# ECSS-Q-ST-70C-Rev1: Materials, Mechanical Parts and Processes

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# Introduction to myself

- 1969 – BSc Mechanical Engineering – Amsterdam
- 1971 – Fokker – working on ANS and ESRO 4
- 1976 – BSc Metallurgy – Univ. Delft
- 1977 – MSc Metallurgy – Univ. Delft: Immiscibility cap in the Cu-Rh-Pt ternary system
- 1982 – PhD Physics – Univ. Groningen: Order-Disorder transistions in Cu-Ni-Zn ternary system
- 1982 – 2001: Principle metallurgist ESA/ESTEC Materials and Processes Section
- 2001 – 2011: Head of Materials Technology Section ESA/ESTEC
- Convenor of the level II standard ECSS-Q-ST-70C
- Convenor of the level III ECSS-Q-ST-70-71C
- Document focal point of all ECSS-Q-ST-70 series of standards
- Developper of the ESA DMPL tool for controlling and aproval of the DML, DPL and DMPL
- Initiator of the European Space Materials Database (only internal to Estec)
- Webmaster of the ESMAT website
- supported all ESA space projects, including telecommunications satellites, space science and the manned Spacelab, Columbus and ISS
- M&P representative in MRB, FRB, PDR, CDR, FAR
- Retired since 2011
- Creator of spacematdb.com

# Content

# PART 1 - GENERAL

# Introduction

One question frequently asked is "Why does ESA not have a preferred materials list whereas such a list does exist for electronic components?"

The reason for this is best summarised by the relationship:

$$\text{Material + Process} \xrightarrow{\text{Environment}} \text{Application}$$

In other words a material can only be considered together with the associated process and the final application. To complicate matters further the effects of the environment (manned or unmanned, LEO or GEO etc.) have to be considered since these can significantly affect the suitability of the application

# ECCS Specification Related to MMPP

**Level 2 standard**

- **ECSS-Q-ST-70C Rev. 1** Space Product Assurance - Materials, Mechanical Parts and Processes.

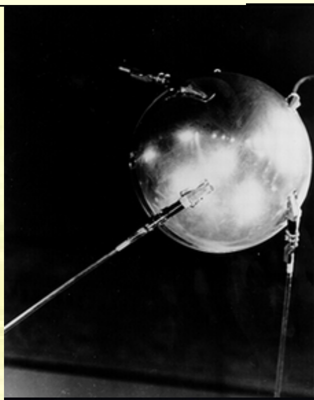
- The purpose of this standard is to define the requirements and statements applicable to Materials, Mechanical Parts and Processes to satisfy the mission performance requirements. This standard also provides details concerning the documentation requirements and the procedures relevant to obtaining approval for the use of MMPP in the fabrication of Space Systems and associated equipment.

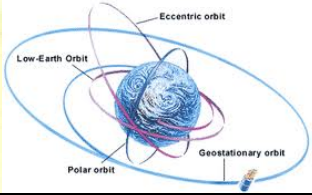
# Tailoring/1

The following section presents the requirements for Materials, Mechanical Parts and Processes (MMPP). However the actual requirements for a particular project depend on several factors, e.g.

- Type of spacecraft (manned or unmanned)
- Spacecraft orbit (LEO, GEO, polar, etc)
- Complexity (satellite, payload, etc.)
- Duration of space exposure (x years, y days, etc.)

The requirements will therefore be specified as part of the contract either in the statement of work or in the PA plan





# Tailoring/2

| Screening | Utilisation | | | | |
|---|---|---|---|---|---|
| | Satellites and Probes on expendable launcher | | Manned Spacecraft | | Ground Packaging |
| | Not Pressurised | Pressurised | Not Pressurised | Pressurised | |
| Thermal Vacuum | X | O | X | O | X |
| Flammability | | | X | X | |
| Offgassing and Toxicity | | | | X | |
| Stress Corrosion | X* | X* | X* | X* | |
| Atomic Oxygen | X(LEO) | | X(LEO) | | |
| Resistance to Microbial Growth | | | | X | |

X = mandatory

O = optional

* = for structure only

LEO = Low Earth Orbit

# European Co-operation for Space Standardisation (ECSS)/1

For materials and processes the situation is presently as follows:

1. Thirty-one specifications have been issued as an ECSS level 3 Specification

| | |
|---|---|
| ECSS-Q-ST-70-01C | Cleanliness and contamination control |
| ECSS-Q-ST-70-02C | Thermal vacuum outgassing test for the screening of space materials |
| ECSS-Q-ST-70-03C | Black-anodising of metals with inorganic dyes |
| ECSS-Q-ST-70-04C | Thermal Cycling test for the Screening of space materials and processes |
| ECSS-Q-ST-70-05C | Detection of organic contamination of surfaces by IR spectroscopy |
| ECSS-Q-ST-70-06C | Particle and UV radiation testing for space materials |
| ECSS-Q-ST-70-07C | Verification and approval of automatic machine wave soldering |
| ECSS-Q-ST-70-08C | The manual soldering of high reliability electrical connections |
| ECSS-Q-ST-70-09C | Measurement of thermo-optical properties of thermal control materials |
| ECSS-Q-ST-70-10C | Qualification of printed circuit boards |
| ECSS-Q-ST-70-11C | Procurement of printed circuit boards |
| ECSS-Q-ST-70-12C | Design rules for printed circuit boards |
| ECSS-Q-ST-70-13C Rev.1 | Measurement of the peel and pull-off strength of coatings and finishes using pressure-sensitive tapes |
| ECSS-Q-ST-70-14C | Corrosion |

# European Co-operation for Space Standardisation (ECSS)/2

- ECSS-Q-ST-70-18C — Preparation, assembly and mounting of RF coaxial cables
- ECSS-Q-ST-70-20C — Determination of the susceptibility of silver-plated copper wire and cable to plague corrosion
- ECSS-Q-ST-70-21C — Flammability testing for the screening of space materials
- ECSS-Q-ST-70-22C — The control of limited shelf-life materials
- ECSS-Q-ST-70-26C Rev.1 — Crimping of high-reliability electrical connections
- ECSS-Q-ST-70-28C — Repair and modification of PCB assemblies
- ECSS-Q-ST-70-29C — Determination of offgassing products from materials and assembled articles to be used in a manned space vehicle crew compartment
- ECSS-Q-ST-70-30C — Wire-wrapping of high reliability electrical connections
- ECSS-Q-ST-70-31C — Application of paints on space hardware
- ECSS-Q-ST-70-36C — Materials selection for controlling stress corrosion
- ECSS-Q-ST-70-37C — Test method for stress corrosion cracking
- ECSS-Q-ST-70-38C Rev.1 — High-reliability soldering for surface mount and mixed technology
- ECSS-Q-ST-70-39C — Welding of metallic materials for flight hardware

# European Co-operation for Space Standardisation (ECSS)/3

| | | |
|---|---|---|
| ▪ | ECSS-Q-ST-70-45C | Mechanical testing of metallic materials |
| ▪ | ECSS-Q-ST-70-46C Rev.1 | Requirements for manufacturing and procurement of threaded fasteners (Public Review) |
| ▪ | ECSS-Q-ST-70-50C | Particle contamination monitoring for spacecraft systems and cleanrooms |
| ▪ | ECSS-Q-ST-70-53C | Materials and hardware compatibility tests for sterilization processes |
| ▪ | ECSS-Q-ST-70-54C | Ultracleaning of flight hardware |
| ▪ | ECSS-Q-ST-70-55C | Microbial examination of flight hardware and cleanrooms |
| ▪ | ECSS-Q-ST-70-56C | Vapor phase hydrogen peroxide bioburden reduction for flight hardware |
| ▪ | ECSS-Q-ST-70-57C | Dry heat bioburden reduction for flight hardware |
| ▪ | ECSS-Q-ST-70-58C | Bioburden control of cleanrooms |
| ▪ | ECSS-Q-ST-70-71C | Materials, processes and their data selection |

2. **An additional two technical memoranda.**

| | | |
|---|---|---|
| ▪ | ECSS-Q-TM-70-51A | Termination of optical fibres |
| ▪ | ECSS-Q-TM-70-52A | Kinetic outgassing of materials for space |

# Terms specific to the present standard

**critical material**

- material that is new to an individual company or non-validated for the particular application and environment, or that has caused problems during previous use that remain unresolved

**critical mechanical part**

- mechanical part that requires specific attention or control due to fracture mechanics aspects and limited-life aspects, or with which the supplier has no previous experience of using the mechanical part in the specific application and environment or that are new or non-qualified, or that has caused problems during previous use that remain unresolved

# Terms specific to the present standard

**Process**

- set of inter-related resources and activities which transforms a material or semi-finished product into a semi-finished product or final product

**critical process**

- process new to an individual company or non-verified for the application in question or has caused problems during previous use that remain unresolved

**special process**

- process where quality cannot be completely ensured by visual inspection of the end article only

# Steps to be taken to get approval for materials, mechanical parts and processes (MMPP)

| Phase | Materials | | Mechanical parts | | Processes | |
|---|---|---|---|---|---|---|
| | Step | Comments | Step | Comments | Step | Comments |
| Critical Analysis | 1 | | 1 | | 1 | |
| Evaluation (usually by test methods defined by ECSS standards) | 2 | Critical materials are tested, e.g. outgassing, SCC, flammability. | 2 | Mechanical parts are tested by, for example, vibration, thermal analysis, off-gassing and life test. | 2 | Critical processes are evaluated by testing "technology samples" including all, for example, electrical interconnection processes and painting, adhesive bonding. |
| Verification | Not applicable | | Not applicable | | 3 | Verification tests usually defined in ECSS standards |
| Validation | 3 | | Not applicable | | Not applicable | |
| Qualification | Not applicable | | 3 | | Not applicable | |
| Approval | | By RFA (Annex D) or DML | | By RFA (Annex D) or DMPL/DPL | | By RFA (Annex D) or DPL |

Note NOTE 1 Project approval is always by means of the request for approval (RFA) form and the projects' declared materials list (DML), declared mechanical parts list (DMPL) and declared processes list (DPL).

Note NOTE 2 The details for approvals of MMPP lists are contained in this Standard.

Note NOTE 3 To summarize: Materials are validated.
Mechanical parts are qualified.
Processes are verified.
In addition: Skills training schools are ESA-certified.
Outside test or evaluation laboratories are certified by agency or company audits.
Operators and inspectors for special and critical processes are trained, certified and monitored.

# Materials Evaluation: Properties Requirements

- During the evaluation process of a material, used for a given application, one has to cope with two sets of requirements that are equally important
  - General Functional, e.g.
    - *Mechanical, Thermal, Electrical*
  - Environmental, e.g.
    - *Vacuum & Radiation stability, AO resistance*
- Quite often, the first set is well known to the user/designer, and can be found for most materials in manufacturer data sheets or databases.
- The second set is much more specific, generally much less recognised, and requiring the knowledge of the environments
- Main tests, e.g., thermal vacuum, thermal cycling, radiation, stress corrosion, flammability, offgassing and toxic analysis and atomic oxygen erosion resistance
- Supplementary tests, e.g. electrical conductivity, optical characteristics, thermo-mechanical…

# Principles & Semantics

- A material is evaluated in order to achieve validation for a given application
- A process is evaluated in order to achieve verification for a given application in a given facility
- A product is evaluated in order to achieve qualification for a given application
- A test facility is evaluated in order to achieve certification for running given tests
- Evaluation is a combination of tests, analyses and possibly audit permitting to pronounce approval, validation or qualification

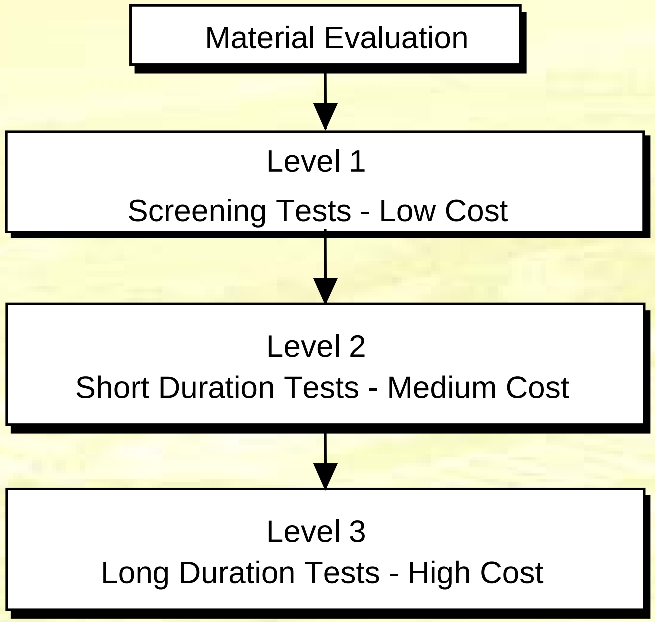
# Materials Evaluation: Environments

Interactions between a material and the different environments to which it is exposed are quite often synergistic and not simply additive; i.e. the sum of both interactions is larger than each of the effects separately.

- Simulation of these combined environments
  - *Technical limitations*
  - *Cost effectiveness/ affordability*

- Tests must be optimised
  - *differentiate between primary and secondary parameters/degradation mechanisms.*

# Material Evaluation



# The Requirements/1

## GENERAL

- The supplier shall prepare, maintain and implement a *MMPP* plan, as part of the overall PA plan in conformance with DRD from Annex A of ECSS-Q-ST-10 and this Standard or as a separate document.

## Establishing and processing of lists

- Each supplier and sub-supplier shall establish, collect, review and deliver the declared materials, mechanical parts and processes lists including all the items intended for use in the flight equipment.

## Management of the lists

- The supplier shall process the lists of lower level suppliers to ensure exchangeabililty, traceability, searchability, sortability, storability and retrievability for that set of lists, before submitting it to the customer.
- The supplier shall establish, collect, review and deliver the declared materials, mechanical parts and processes lists in an electronic format

# The Requirements/2

## CLEANLINESS/CONTAMINATION CONTROL

- The supplier shall establish and maintain a contamination and cleanliness control programme including, as a minimum:
  - *Cleaning procedures,*
  - *Cleanliness-monitoring procedures or methods.*
  - *The risks of chemical or particle pollution generated by parts, materials or processes used shall be identified and reduced as specified in ECSS-M-ST-80, in conformance with mission requirements.*
  - *For cleanliness- or contamination-critical applications, a chemical and particle requirement specification and a specific cleanliness control plan shall be established*

# The Requirements/3

**MMPP Manager and MPCB**

- The supplier shall appoint a MMPP manager.
- The MMPP manager shall organize Materials, Mechanical Parts and Processes Control Board (MPCB) at all suppliers

**Minimum tasks of the MPCB shall be as follows:**

- Coordination of the initiation and approval of RFA's in conformance with DRD from the Annex D of ECSS-Q-ST-70C by involving the relevant technical discipline.
- Review and approval of test programme and related results.
- Review of preliminary Declared Materials, Mechanical Parts and Processes Lists and of any available evidence to support the approval, by the PDR.
- Review and approval of Declared Materials, Mechanical Parts and Processes Lists and of the evidence for the approval by the CDR.
- Review and approval of any change to the approved Declared Materials, Mechanical Parts and Processes Lists.

# The Requirements/4

**Supplier role and responsibilities**

– The supplier shall perform the following tasks:
  - *obtaining the correct and complete lists from lower level suppliers;*
  - *providing provisional and, later, definitive approval for each list;*
  - *submitting the project declared lists for approval prior to initiation of the hardware phase, before CDR*

- The lists shall include all the information described in this Standard.

- Amendments to the lists shall be implemented through established change procedures.

