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THE SPACE TECHNOLOGY DEMAND ON MATERIALS AND PROCESSES

J. Dauphin

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16. Abstract

Space technology requires a rational and accurate policy of materials and processes selection. This paper examines some areas of space technology where materials and process problems have occurred in the past and how they can be solved in the future.

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THE SPACE TECHNOLOGY DEMAND ON MATERIALS AND PROCESSES*

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Abstract. Space technology requires a rational and accurate policy of materials and processes selection. Due to limited volume, space technology does not generally fund new material and process developments, but tries to select among the advanced commercial products those which, after suitable modification and testing, will provide the required performance and reliability. The present paper reviews some areas of space technology where materials and process problems have occurred in past years and shows how these were solved or how they will hopefully be solved in the future. These "critical" areas cover clean satellites, new thermal control materials with electrical conductivity, advanced structures and reusable hardware. /39/***

No technology can be developed or even survive without acquiring a rational and precise policy in the selection of materials and fabrication processes. One can illustrate this truism by the following sequence:

Environment / Materials

Mission → Criteria → Cost

Function / Processes

The aim of a policy will be to carry out the mission required with sufficient reliability and at minimum cost. Looked at in this way, space technology does not differ basically from classical industrial technology, but the volume of production under consideration is very much smaller. There results a difference in the techniques of resolving the problems encountered; statistical methodology applies poorly to small output: the methodology of analysis runs up against limited experience in the space regime. Therefore, the solutions are generally obtained thanks to the combined working-up of tests and analyses; this renders the life for space materials specialists somewhat exciting ! A small volume of production also involves making large usage of materials and processes taken over from other technological areas because the cost of new development would be out of proportion to the attendant bene-

Author's note: The mention of commercial names in the body of this article is of necessity. It is not in any way an endorsement for the products mentioned, or anything against those not mentioned. Users will have to form their judgements on all data which they can avail themselves of.

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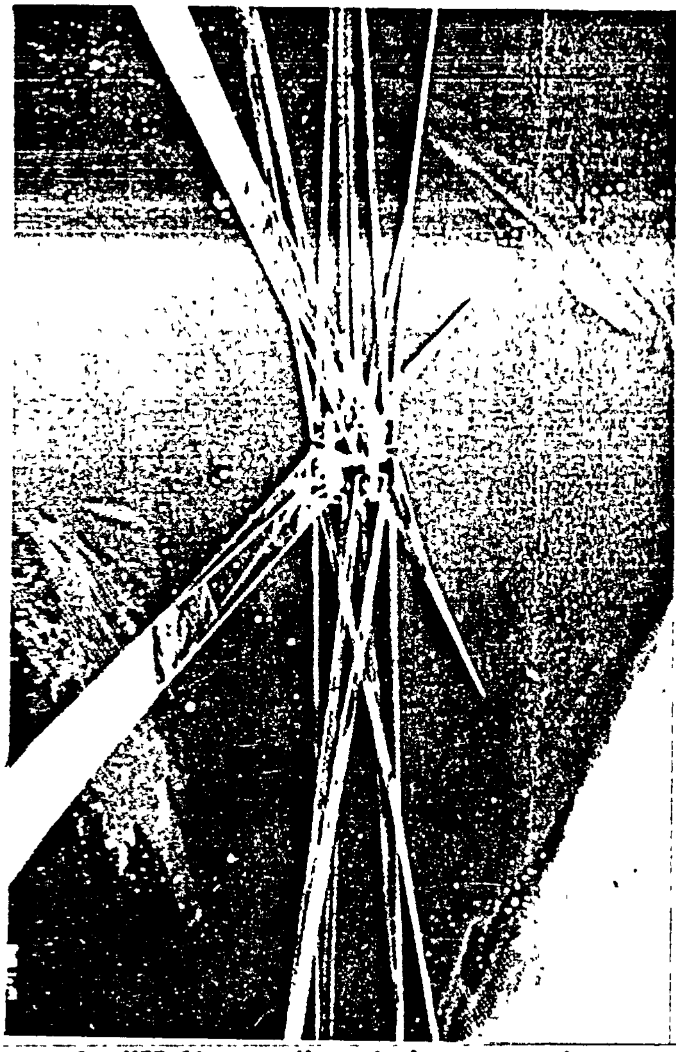

