phenomena in unstable glass compositions.

In spring 1986, the 3rd Intercosmos Seminar "Materials Sciences" took place in the German Democratic Republic and was attended by 50 participants from 7 countries. The mathematical analysis of hydrodynamic processes of crystal growth and the application of this knowledge concerning the influence of convection processes on chemical composition and physical real structure were the main topics of contributions and of discussion.

3. Other national programmes

In Japan, the basic research on ground and on aircraft, including some low gravity experiments has been conducted. A few material processing experiments have been carried out in the Getaway Special; experiments on collisions between small metal ball and water balls have yielded interesting results.

The Challenger catastrophe affected the US programme, resulting in the delay of a number of material sciences experiments, among others.

At DFVLR (German Research & Experimentation Institute for Air & Space Travel), the preparation of the D-2 mission is for mid-1991. DFVLR will also host the MUSC (Microgravity User Support Center). This centre is in development and should be active for the EURECA mission. (Please see page 43 "Microgravity User Support Centre")

The French materials science experiments remain very active in preparing new furnaces and new projects. They conducted a number of experiments in 1985 using the Texus 12 sounding rocket, as well as in the FRG Spacelab D-1 mission. They are also elaborating a number of co-operative programmes, in particular the Mephisto project on the in-situ study of the parameters governing directional solidification. Experiments are also being prepared for the EURECA platform.

Space research and developing countries

COSPAR continues its endeavors for the promotion of space research in developing countries. It reconstituted a Panel on Space Research in Developing Countries in 1983 which has been taking many steps jointly with the United Nations and COSTED to promote this activity and, in particular, space science. At the 25th COSPAR Plenary at Graz, Austria, a Workshop on the Promotion of Space Research in Developing Countries was organized.

In 1986, another workshop devoted to Remote Sensing of interest to developing countries took place in conjunction with the 26th COSPAR Meeting in Toulouse, France in July. This workshop was co-sponsored by the United Nations, COSTED, and other intergovernmental and non-governmental organizations.

The activities of the Panel in 1986 were partially supported by COSPAR's parent organization - ICSU (International Council of Scientific Unions) - and the support of the United Nations and other organizations is also gratefully acknowledged.

For the 27th Plenary in 1988, arrangements are being made to organize a Workshop on Possible Ways of Promoting Higher Education and Research in Atmospheric Sciences as a means of self-reliant manpower generation to support space application programmes in remote sensing, meteorology and communication in developing countries. It is expected that this Workshop will also be co-sponsored by the United Nations, COSTED, ICSU, etc. All these activities have already shown evidence of increasing participation of scientists from developing countries in the COSPAR Plenary meetings for which travel support is provided in many cases by COSPAR, United Nations, UNEP and COSTED.

A/AC.105/374. Report on the United Nations Regional Meeting of Experts on Space Technology Applications in the Indian Ocean Region hosted and co-sponsored by the Government of Sri Lanka, Colombo, 15-19 September 1986

A/AC.105/366. Education, training, research and fellowship opportunities in space science and technology and its applications; a directory, United Nations Department of Political and Security Council Affairs, 1986, 244 p.

A/AC.105/193. Space Activities and Resources, United Nations Department of Political and Security Council Affairs, 1977.

Mr. Mir Akbar Ali who wrote an article for this monitor has already written one earlier for UNIDO "Potential Applications of Space-Related Technologies to Developing Countries" in 1982. It was the background paper for the "Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space" held in Vienna, August 1982. (Document No. A/CONF.101/BP/IGO/13, 26 July 1982)

ACC/M/210. Inter-Agency Meeting on Outer Space Activities, IMO Headquarters, London, 7-9 October 1987

The Organizational Committee of the Administrative Committee on Co-ordination, at its meeting in Rome in April 1987, authorized the convening of the ninth Inter-Agency Meeting on Outer Space Activities.

Information on the proposed seminars and other activities to be held under the United Nations Space Applications Programme during the 1987-1988 period, as approved by the Scientific and Technical Sub-Committee, is contained in the report of the Sub-Committee (A/AC.105/383 and Corr. 1) and that of the Expert on Space Applications (A/AC.105/380). The Inter-Agency Meeting will be briefed on further developments in the preparation of these activities, with a view to considering suggestions for further planning, particularly for those programmes conducted jointly with the agencies and organizations within the United Nations system.

11. UNIDO MEETINGS ON NEW MATERIALS

1987

11-13 September. Third Meeting of Experts of Non-Aligned Movement and Other Developing Countries in the Sphere of Standardization, Metrology and Quality Control (Bureau of Indian Standards, Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110002), Belgrade, Yugoslavia.

23 September - 13 November. 18th In-Plant Training Programme in the Field of Plastic Technology, Vienna, Austria.

14-22 October. UNIDO/UCIMU Seminar on Production and Use of Machine Tools in Selected Developing Countries - 7th EMO, Milan, Italy.

19 October - 20 November. 14th In-Plant Group Training Programme on Man-made Fibres, Vienna, Austria.

26-31 October. Joint UNIDO/UNESCO/KIER Workshop on energy conservation and NRSE for small and medium industries, Daejon, Korea.

2-27 November. In-Plant Group Training Programme in the Field of Mould Making, Vienna, Austria.

30 November - 4 December. First Consultation on Non-ferrous Metals Industry, Budapest, Hungary.

12. PAST EVENTS AND FUTURE MEETINGS ON NEW MATERIALS

1979

The Indian Institute of Science and the Indian Space Research Organization organized a Workshop on Materials and Materials Processing in Space in Bangalore from 24 to 29 September 1979.

1986

30 September - 2 October. 5th European Symposium on Photovoltaic Generators in Space, The Hague, The Netherlands. (Netherlands Agency for Aerospace Programs, ASE, ESA, P.O. Box 35, NT 2600 AA Delft, The Netherlands).