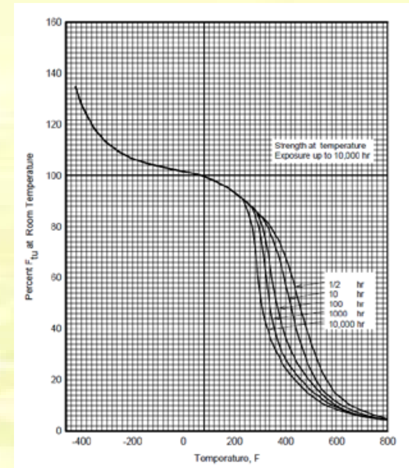
- The following documentation shall be delivered to the customer upon request:
  - *RFA*
  - *evaluation reports;*
  - *deviation requests.*

- The material, mechanical parts or process justification files shall be made available to the customer upon request either on the supplier site, or by any other process agreed by both parties.

# Mission constraints/1

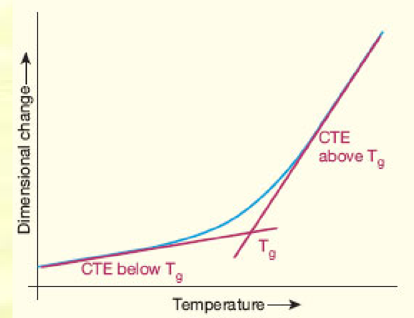
**Temperature**

The range of temperatures experienced will play a large part in the materials selection. Extremes are illustrated by the examples of cryogenic tanks and thermal protection systems for re-entry applications. **Temperatures below room temperature** generally cause an increase in strength properties, however the ductility decreases. Ductility and strength may increase or decrease at temperatures above room temperature. This change depends on many factors, such as temperature and time of exposure.




- Materials shall be compatible with the **thermal environment** to which they are exposed.

*Examples of thermal environment are also the passage through transition temperatures, e.g. phase transitions, ductile-brittle transition temperatures for metals, glass transition ($T_g$) for polymer materials, and environmental factors which affect these properties, such as moisture.*




**Hints, Tips & Techniques** [The Importance of $T_g$ in Polymers]

# Mission constraints/2


**Vacuum**

Vacuum compatibility is a major factor influencing the selection of materials for space applications. Many materials lose weight when exposed to reduced pressure. Both the extend of this loss and any corresponding changes in material properties depend on a number of factors.

- All organic materials for use in space systems shall be evaluated to determine their outgassing characteristics.
- Outgassing screening tests shall be carried out in conformance with requirements from clause 5 of ECSS-Q-ST-70-02.
- The need for retest outgassing characteristics of materials used for an extended period of time at a temperature higher than 50 °C should be mutually agreed with the customer.

**Note:** The screening process applied depends on the application, e.g inks

| Mass of material concerned, (grams) | CVCM | RML |
|---|---|---|
| >1000 | <0,01 | <1 |
| 100–1000 | <0,01 | <1 |
| 10–100 | <0,01 | <1 |
| 1–10 | <0,03 | <1 |
| <1 | <0,1 | <1 |

# Mission constraints/3

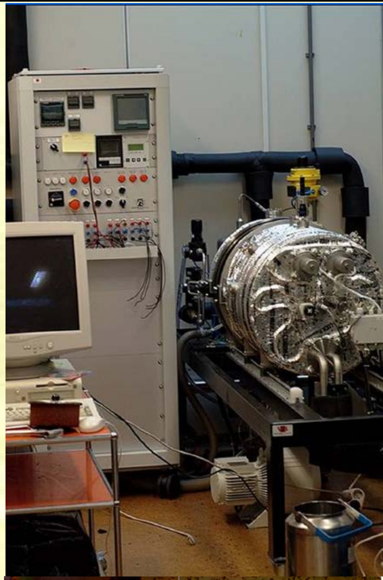
**Thermal cycling and Thermo optical**

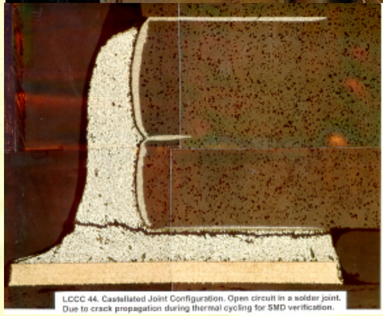
Thermal cycling can induce **thermal stresses** and due to the difference in coefficient of thermal expansion between fibres and matrix for composites and between base metal and coating micro-cracks can form which could jeopardise long-term properties.

- Materials subject to thermal cycling shall be assessed to ensure their capability to withstand the induced thermal stresses.

- Materials susceptible to thermal vacuum effect and materials of unknown characteristics in respect to thermal vacuum shall be tested in conformance with requirements from clause 5 of ECSS-Q-ST-70-04

- Materials subject to thermal cycling except the case specified above, shall be tested in conformance with a procedure approved by the customer.






**Hints, Tips & Techniques** materials or assemblies that can be evaluated by means of this test

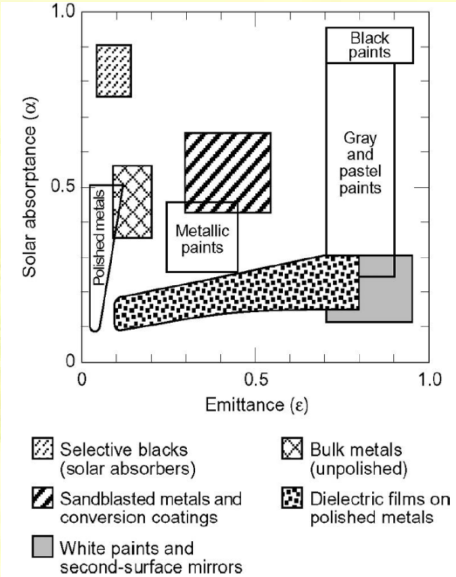
# Mission constraints/3

**Thermal cycling and Thermo optical**

The thermo-optical properties of materials are of importance to enable the calculation of the thermal housekeeping and radiative heat transfer.
In performing a heat design of a satellite one has to know how much solar energy its surface materials absorbs (normal solar absorptance) and how much heat it emits in the infrared region (hemispherical infrared emittance).

- Thermo optical properties shall be evaluated in conformance with requirement from [clause 4 of ECSS-Q-ST-70-09.]

- Directional effects due to manufacturing or processing shall be evaluated via dedicated testing to be agreed with the customer.



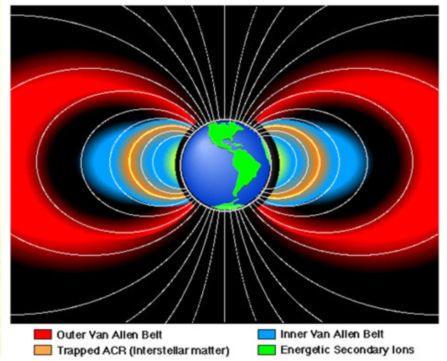

**Hints, Tips & Techniques**

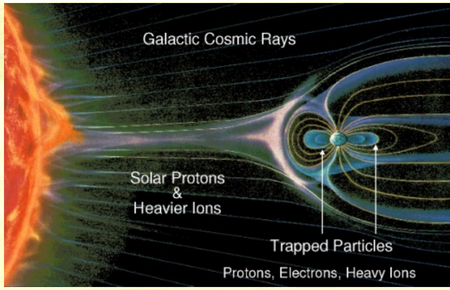
[Some optical values of materials]

# Mission constraints/4

## Radiation

The hazards of space radiation pose significant problems in a long duration space flight and they must be included in the design consideration. In particular, the radiation hardiness of the materials used in structure, shielding, and electronics equipments plays a large role in determining the useful lifetime of the satellite




- ❑ Materials exposed to radiation shall be assessed in conformance with requirements from clause 5 of ECSS-Q-ST-70-06 to determine their resistance to the radiation dosage expected during the mission.
- ❑ Evaluation of materials resistance to radiation shall include the combined effects of particle radiation and ultraviolet radiation in the normal space environment, along with any mission-specific radiation levels.

**Hints, Tips & Techniques**

- Implications for space travel
- Van Allen Belt effect
- Types of radiation
- High energy solar flux
- Charged particles

# Mission constraints/5

## Hydrogen embrittlement

Three forms of hydrogen damage can occur from metal processing: (1) Hydrogen that has been dissolved in the liquid metal subsequently forms $H_2$ gas pockets in the form of pores and cracks in the solid metal due to the buildup of internal pressure; (2) Hydride phases form inside the metal to embrittle it; (3) Previously absorbed hydrogen in the metal causes crack initiation and growth while the metal structure is under a sustained tensile load. This third form, called hydrogen-assisted cracking (HAC) or hydrogen embrittlement, has been responsible for numerous aerospace failures.

- The possibility of hydrogen embrittlement occurring during component manufacture or use shall be assessed.
- The material evaluation shall be performed including the assessment of a protection and control.
- Based on the assessment specified in the previous two requirements, protection and control measures shall be implemented to avoid hydrogen embrtittlement during both mechanical parts manufacturing or use.
- Mechanical parts subject to fatigue or sustained loading stresses, which are made of material susceptible to hydrogen embrittlement, shall be heat treated after coating.

**Hints, Tips & Techniques**

Hydrogen embrittlement

# Mission constraints/6

**Stress Corrosion**

The metallic components proposed for use in most spacecraft must be screened to prevent failures resulting from SCC.
Such metal-alloy selection must in particular be applied during the design phases.

- Materials used for structural and load-bearing applications (i.e. subject to tensile stress) shall selected in preference from Table 5.1 of ECSS-Q-ST-70-36, if not available in Table 5.1 from Table 5.2 or Table 5.3.
  - *Selecting an alloy from table 5.1 avoid the need to perform a stress corrosion evaluation.*
  - *Alloys and tempers listed in Table 5.2 shall only be considered for use when a suitable alloy cannot be found in Table 5.1.*
  - *Materials listed in Table 5.2 shall not be used for applications involving high installation stress and shall only be considered for use when a suitable alloy cannot be found in Table 5.1.*
  - *Alloys and tempers listed in Table 5.3 shall only be considered for use in applications where the probability of stress-corrosion is remote.*
- Any material not covered by cases specified in above standard shall be tested in conformance with requirements from clause 5 of ECSS-Q-ST-70-37.

**Hints, Tips & Techniques**

SCC Materials criteria

# Mission constraints/6: Stress Sources

| Stress type | Source |
|---|---|
| Assembly | • improper tolerances during fit-up (Figure D-3 and Figure E-1)<br>• overtorquing<br>• press fits<br>• high-interference fasteners<br>• welding |
| Residual[1] | • machining<br>• forming<br>• heat-treating |
| Transportation | |
| Storage | |
| Operational | |

1 Some typical residual-stress distributions through plate and rod are illustrated in Figure D-1 to provide an indication of the magnitudes of stress which can be developed as the result of conventional heat treating and forming operations.

# Mission constraints/6: Stress Corrosion Evaluation Form

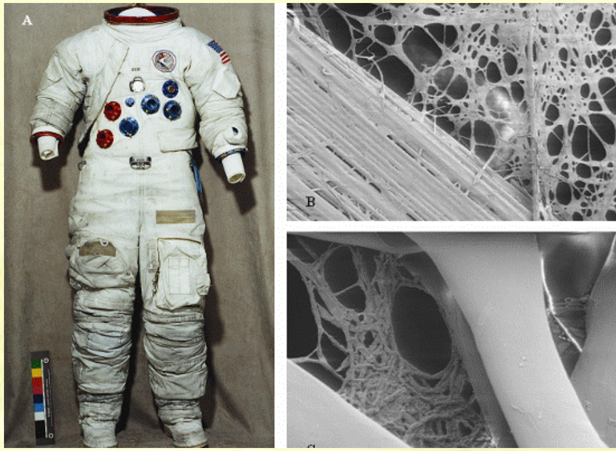
| |
|---|
| Originator (Name, Organization, Address): |
| Used on system/subsystem: |
| Project: |
| 1. Declared material list identification |
| 2. Use and location |
| 3. Number of identical parts |
| 4. Manufacturer |
| 5. Material |
| 6. Heat treatment |
| 7. Size and form |
| 8. Sustained tensile stresses - magnitude and direction: |
| a. Process residual |
| b. Assembly |
| c. Design, static |
| 9. Special processing |
| 10. Weldments: |
| a. Alloy form, temper of parent metal |
| b. Filler alloy (if none, indicate) |
| c. Welding process |
| d. Weld bead removed: Yes ( ) No ( ) |
| e. Post–weld thermal treatment |
| f. Post–weld stress relief |
| 11. Environment |
| 12. Protective finish |
| 13. Function of part |
| 14. Effect of failure |
| 15. Evaluation of stress–corrosion susceptibility |
| 16. Remarks |

# Mission constraints/7

## Bacterial and fungus growth

Some species of microorganisms, can rapidly accommodate on various materials (for example, polymers) and start proliferating. These bacteria and fungi colonise the infrastructure and equipment and play a particular role in adding to technical risks. These microorganisms, through their life activity, are able to cause biointerference in hardware functioning, degrade various structural materials including synthetic polymers, produce or provoke corrosion of metals. This may result in change in colour, deterioration of mechanic strength, dielectric and other properties. The problem of microbial colonization of materials is even more critical when regenerative life support systems are involved, e.g. the systems of water regeneration from air condensate. Existence of microorganisms in the space vehicle environment induces also serious medical risks.

- Materials selected for manned or fluid systems shall:
  - *not support bacterial or fungus growth,*
  - *be sterilizable.*



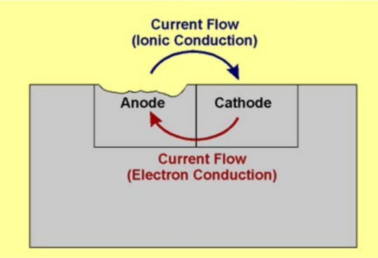
*Fungi belonging to the genera Paecilomyces and Cladosporium were cultured from two synthetic polymers contained within the suits from the Apollo lunar missions which took place between 1968 and 1972*

Hints, Tips & Techniques [Full requirements]

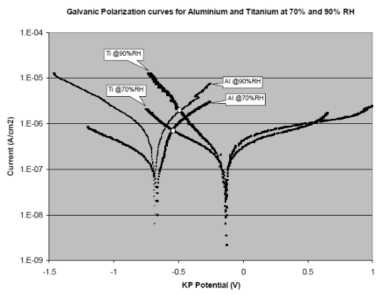
# Mission constraints/8

## Galvanic compatibility

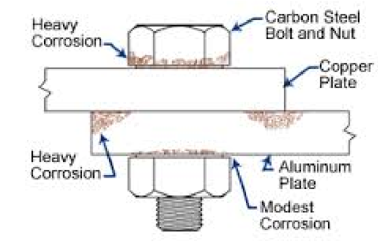
If two or more dissimilar materials are in direct electrical contact in a corrosive solution or atmosphere galvanic corrosion might occur. The less resistant material becomes the anode and the more resistant the cathode. The cathodic material corrodes very little or not at all, while the corrosion of the anodic material is greatly enhanced.




- Galvanic compatibilities shall be selected in conformance with Table 5-1. of ECSS-Q-ST-70C
- Materials not listed in Table 5-1 shall be evaluated in a flight-simulated configuration using an accelerated environment to be agreed by the customer.
- When bimetallic contacts are used, the choice of the pair of metallic materials used shall be agreed with the customer.




In the construction of a satellite, two metals that form a compatible couple may have to be placed in close proximity to one another. Although this may not cause anomalies or malfunctions in the space environment, it has to be borne in mind that spacecraft often have to be stored on earth for considerable periods of time and that during storage they may inadvertently be exposed to environments where galvanic corrosion can take place.