Figure 1- "Heliogyro" artist's conception
(Original by W.F. Carroll-JPL-USA)

fits. This is why, with certain exceptions, there does not exist a group of materials and processes which are space-typical. /40/

Either space technology uses classical materials having undergone sufficient testing to confirm their characteristics, or judicious combinations and modifications of classical materials. The setting into motion of great plans for large space stations could well change this situation; one had a first quick glimpse of this at the time of the American study of 1977 dedicated to the solar sail in preparation for the Halley Comet encounter.

The concept selected, and which was later abandoned for budgetary reasons, was a system of the "Heliogyro" pattern having 12 blades each 8 meters wide by 7.5 km length made of 2.5 μ Kapton, metallized on one side (Al 1000 Å) and covered on the other with chromium of 125 Å thickness. (Figure 1). At the time when the Du Pont Company had been queried on the possibility of producing a large quantity of Kapton of 2.5 μ thickness, it was not, nor had it ever been, a commercial product. Cases of this type are cited as representative of the planning for the placing into orbit of large space structures.

To return to the series outlined above, one can recall that the space environment has been described in detail in many publications (1), and sometimes with direct reference to materials problems. (2) Therefore, it is not useful to repeat this here.

In space vehicles, materials are able to fill very diverse functions:

- structural (primary and secondary structures, extendibles etc)

- thermo-optical (absorption, emission, conduction etc.)

- interfacial (adhesion, lubrication etc.)

- electrical (conduction, insulation etc.)

The combination of environmental knowns and of functions leads to the definition of a certain number of criteria to which the materials and processes would have to be responsive in order to be selected. This choice then results in a certain cost, which must, moreover, include fabrication, factors such as maintenance and repair expenses, and an evaluation of the consequences of failure.

The rest of this article will be devoted to presenting some solutions arrived at by ASE and its contractors to several critical problems of space technology, chosen to illustrate the principles of selection, of combination and modification of materials and processes with the object of satisfying criteria for space utilization.

Appropriate Materials for Satellites

From the beginning, cleanliness has been a fundamental requirement for scientific and observation satellites. (3, 4)

Recent problems with telecommunications satellites are proof that contamination can also be dangerous in this application. (5)

There results an increased demand for "appropriate" materials, and particularly in certain critical areas such as thermal control paints, adhesives for solar panels, lubricants for mechanical parts etc. Thermal control materials will be discussed more specifically later in this section. For the moment, one can simply say that, for the sake of cleanliness, it is indispensable to have a paint base that is non-outgassing.

Adhesives for Solar Panels

Construction of a solar panel requires, in general, the use of two adhesives--one which must be optically transparent and which glues together the contact glass to the solar cells, and the other which attaches the cells to the structure. Silicones hardening at ambient temperatures are preferred because of their excellent resistance to thermal cycling; however, they are generally an important source of contamination in a vacuum. This problem /41/ was long since detected by flight measurements (6), and some manufacturers have tried to introduce "appropriate" silicones into the market. (Table 1) Normally, one obtains these products by a suitable purification of commercial silicones, in general by distillation in a vacuum (7), which brings its price up to a high level.

The production of these adhesives is small, which makes their procurement tricky. A strict inspection by the vendor must allow verification that the cleanliness of the product is satisfactory. Likewise, whenever one makes use of these materials themselves, one runs the risk of some contamination because the standard test temperature for selection (micro VCM*) is not necessarily representative of the utilization, and besides the condensate measurements (CVCM) are not rigorously zero. For critical applications, a determination of actual potential for contamination is justified. (8)

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* ESA Specification PSS09-QRMO2T

Table 1- Appropriate Adhesives for Solar Panels

Designation	Manufacturer	Color	Typical Out-Gassing TML %/ RML%/CVCM%	Remarks
RTV 566	General ElectricUSA	Red	0.2/0.17/0.02	
RTV S691	Wacker Chemical D	Red	0.37/0.33/0.07	
DC 93500	Dow Corning USA	Clear	0.3/0.28/0.03	
SLM 71455	Wacker Chemical D	Clear	0.11/0.10/0.03	Not qualified at present
SILCO 14	Cnes F	Clear	0.32/.../0.06	Preliminary findings
SILCO 17/18	Cnes F	Grey	0.42/.../0.09	Preliminary findings

Appropriate Lubricants

It is generally agreed to recommend dry lubricants for space applications; in fact, some dry lubricants are sufficiently satisfactory in a vacuum.