19-24 October. Symposium on Corrosion of Aerospace Materials during the 170th Meeting of the Electrochemical Society, San Diego, CA., USA. (Electrochemical Society)

22-24 October. 5th Conference on Photovoltaic Generators in Space, Amsterdam, The Netherlands. (ASE: Agence Spatiale Européene, ESA Publications Division, European Space Research and Technology Center, ESTEC Keperlaan 1, NL 2200 AC, Noordwijk, The Netherlands)

1-15 December. Symposium on Materials Processing in the Reduced Gravity Environment of Space, Boston, MA, USA. (Doremus Materials Eng. Dept. Rensselaer Polytechnic Institute, Troy, N.Y. 12180, USA)

1987

7-8 January. International Conference on Polymers at Low Temperatures, London, UK. (The Polymer Properties Group of the Plastics and Rubber Inst., Centre for Composite Materials, Imperial College, Prince Consort Rd., London SW7 2BY, UK).

18-23 January. 11th Annual Conference on Composites and Advanced Ceramics, Cocoa Beach, FL. USA. (Eng. Ceramics Div., American Chemical Society).

7-14 February. Aerospace Applications Conference, VIL, CO., USA. (IEEE Conference Co-ordination, 345 East 47th St., New York, N.Y.)

17-19 February. American Institute of Aeronautics and Astronautics Aerospace Engineering Conference and Show, Los Angeles, CA. (AIAA, 1290 Ave. of the Americas, New York, N.Y.)

27-28 March. 34th International Congress on Electronics in Space; 27th International Meeting on Space, Rome, Palazzo dei Congressi. (Riens, Secretariat via Corescencio, 9, I-00193, Italy)

May and 11-21 June. International Aeronautics and Space Show, Le Bourget, France. (Salon International de l'Aeronautique et de l'Espace, 4 rue Galilee, F-75116 Paris)

3-7 May. Aerospace Industries/Test Measurement Symposium, Las Vegas, USA. (ISA: Instrument Society of America, 67 Alexander Drive, Research Triangle Park, NC 27709, USA)

12-15 May. ACZ 87th Int. Airport Construction and Aerospace Engineering Exhibition and Conference, Osaka, Japan. (Osaka International Trade Fair Commiss.)

7-10 June. Symposium on Advances in Space Science Technology and its Applications, Beijing, China. (Chinese Society of Astronautics, Japanese Rocket Society)

18-19 June. Recyclingplas II, Washington, DC. (Plastics Inst. of America, USA and Stevens Inst. of Technology, Castle Pt., N.J. 07030, USA)

13-16 July. Recent Advances in Polyimides and Other High-Performance Polymers, Reno, NV, USA. Sponsored by ACS (American Ceramic Society); (Polytechnic University, Div. of Polymer Chemistry, 333 Jay St., Brooklyn, NY 11201, USA)

13-17 July. Corrosion: The Environmental Degradation of Materials, Cambridge, MA., USA. (Massachusetts Inst. of Technology, 77 Massachusetts Ave., Cambridge, MA 02139)

14-17 July. Malaysian Intl. Plastics & Rubber Exhibition, Kuala Lumpur, Malasyia. (Fairs & Exhibitions Ltd., 51 Doughty St., Gray's Inn, London WC2X 2LB)

19-24 July. 18th Biennial Conference on Carbon. Worcester Polytechnic Inst., Worcester, MA, USA. (Wooster Polytechnic Inst., 20 Trowbridge Rd., Worcester, MA 01609)

20-24 July. 6th Int. Conf. on Composite Materials/Second European Conf., Imperial College, London, UK. (Centre for Composite Materials, Imperial College, Prince Consort Rd., London SW7 2BY, UK)

26-31 July. 10th World Congress of the Space Systems, Munich, Federal Republic of Germany. (IFAC Secretariat, Schlossplatz 12, A-2361 Laxenburg, Austria)

27-29 July. 4th Intl. Conf. on Composite Structures, Paisley College of Technology, UK. (E.I. du Pont de Nemours & Co., Inc., Composites Div., Chestnut Run 702, Wilmington, DE 19898, USA)

2-5 August. Silicon Carbide Symposium, Columbus, OH, USA. (American Ceramic Society, 757 Brooksedge Plaza Dr., Westerville, OH 43081-2821)

16-21 August. IUPAC Intl. Symp. on Polymers for Advanced Technologies, Jerusalem, Israel. (Symp. Organizers and Secr., Ortra Ltd., 2 Kaufman Str., P.O. Box 50432, Tel Aviv, Israel, 61500)

17-19 August. Symp. on Polymer Melt Dynamics, Midland, MI, USA. (Michigan Molecular Inst., 1910 West St. Andrews Rd., Midland, MI 48640, USA)

18-20 August. Conference on Emerging Technologies in Materials, Minneapolis, MN, USA. (American Inst. of Chemical Engineers, 345 E. 47th St., New York, N.Y. 10017)

18-20 August. 1st Intl. SAMPE (Soc. for the Advancement of Material and Process Eng.) Metals & Metals Processing Conf., Cherry Hill, N.J., USA. (Soc. for the Advancement of Material & Process Eng., 843 West Glentana, Covina, CA 91722)

25-27 August. Testing High-Performance Ceramics, Boston, MA, USA. (ASNT - American Soc. for Nondestructive Testing, and American Ceramic Society. ASNT: 4153 Arlingate Plaza, Columbus, OH 43228-0518)

30 August - 4 September. Intl. Symp. on Polymer Materials, San Sebastian, Spain. (Intl. Symp. on Polymer Materials, Facultad de Ciencias Quimicas, Univ. del Pais Vasco, Apartado 1072, San Sebastian, Spain)