Effects of Galvanic Corrosion

**Hints, Tips & Techniques**

EMF table

Bimetallic corrosion in atmosphere

# Mission constraints/9

**Chemical (corrosion)**

The chemical environment to which a material is subjected in its life span may cause changes in the material properties. Corrosion is the reaction of the engineering material with its environment with a consequent deterioration in properties of the material. Corrosion will include the reaction of metals, glasses, ionic solids, polymeric solids and composites with environments that embrace liquid metal, gases, non-aqueous electrolytes and other non-aqueous solutions, coating systems and adhesion systems.

- For all materials that come into contact with atmospheric gases, cleaning fluids or other chemicals, it shall be demonstrated that the degradation of properties during their anticipated service-life does not prevent to meet the performance and integrity requirements.

- All mechanical parts, assemblies and equipment, including spares, shall be finished to provide protection from corrosion.

*NOTE* *This applies equally to fasteners and other fixing devices, such as insert systems*

# Mission constraints/10

**Moisture absorption/desorption**

- The properties of hydroscopic materials are susceptible to changes induced by the take-up of moisture. Moisture absorption occurs during production of components and launch of the spacecraft, desorption occurs in the space vacuum.

**Fluid compatibility**

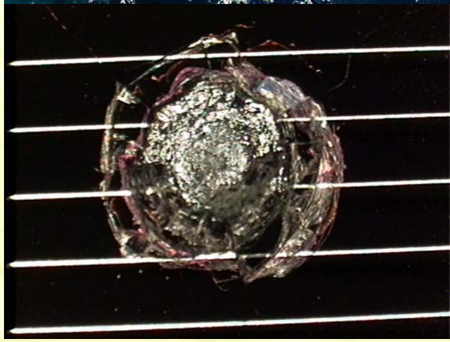
- In some occasions materials are in contact with liquid oxygen, gaseous oxygen or other reactive fluids or could come into contact with such a fluid during an emergency situation.

Hints, Tips & Techniques    ECSS Clause

**Micrometeoroids and debris**

- The effect of impacts by micrometeoroids and debris on materials shall be reviewed and assessed on a case by case basis.

Hints, Tips & Techniques    ECSS Clause



**Life**

- Materials shall be selected to ensure that they will meet the material performance requirements during all their specified lifetime

# Mission constraints/11

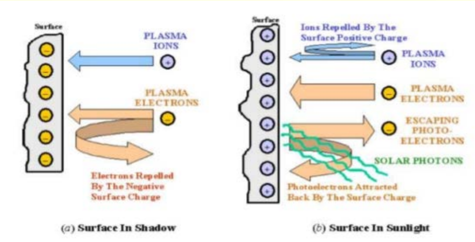
## Electrical charge and discharge

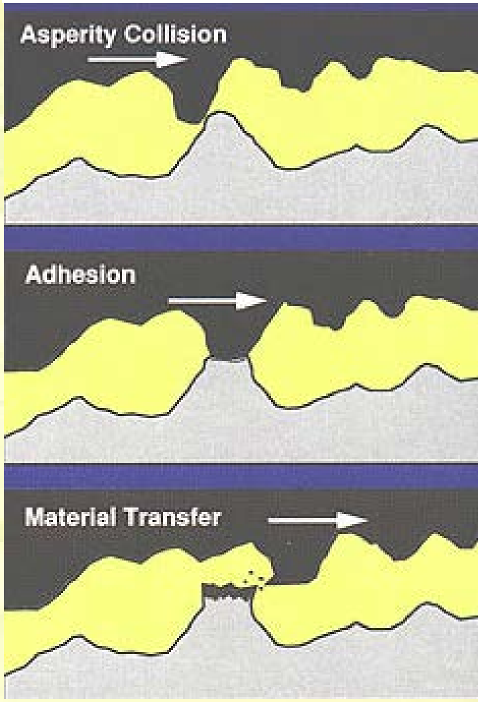
External surfaces of the spacecraft shall be sufficiently conductive, interconnected and grounded to the spacecraft structure to avoid the buildup of differential charges in conformance with requirements from clause 6 to clause 10 of ECSS-E-ST-20-06.

## Mechanical contact surface effects: (cold welding, fretting, wear)

For all solid surfaces in moving contact with other solid surfaces, it shall be demonstrated that the degradation of surface properties over the complete mission does not prevent to meet the performance requirements.

- For all solid surfaces, moving or in static contact with other solid surfaces, and intended to be separated it shall be demonstrated that the increase in separation force during the physical contact does not exceed the specified limit.




Hints, Tips & Techniques

definitions

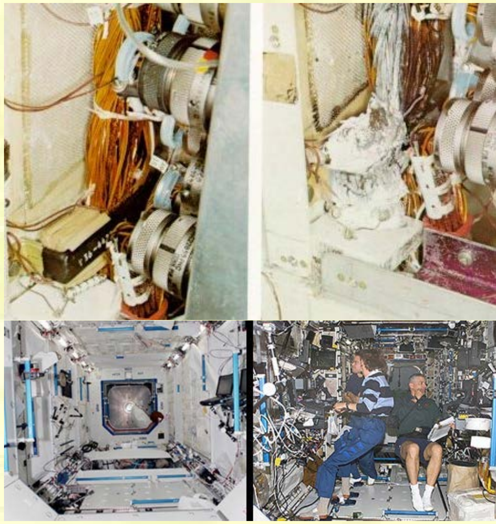
# Mission constraints/12

## Flammability

- The materials flammability resistance, shall be evaluated in conformance with requirements from the clause 5 of ECSS-Q-ST-70-21 for the most hazardous environment envisaged for their use, and be applicable to:
  - *unmanned spacecraft or space segment elements launched by a manned space transportation system when powered on launch, and*
  - *manned spacecraft and space segment elements.*

  ***Note** :Upward propagation according to NHB 8060-1B measured in 21% $O_2$, 23.8% $O_2$ and 24.5% $O_2$*

Apollo 1 Fire



## Offgassing and Toxic analysis

- For materials for the use in manned compartments of a spacecraft or space segment elements, offgassing and toxicity analysis shall be performed.
- Requirements from clause 4 of ECSS-Q-ST-70-29 shall apply for the characterization of offgassing products.

Toxicity classes according to NHB 8060.1A:
OK : CO<=25 and TO<=100 and OD<=26
Reject 1: CO<=25 and TO<=100 and OD > 26
Reject 2: CO < 25 and TO > 100 and OD > 26
Reject : CO> 25 and TO> 100

MACs in ppm
CO : Carbon Monoxide
TO : Total organic
OD : Odor

# Mission constraints/13

## Atomic Oxygen

- All materials for use on the external surfaces of spacecraft for use in Low Earth Orbit (LEO) altitudes, approximately between 200 km and 700 km, shall be evaluated for their resistance to atomic oxygen.
- Test procedures shall be subject to the approval by the customer.
- The effect of ATOX on thermo optical properties including specularity shall be evaluated

**Note**: *The flux level varies with altitude, velocity vector and solar activity. Fluence levels vary with the duration of exposure.*

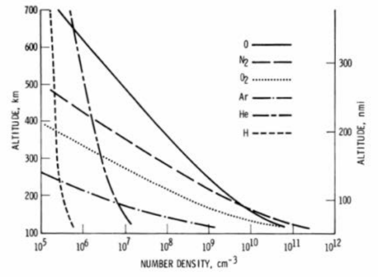
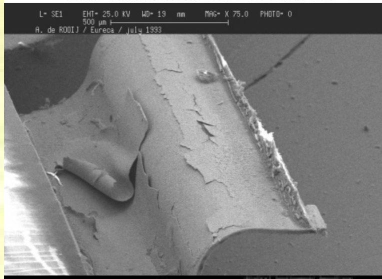
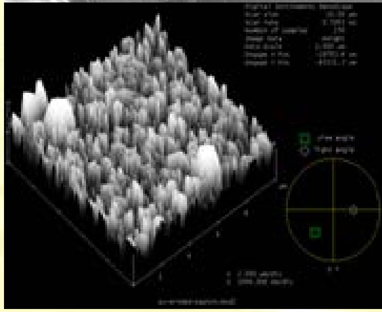


*Figure 1: Atmospheric composition in Low Earth Orbit*





**Hints, Tips & Techniques**

Corrosion in Space

Polymers Erosion Yield Data

# Material/Mechanical Part Engineering/1

## Declared Material List (DML) / Declared Mechanical Parts Lists (DMPL)

- The supplier shall establish and maintain a DML and DMPL of all items used in the system.

  Note: *The Project may decide not to require a separate DMPL. In this case the items are added to the DML;*

- The format and content of the DML/DMPL is given in ECSS-Q-ST-70C. This can be modified by a Project (subject to approval) if the specific requirements of the Project make this necessary.

**DECLARED MATERIALS LIST (DML)**

Programme name: ABCDEFG | CI no.: 12345676890 | Group (Title): abcdefg | Doc no.: 001 | Issue/Revision: 1/4 | Date: 01.10.2000 | Page: 1

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | | | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 9.1 | 9.2 | 9.3 | |
| Item no. and user code | Commercial identification or standardized designation | 1) Chemical nature<br>2) Product type | 1) Manufacturer/ supplier name<br>2) Procurement spec.<br>Issue/RevDate | Summary of process parameters | 1) Subsystem<br>2) Equipment<br>3) Use | 1) R<br>2) A<br>3) T | 1) A<br>2) V<br>3) M | Acronym/ rating/ Validation Ref. for applicable properties | 1) Justification for approval<br>2) Prime comments | Prime approval status | Customer approval status/ comments |
| 1.2.1.TXES | AZ5GU | 1) Al.Zn5.6 Mg2.5 Cdu1.6, Cr0.3 eq. AA7075<br>2) Plate | 1) Almet Pechiney<br>2) CBB 527<br>01/02/01.02.1996 | T7351 and Iridit 14 heat treatment | 1) PL<br>2) E4 package<br>3) Structure | 1) LS<br>2) V<br>3) 3 | 1)<br>2)<br>3) M3 | | 1) Used on ETS2<br>2) | A | Give evidence of ETS2 specific usage A |
| 10.1.1.ETCA | DC93500 | 1) Silicon<br>2) Two parts | 1) Dow Corning<br>2) E3846MC105<br>02/02/1984 | Mixture: 10/1 in g<br>Curing: 4h/65 °C | 1) PCU<br>2) Experiment tray<br>3) Part potting | 1) G<br>2) V<br>3) 3-4 | 1)<br>2)<br>3) M3 | | 1) ECSS-Q-ST-70-01<br>2) | A | A |
| 11.5.1.KOF | ECCOFOAM EPH | 1) Polyurethane<br>2) Resin/Catalyst 1202H | 1) Emerson and Cuming<br>2) SP/FOK/05/684<br>03/01/25.06.1992 | Resin/ Cat: 100/65g 4h/40 °C +48h/100 °C | 1) GP<br>2) Platform<br>3) Package potting | 1) LS<br>2) M<br>3) 3-4 | 1)<br>2) V3<br>3) | | 1) DU-96-352<br>2) Used at T > 100 °C (Risk of distortion beyond) | A | A |

**DECLARED MECHANICAL PARTS LIST (DMPL)**

Programme name: ABCDEFG | CI no.: 12345676890 | Group (Title): abcdefg | Doc no.: 001 | Issue/Revision: 1/4 | Date: 01.10.2000 | Page: 1

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 9.1 | 9.2 | |
| Item no. and user code | Commercial identification | Type of part | 1) Procurement specification<br>2) Issue/Revision/ Date | 1) Elementary function<br>2) Main characteristics | 1) Subsystem<br>2) Equipment<br>3) Use | 1) R<br>2) A<br>3) T | 1) Criticality<br>2) Reason and method of control | 1) Supplier Reference<br>2) prime comments | Prime approval status | Customer approval status/comments |
| 51.2.1.ACSA | ESA003521000 120 | Copper/AL bimetal ring | 1) AIEV<br>2) From catalogue | 1) Separator ring<br>2) Heat conductor | 1) TC<br>2) Plate interface<br>3) Spacing and heat inspection | 1) G<br>2) V<br>3) 3-4 | 1) N<br>2) | 1) Used on all projects<br>2) | A | A |
| 52.2.1.ASAD | A0090TX...XA | Ti6Al4V screws > M4 | 1) White areo<br>2) ASNA0090 DSN2413 | 1) assembly<br>2) | 1) PTANK<br>2) plate<br>3) fixing | 1) G<br>2) V<br>3) 3-4 | 1) N<br>2) | 1) Used on TC2<br>2) | A | A |
| 60.1.1.ACSA | 42908TC/F | Ferrite cores magnetic | 1) Magnetics, Data sheet<br>2) SP/MAGN/003<br>01.02/03.06.1999 | 1) Coil core of transformer<br>2) Magnetic component | 1) TC<br>2) South face<br>3) Heat regulation | 1) G<br>2) V<br>3) 3-4 | 1) C<br>2) to be qualified | 1)<br>2) | | |

# Material/Mechanical Part Engineering/2

## Specifications / Standards

- Each type of material/mechanical part used by the Contractor and listed in the DML/DMPL shall be covered by a specification or standard.

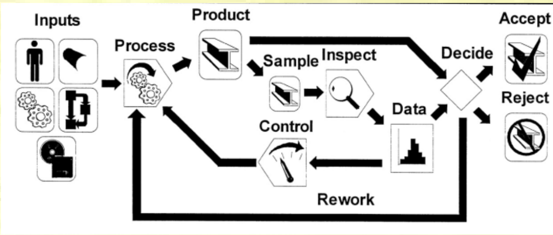
## Non-Conformances

- Non-conforming materials/mechanical parts found during incoming inspections, assembly or test shall be dispositioned in accordance with ECSS-Q-ST-20C.

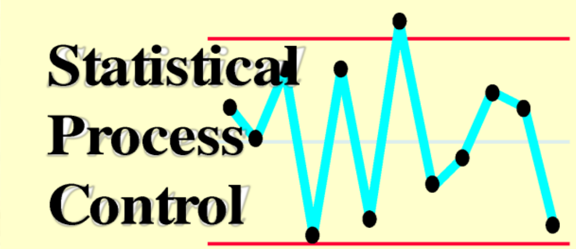
# Process Engineering/1

## Selection

- Processes shall be chosen from already verified processes according to the following order of preference and priority:
  - *processes covered by space agencies or other governmental organization certification for identical conditions of use;*
  - *processes for which satisfactory evaluation and verification results are obtained on samples representative of the application with a sufficient margin as regards conditions of use;*
  - *processes already used by the same supplier for other space programmes in the same conditions of use.*




- Whether the processes are already verified or remain to be verified, their selection shall take into account the following criteria:
  - *reliability;*
  - *inspectability;*
  - *reworkability of the process item;*
  - *reproducibility.*




NOTE *Best practice is to implement a statistical process control*

# Process Engineering/2

## Critical Processes

- The supplier shall analyse all the processes contained in their preliminary lists with respect to criticality and in correlation with the risk analyses performed.
- Critical processes shall be identified in the DPL and included in the list of critical items.
- Any critical process shall be the subject of an RFA submitted to customer approval.
- For each critical process, the supplier shall implement a verification programme.