Along these lines, ASE some years ago perfected a method of lubrication with lead film which is now state of the art in space mechanisms. (9)

However, there are cases in which a liquid lubricant is indispensable and one cannot protect it from the vacuum of space. Some years ago, Dow Corning in the U.S. perfected a series of silicone lubricants of low contamination potential; they obtained these by purifying their corresponding commercial products. These products have since been taken off the market; at any rate, their lubrication efficiency was not very remarkable. The fluorocarbon compounds have much better qualities in this respect, and ASE has encouraged production by Montedison (I) of pilot quantities of a specially purified and non-contaminating fluoro-lubricant known under the name Fomblin 225. This product can be employed in space vacuum without any special precautions.

Electronic Coatings and Potting

Space electronics is a field in which some ordinary and cheap products have proved entirely adaptable.

One can particularly mention Solithane 113 from Thiokol (US) of which numerous formulations have been used with success.

This material is, however, not used when inflammability is a requirement, such as in manned cabins; in this case, one can employ the products mentioned in Table 1 as coatings or potting, or likewise as an insulation layer on top of Solithane. Cofis (F) has perfected a monocomponent varnish, Silco 37, which is under evaluation.

Materials for Thermal Conduction

It is difficult to assure proper cooling of space electronics; conduction across mounting brackets is often quite insufficient in a vacuum.

A number of products exist in the market which permit augmentation of thermal conductivity. Frequently these are composed of silicone grease charged with different kinds of mineral powders. These materials are a constant threat to the cleanliness of the system because they degas great quantities of contaminants, and in addition they have a tendency to migrate along surfaces.

Some years ago, a material of "space quality" was available from Dow Corning under the designation C6-1102, but this has since been withdrawn from the market. Besides, this product was also not immune to migrational behaviour.

The adhesives mentioned above can be used, and particularly those which contain a charge, however, it is a disadvantage to create a permanent bond which is difficult to disassemble at the time of modification or repair.

Good results have been obtained by using a fine packing of graphite (Sigraflex from Sigri D) which creates a supple joint and does not have to be cut to form.

The use of commercial conducting greases can also be tolerated, but on condition that they are completely closed off behind an air-tight barrier of a suitable material.

CNES (F) has developed a non-outgassing conductive grease (10) on a base of purified silicone; this product is not yet commercially used; if this develops, it will be necessary at the same time to take into account the risk of contamination by migration.

New Thermoregulating Materials

Thermoregulating materials fill a critical role in space devices. The search for perfection has been going on since the dawn of the "space age" /42/ and yet a perfect material does not yet exist, so that compromises have to be accepted for different situations.

Solar reflectors pose the most difficult problem; here we have materials of weak solar absorbance (α_S) and high emittance (ϵ_H); it is also required that its characteristics be very stable under the effects of space radiation (UV and particles) and this for the duration of a long lifetime; it is also required that they be non-contaminating, and also very frequently that they exhibit an electrical conductivity sufficient to suppress charging effects in the geostationary orbit.

Space Paints

White terrestrial paints turn out to be unuseable very rapidly in space.

Therefore, one falls back on special formulations chiefly looking for good resistance to radiation. This is the origin of the well-known paints S13G and Z93 from IITRI (US). Similar paints were developed in the United Kingdom and in France. In the latter country they have always been manufactured by Astral under the designations PSG 120 (silicone / ZnO) and PSZ 185 (silicate/ZnO). The contaminating potential of silicone paints was very high for applications relating to satellites proper and purified versions appeared on the market under the designations S13GLO (US) and PSG 120FD (F). (11)

The criterion for electrical conductivity is at the moment not met by any white commercial paint.