30 August - 4 September. 9th Intl. Congress of Chemical Engineering, Chemical Equipment Design & Automation, Prague, Czechoslovakia. (Congress CHISA '87, P.O. Box 857, 11121 Prague 1)

7-9 September. Advanced Materials and Processing Techniques for Structural Applications: Assessing the Progress made in Advanced Materials and Processing from Practical and Fundamental Standpoints, Paris, France. (Dr. Khan, c/o ASM Europe Secretariat, BP 42809, 75424 Paris, Cedex 09)

7-9 September. Intl. Conf. on the Science of Ceramics, University of Kent, UK. (Association Europeene de Ceramique and organized by Inst. of Ceramics, Shelton House, Stoke Rd., Shelton, Stoke-on-Trent, ST4 2DR, UK)

7-10 September. Second Intl. Conf. on Low Cycle Fatigue and Elasto-Plastic Behaviour of Materials, Munich, FRG. (Deutscher Verband fuer Materialpruefung)

7-11 September. First Intl. Congress on Materials Science: Construction Materials Engineering AFREM, Paris, France. (12 rue Brancion, F-75737 Paris Cedex 15)

9-11 September. Hazardous Materials Management Conference & Exhibition, Toronto, Canada. (Tower Conf. Management Co., 331 West Wesley St., Wheaton, Ill. 60187)

11 September. Recycled Plastics: Developments & Applications, East Lansing, MI, USA. (School of Packaging, Michigan State Univ., East Lansing, MI 48824-1223)

14-17 September. Pilot for Plastics in Agriculture, Engineering and Packaging, Tel Aviv, Israel. (Soc. of Plastics Eng., 14 Fairfield Dr., Brookfield Center, Conn. 06805)

15-16 September. Conf. on Systems in Plastics Finishing, Louisville, KY. (Soc. of Plastics Eng., 14 Fairfield Dr., Brookfield Center, Conn. 06805)

15-17 September. Advanced Composites Conf., Detroit, MI, USA. (ASM International, Metals Park, Ohio)

16 September. Investment Seminar on High-Performance Materials, World Trade Center, New York. (Strategic Analysis, Inc., Box 3485, R.D.3, Fairlane Road, Reading, PA 19606, USA)

18-19 September. Symp. on High-Temperature Superconducting Materials, Chapel Hill, N.C., USA. (Dept. of Chemistry, Venable Hall 045 A, Univ. of North Carolina, Chapel Hill, N.C. 27514, USA)

21-23 September. ICS '87 - Intl. Conf. Secondary Metallurgy, Aachen, FRG. (VEDH, Sohnstrasse 65, D-4000 Duesseldorf 1, Postfach 8209, FRG)

22-24 September. New Materials Make Versatile New Product, Rosemont, Ill. (Soc. of Plastics Eng., 14 Fairfield Dr., Brookfield Center, Conn. 06805)

22-24 September. TEQC87, Second International Conference on Testing, Evaluation and Quality Control of Composites, University of Surrey, Guildford, UK. Sponsored by the journals: Composites and NDT International. (Conference Organizer-TEQC87, Butterworth Scientific Ltd., P.O. Box 63, Westbury House, Bury Street, Guildford, Surrey GU2 5BH, UK)

22-24 September. Test, Measurement and Inspection for Quality Control Conference and Exhibition, Detroit, MI, USA. (Tower Conference Management Co., 331 W. Wesley St., Wheaton IL 60187)

22-25 September. New Materials and Their Applications. University of Warwick, Coventry, UK. (Institute of Physics, 47 Belgrave Square, London SW1X 8QX)

29 September - 2 October. Society of the Plastics Industry, polyurethanes division, polyurethanes world congress. Eurogress Center, Aachen, FRG.

30 September - 3 October. Machine Asia 87, Singapore. Singapore Exhibition Services Pte Ltd., 11 Dhoby Ghaut 15-09, Cathay Building, Singapore 0922.

1-31 October. Aerotech '87; Conference and Exposition of the Society of Automotive Engineers Aerospace Technology, Long Beach, CA., USA. (Society of Automotive Engineers; MRG MTG Promotion and Communication, 400 Commonwealth Dr., Warrendale PA 15096, USA)

4-9 October. IXth Inter-American Conf. on Materials Technology, Santiago, Chile. (Dept. of Scientific Affairs, Org. of American States, 17th and Constitution Ave., Washington, D.C. 20006)

5-9 October. American Society for Nondestructive Testing. Fall Conference and Quality Testing Show, Atlanta, GA. USA. (ASNT, 4153 Arlingate Plaza, Columbus, OH 43228-518)

5-9 October. Siderometalurgica - Exhibition for the Steel Metallurgy Industry, Bilbao, Spain. (Feria Internacional de Bilbao, Apdo. 468, 48080 Bilbao, Spain)

8-11 October. Plastics: the next 50 years, Charleston, SC., USA. (Soc. of the Plastics Industry Inc., 1275 K St., NW. Suite 400, Washington, D.C. 20005)

10-16 October. MATERIALS WEEK '87, Cincinnati, OH, USA. (ASM - American Society of Metals, Metals Park, Ohio, Route 87)

13-15 October. Materials Applications & Services Exposition, Cincinnati, OH, USA. (ASM Manager of Expositions, Metals Park, OH 44073)

13-15 October. 19th Intl. SAMPE (Soc. for the Advancement of Material and Process Engineering), Technical Conf., Crystal City, VA., USA. (SAMPE, 843 W. Glentana, Box 2459, Covina, CA 91722, USA)