## Declared Process List (DPL)

- The supplier shall establish and maintain a declared processes list.
- The format and content of such a DPL is given in ECSS-Q-ST-70C.
    - *Processes refer back to materials in the DML*

**DECLARED PROCESS LIST (DPL)**

Programme name: ABCDEFG | CI no.: 1234567890 | Doc no.: 001 | Date: 14.05.2000
Group (Title): abcdefg | Issue/Revision: 1/5 | Page: 1

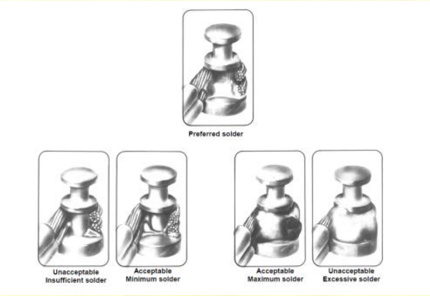
| 1 | 2 | 3 | 4 | 5 | 7 | 8 | 9 – 9.1 | 9 – 9.2 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Item no. and user code | Process identification | 1) User name 2) Associated procedure issue/revision/ date | Process description | 1) Subsystem code 2) Equipment code 3) Use | Associated DML or DMPL item number | 1) Criticality 2) Reason for criticality | 1) Supplier Reference 2) Prime comments | Prime approval status | Customer approval status/ comments |
| 1.2.1.SSEX | Bonding | 1) EREMS 2) E/SQ/PI/012 02/01/02.08.1984 | Applying a spot of glue with a stainless steel dispenser | 1) BE3 2) C5 board 3) To fix parts | 6.1.2.ETC | 1) N 2) | 1) Used on ANTARES 2) | A | ~~A~~Give evidence of ANTARES specific usage |
| 4.3.1.KOF | Coating | 1) CERCO 2) E/SQ/PI/023 02/01/08.12.1985 | Coating by paintbrush or by immersion in the resin | 1) BE3 2) C1 C2 boards 3) Protection of CI and EEE parts | 2.1.1.KOF | 1) N 2) | 1) Used on PASTEC, ANTARES 2) | A | Give evidence of PASTEC~~A~~ ANTARES specific usage |
| 8.3.1.KOF | Vapour phase soldering of SMDs | 1) EREMS 2) E/SQ/PI/026 01/02/09.09.1997 | ECSS-Q-ST-70-38 | 1) BE3 2) C3 3) | 15.1.1.AST | 1) C 2) | 1) QM/04L123/ BD/MH Table 1 2) | A | A |

# Process Engineering/3

## Process Specifications or procedures

- Each process to be used in the manufacturing or assembly of a product shall be identified by a specification or procedure.
- Reference shall be made to accept and reject criteria.

## Workmanship Standards




- Before implementation of a process, the supplier shall ensure that personnel are trained and that environment, means and documentation are adequate.
- And that manufacturing and quality control tools associated with the process are adequate, calibrated and properly maintained
- And that the processes specifications, manufacturing and inspection procedures and workmanship standards including clear definition of manufacturing operations and clear acceptance criteria exist.

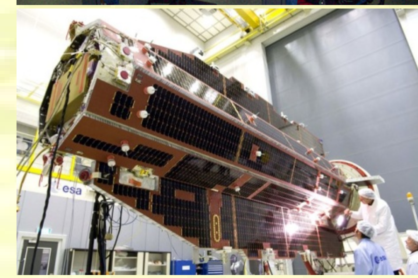
# Process Engineering/4

## Non Conformances and Alerts

- Non conformances and alerts shall be processed in conformance with requirements from clause 5 to clause 6 of ECSS-Q-ST-10-09 and clause 5.2.9 of ECSS-Q-ST-10.

## Training

- Operators shall be trained for all processes.
- Operators performing special processes shall be certified in conformance with the requirements of the relevant standard
- Inspectors shall be trained and certified for all processes.
- Certification shall be reassessed at least every two years.



# Management of the lists

- The supplier shall process the lists of lower level suppliers to ensure exchangeabililty, traceability searchability, sortability, storability and retrievability for that set of lists, before submitting it to the customer
- The supplier shall establish, collect, review and deliver the declared materials, mechanical parts and processes lists in an electronic format in conformance with Annex A, Annex B, and Annex C of ECSS-Q-ST-70C
- Any change after CDR or QR shall be reflected in the list and shall be in accordance with ECSS-Q-ST-70C
- Lists shall be updated during the course of the project.
- The supplier shall demonstrate that the lists specified in ECSS-Q-ST-70C have been formally approved prior to their delivery to the customer.

# MMPP documents delivery w.r.t. milestones

Hints, Tips & Techniques

Definition of mission phases

| Document Title | Phase | | | | | | | | | | | | DRD Ref. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | A | B | | C | D | | E | | | | | |
| | MDR | PRR | SRR | PDR | CDR | QR | AR | ORR | FRR | LRR | CRR | ELR | |
| Declared materials list (DML) | | | | + | + | + | + | | | | | | ECSS-Q-ST-70, Annex A |
| Declared mechanical parts list (DMPL) | | | | + | + | + | + | | | | | | ECSS-Q-ST-70, Annex B |
| Declared process list (DPL) | | | | + | + | + | + | | | | | | ECSS-Q-ST-70, Annex C |
| Request for approval (RFA) | | | | + | + | + | + | | | | | | ECSS-Q-ST-70, Annex D |
| Cleanliness Requirement Specifications (CRS) | | | + | + | + | + | + | | | | | | ECSS-Q-ST-70-01, Annex A |
| Cleanliness and contamination control plan (C&CCP) | | | | + | + | + | + | | | | | | ECSS-Q-ST-70-01, Annex B |

# Example of DML

## DECLARED MATERIALS LIST (DML)

Programme name: ABCDEFG | CI no.: 12345676890 | Doc no.: 001 | Date: 01.10.2000

Group (Title): abcdefg | Issue/Revision: 1/4 | Page: 1

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | | | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 9.1 | 9.2 | 9.3 | |
| Item no. and user code | Commercial identification or standardized designation | 1) Chemical nature<br>2) Product type | 1) Manufacturer/ supplier name<br>2) Procurement spec.<br>Issue/RevDate | Summary of process parameters | 1) Subsystem<br>2) Equipment<br>3) Use | 1) R<br>2) A<br>3) T | 1) A<br>2) V<br>3) M | Acronym/ rating/ Validation Ref. for applicable properties | 1) Justification for approval<br>2) Prime comments | Prime approval status | Customer approval status/ comments |
| 1.2.1.TXES | AZ5GU | 1) Al.Zn5.6 Mg2.5 Cdu1.6, Cr0.3 eq. AA7075<br>2) Plate | 1) Almet Pechiney<br>2) CRB 527<br>01/02/01.02.1996 | T7351 and Iridit 14 heat treatment | 1) PL<br>2) E4 package<br>3) Structure | 1) LS<br>2) V<br>3) 3 | 1)<br>2)<br>3) M3 | | 1) Used on ETS2<br>2) | A | A |
| 10.1.1.ETCA | DC93500 | 1) Silicon<br>2) Two parts | 1) Dow Corning<br>2) E3846MC105<br>02/02/1984 | Mixture: 10/1 in g<br>Curing: 4h/65 °C | 1) PCU<br>2) Experiment tray<br>3) Part potting | 1) G<br>2) V<br>3) 3-4 | 1)<br>2)<br>3) M3 | | 1) ECSS-Q-ST-70-01<br>2) | A | A |
| 11.5.1.KOF | ECCOFOAM EPH | 1) Polyurethane<br>2) Resin/Catalyst 1202H | 1) Emerson and Cuming<br>2) SP/FOK/05/684<br>03/01/25.06.1992 | Resin/ Cat: 100/65g<br>4h/40 °C<br>+48h/100 °C | 1) GP<br>2) Platform<br>3) Package potting | 1) LS<br>2) M<br>3) 3-4 | 1)<br>2) V3<br>3) | | 1) DU–96–352<br>2) Used at T > 100 °C (Risk of distortion beyond) | A | A |

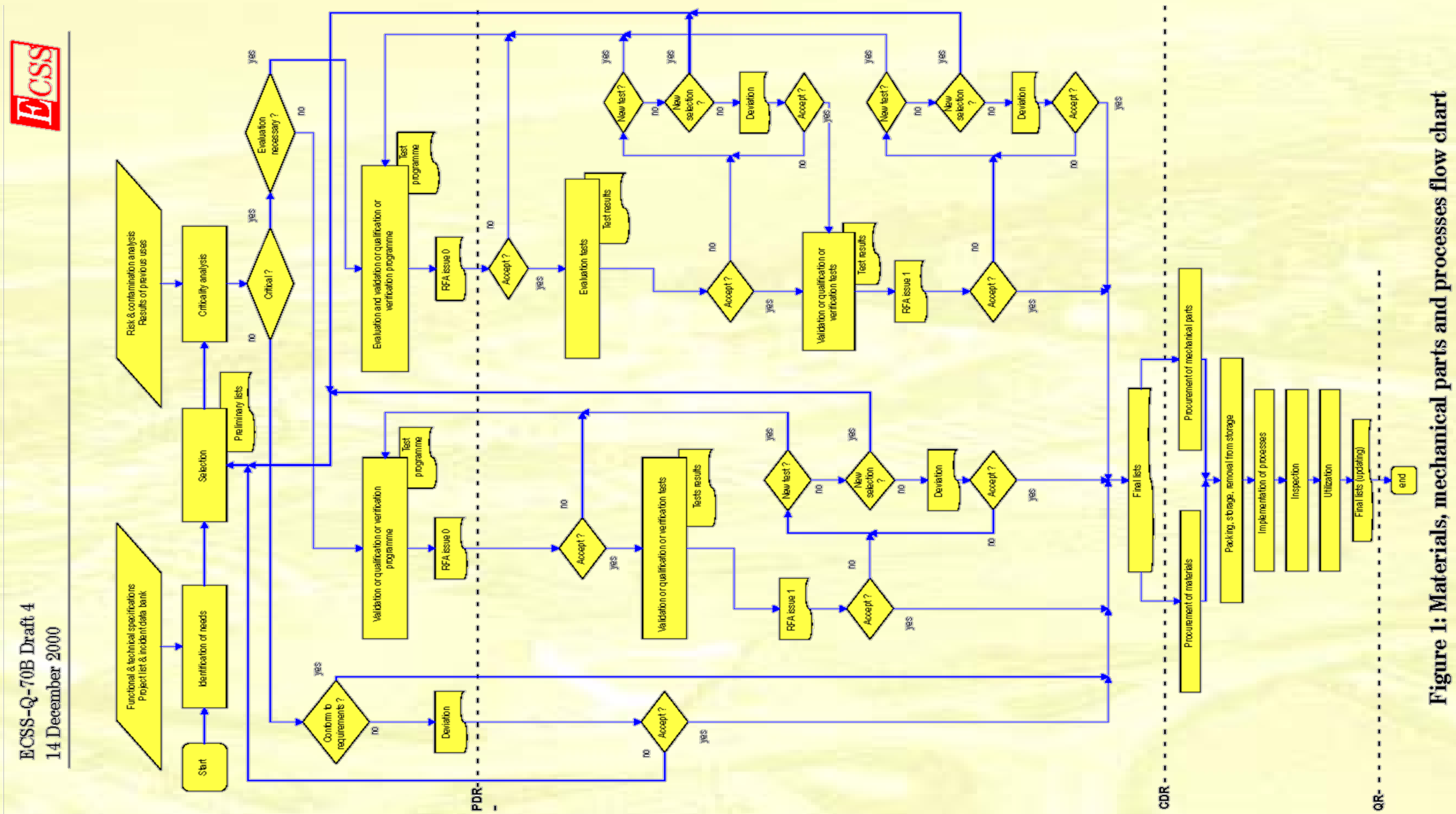
# Example of DPL

| DECLARED PROCESS LIST (DPL) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Programme name: ABCDEFG | | CI no.: 1234567890<br>Group (Title): abcdefg | | Doc no.: 001<br>Issue/Revision: 1/5 | | | Date: 14.05.2000<br>Page: 1 | | |
| | | | | | | | 9 | | |
| 1 | 2 | 3 | 4 | 5 | 7 | 8 | 9.1 | 9.2 | 10 |
| Item no. and user code | Process identification | 1) User name<br>2) Associated procedure issue/revision/ date | Process description | 1) Subsystem code<br>2) Equipment code<br>3) Use | Associated DML or DMPL item number | 1) Criticality<br>2) Reason for criticality | 1) Supplier Reference<br>2) Prime comments | Prime approval status | Customer approval status/ comments |
| 1.2.1.SSEX | Bonding | 1) EREMS<br>2) E/SQ/PI/012<br>02/01/02.08.1984 | Applying a spot of glue with a stainless steel dispenser | 1) BE3<br>2) C5 board<br>3) To fix parts | 6.1.2.ETC | 1) N<br>2) | 1) Used on ANTARES<br>2) | A | A |
| 4.3.1.KOF | Coating | 1) CERCO<br>2) E/SQ/PI/023<br>02/01/08.12.1985 | Coating by paintbrush or by immersion in the resin | 1) BE3<br>2) C1 C2 boards<br>3) Protection of CI and EEE parts | 2.1.1.KOF | 1) N<br>2) | 1) Used on PASTEC, ANTARES<br>2) | A | A |
| 8.3.1.KOF | Vapour phase soldering of SMDs | 1) EREMS<br>2) E/SQ/PI/026<br>01/02/09.09.1997 | ECSS-Q-ST-70-38 | 1) BE3<br>2) C3<br>3) | 15.1.1.AST | 1) C<br>2) | 1) QM/04L123/ BD/MH Table 1<br>2) | A | A |

# Example of DMPL

| DECLARED MECHANICAL PARTS LIST (DMPL) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Programme name: ABCDEFG | | | | CI no.: 12345676890<br>Group (Title): abcdefg | | Doc no.: 001<br>Issue/Revision: 1/4 | | | Date: 01.10.2000<br>Page: 1 | |
| | | | | | | | | 9 | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9.1 | 9.2 | 10 |
| Item no. and user code | Commercial identification | Type of part | 1) Procurement specification<br>2) Issue/Revision/ Date | 1) Elementary function<br>2) Main characteristics | 1) Subsystem<br>2) Equipment<br>3) Use | 1) R<br>2) A<br>3) T | 1) Criticality<br>2) Reason and method of control | 1) Supplier Reference<br>2) prime comments | Prime approval status | Customer approval status/comments |
| 51.2.1.ACSA | ESA003521000 120 | Copper/AL bimetal ring | 1) AIEV<br>2) From catalogue | 1) Separator ring<br>2) Heat conductor | 1) TC<br>2) Plate interface<br>3) Spacing and heat inspection | 1) G<br>2) V<br>3) 3-4 | 1) N<br>2) | 1) Used on all projects<br>2) | A | A |
| 52.2.1.ASAD | A0090TX...XA | Ti6Al4V screws > M4 | 1) White areo<br>2) ASNA0090 DSN2413 | 1) assembly<br>2) | 1) PTANK<br>2) plate<br>3) fixing | 1) G<br>2) V<br>3) 3-4 | 1) N<br>2) | 1) Used on TC2<br>2) | A | A |
| 60.1.1.ACSA | 42908TC/F | Ferrite cores magnetic | 1) Magnetics, Data sheet<br>2) SP/MAGN/003 01.02/03.06.1999 | 1) Coil core of transformer<br>2) Magnetic component | 1) TC<br>2) South face<br>3) Heat regulation | 1) G<br>2) V<br>3) 3-4 | 1) C<br>2) to be qualified | 1)<br>2) | | |

# PMP Flow chart



# RFA

The objective of an RFA is to enable the supplier to request from the customer permission to use a critical mechanical part, material or process.

| | | | | |
|---|---|---|---|---|
| 1 | Company: | Project: | Reference: RFA- | Page 1 of 2 |
| | | | Issue | |
| | | | Revision | |
| | | | Date | |

**Request for approval (RFA)**

| | |
|---|---|
| 2 Originator: | 3 Subsystem: |
| Originator reference: | Equipment: |
| 4 Item description: | 5 PMP list item number: |
| | PMP list reference: |
| **6 Item status** | |
| Manufacturer: | Manufacturer qualification reference: |
| Supplier: | Qualification status: |
| Product/material specification: | Procurement specification: |
| Process/handling specification: | Related specification: |
| Verification/qualification specification: | Report: |
| **7 Reason for RFA** | |
| 8 Application/location details: | CIL Reference: |
| **9 Evaluation/validation programme (title, reference)** | |
| **Tests** | |
| **Plan, procedures, schedule to be attached** | |

| | | | | |
|---|---|---|---|---|
| 1 | Company: | Project: | Reference: RFA- | Page 2 of 2 |
| | | | Issue | |
| | | | Revision | |
| | | | Date | |

**Request for approval (RFA)**

| | | Materials and processes responsible | PA responsible | Project responsible |
|---|---|---|---|---|
| 10 | Supplier approval on RFA first issue | | | |
| 11 | Decision on RFA first issue:<br>- Request refused:<br>- Submit deviation:<br>- Proceed with validation programme: | Comments: | | |
| 12 | **Decision** | Materials and processes responsible | PA responsible | Project responsible |
| | Customer agree/disagree | | | |
| | Final customer (if applicable) agree/disagree | | | |
| 13 | **Justification results**<br>Validation report (title and reference)<br>Conclusion:<br>**Validation report to be attached** | | | |
| 14 | Supplier approval on RFA final issue | Materials and processes responsible | PA responsible | Project responsible |
| | | | | |
| 15 | Decision on RFA final issue | Materials and processes responsible | PA responsible | Project responsible |
| | Customer agree/disagree | | | |
| | Higher level customers (as necessary) agree/disagree | | | |

# Part 2 - Materials

# Properties and requirements to be considered for material selection

**Properties that shall be considered in material selection include, but are not limited to:**

- mechanical properties,
- fracture toughness,
- flammability and offgassing characteristics,
- corrosion and stress corrosion,
- thermal and mechanical fatigue properties,
- glasstransition temperature,
- coefficient of thermal expansion mismatch,
- vacuum outgassing,
- fluids compatibility,
- microbial resistance, moisture resistance,
- fretting, galling,
- susceptibility to electrostatic discharge
- contamination.