NASA (GSFC) has produced small quantities of a white paint called "conductive" under the designation NS43C. The materials laboratories of ESA have demonstrated that the conductivity disappears with exposure to vacuum. (12) CNES (F) has attacked this problem and has already produced a number of test formulations (11), but the road is still a long one before one will be able to create the combination of high solar reflectance, good radiation resistance and adequate electrical conductivity.

Luckily, the paints have only a very small tendency to discharge electrically in the conditions of the geostationary environment. Experiments carried out by the DFVLR (13) have shown that the discharges only appear at very low temperatures. It seems that the escaping currents would be sufficient, at least at ambient temperature, to prevent high tension sparking.

Quartz Fabric

To make up for the absence of a suitable conductive white paint, the

US Air Force has developed a fabric based on fine fibers of very pure quartz. (14) This material is applied on surfaces with or without an intermediate film of Teflon FEP,and it allows production of satisfactory solar reflectors which have good radiation resistance and do not acquire very much of an electrical charge. This last property can be explained by the secondary emission of the ... quartz fibers under an electron flux; there is produced a kind of avalanche phenomenon which gives rise to a free electron concentration in the interior of the fabric and allows the charge to flow off.

The work of DERTS (F) has confirmed this mechanism (15), but has shown that the potential in the material can build up to several hundreds of volts. Thus, one cannot make use of this solution on scientific satellites which frequently specify "less than 1 V between any two points anywhere on the surface"; however, the process is adaptable to applications satellites whose specification is "no discharge"; it must, however, be noted that quartz fabric is expensive and somewhat sensistive to contaminants on account of its specifically increased surface.

Fixed Cold Mirrors

ASE uses the term OSR (optical solar reflector) to designate cold mirrors consisting of a thin sheet of glass or quartz, metallized on the back and characterized by low absorptance ($\alpha_s = \pm 0.08$) and high emittance ($\epsilon_H = \pm\ 0.8$). Such a system is perfectly adapted to the fabrication of radiating components and has been developed by OCLI (US) and also by PPE (GB). In the United States, quartz is used, in Europe glass doped with cerium oxide. The reflecting base is always of silver; tarnishing is avoided thanks to protective wrappings, sometimes multiple ones, of metal (inconel), of oxide, or of varnish. The "OSR's" are very resistant to radiation, but present some drawbacks--high price (price of mirror and mounting), significant weight, difficulty of encasing the curved surface, and sensitivity of the thin deposits to contamination.

The OSR's of the type described are non-conductors of electricity. The OCLI mirrors give rise to discharges under electron flux; the PPE mirrors exhibit a very slight insulative resistance due to their glazing in cerium glass and do not discharge at ambient temperature (20-25°C); below zero, discharges appear. (16)

The two types of mirrors can be made into conductors by an anterior deposit of a mixed oxide of indium and tin (ITO). The interconnection of the mirrors is done in such a case either using contacts evaporated on the front in front of which metallic ribbons are soldered on, but the method costs a lot, or by dressing the edges of the mirror with a conductive paint, electrically connecting the front and rear faces, and by using a conductive adhesive to fasten the OSR's on a substrate which is also conductive. The latter method is recommended by ASE and a suitable adhesive is prepared by mixing RTV 556 (General Electric US) and Cho-Bond 1029B (Chromerics-US) (17).

<u>Flexible Cold Mirrors</u>

ASE uses the English term SSM (second surface mirror) arbitrarily to designate flexible cold mirrors made from a sheet of polymer metallized on the back. These materials play the same role as the OSR, but are of less satisfactory optical properties. Table II summarizes the characteristics of the most current systems. The radiation resistance of the FEP films is less than that of fixed mirrors, but at the same time sufficient for geostationary missions of long duration, if one takes into account degradation in the thermal computations, and if one plans for mechanically supporting /43/ the film in order that it does not deteriorate for it will become fragile through radiat...

The SSM's based on Teflon TFE are probably unacceptable for the geostationary orbit, but would be very useful in low orbit where one has a precise need for diffusing materials for manned missions.