14-22 October. 7th EMO Machine Tool Show, Milan, Italy. Sponsored by the European Committee for Co-operation of the Machine Tool Industries (CECIMO). (7. EMO, c/o CEU, viale Fulvio Testi, 128, 20092 Cinisello Balsamo (MI), Italy)

19 October. Superconductivity - The Opportunities, Implications and Applications, London, UK. (IBC Technical Services Ltd., Bath House, 56 Holborn Viaduct, London EC1A 2EX)

19-20 October. Symposium on Advances in Thermoplastic Matrix Composite Materials, Sheraton Bal Harbour, Bal Harbour, FL. (ASTM, 1916 Race St., Philadelphia, PA 19103)

19-21 October. 1987 Powder Metallurgy Group Meeting, Powder Shaping and Compacting, Cavendish Hotel, Eastbourne, UK. (The Institute of Metals, 1 Carlton House Terr., London SW1 Y 5DB, UK)

26-30 October. 11th Intl. Fibre Optic Communications, Anaheim, Calif., USA. (Information Gatekeepers Inc., 214 Harvard Ave., Boston, MA 02134, USA)

27-28 October. Glass and Ceramics Developments, Munich, Federal Republic of Germany. (Metal Bulletin Conferences Ltd., Park House, Park Terrace, Worcester Park, Surrey KT4 7HY, UK)

27-30 October. Aerotech '87 - The Aerospace Technology Exhibition and Conference, N.E.C. Birmingham, UK. (Exhibitions & Events Div., The National Exhibition Centre Ltd., Birmingham B40 1NT, UK)

29-31 October. IX. National Conference on Glass and Fine Ceramics, Varna, Bulgaria. (Central Union of the Scientific Technical Unions, 198 Rakovsky Str., 1000 Sofia, Bulgaria)

2-4 November. Production of Nondestructive Testing - The Development Key for Process Control, Hyatt Dearborn, Dearborn, Michigan,USA. (ASM International, Metals Park, OH 44073, USA)

2-4 November. Intl. Conf. and Exhibition "PM Aerospace Materials", Lucern, Switzerland. (MPR Publishing Serv., Ltd., Old Bank Buildings, Bellstone, Shrewsbury, SY1 1HU, UK)

2-6 November. Plastics - A series of conferences held in association with Interplas '87, Birmingham, UK. (Plastics and Rubber Inst., 11 Hobart Place, London SW1W 0HL, UK)

3-5 November. Fibre-Tex '87 (Conf. on advanced eng. fibres and textile structures for composites), Greenville, SC, USA. (National Aeronautics and Space Administration and Clemson Univ., NASA-Langley Research Center, Hampton, VA 23665-5225)

3-7 November. Interplas '87, National Exhibition Centre, Birmingham, UK. (Industrial and Trade Fairs Ltd., Radcliffe House, Blenheim Court, Solihull, West Midlands B91 2BG, UK)

3-7 November. Third Intl. Exhibition of New Technologies & Innovation Automation & New Materials, Turin, Italy. (Tiber-Potomac, 1199 N. Fairfax Street, Suite 601, Alexandria, VA 22314, USA)

4-5 November. Magnetic Materials Attract Business, London, UK. (ERA Technology Ltd., Cleeve Rd., Leatherhead, Surrey, KT22 7SA)

5 November. Composites Towards 2000 (to coincide with INTERPLAS '87), Birmingham, UK. (British Plastics Federation and IAL Consultants Ltd.; British Plastics Fed., 5 Belgrave Square, London SW1X 8AZ)

7-11 November. Tenth Intl. Congress on Metallic Corrosion, Madras, India. (Central Electrochemical Research Inst., Karaikudi 623006, India)

9-11 November. Third Arab Congress on Iron & Steel, Algiers. (AISU, B.P. 04, Cheraga, Algeria)

9-11 November. ECMRA - The Chemical Industry in Times of Change, Barcelona, Spain. (EVAF/ECMRA Secretariat, Gainsford House, 115 Station Road, West Wickham, Kent BR4 0PX, UK)

9-12 November. Managing Corrosion with Plastics, New Orleans, USA. (Nat. Ass. of Corrosion Engineers, P.O. Box 218340, Houston, Texas, USA)

9-13 November. Florida Advanced Materials Conf., Sheraton Palm Coast Resort. (Dept. of Chemistry, Univ. of Florida, Gainesville, FLA 32611)

14-30 November. International Trade Fair; Plastics Technology, Applications and Export Capabilities, India. Trade Fair Authority of India

15-17 November. Asia-Pacific Convention and Exposition on NDT, Parkway Parade, Singapore. (Cementech Consultants, 80 Marine Parade Rd., Singapore 1544)

15-18 November. 8th SERI Photovoltaics Advanced Research & Development Project Review Meeting, Denver, Colorado, USA. (Solar Energy Research Inst., 1617 Cole Blvd., Golden, CO 80401-3393)

16-18 November. Superfund '87, Washinton, D.C. (Hazardous Materials Control Research Institute, 9300 Columbia Blvd., Silver Spring, MD 20910-1702, USA)

16-20 November. Composants Electroniques 87, Paris, France. (S.D.S.A. - 20 rue Hamelin, F-75116, Paris)

17-18 November. The 1987 BCC Conf. on Plastics, Stamford, CO., USA. (Business Communications Co., Inc., 25 Van Zant Str., Norwalk, CO 06855, USA)

17-20 November. The First Major International Commercial Space Exposition and Conf. in the USA "SPACE", Houston, Texas, USA. (SPACE: Technology, Commerce & Communications, 79 Milk St., Suite 1108, Boston, MA 02109)

18-19 November. Wear Resistant Materials - Influence of Surface Treatments, St. Etienne, France. (Heat Treatment Technical Ass. and French Ceramics Group, Secr. of Cercle d'Etudes des Metaux, 159 Cours Fauriel, 42023 Saint Etienne, France)