**The operational requirements shall include, but shall not be limited to:**

- operational temperature limits,
- loads,
- contamination,
- life expectancy,
- moisture or other fluid media exposure,
- vehicle-related induced and natural space environments.

# Material Selection (general)

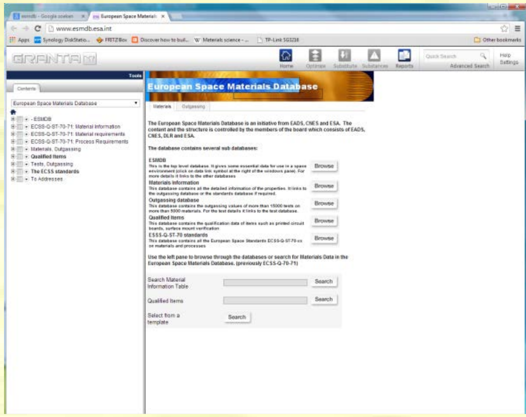
**Selection**

- The supplier shall be responsible for the selection of materials that are capable of meeting the requirements of his business agreement .

**Materials shall be chosen as follows:**

- if an identical application in other space programmes similar with respect to environment constraints and lifetime to the proposed application exist, use materials used in such an application;
- if materials exist for which satisfactory evaluation results are obtained on samples representative of the application with margin above the specified ones as regards conditions of use, use such materials;;
- use materials included in approved data sources.

  ***Note***: *For example: ESMDB (see Annex A of ECSS-Q-ST-70-71)*
  *ESA and NASA data banks..*




**Selection of other (new or non-validated) Materials**

- Each critical material shall be validated for the specific application

# Material Selection

**Main Drivers**

- Properties Requirements
  - *functional e.g. mechanical, thermal, structural…*
  - *environmental e.g. ATOX, corrosion, radiation resistance*
- lightweight, high stiffness and strength
- reliability, cost

**Secondary Drivers**

- manufacturing complexity
- product availability
- ease of integration
- safety

# Metallic Materials used in space

**Light metals**

- Beryllium
- Magnesium
- Aluminium
- Titanium and their alloys

**Steels**

- low-alloy
- tool steels
- corrosion resistant
- precipitation hardeble
- maraging

**Nickel and nickel base alloys**

- pure nickel
- Monel alloys
- Inconel alloys
- other nickel- and cobald-base superalloys

**Refractory metals**

- Niobium
- Molybdenum

**Copper-base alloys**

- pure coppers
- beryllium coppers
- Bronzes
- Brasses

**Precious metals**

**Welding, brazing and soldering alloys**

**Various plating alloys**

# Polymer Materials used in space/1

**Structural**

- ❑ polyacetal (DELRIN®), PEEK
- ❑ fibre reinforced
  - *GFRP, CFRP*

**Films**

- ❑ thin films such as polyimide, polyethylterephtalate…
- ❑ fluorinated polymers
  - *PTFE, FEP…*

**Fibres/Cloths/Tissues**

- ❑ polyethylene, polyaramid

**Acoustic, Vibration Absorbers**

- ❑ Foams
  - *polyurethane, polyimide, PEEK…*

# Polymer Materials used in space/2

## Paints

- Binder

  *organic .......... siloxanes, polyurethanes, polyvinylfluoride…*

  *inorganic ........silicates…*

## Pigment

- metal oxides, graphite…

## Electrical

- insulation ........................ PI, PTFE, FEP,ETFE…
- connectors ...................... PET, Siloxanes…
- PCB ..................................flexible: PI, rigid: FRP
- shrink sleeves .................fluoropolymers, polyolefines…
- conformal coatings .........polyxylene, polyurethane, siloxanes…

## Potting materials

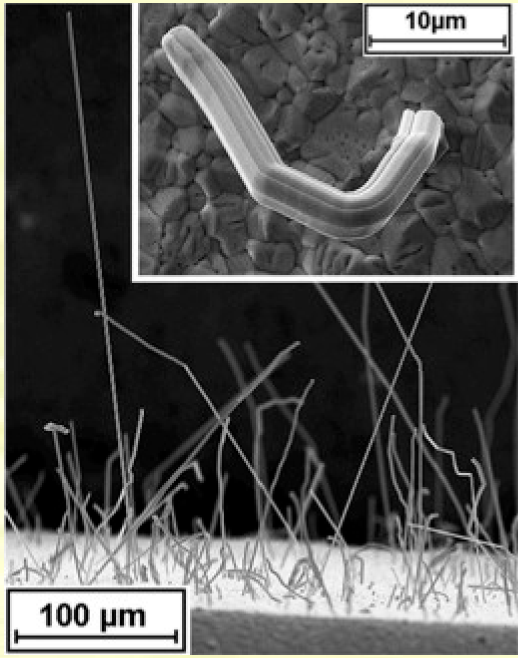
- polyurethanes, siloxanes…

# Constraints/1

- Pure tin finish with more than 97 % purity shall not be used.

  NOTE *This is due to the possibility of whisker growth and transformation to grey tin powder at low temperatures.*

  Hints, Tips & Techniques Problems with Pure Tin Coatings




- Cadmium and zinc shall not be used as raw material or surface treatment for flight hardware.

- Cadmium and Zinc shall not be used for ground support equipment exposed to vacuum or when in contact with the flight hardware.

  *NOTE For example during thermal vacuum testing phases on ground.*

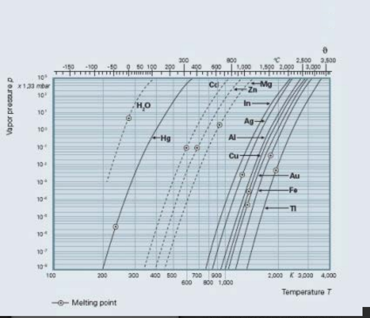
# Constraints/2

- The incoming inspection of each non-EEE component batch shall include the verification of the metallic surface treatment to avoid assembly of
  - *pure tin*
  - *Cadmium finish*
  - *zinc finish.*

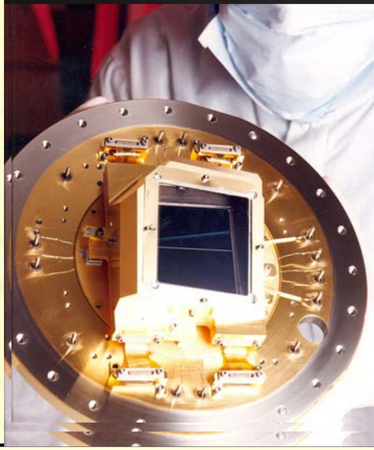
- The materials presented in the following, not exhaustive list, shall not be used:
  - *Beryllium oxide*
  - *Mercury and its compounds*
  - *Polyvinyl chloride (PVC)*
  - *Radioactive material*

- Beryllium shall not be used for structures.

- Beryllium shall not be used in applications other than structures, unless:
  - approved by the customer , and
  - all safety requirements are implemented by the supplier.







# Aluminium and its alloys/1

Aluminium alloys are some of the basic building materials of existing spacecraft and appear in many subsystems.

**Light alloys based on aluminium are used in:**

primary and secondary structures;

- plumbing;
- plating in many applications (electronics, thermal control, corrosion protection etc); aluminised layers on other materials (see 'adhesive tapes' and 'plastic films');
- fillers in other materials to provide electrical or thermal conductivity.

**In addition to standard alloys, more recent alloy developments include:**

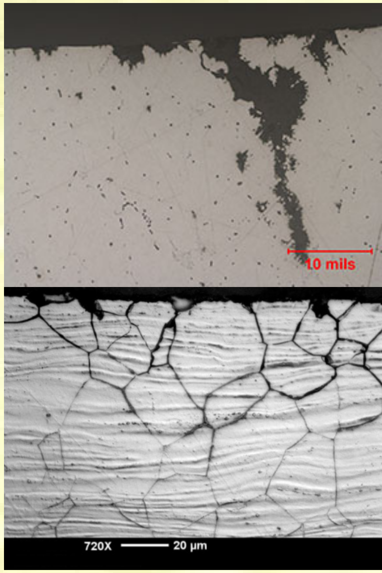
additions of lithium to increase mechanical performance and decrease density. Li-additions are often lower than other 'conventional' alloying elements, so Al-Li alloys may appear within different alloy groups (2000-, 7000- and 8000-series wrought products).

- reinforced alloys (metal matrix composites - MMC) consisting of aluminium alloys reinforced with whiskers, metal wires, boron fibres or carbon fibres.
- thin Al-alloy sheets with layers of fibre-reinforced polymer composite in between (Fibre Metal Laminates - FML).

# Aluminium and its alloys/2

## Main categories

A large number of commercial, wrought and cast, alloys are available. A similarly large number of mechanical and thermal tempers are used to optimise certain properties, often at the expense of others (e.g. higher strength, but poorer corrosion resistance). Not all of these alloys or tempers are suitable for aerospace engineering, from the point of view of either mechanical performance or environmental resistance.




Many aluminium alloys exhibit excellent corrosion resistance in all standard tempers. However, the higher-strength alloys, which are of primary interest in aerospace applications, must be approached cautiously.

In structural applications preference should be given to alloys, heat treatments and coatings which minimise

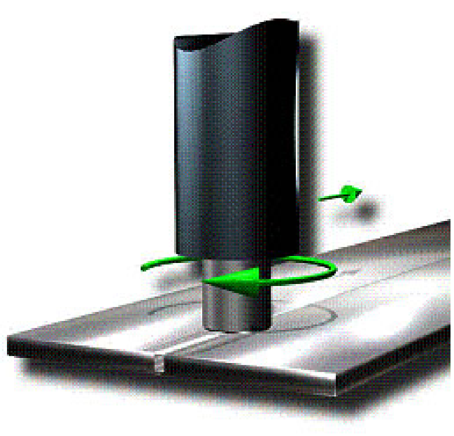
- susceptibility to general corrosion
- Pitting
- Intergranular corrosion
- stress-corrosion cracking.

Some alloys are clad with thin layers of pure aluminium to improve corrosion performance.

# Aluminium and its alloys/3

## Processing/Assembly

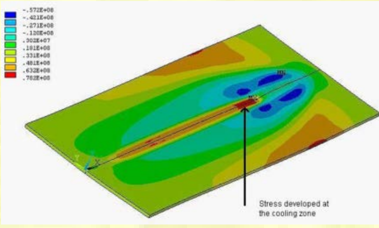
- All classical methods find a use: shaping and forming processes (wrought products produced by rolling, extrusion, forging; cast products); joining by welding, brazing, riveting, bolting, adhesive bonding etc.
- Not all alloys are weldable . Most high-strength alloys cannot be brazed.
- Space use does not raise special problems in this respect; except that processes must be extremely reliable. Aircraft industry standards are normally followed.
- Processing of metals gives rise to residual stresses that may cumulatively reach design-stress levels, particularly as regards fatigue phenomena.

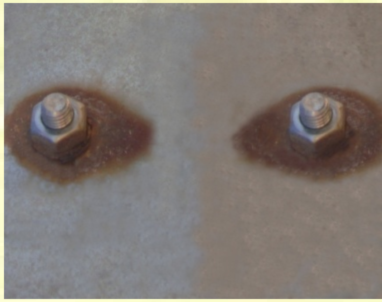


# Aluminium and its alloys/4

## Precautions

The properties of aluminium alloys are strongly dependent on their previous thermal and/or mechanical history.



- Residual stresses from processing (forming and heat-treatments), machining, assembly (improper tolerances during fit-up, over-torqueing, press-fits, high-interference fasteners and welding), operational use, storage and transportation need evaluation

- Corrosion must be considered during the whole manufacture and prelaunch phase; electrolytic couples should be avoided and all metals should be suitably protected against external damage by the use of plating, conversion coatings, paints and strippable coatings.

- This is particularly important in special operating environments (fuel tanks for example).

# Aluminium and its alloys/5

## Stress Corrosion

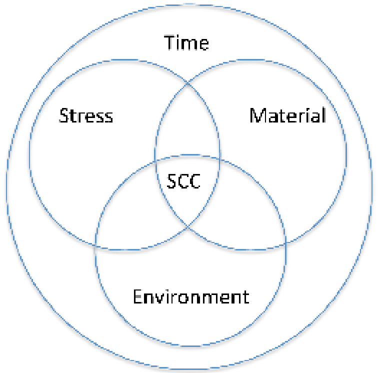
- Stress corrosion cracking (SCC), defined as the combined action of sustained tensile stress and corrosion, can cause premature failure of aluminium alloys.

- Because metallurgical processing of aluminium alloys usually results in a pronounced elongation of grains, the variation of susceptibility with grain orientation is more extensive than for other metals (see ECSS-Q-70-ST-36C).

- Because conventional processing are designed to optimise strength, residual stresses - especially in thick sections - are usually greater in aluminium products than in wrought forms of other metals.

- Both the residual stress distribution and the grain orientation shall be carefully considered in designing a part to be machined from wrought aluminium.

- Wrought heat-treatable aluminium products should be mechanically stress-relieved (TX5X or TX5XX temper designations) whenever possible.




# Aluminium and its alloys/6

## Hazardous/precluded

- Certain alloys and tempers are unsuitable for structural applications in long-term, manned structures, such as International Space Station (ISS):
- Some 5000-series alloys and tempers are limited to a maximum use temperature of 66°C in ISS.
- Some 5000-series alloys with a high magnesium content require specific tempers to provide resistance to stress-corrosion cracking and exfoliation.
- Porous platings (corrosion protection) and aluminised layers are not permitted, because they fail to provide adequate protection and can act as sources for contamination.
- Electrolytic couples must be avoided or corrected by a suitable insulation between the metals concerned.
- Bare metal-to-metal contact is to be avoided in any moveable part.

# Aluminium and its alloys/7

## Effects of space environment

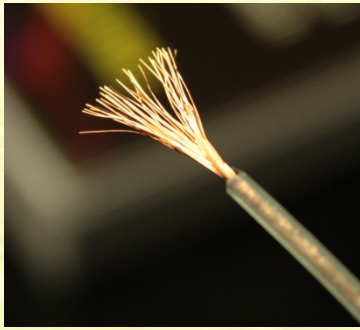
In general, metals do not suffer from space-environment conditions.