Kapton films are of inferior optical properties, but are traditionally used on the exterior of insulating multilayers where their properties are less critical.

Aluminized Kapton will also be used as windows for certain space experiments. Their role in this case is to assure thermal regulation without absorbing the radiation to be measured, for example X-rays. For this application, the thicknesses which are commercially available are very important; a process of controlled chemical attack has been developed to reduce the thickness to $\pm 5 \mu$, which is adequate for the use in question. (18)

More complex SSM's have been tested with the goal of obtaining better stability against radiation while keeping a sufficiently low solar absorptance. The firm MBB (D) in particular protects the back face of an FEP film using interference filters. (19) As far as we know, this technique has not been put out commercially; it is probable that its cost is high relative to the properties obtained.

Table 2- Typical SSM Materials

Structure	Manufacturer	Optical Properties	Remarks
FEP/AL 50 μm	Sheldahl	≤0.14/≥0.6	Specular
FEP/AL 125 μm	Sheldahl	≤ 0.14/≥ 0.75	Specular
FEP/Ag 50 μm	Sheldahl	≤0.09/≥0.6	Specular
FEP/Ag 125 μm	Sheldahl	≤ 0.09/≥ 0.75	Specular
TFE/AL	Sheldahl	± 0.13/± 0.87	Diffuse/not qualified at present
Kapton/AL 50 μm	Nombreux	± 0.44/ ± 0.78	Yellow

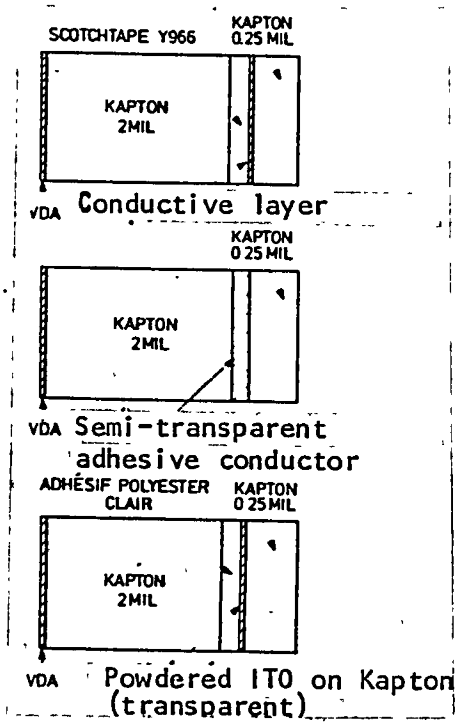

Figure 2- Three possible concepts for a non-discharging SSM

All the systems described up until now can be charged and discharged in the geostationary orbit. To avoid this, there have been developed SSM's carrying on the front side a deposit of mixed oxide of tin and indium (Sheldahl US). This approach has been crowned with success in the case of Kapton; FEP treated this way shows a conductive layer unstable against thermal cycling (15). It is necessary to improve these last products. BADG (GB) is testing another method and seeks to limit the habit of Kapton to discharge by laminating a conductive layer of small depth onto the film. (Figure 2) This approach will be able to be applied in the case of applications satellites, but it requires some more testing.

For all of the films carrying a conductive layer on the front side (oxides of indium and tin, or metal), the Materials Section of ESTEC has developed a method of aggregation based on the above mentioned conductive silicone adhesive RTV 566+ Cho-Bond 1029B. This method has been prequalified on Kapton/ITO, FEP/ITO, and on aluminized mylar. (20)

Materials for Long Life-Duration Vehicles

The generation of applications satellites that is actually on orbit or that is going to be launched soon anticipates a lifetime of 7-10 years. The supplying of commercial service involves the possibilities of stockpiling for long periods, either on the ground or on orbit. Future space stations which are being described will have lifetimes on the order of 30 years. All of this represents a challenge for the materials and processes specialists. Methods of /44/ selection and testing, a fastidious quality assurance, and understanding of the mechanisms of degradation are the answers to provide to the growing requirements in the area of mission reliability.