21-24 November. ACS (American Chemical Soc.)/Polymer Div. Conf. on Advances in Silicon-Based Polymer Science, Makaha, Oahu, Hawaii. (Sandia National Labs, Albuquerque, N.M. 87185, USA)

23-24 November. Metal Matrix Composites, Structure and Property Assessment, Royal Aeronautical Society, London. (The Institute of Metals, Technology Committee, 1 Carlton House Terr., London SW1Y 5DB, UK)

23-24 November. Engineering Ceramics, Second European Symposium, Park Lane Hotel, London. (IBC Technical Services Ltd., Bath House, 56 Holborn Viaduct, London EC1A 2EX, UK)

23-24 November. Second European Symp. on Engineering Ceramics, London, UK. (IBC Technical Services Ltd., Bath House, 56 Holborn Viaduct, London EC1A 2EX, UK)

24-26 November. Carbon Fibre Update, Cranfield UK. (Cranfield Inst. of Technology, Cranfield, Bedford MK43 0AL, UK)

24-28 November. EURO Plastica; Exhibition of the Applications of Synthetic Materials and Composites, Brussels, Belgium. (Brussels Intl. Trade Fair, c/o Belgo-Luxembourg Chamber of Commerce in Great Britain, 36-37 Picadilly, London W1V 0PL, UK)

28 November - 3 December. Materials Research Society Fall Meeting, Boston, USA. (Materials Research Society, 9800 McKnight Rd., Suite 327, Pittsburgh, PA 15237)

29 November - 2 December. The 1987 Metallurgical Society Extractive and Process Metallurgy Fall Meeting, Marriott's Desert Springs, Palm Springs, CA. (The Metallurgical Society, 420 Commonwealth Dr., Warrendale, PA 15086)

30 November - 5 December. Fall Meeting of the Materials Research Society, Boston, USA. (Materials Research Soc., 9800 McKnight Rd., Suite 327, Pittsburgh, PA 15237, USA)

1 December. COMPOSITES, London. (The Institute of Metals, Materials Engineering, 1 Carlton House Terrace, London SW1Y 5DB)

1-3 December. Hazardous Materials Management Conf. & Exhibition/West, Long Beach, Calif., USA. (Tower Conf. Management Co., 331 West Wesley St., Wheaton, Ill, 60187, USA)

1-4 December. SP '87 Speciality Plastics Conference, Zurich, Switzerland. (Maack Business Serv., CH-8804 Au/near Zurich, Switzerland)

3-4 December. Polymers for Composites, Solihull, UK. (The Plastics and Rubber Inst., 11 Hobart Place, London SW1W 0HL)

9 December. Tribology of Metal Matrix Composites, Univ. of Bradford, UK. (The Institute of Physics, UK)

11-16 December. Ceramic China '87, Guangzhou, Guangdong, People's Republic of China. (China Science and Technology Exchange Centre; for info.: Focusworld Exhibitions, Bras Basah Post Office, P.O. Box 292, Singapore 9118)

1988

6-9 January. International Conference on Composite Materials and Structures, IIT Madras, India. (Organisers: FRP Research Centre, Indian Institute of Technology, Madras, India. Sponsors: Indian Institute of Technology, Madras. Aeronautical Society of India. Indian Space Research Organization. Aeronautical Research and Development Board. Indian Academy of Sciences. Chinese Society of Theoretical and Applied Mechanics. Indian Rocket Society. Contact: Dr. K.A.V. Pandalai, Co-ordinator, ICCMS-88, FRP Research Centre, IIT (PO), Madras-600 036, India.)

11-14 January. 26th Aerospace Sciences Meeting, Reno, NV, USA. (AIAA = American Inst. of Aeronautics and Astronautics)

17-20 January. 12th Annual Conference on Composites and Advanced Ceramics, Cocoa Beach, Florida (sponsored by ACerS Engineering Ceramics Division, University of Florida, Dept. of Materials Science and Eng., Gainesville, FL 32611)

18-20 January. Intl. Conf. on Technology Transfer in the Developing Nations, New Delhi, India. (School of Management, SUNY, Binghamton, Binghamton, N.Y. 13901)

25-29 January. Second. Intl. Symp. on Experimental Methods for Microgravity Materials Science Research, Phoenix, USA. (Technical Program Co-ordinator-TMS, 420 Commonwealth Dr., Warrendale, PA 15086, USA)

January. Asian Aerospace 88, Singapore. (Cahners Exhibition Group, S.A.)

1-5 February. 43rd Annual Conference of the Composites Institute, Cincinnati, Ohio (Composite Inst., Society of Plastics Industry Inc., 355 Lexington Ave., New York, N.Y. 10017, USA)

15-17 February. Seminar on thermoplastic composites, composite fatigue, metal-polymer interfaces, hazards, and problems in aircraft applications, Florida. (Shawco, 4227 East 99th St., Tulsa, OK 74237, USA)

21-24 February. Annual Convention of the Canadian Ceramic Society in Toronto, Canada (Canadian Ceramic Soc., 2175 Sheppard Ave., E., Suite 110, Willowdale, Ont., M2J 1W8, Canada)

23-25 February. 2nd Advanced Ceramics Conference in Chicago, Ill. (Society of Manufacturing Engineers, ONE SME Dr., Box 930, Dearborn, MI 48121, USA)

1-3 March. Engineered Materials for Advanced Friction and Wear Application, Gaithersburg, MD., USA (ASM International, Metals Park, Ohio 44073)

7-10 March. Int. Conf. on Rapidly Solidified Materials, San Diego, CA, USA. (Am. Soc. of Metals, Metals Park, OH 44073, USA)