- Vacuum does not affect aluminium alloys. All metals in contact under vacuum conditions or in inert gas have a tendency to cold weld. This phenomenon is enhanced by mechanical rubbing or any other process which can remove oxide layers.
- Radiation at the level existing in space does not modify the properties of metals.
- Temperature problems are analogous to those encountered in technologies other than space, except for a complication arising from the difficulty of achieving good thermal contact in vacuum and due to the absence of any convective cooling. Aluminium alloys with magnesium contents greater than 3% are not recommended for applications where temperatures may exceed 66ºC.
- Atomic oxygen in low earth orbit (LEO) does not degrade aluminium alloys.

# Copper and its alloys/1

## General

- Copper and copper-based alloys are established materials in electrical, electronic and also in more general engineering applications (such as bearing assemblies, etc). Not all are acceptable for space, so discussion is limited to those alloys which have been evaluated and to specific comments relating to their use in space.



## Use in spacecraft

- The main applications for copper are in electrical/electronic subsystems (wiring, terminals in soldered assemblies) and plating (electronics, thermal control, corrosion protection etc). Copper is also used as a metallising coating -see Plastic Films - and as an additive in other materials -see Lubricants.

# Copper and its alloys/2

**Main categories**

Copper materials are generally grouped as:

- commercially pure grades, of which there are many different 'named' varieties that indicate the manufacturing method and the level of control of impurities, including oxygen;
- alloys in which the alloying additions affect the metallurgical microstructure and consequently their characteristics (mechanical, electrical and thermal properties, environmental resistance). The main alloying addition generally provides the named classifications:
  - *brass: copper - zinc alloys, often containing other alloying elements, such as lead which acts as a 'lubricant' for machining operations - so-called 'free-machining';*
  - *bronze: copper - tin alloys, often containing other alloying elements.*

Electronic assemblies use wires made of high-purity copper or copper alloy and terminals of copper alloy.
Beryllium-copper (also known as copper-beryllium) is a copper alloy with small additions of Be.
These alloys are used for electrical/electronic applications (spring contacts); for low temperature applications; for high-strength corrosion resistant components and in safety applications in hazardous environments (no sparks produced when impacted).

Copper is also used as a matrix phase in some reinforced metals

# Copper and its alloys/3

## Processing/Assembly

- In electronic assembly operations, copper wires are soldered to terminals (either manually or automatically). The correct selection and use of process materials (approved solders and fluxes for space hardware, solvents, etc) is a controlling factor in making reliable soldered connections

- Beryllium-copper alloys are heat treated to optimise mechanical performance. Fabrication processes (forming, machining, joining, etc) are generally performed in a softened condition and the material subsequently solution treated and aged.

## Hazardous/precluded

- Beryllium and beryllium oxide are toxic. Processing methods which may release beryllium from the alloy or produce beryllium oxide (heat treatment, welding, machining, etc) require appropriate safety equipment for operatives and proper facilities for the collection and disposal of dust and debris.

# Copper and its alloys/4

## Precautions

- Heating brass in an oxidising atmosphere or under corrosive conditions can cause dezincification of the alloy (loss of zinc from the exposed surface layer).
- Cold worked brass alloys are sensitive to stress-corrosion cracking. Annealing heat treatments are used to remove the cold work.
- Atmospheres containing sulphur dioxide, oxides of nitrogen and ammonia can cause SCC of some copper alloys. Chlorides in marine atmospheres may cause stress corrosion problems, but to a lesser extent than the above pollutants.
- Many copper alloys containing over 20% zinc are susceptible to SCC.
- In electronic assemblies, terminals fabricated from bronze are preferred. Brass terminals require a barrier layer (plating), to prevent diffusion and surface oxidation of zinc, prior to applying a tin-lead coating.
- Some constituents of potting compounds and sealants (catalysts) are corrosive to copper, and other metals.

# Copper and its alloys/5

**Effects of space environment**

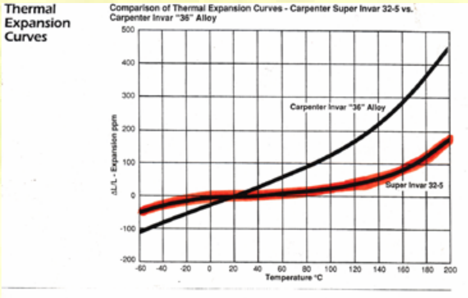
- Vacuum presents no special problem for copper-based materials, although copper-zinc alloys are generally plated - see Miscellaneous metals.
- All metals in contact under vacuum conditions or in inert gas have a tendency to cold weld. This phenomenon is enhanced by mechanical rubbing or any other process which removes or disrupts surface oxide layers.
- Radiation at the level existing in space does not modify the properties of copper alloys.
- Temperature problems are similar to those encountered in technologies other than space, but are complicated by the difficulty of achieving good thermal contact in vacuum and the absence of any convective cooling.
- Atomic oxygen in low earth orbit attacks copper.

# Nickel and its alloys/1

## General

As a family, the Ni-based alloys are used in many engineering fields for their corrosion resistance and high-temperature performance.
Ni-alloys are often known by trade names, rather than by their specification code numbers.

- Some alloys are used in electrical applications (such as heating elements).
- The magnetic characteristics of certain alloys are utilised in transformer components.
- A few alloys have controlled-expansion and constant-modulus properties (bimetals, thermostats, glass sealing, precision equipment).
- Others have been developed for specific applications (hydrogen storage) or to exploit a particular peculiarity (shape-memory effect).
- There are also a number of alloys used as welding and brazing filler materials. Some Ni-based materials are applied as coatings or hard facings to other materials to provide wear or corrosion resistance.



# Nickel and its alloys/2

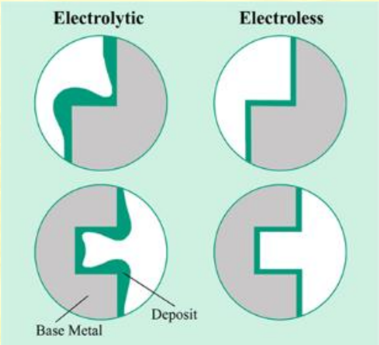
## Use in spacecraft

- Nickel plating appears in many applications (electronics, thermal control, corrosion protection etc).
- Ni-alloys are applied to subsystems requiring corrosion resistance (storage and delivery systems); high-temperature performance, often combined with oxidation resistance (propulsion units - gas turbines and rocket motors, power generation, heat-exchangers and turbines); high-reliability, high-strength fasteners.
- Magnetic alloys find a limited but important role.
- Memory alloys may find use as actuators.

# Nickel and its alloys/3

## Main categories

- The main use of commercially pure nickel is in platings (by electro- or electroless deposition) to provide corrosion protection to the underlying substrate materials.
- Electroless nickel can be hardened to provide abrasion resistance whilst retaining corrosion resistance.
- Nickel provides elevated-temperature corrosion resistance to many acids.
- As it is ferromagnetic, care is needed in its use in some applications (electronics, some science missions).
- Nickel-based materials can be grouped by principal alloying additions. However, alloys within one composition grouping may be used in more than one general application group.




| | LOW PHOSPHORUS | MEDIUM PHOSPHORUS | HIGH PHOSPHORUS |
|---|---|---|---|
| Nickel content | 95-99% | 92-95% | 88-91% |
| Phosphorus content | 1-5% | 5-8% | 9-12% |
| Hardness (Rc) | | | |
| as plated | 58-62 | 46-50 | 44-48 |
| heat treated | 68-70 | 65-68 | 65-67 |
| Abrasion Resistance | Very Good | Very Good | Very Good |
| Wear/Galling | Superior | Excellent | Excellent |
| Corrosion | + Alkaline, - Acidic | Mild environments | + Acid, fair in Alkaline |
| Stress | Compressive in some cases | Tensile | Compressive in most cases |
| Magnetic properties | Magnetic | Slightly Magnetic | Non-Magnetic |

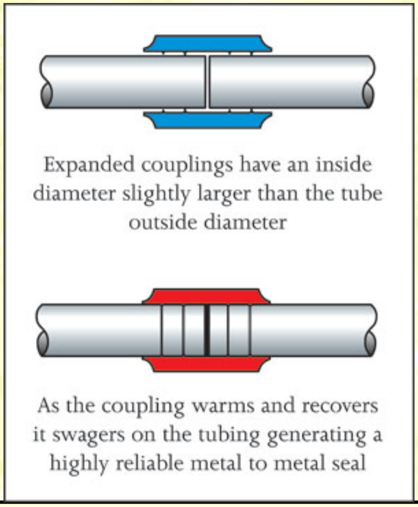
**Hints, Tips & Techniques**

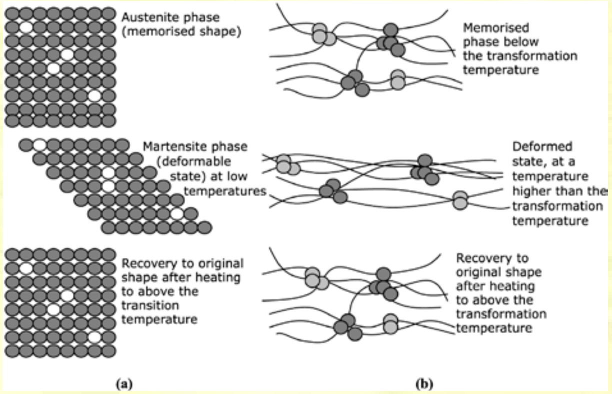
[Minimizing Stray Magnetic Fields through Materials Selection]

# Nickel and its alloys/4

- Some Ni-Fe alloys exhibit positive temperature coefficients of elastic modulus (most other metallic materials have negative values).
  - *These materials find specialist uses in springs and vibrating devices.*

- Ni-Ti memory alloys are based around the 50/50 composition. They can be deformed below a specific temperature, then, on heating above a higher temperature (these systems show some thermal hysterisis), will return to the original shape.
  - *Applications include temperature sensitive actuators, fixing and gripping devices (often in inaccessible locations).*



# Nickel and its alloys/5

## Processing/Assembly

- The chemical composition largely dictates the processing methods applicable to a particular alloy.
- In addition to casting, normally under vacuum, and forging, powder metallurgy techniques are used to produce highly-alloyed or dispersion-strengthened materials from metal powders.
- Similar processes, i.e. hot isostatic pressing, can be used for the consolidation (porosity elimination) of cast components.
- All processes require strict control and the specifications applied to aircraft and other critical industry applications (power generation) are used.

# Nickel and its alloys/6

## Precautions

- In electronic assemblies, brass terminals may be plated with a barrier layer of nickel provided that its magnetic properties are acceptable in the final assembly. (Nickel may have poor solderability compared with copper platings).

- Thermal cycling can affect oxidation and hot-corrosion resistance by affecting the surface composition of alloys. Spalling of the protective layer increases attack by corrosive media.

- The selection and use of coatings for oxidation/corrosion resistance requires full evaluation of service conditions and interfacial effects (thermal mismatch, diffusion, etc). Barrier, ceramic-type coatings can crack and spall during thermal cycling and elements of metal coatings may diffuse into the substrate at prolonged elevated temperatures.

# Nickel and its alloys/7

## Effects of space environment

- Vacuum presents no special problems. All metals in contact under vacuum conditions or in inert gas have a tendency to cold weld. This phenomenon is enhanced by mechanical rubbing or any other process which can remove or disrupt oxide layers.
- Radiation at the level existing in space does not modify the properties of metals.
- Temperature problems are similar to those encountered in technologies other than space, but are complicated by the difficulty of achieving good thermal contact in vacuum and the absence of any convective cooling.
- Atomic oxygen in low earth orbit does not affect Ni-based materials.

# Titanium and its alloys/1

## General

- Titanium and Ti-alloys are generally chosen for their mechanical properties, temperature resistance and/or chemical resistance. The specific points of special interest for the spacecraft designer are considered here, since the basic aspects of titanium alloy assemblies are similar to those for aeronautic design.


## Use in spacecraft

- Conventional Ti-alloys are used for primary and secondary structures; fasteners; in plumbing systems (standard tube alloy grades and commercially pure CP-grades) and in areas where operating temperatures preclude the use of aluminium alloys. 'Memory alloys' based on titanium may find specialised uses as actuators.

# Titanium and its alloys/2

## Main categories

The characteristics of titanium alloys are generally grouped according to their metallurgical structure which is, in turn, controlled by the chemical composition and heat-treatment history.

- Commercially pure (CP Ti) products are normally selected for chemical resistance. Impurities in CP Titanium can increase strength but with a loss in corrosion resistance.
- Titanium alloys are normally selected for their strength properties, which depend on a number of specific heat-treatments (age hardening, quench and temper). The most commonly used titanium alloy is Ti6Al4V for which extensive mechanical and corrosion property data is available.

**Hints, Tips & Techniques**

Extra info Ti6Al4V

# Titanium and its alloys/3

## Processing/Assembly

- All classical methods of shaping and forming processes can be used, with wrought products being produced by rolling, extrusion, forging; cast products. Owing to titanium's high-affinity for oxygen and other gases, melting and casting processes are carried out under vacuum to prevent contamination and subsequent property degradation.

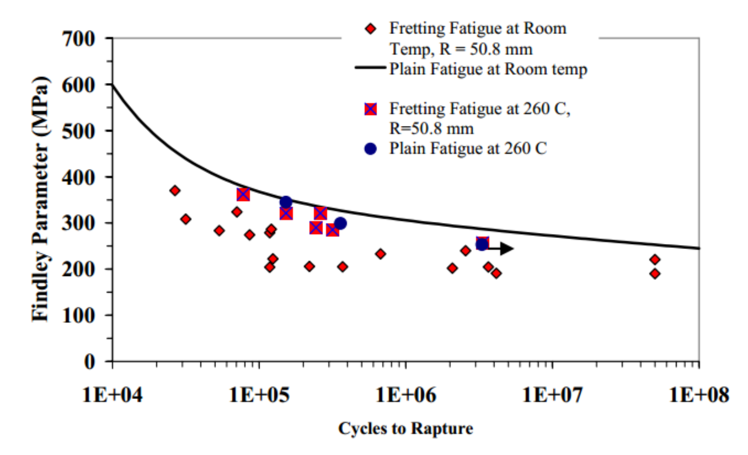
- Titanium alloys can generally be joined by welding, brazing, riveting, bolting and adhesive bonding, although only certain alloys can be brazed. Not all alloys are weldable and a protective atmosphere is required (inert-gas or vacuum) to avoid pick-up of O, N and H which degrade properties.

- Some metals and processing chemicals can degrade the properties of titanium alloys by inducing stress corrosion or hydrogen embrittlement or by reducing fracture toughness.

# Titanium and its alloys/4

## Precautions

- The properties of titanium alloys are strongly dependent on their previous thermal and/or mechanical history.
- Some alloys have a limit on the section dimensions that can be successfully hardened by heat-treatment.
- The fatigue life of titanium alloys is reduced by fretting at interfaces (either between Ti-alloy parts or Ti-alloy and other metals). Structural designs should avoid fretting.



# Titanium and its alloys/5

- The corrosion and chemical resistance of titanium alloys relies on the adherent, protective oxide layer which is stable below 535 °C. Above this temperature, the oxide film breaks down and small atoms (such as C, O, N and H) embrittle the metal. Consequently high-temperature processing methods are done under vacuum or in an inert-gas atmosphere.
- During production, the selection of appropriate processes and avoidance of surface contamination are vital to avoid property degradation. Contamination zones formed during processing can be removed by subsequent machining or by chemical milling of the surfaces of titanium parts.