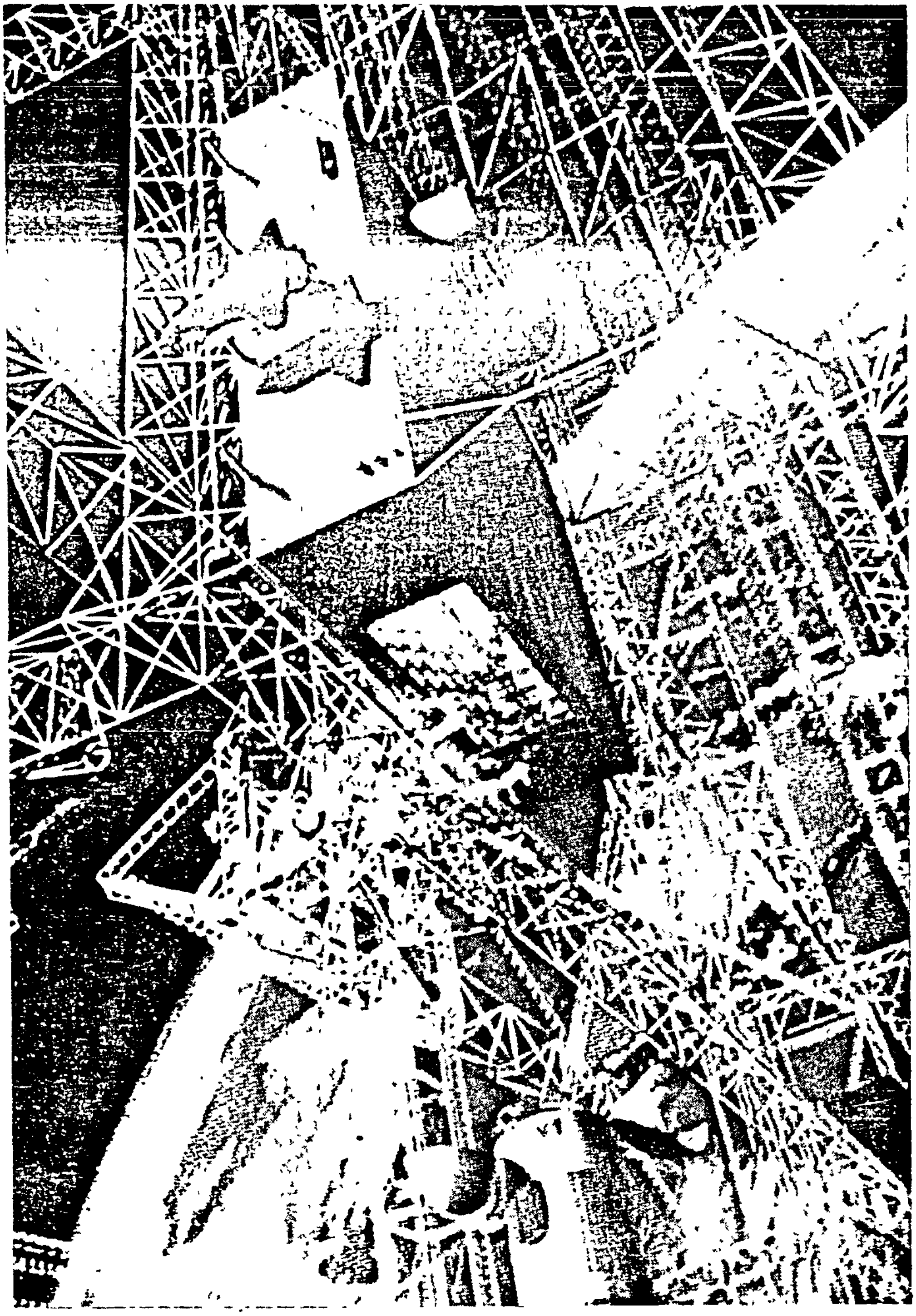

Figure 3-- Rockwell Concept for a Power Space Station

Highly Reinforced Materials

The great advances in this area are particularly the achievement of the transportation industry, especially aeronautics. The structures of space ships use more and more the composites of high performance and constitute special requirements in the domain of very thin laminates for quality and duration of use in unusual environments.