7-10 March. 33rd Intl. Techn. Conf. on Materials and Processes, Anaheim, Calif. (Soc. for Advancement of Materials and Process Engineering, 843 West Glentana, Box 2459, COVINA, Calif. 91722)

21-24 March. Materials Testing '88 Exhibition, Birmingham, UK (Mack-Brooks Exhibitions Ltd., Forum Place - Hatfield, Herts AL 0BR (UK))

22-25 March. Strategies for the Development of New Materials, in Japan. Intl. Symposium on Frontier Technology, Kobe and Agency of Industrial Science and Technology of MITI

23-25 March. Metals and Materials '88 in Birmingham, UK (Materials Science Committee and Institute of Metals, 1 Carlton House Terrace, London SW1Y 5DB, UK)

23-25 March. Fibre-reinforced Composites, Liverpool, UK (Plastics and Rubber Inst., 11 Hobart Place, London SW1W 0HL)

5-9 April. Materials Research Society Spring Meeting, Reno, NV, USA. (Materials Res. So. 9800 McKnight Rd., Suite 327, Pittsburgh, PA 15237)

11-14 April. 7th Intl. Conference on Deformation, Yield and Fracture of Polymers, Cambridge, UK (Plastics and Rubber Inst., 11 Hobart Place, London SW1W 0HL)

11-15 April. ASNT's 1988 Spring Conf.: Characterization of Materials and Flaws, Orlando, Florida (ASNT, 4153 Arlingate Plaza, Caller No. 28518)

12-15 April. Second Brazilian Intl. Plastic Show, Brazil. (Goal Promocoes e Feiras Ltda, Rua da Assembleia 45 - 7 Andar, CEP 20011, Centro, Rio de Janeiro, Brazil)

13-21 April. Intl. Machine Tool and Manufacturing Technology Exhibition, Birmingham, UK. (The Machine Tool Trade Ass., 62 Bayswater Road, London W2 3PH)

18-20 April. 29th Structures, Structural Dynamics and Materials, Williamsburg, VA, USA. (Am. Inst. of Aeronautics and Astronautics, Am. Soc. of Mechanical Engineers)

19-20 April. High Temperature Engineering Polymers, Cardiff, UK (Plastics and Rubber Inst., 11 Hobart Place, London SW1W 0HL)

20-27 April. Industrie '88 - New Materials 1988, Hannover, FRG. (Hannover Fairs Info. Centre, P.O. Box 283, Sanderstead Rd., Sanderstead, South Croydon, Surrey CR2 0AJ)

21 April. Developments in Materials Technology for the Automobile Industry, Coventry, UK (Metals Technology Committee of the Institute of Metals, 1 Carlton House Terrace, London SW1Y 5DB)

25-26 April. Symposium on Metal Matrix Composites: Testing, Analysis and Failure Modes, Reno, Nevada (ASTM, 1916 Race St., Philadelphia, PA 19103, USA)

25-27 April. Intl. Conf. on Hot Isostatic Pressing of Materials: Applications and Developments, Antwerp, Belgium (Technologisch Instituut, Metallurgical Section, Jan van Rijswijcklaan 58, B-2018 Antwerpen, Belgium)

26-28 April. 3rd Intl. Conf. on Joining of Ceramics, Glass and Metal, Bad Nauheim FRG (Deutsche Gesellschaft für Metallkunde eV., Adenauerallee 21, D-6370 Oberursel, FRG)

2-6 May. New Applications for Steel in View of the Challenge from Substitute Materials, Luxembourg (UN ECE Commission for Europe, Palais des Nations, CH-1211 Geneva 10, Switzerland)

5-12 May. ILA HANNOVER '88 (17th Intl. Air and Space Exhibition), Airport Hannover-Langenhagen, FRG. (Bundesverband der Deutschen Luftfahrt-, Raumfahrt- und Ausruestungsindustrie e.V., Bonn, und die Deutsche Messe- und Ausstellungs-AG, Hannover)

9-13 May. Materials '88. Materials and Engineering Design, London (Institute of Metals, 1 Carlton House Terrace, London SW1Y 5DB)

9-13 May. 8th European Photovoltaic Solar Energy Conf., Florence, Italy (WIP, Sylvensteinstrasse 2, D-800 München 70, FRG)

17-19 May. International Congress of Metallurgy, Palazzo di Congressi, Bologna, Italy. (Sponsored by the Associazione Italiana de Metallurgia (AIM), Piazzale R. Morandi 2, I-20121 Milano, Italy)

24-26 May. IRPLAST '88 - Intl. Plastics & Rubber Exhibition, Dublin, Royal Dublin Society. (International Fairs and Exhibitions Ltd., Belgrave House, 15 Belgrave Road, Rathmines, Dublin 6)

25-26 May. Recyclingplas III, 3rd Annual Conf. dealing with the issue of plastics recycling, Washington, D.C. (Plastics Institute of America and US Dept. of Energy)

16-17 June. Intl. Symp. on Polymers, Plastics & Rubber Processing Technology, Toronto, Canada. (V.M. Bhatnagar, P.O. Box 1779, Cornwall K6H 5V7, Ont., Canada)

20-23 June. 10th Symp. on Thermophysical Properties, Gaithersburg, MD, USA. (National Bureau of Standards, Gaithersburg, MD, American Soc. of Mechanical Engineers and the University of Maryland)