**Hints, Tips & Techniques**

Extra info on corrosion

# Titanium and its alloys/6

## Stress corrosion (table I)

| Miscellaneous Alloy (wrought) | Condition |
|---|---|
| Titanium, 3Al-2.5V | All |
| Titanium, 6AI-4V | All |
| Titanium, 13V-11Cr-3AI | All |

## Hazardous/precluded

- Titanium alloys may be susceptible to hydrogen-embrittlement and are generally unsuitable for hydrogen-containing atmospheres.
- Care shall be exercised to ensure that cleaning fluids and or other chemicals used on titanium are not detrimental to performance.
- Surface contaminants which can induce stress corrosion, hydrogen embrittlement, or reduce fracture toughness include: hydrochloric acid, cadmium, silver, chlorinated cutting oils and solvents, methyl alcohol, fluorinated hydrocarbons, mercury and compounds containing mercury.

# Titanium and its alloys/7

## Effects of space environment

- Vacuum poses no special problems. All metals in contact under vacuum conditions or in inert gas have a tendency to cold weld. This phenomenon is enhanced by mechanical rubbing or any other process which can remove or disrupt oxide layers. Fretting is a particular concern for titanium alloys.

- Radiation at the level existing in space does not modify the properties of metals.

- Temperature problems are similar to those encountered in technologies other than space, but are complicated by the difficulty of achieving good thermal contact in vacuum and the absence of any convective cooling.

- Atomic oxygen in low earth orbit has no effect on titanium.

# Steels/1

## General

- Steels, as a family of materials, offer a wide range of characteristics that find uses in many and varied applications. This section concentrates on those materials, normally aircraft grades, which may be considered for use in space and any precautions required for their application.

## Use in spacecraft

- Steels are used in structural items (e.g. rocket motor casings) and within engineering components (bearings, springs, etc.) in a variety of subsystems and devices

# Steels/2

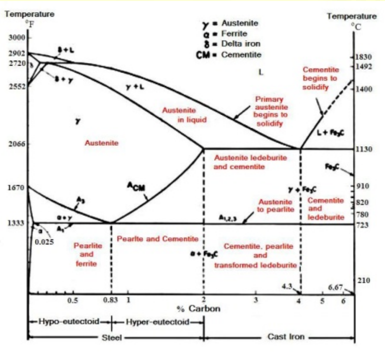
## Main categories

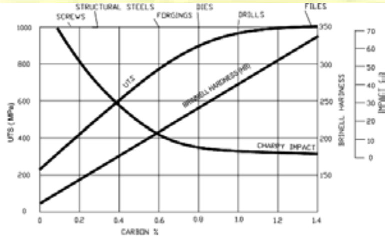
- Steels are based on alloys of iron and carbon (between 0.05% and 2%C). All contain some level of other elements, i.e. even plain carbon steels (up to 1.7% C) contain manganese up to about 1%Mn.

- Impurity levels (e.g. phosphorus and sulphur) depend mainly on the smelting and melting processes used

- Alloy steels contain one or more additional alloying elements to improve properties and workability.

- The tensile strength of plain carbon steels increases with carbon content up to approximately 0.8%C, reaching a theoretical maximum of about 900 MPa, with a corresponding decrease in ductility. Hardness increases progressively with C-content, so that low- (0.1-0.3%C) to medium-carbon steels (0.3-0.6%C) are used for various 'engineering' components, whereas high-carbon steels (0.6-0.9%C) are used for applications requiring hardness and wear resistance.



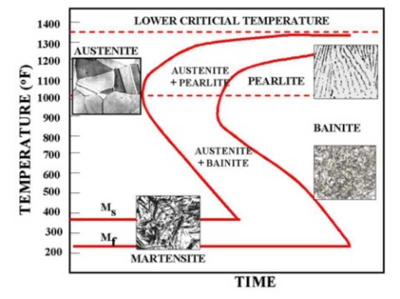
# Steels/3

- Alloying additions to plain carbon steels produce a wide range of alloy steels with improved performance.
- The tensile strengths attainable from alloy steels depend on the composition, mechanical working and heat-treatment processes.
- For engineering uses (i.e. materials having a combination of useful properties such as strength, toughness, processability etc.) strengths rarely exceed 1250MPa.
- The exceptions being some cold-worked products, e.g. wires, some hardened and tempered items such as ball bearings and some spring steels and 'maraging' steels. Where the UTS exceeds 1250MPa, stress-corrosion becomes an issue.
- 'Maraging' steels (from 'martensite-ageing') contain Ni (either 12 or 18% typically) with various combinations of Cr, Co, Mo, Ti and Al and very low levels of carbon (0.03%). This group of alloys have a number of benefits: very high tensile strengths; high toughness; weldability; ease of heat-treatment and machinability. They are also high-cost materials.

# Steels/4

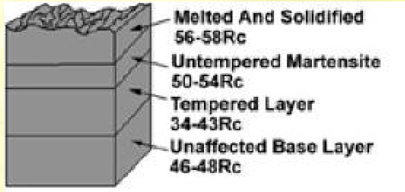
## Processing/Assembly

High quality aircraft steels are normally produced by electric-melting processes. Vacuum-melting is applied to grades for forged heavy-duty aircraft components.




- Most conventional processing techniques are applied to steels (machining, welding, fastening, etc).

- Heat treatments may be applied to the bulk of the material or used to selectively harden the surface. A wide range of compositional and mechanical surface treatments are available to selectively improve surface properties (e.g. carburising, nitriding, shot peening, thread rolling).




Typical example of the various layers in an EDM Machined Surface of H-13 Steel

**Hints, Tips & Techniques** [Heat treatments and micro structures]

- High-strength martensitic steels (UTS >= 1225 MPa) require careful machining using carbide-tipped tools and other techniques to ensure that the formation of an untempered martensitic (very hard white layer) structure does not occur on surfaces.

# Steels/5

## Precautions

- Carbon and low-alloy steels with ultimate tensile strengths below 1225 MPa (180ksi) are generally resistant to stress-corrosion cracking.
- Some steels have a ductile-brittle transformation which, depending on the alloy composition, can occur within the normal service conditions for some space components.
- Depending on the alloy, some steels exhibit poor weldability. This is linked to the carbon content (or carbon-equivalent value) and can produce brittleness in the weld affected zone.
- Steels are prone to corrosion in atmospheric and acidic aqueous solutions.
- Low-alloy steels, depending on the composition, tend to have better resistance to atmospheric corrosion.
- High-alloy steels with nickel contents >3% show improved resistance to atmospheric and marine environments.
- Higher strength steels are also prone to SCC in seawater and other chloride solutions.

# Steels/6

## Hazardous/precluded

- Platings on steels commonly used in terrestrial applications for improved corrosion resistance may not be suitable for space. These include zinc, cadmium or other volatile metals - see Miscellaneous Metals.

## Effects of space environment

- Vacuum poses no special problems. All metals in contact under vacuum conditions or in inert gas have a tendency to cold weld. This phenomenon is enhanced by mechanical rubbing or any other process which can remove or disrupt oxide layers.
- Radiation at the level existing in space does not modify the properties of metals.
- Temperature problems are similar to those encountered in technologies other than space, but are complicated by the difficulty of achieving good thermal contact in vacuum and the absence of any convective cooling.
- Atomic oxygen in low earth orbit does not affect steels.

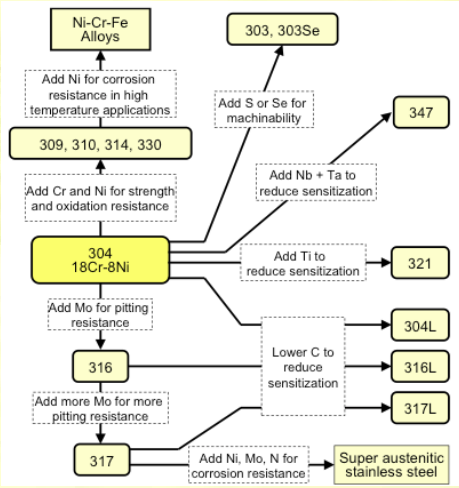
# Stainless steels/1

## General

- Stainless steels - also known as corrosion-resistant steels - have alloying additions specifically to provide a continuous, adherent, self-healing oxide film and so reduce the attack of corrosive media.

- In addition to corrosion resistance, they also exhibit a number of other properties making them useful engineering materials (oxidation resistance, creep resistance, toughness at low temperature, magnetic or thermal characteristics).

- This section concentrates on those materials, normally aircraft grades, which may be considered for use in space and discusses precautions required for their application.




## Use in spacecraft

- Use of stainless steels in spacecraft centre on applications requiring corrosion resistance (e.g. storage and handling of liquids and waste), components within some thermal protection systems and fasteners such as high-reliability, high-strength bolts.

# Stainless steels/2

**Main categories**

Stainless steels contain chromium (at least 12%) which provides the protective oxide film, plus a number of other alloying elements to enable a range of characteristics.

- austenitic - derived from the basic 18Cr/8Ni compositions (300-series), or higher strength versions in which some of the Ni-content has been replaced by nitrogen and manganese (200-series). Strength is increased by cold-working and properties are retained at low temperatures.

- ferritic - 400-series materials contain between 11-30%Cr and a maximum of 0.1%C. Often used in the annealed or cold-worked condition, increased strength can be obtained by heat-treatment.

- martensitic - also fall within the 400-series, normally have chromium contents between 11 and 18%. Some can be heat-treated to give high tensile strengths (>1400MPa).

- duplex – mixed ferritic/austenitic microstructures. High Cr and Mo contents provide pitting corrosion resistance and reasonable resistance to SCC in chloride environments, (i.e. better than some austenitic grades).

- precipitation hardened - based on martensitic or duplex grades with additions of copper and aluminium for precipitation hardening. They can be heat-treated to give high strengths combined with high corrosion resistance.

Click on MORE to see more details ... more

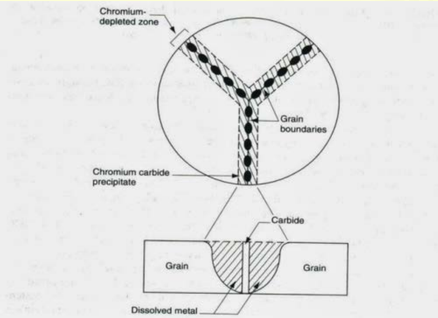
# Stainless steels/3

## Processing/Assembly

- Most conventional processing techniques are applied to steels (machining, welding, fastening, etc).
- Care is required with some alloys that the processing does not degrade the microstructure, hence properties.
- Welding can affect the corrosion resistance of the weld and heat-affected zone (localised reduction of Cr-content) and produce heat distortion of the assembly. Correct choice of filler rod is important.
- Aircraft specifications for heat-treatments and processing are used.

# Stainless steels/4

## Precautions




- Chromium within the alloy may react with carbon and form localised Cr-depleted areas and brittle compounds, normally at grain boundaries. This effect is known as 'sensitisation' and can have serious consequences for corrosion resistance, especially stress-corrosion cracking.
- 'Stabilised' stainless steels have alloying additions (Ti, Mo, Nb) specifically to 'tie-up' carbon as carbides and so prevent sensitisation (also known as weld decay).
- Unstabilised, austenitic steels have a service temperature limit of 370°C.
- With the exception of stabilised or low-carbon grades (such as 321, 347, 316L, 304L), welded assemblies require solution treating and quenching after welding.

Hints, Tips & Techniques

Extra info on precautions

# Stainless steels/5

**Precautions, cont…**

- Austenitic stainless of the 300-series and the and ferritic steels of the 400 series are generally resistant to stress-corrosion cracking.
- Martensitic stainless steels of the 400-series are more or less susceptible, depending on composition and heat treatment.
- Precipitation hardening stainless steels vary in susceptibility from extremely high to extremely low, depending on composition and heat treatment. The susceptibility of these materials is particularly sensitive to heat treatment, and special vigilance is required to avoid problems due to SCC.
- Stainless steel parts and fabrications normally require careful cleaning prior to operation in service. Cleaning processes are normally chemical pickling using various combinations of acids, the residues of which also have to be removed thoroughly. Some grades may be susceptible to hydrogen embrittlement resulting from hydrogen pick-up during pickling processes.

# Stainless steels/6

## Hazardous/precluded

- Alloys prone to sensitisation require careful consideration of their stress-corrosion characteristics and service at elevated temperatures.

## Effects of space environment

- Vacuum poses no special problems. All metals in contact under vacuum conditions or in inert gas have a tendency to cold weld. This phenomenon is enhanced by mechanical rubbing or any other process which can remove or disrupt oxide layers.
- Radiation at the level existing in space does not modify the properties of metals.
- Temperature problems are similar to those encountered in technologies other than space, but are complicated by the difficulty of achieving good thermal contact in vacuum and the absence of any convective cooling.
- Atomic oxygen in low earth orbit does not affect stainless steels.

# Filler materials: welding, brazing, soldering/1

## General

- Fusion joining techniques produce permanent joints. Soldered joints and some brazed joints can be disassembled with care.

## Use in spacecraft

- Welding is a common fabrication method for metals used in spacecraft.
- Brazing usually refers to joining with alloys of copper, silver and zinc and is preferred to soldering when stronger joints and an increase in temperature resistance is required.
- Soldered joints are used for electrical and thermal conducting paths and for low mechanical strength joints. Soldering is commonly referred to as 'soft-soldering' in which low-melting point alloys, such as tin-lead or indium-based materials are used.

# Filler materials: welding, brazing, soldering/2

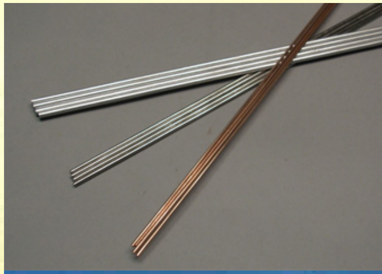
## Main categories

- Filler materials, welding procedures and post-weld processes are detailed in aerospace standards and specifications

- Comments on weld filler materials also apply to braze metals and processes. An added complication is that braze fillers are generally very different from the parent weld materials and so galvanic couples and other corrosion effects also need consideration.

- Solder alloys that are acceptable for use in electronic assemblies in space, and their associated fluxes and process chemicals (solvents; cleaning baths, etc), have been subject to intense evaluation, see the tables 'Guide to choice of solder-types for space use' and 'Representative products' table (from ECSS-Q-ST-70-08C).

- Solder alloys consist of the tin-lead and indium-lead alloys defined in ECSS-Q-ST-70-08C and ECSS-Q-ST-70-38C. They are procured according to these specifications, which define purity levels and, where necessary, fluxes of suitable formulation for the assembly of spacecraft electronics.



# Filler materials: welding, brazing, soldering/3 (info only)

## Guide to choice of solder-types for space use

| Solder Type | Solidus | Liquidus | Use |
|---|---|---|---|
| 63 tin solder (eutectic) | 183 | 183 | Soldering PCBs where temperature limitations are critical and in applications where an extremely short melting range is required. |
| 62 tin silver loaded | 175 | 189 | Soldering of components having silver-plated or 'paint' finish, i.e. ceramic capacitor. This solder composition is saturated with silver and prevents the scavenging of silver surfaces. |
| 60 tin solder | 183 | 188 | Soldering electrical wire/cable harnesses or terminal connections and for coating or pre-tinning metals. |
| 96 tin silver (eutectic) | 221 | 221 | May be used for special applications such as soldering terminal posts. |
| 75 Indium lead | 145 | 162 | Special solder used for low temperature soldering process when soldering gold and gold-plated finishes.(smd). Can be used for cryogenic applications |
| 70 indium lead | 165 | 175 | For use when soldering gold and gold-plated finishes when impractical to degold.(smd) |
| 10 tin lead | 268 | 290 | May be used for special applications such as soldering terminal posts. |

# Filler materials: welding, brazing, soldering/4

## Approved solder compositions for space use

| Composition | | 63 tin solder (eutectic) | 62 tin silver-loaded solder | 60 tin solder | 96 tin silver solder (eutectic) | 10 tin lead solder (10/90) |
|---|---|---|---|---|---|---|
| | Min% | 62.5 | 61.5 | 59.5 | | 9 |
| Tin (Sn) | Max% | 63.5 | 62.5 | 61.5 | remainder | 10.5 |
| Lead (Pb) | Max% | remainder | remainder | remainder | 0.10 | remainder |
| Antimony (Sb) | Max% | 0.05 | 0.05 | 0.05 | 0.12 | 0.05 |
| | Min% | - | 1.8 | - | 3.5 | - |
| Silver (Ag) | Max% | - | 2.2 | - | 4.0 | - |
| Bismuth (Bi) | Max% | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Copper (Cu) | Max% | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| Iron (Fe) | Max% | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| Aluminium (Al) | Max% | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| Zinc (Zn) | Max% | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| Arsenic (As) | Max% | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| Cadmium (Cd) | Max% | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 |
| Others | Max% | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 |

# Filler materials: welding, brazing, soldering/5

## Processing/Assembly

- Aircraft standards and specifications are normally applied. Other critical industry sectors (nuclear, power-generation, etc) may offer guidance on specialist materials.