At ASE, the problems posed by highly reinforced materials have been put in the spotlight by the failures encountered at the time of the qualification of the MARECS antenna. A certain apprenticeship phenomenon is certainly /45/ noted among design engineers who are used to metallic structures and who have to learn to work with different materials. But it will also be a critical problem of quality control at all stages of manufacturing: the base resin, the reinforced fibers, preimpregnates, hardening procedures, and the finished material. This control requires intensive use of physico-chemical analysis techniques: high pressure liquid chromatography (HPLC), thermal analysis methods, IR spectrometry etc.

The goal of these operations is to assure that, once one has chosen and bought good material, one uses besides a hardening procedure adequately allowing the attainment of optimum properties in the product.

This approach is not specific to space technology, but it is particularly needed by reason of the very narrow scope of the concept and of the tendency to employ thin and light structures which are especially sensitive to flaws.

Non-destructive test methods are also an indispensable tool of quality control on these structures. (21)

The resistance of reinforced materials to the space environment on long duration missions is also a regime in which our knowledge is fragmentary. Test methods suited for these studies and the technique of extrapolation of the results are still in their infancy. (22) Structures destined to be assembled or deployed in space pose a particular problem. The United States is very active in the domain of large space structures to be assembled, or even to be manufactured in orbit. (Figure 3) However, it is sometimes hard to know where the frontier runs between the possible and science fiction.

At ASE our forecasts are of modest proportions, but one can cite for example the investigations underway at Contraves (CH) to clarify the practical problems posed by large expandable antennas. The principle developed up until now is to use a very thin preimpregnate reinforced with glass or Kevlar fibers; the anten na will be deployed, inflated and then hardened in space. (23)

Reuseable Metallic Structures

Materials made for ASE have up until recently been destined to be lost in the depths of space or to be burnt up in the atmosphere. The availability of the Space Shuttle, and for us especially the Spacelab, has changed this situation; space material is becoming reuseable. The problems associated with this type of material are not new; aeronautics, for example, has been putting them into practice for a long time; but in the case of space, this constraint is joined to an impressive number of other factors. For those structures that are of metal, space seems in all cases less hazardous than the stay on the ground between missions where corrosion can exercise its pernicious influence.

The selection of alloys for missions embarked aboard the Space Shuttle demands, however, an evaluation of their resistance to corrosion, and very particularly corrosion while under constraint. ASE, like NASA, has published very strict specifications in this area. (24)

Aging of Materials

The combination of long duration missions, of possible reutilization of material, of the necessity of stocking systems or subsystems for replacement leads to the study more especially of the phenomena of aging which are produced in space, on the ground, or in the course of variable sequencing of the two environments. It is an area in which our current knowledge is rather limited. One can obviously identify a certain number of materials more suspect than others of being able to become sources of fatigue, for example thermoregulating barriers, electrical contacts, very corrodible metals materials capable of flowing etc. However, it is impossible to quantify these effects in the current state of our knowledge.

There exists a solid reservoir of experience concerning aging in the terrestrial environment but not necessarily applicable to properties which are of interest to space technology and not necessarily with the level of precision desired.

We are certainly lacking in proven methods for simulation of the long-term space environment and of the space-ground/alteration. ESTEC has started limited work founded on a study of Meteosat material which has now attained a sufficiently advanced age. In any case, it will be a means for defining the regimes where complementary studies are desireable, if they can be budgeted for.

Conclusions

One of the characteristics of space technology is the mass of specific and precise requirements which are applied to materials and processes, whereas the corresponding market is of limited size. Therefore, the specialist in space materials and procedures has to apply all his guile to the resolution of problems posed, and to have available a vast knowledge of what the market can offer and what has been developed in other technology areas.

Methods of selection, of evaluation, and of testing are continually refined so as to allow better use of the materials and processes existing in the construction of space devices. In some very particular cases, completely new materials and processes are developed specifically for space.

The requirement in the domain of suitable materials, reuseables, stockables and those with long lifetimes grows unceasingly; it is a /46/ challenge for the specialist in space materials; he also must be on the lookout to assure a higher and higher reliability for the recommended solutions.

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