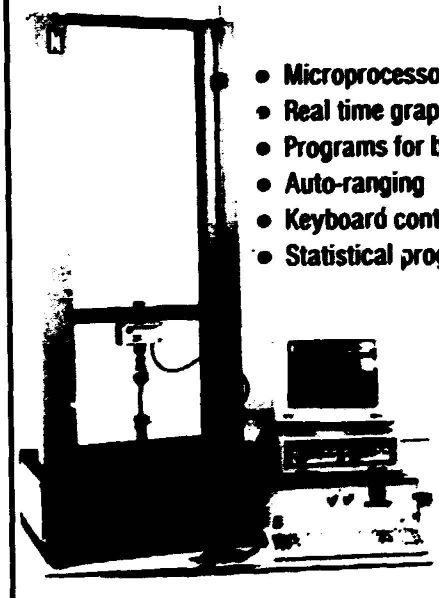
28-29 June. Symp. on Corrosion Rates of Steel in Concrete, Baltimore, MD, USA. (N.S. Berke, W.R. Grace Co., 62 Whittemore Ave., Cambridge, MA 02140)

4-11 July. Interplastica '88, Moscow, USSR. (NOWEA Intl. GesmbH, Postfach 32 02 03, Stockumer Kirchstrasse 61, D-4000 Duesseldorf 30, FRG)

12-14 July. 4th National Space Engineering Symposium, sponsored by the National Panel on Space Eng., the Joint College Board of the Inst. of Engineers, Australia, Adelaide, Australia. (The Conference Manager, Fourth National Space Eng. Symp. The Institution of Engineers, Australia, 11 National Circuit, Barton ACT 2600, Australia)

24 July - 30 September. 1988 World Materials Congress, Chicago, USA. (ASM Intl., Metals Park, Ohio 44073, USA)

November. 8th Argentine Congress-Exposition and Second Ibero-American Ceramic, Glass, and Refractory Congress, Buenos Aires, Argentina. (Argentine Technical Ceramic Ass., Peru 1420, 1141 Buenos Aires, Argentina)



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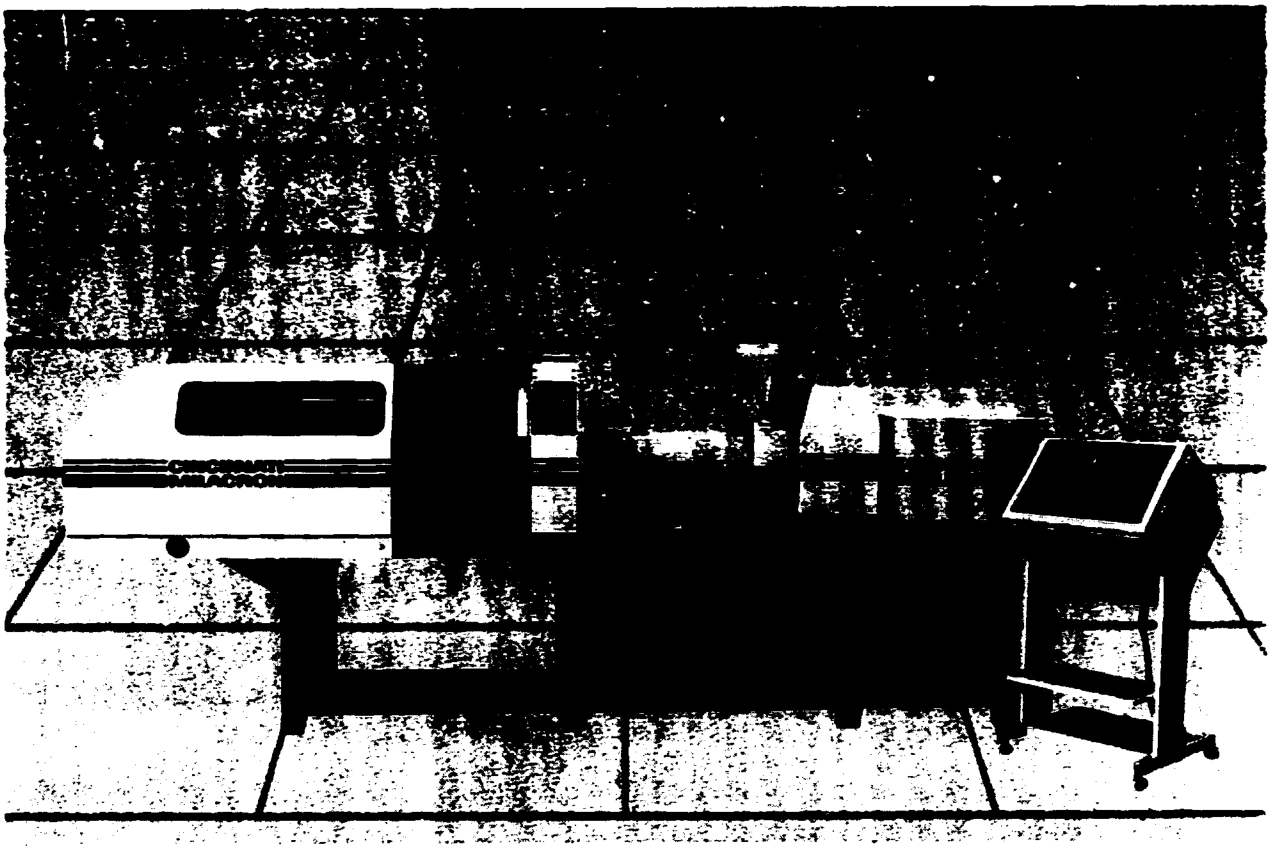
Know-how, designs and licences offered to manufacture drilling machines for water wells of up to 2.5-m diameter and 80-m depth and for concrete-injected piles of up to 2-m diameter and 45-m depth. Claude Bourg, Drill-France, B.P. 15, Le Haillan 33160, France.

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.

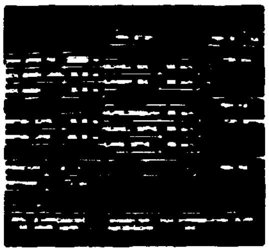
Manufacturers of various metal powders offer know-how for the production of electrolytic copper and iron powder, atomized aluminium powder and synthetic iron oxide. R. Devroy, Radar International, Post box No. 2014, Calcutta 700 001, India.

Technical know-how and complete turnkey plants available for the production of mono-crystalline 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.



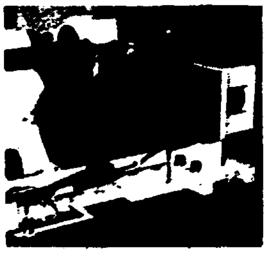
Fully electronic plastic injection molding machines "ACT" provide versatile, high-precision molding.



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 expended 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.

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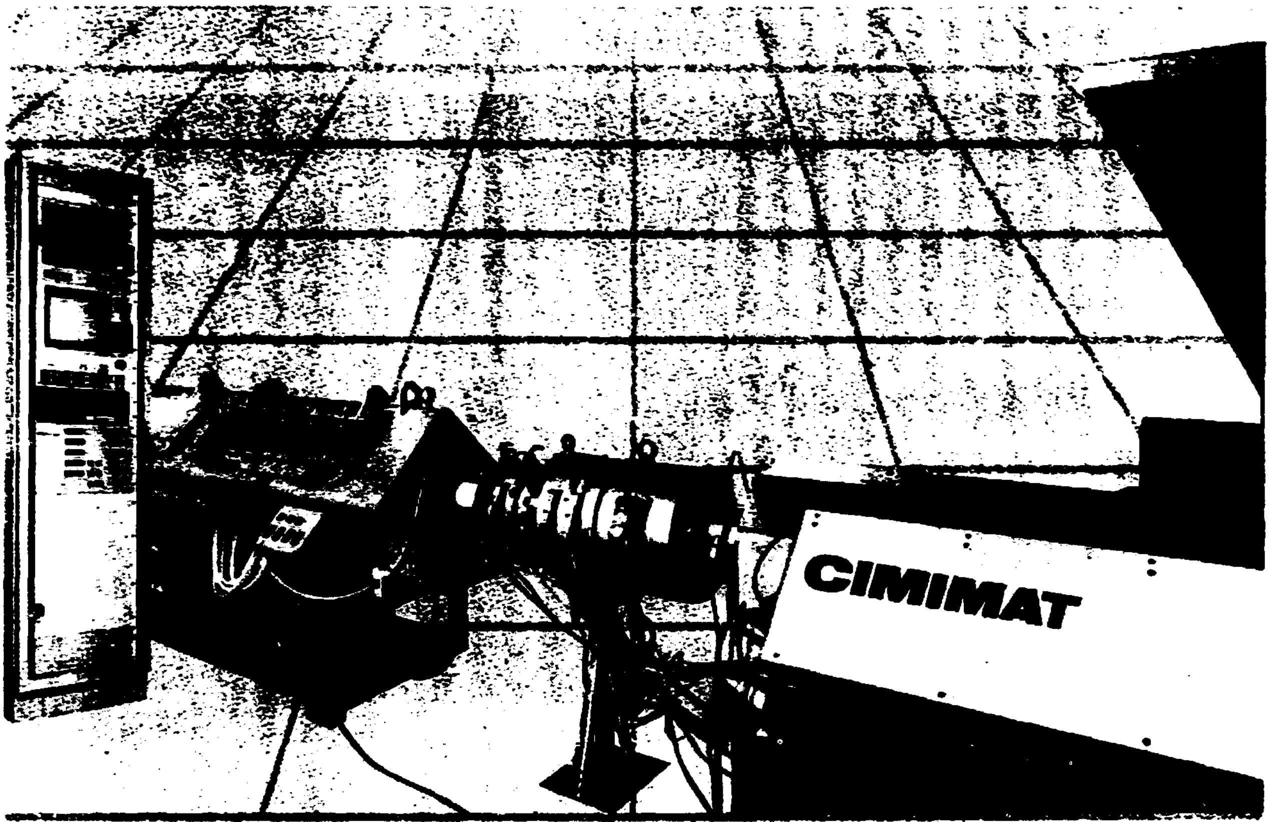
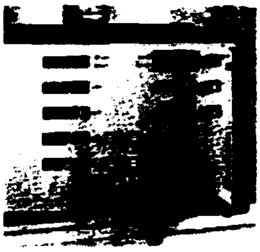


Why should pipe producers consider the new automatic pipe plant "CIMIMAT®"?



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 ¼ 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 fault-free and is able to centralise thin or thick areas by equalising oposing 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.

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Finding better ways
to more profit.

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Advances in Materials Technology: Monitor
Reader Survey

The Advances in Materials Technology: Monitor has now been published since 1983. Although its mailing list is continuously updated as new requests for inclusion are received and changes of address are made as soon as notifications of such changes are received, I would be grateful if readers could reconfirm their interest in receiving this newsletter. Kindly, therefore, answer the questions below and mail this form to: The Editor, Advances in Materials Technology: Monitor, UNIDO Technology Programme at the above address.

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Do you wish to continue receiving issues of the Advances in Materials Technology: Monitor?

Is the present address as indicated on the address label correct?

How many issues of this newsletter have you read?

Optional

Which section in the Monitor is of particular interest to you?

Which additional subjects would you suggest be included?

Would you like to see any sections deleted?

Have you access to some/most of the journals from which the information contained in the Monitor is drawn?

Is your copy of the Monitor passed on to friends/colleagues etc.?

Please make any other comments or suggestions for improving the quality and usefulness of this newsletter.

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Readers' comments

We should appreciate it if readers could take the time to tell us in this space what they think of the tenth 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.