- Fusion joining processes are skilled operations and personnel must have appropriate training and certification to produce the required high-quality, reliable joints.

## Precautions

- Not all metals and alloys can be joined by welding or brazing.

- Not only the weld itself (fusion zone), but the heat-affected zone and the unaffected parent (base) metals must be considered.

- Not all 'industrial' welding techniques can be used on all materials.

- The correct selection of parent materials and weld methods requires consideration of all factors that affect operational capability of the parts concerned

# Filler materials: welding, brazing, soldering/6

## Precautions, cont…

- Brazing is normally restricted to joints in structural parts that experience shear loading rather than tensile loading.
- Fluxes used to produce welded, brazed or soldered joints may be corrosive and need to be removed thoroughly prior to post-joining processes (heat-treatment) and operation in service.
- Residues of chemicals or processes used for flux removal must also be cleaned from components. Common soldering fluxes, their application and use are detailed in ECSS-Q-ST-70-08.

## Hazardous/precluded

- Corrosive acid fluxes available for the pre-tinning of soldered joints can provoke stress-corrosion cracking and general surface corrosion of component leads or terminal posts. Their general use is therefore restricted and precise control of the flux-removal processes is required

Hints, Tips & Techniques

Situation on Sn-Pb and lead free

# Miscellaneous metallic materials/1

## General

- A metal is classed as miscellaneous if it does not fall within another Declared Materials List (DML) category in ECSS-Q-ST-70C. Also included in this section are comments on metal-based materials that are either prohibited or should be approached with caution for space applications.

## Use in spacecraft

- Light alloys based on magnesium and beryllium are used in some primary and secondary structures.
- Plating appears in many applications (electronics, thermal control, corrosion protection etc) and calls mainly for silver and gold.
- 'Memory alloys' based on titanium and nickel may find uses as actuators
- In addition to standard conventional alloys, more recent material developments include:
  - *reinforced alloys (metal matrix composites - MMC) consisting of magnesium alloys reinforced with carbon fibres;*
  - *lithium additions to conventional magnesium alloys;*
  - *reinforced silver alloys.*

# Miscellaneous metallic materials/2

## Main categories

Miscellaneous metals include, but are not limited to:

- magnesium alloys;
- beryllium and Be-alloys. (See: 'Copper and Cu-alloys' for Be-Cu alloys);
- refractory alloys;
- superalloys, which as a group include cobalt-, iron- or nickel-based alloys. (See: 'Nickel and Ni-alloys' for Ni-based superalloys);
- mercury;
- plating materials: cadmium, zinc, tin, gold, silver, osmium etc.

This section also includes comments on metal-based materials that are either prohibited or should be approached with caution for space applications.

# Miscellaneous metallic materials/3

## Processing/Assembly

- Magnesium alloys are available as wrought forms or for casting. Care is needed in storing magnesium alloys due to their tendency to corrode.
- Processing of beryllium requires sophisticated techniques and rigorous safety procedures to avoid the formation and release of beryllium oxide, metal particles and compounds which are toxic.
- Superalloys are processed following recognised aerospace procedures or other appropriate industry standards.
- Specialist methods for processing refractory metals and alloys are applied.

# Miscellaneous metallic materials/4

## Precautions

- **Magnesium alloys**
  Dusts of magnesium and its alloys are flammable; requiring special safety measures. Some magnesium alloys (with thorium) may have a slight residual radioactivity.

- **Beryllium and Be-alloys**
  This metal is produced by powder metallurgy involving hot isostatic processing and it is recommended that component parts are initially rough machined, heat treated to remove major residual stresses and then fine machined.

- A final chemical etching treatment is strongly recommended to remove 0.1mm from the surface of machined parts. This will generally remove mechanical damage such as subsurface microcracks and deformation twins.

- **Beryllium dust and vapours are toxic**;
  work on this material requires special precautions.

Hints, Tips & Techniques

Extra info on beryllium

# Miscellaneous metallic materials/5

## Precautions, cont...

### Miscellaneous

- Refractory alloys are generally selected for extreme high-temperature applications where other metals cannot be used. However, engineering data on refractory alloys are limited, especially under the extreme environments encountered on spacecraft.
- Nickel-based and Cobalt-based superalloys possess various combinations of high-temperature mechanical properties and oxidation resistance up to approximately 550°C. Many of these alloys also have excellent cryogenic temperature properties.
- Some metals, such as cadmium and zinc, are rather volatile and should not appear in space hardware. Platings of these metals, as well as tin, are known to grow whiskers both in air and under vacuum. They should be excluded from all spacecraft and ground-support equipment.
- Porous platings are potential sources of danger and this occurs frequently with gold plate over silver.
- Osmium oxide is toxic; work on this material requires special precautions.

# Miscellaneous metallic materials/6

## Hazardous/precluded

- Mercury and mercury-containing compounds can cause accelerated cracking of aluminium and titanium alloys. It is therefore a prohibited substance for the manufacture of aerospace structures and subsystems.
- Specialised safety equipment and procedures for the collection and disposal of dust and debris are required for operatives working with toxic materials, such as beryllium and osmium, and for materials with a risk of ignition and burning, such as magnesium.
- In electronic assemblies, tin-, silver- and gold-plating on terminals of PCBs is removed in order to achieve an approved tin-lead finish.
- Soldering directly to gold finishes is unacceptable and de-golding processes are used. In unavoidable use of gold-finishes, such as in RF circuitry, selective plating processes are used for soldered connections.

# Miscellaneous metallic materials/7

## Effects of space environment

- Vacuum affects volatile metals, such as cadmium and zinc. These metals sublime readily at temperatures over 100°C and 150°C respectively, and may form conductive deposits on insulators or opaque deposits on optical components.
- Radiation at the level existing in space does not modify the properties of metals.
- Temperature problems are similar to those encountered in technologies other than space, but are complicated by the difficulty of achieving good thermal contact in vacuum and the absence of any convective cooling.
- Atomic oxygen in low earth orbit attacks some metals, such as silver (solar-cell interconnectors) and osmium (extreme-UV mirrors).

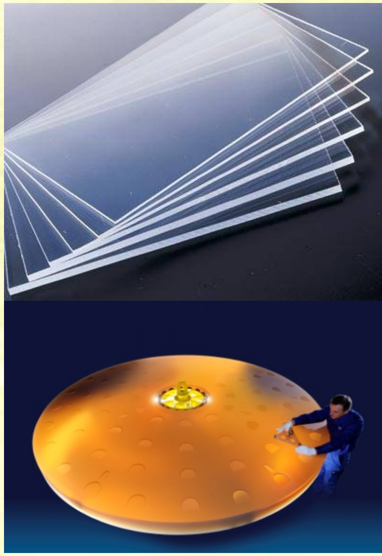
# Optical materials/1

## General

- The meaning of the word “glass” is extended to cover “organic glass” and some crystalline optical materials

## Use in spacecraft

- Glasses, inorganic as well as organic, appear as optical elements: e.g. windows, lenses, prisms, solar-cell covers and filters.



## Main categories

Optical materials can be grouped as:

- inorganic glasses - such as silicates, alumino-silicates and boro-silicates;
- organic “glasses” - polymers based on acrylic and methacrylic polymers, polycarbonate and some polystyrene grades;
- crystalline optical materials - pure silica, sapphire and transparent fluorides.

# Optical materials/2

## Precautions

- Glasses are transparent only to a certain wavelength range and shall be chosen in accordance with the mission requirements. Inorganic glasses are sensitive to mechanical and thermal shocks. Organic glasses are easily scratched and lose their polish.

## Hazardous or precluded

- Organic glasses should not appear in high-precision equipment except as plain windows or light-pipes.

## Effects of space environment

- Vacuum exposure does not affect inorganic glasses or most organic glasses.
- Radiation is the most harmful factor to be considered for glasses. Plastics can be damaged by particle and UV radiation. The result is, in general, a “yellowing”, and the damage under sunlight can be auto-accelerated by the increase in temperature due to higher absorption.
- Thermal shock can lead to fracture in inorganic glasses. Organic glasses soften at quite low temperature (80 ºC to 100 ºC frequently) and have rather high expansion coefficients.
- Atomic oxygen can attack organic glasses.

Hints, Tips & Techniques Full text

# Adhesives, coatings and varnishes/1

## Use in spacecraft

- Structural adhesives appear where high load-bearing capability is needed, e.g. in the face-to-core bond of honeycombs.
- Non-structural adhesives (glues, bonding agents) are found particularly in, for example, solar-cell assembly, optical-component bonding and screw locking. Adhesives are most useful in the bonding of dissimilar materials which are difficult (or impossible) to assemble by other means: e.g. glass and ceramics.
- Coatings and varnishes appear as electrical insulating layers, corrosion protection and mechanical protection mainly in electronic circuitry. Finished layers can be thin (e.g. varnishes) or rather thick (e.g. conformal coatings).

Hints, Tips & Techniques

Locking materials

## Main categories

- Adhesives: in current use are epoxies, phenolics, "modified" epoxies, acrylates, polyurethanes, silicones, polyimides and cyano-acrylates. Their consistency is quite variable: liquid, paste, powder, supported or unsupported films.
- Coatings and varnishes: Current polymer bases are alkyd, epoxy, polyester, polyimide, polyurethane, silicone, polyesterimide and polybenzimide. Coatings appear as one- or two-component systems, frequently containing solvents (thinners) to give the necessary low viscosity.

# Adhesives, coatings and varnishes/2

## Processing

- Adhesives: Processing varies from simple room temperature curing under contact pressure to intricate pressure or temperature exposures depending upon the category and type of adhesive. Many non-structural adhesives cure under contact pressure at moderate temperatures, e.g. RTV silicone rubbers (some of which cure with atmospheric moisture), cyano-acrylates (moisture cure) and anaerobics (which cure by air exclusion) and polyurethanes.
- Coatings and varnishes: Application is by brush, dipping, flow or spray processes. Curing is very similar to that of adhesives but no pressure is applied. Since coatings and varnishes frequently contain solvents, these shall be dried out before curing commences

## Precautions

- It is very easy to misuse adhesives, particularly in critical applications. They normally have a limited shelf life (marked on the packaging and suppliers' data sheets) which shall be respected, and the conditions under which they are stored shall be adequately controlled
- Material selection factors for conformal coatings are detailed in ESA SP1173 and are dependent on electrical requirements and anticipated service environment.

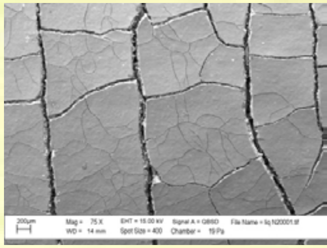
# Adhesives, coatings and varnishes/3

## Effects of space environment

- Exposure of adhesives to vacuum provokes outgassing. As the exposed surface is small (only the bondline), outgassing rates can be quite low. All coatings and varnishes outgas. This is particularly noticeable for types containing solvent.

- Particle radiation at the level encountered in space is not harmful for adhesives, which are in any case protected by the items (adherends) they are bonding. Only coatings on satellite surfaces experience exposure to radiation, often combined with UV. UV radiation can darken optical adhesives. In this regard silicones are superior to epoxies. UV and particle radiation can both increase the outgassing rate of adhesives.

- High temperature degrades adhesives. Polyimide can be used up to more than 300 ºC; the best epoxies are normally limited to 170 ºC. Phenolics and silicones lie between. Low temperature stiffens adhesives and causes brittle bonds.



- Thermal cycling leads to failure of the adhesive bond when the expansion coefficients of the adherents and adhesives are not matched and when the adhesive is not flexible enough to cope with the strain.

- Atomic oxygen (in LEO) is only applicable to adhesives exposed to ATOX (such as those on solar-cell and panel assemblies) which can be attacked. Exposed coatings are susceptible: silicones are resistant.

# Adhesive tapes/1

## Use in spacecraft

- In existing satellites, adhesive tapes are used mainly in the thermal-control subsystems. They can also be used in electrical insulators. Some conductive adhesive tapes are used for electrical grounding.

## Main categories

- The backing of adhesive tapes can be made from polyester, polyimide, polyolefin, fluorinated polymers, fibreglass cloth, metal sheet, metallised (aluminized, gold-plated) polymers and pigmented polymers.
- Most common tapes have a “pressure-sensitive” adhesive based on rubber-like polymers containing a number of additives.

Hints, Tips & Techniques Pressure sensitive tapes

## Precautions

- Because of the complex and frequently unknown nature of their adhesives, use of tapes should be minimized and then only with great care in their choice and application. When an adhesive tape is applied temporarily, it generally contaminates the underlying surface which shall be carefully cleaned after tape removal.
- When tape is applied permanently it can be displaced by creep and leaves a dirty spot.

# Adhesive tapes/2

## Hazardous or precluded

- Polyvinylchloride backing tapes which are frequently used for electrical insulation shall not be applied to space vehicles. Also cellulose (cellophane), cellulose acetate, paper and fabric should be avoided.

## Effects of space environment

- Vacuum exposure can draw products out of the backing when it is a polymer and also out of the adhesive.
- Radiation (UV and particle) shall be considered mainly when tapes are used for thermal-control purposes. Most polymer backings are sensitive and their solar absorptivity increases rapidly under irradiation.
- Low temperatures stiffen the adhesive and backing. Polyimide and Teflon based tapes can still be used as well as metal.
- Thermal cycling is in general not a problem since the pressure-sensitive adhesives are quite flexible except at low temperatures.
- Atomic oxygen in low orbit can attack polymer tapes.

# Paints and inks/1

## General

- Most commercial paints are unsuitable for use in space.

## Use in spacecraft

- The most critical use of paints is in the thermal-control subsystem. They can also be employed for corrosion protection. Inks are used for marking and for identification purposes.

## Main categories

- Common organic binders are epoxies, acrylics, silicones, and polyurethanes. Inorganic bases are mainly silicates. Pigments are chosen to produce the specified optical properties:
  - *white pigments for low solar absorptance and high emittance (zinc oxide aluminium flakes for medium absorptance and emittance;*
  - *carbon black for high absorptance and emittance.*

- Electrically conductive thermal-control paints were developed to avoid charging and discharging in geostationary orbit.

Outgassing of Marking Inks

**Hints, Tips & Techniques**

Surface Condition for Good Adherence of Thermal Control Paints

# Paints and inks/2

## Effects of space environment

- Vacuum exposure of paints results in high outgassing due mainly to solvent residues

- Radiation is the most damaging environmental factor for paints used on the exterior of spacecraft. Particles and UV tend to embrittle paint layers. Their main effect, however, is the degradation of optical properties. Inorganic-based white paints (silicate binder) are more stable than those with an organic base.

- High temperature degrades paints ("smoking" under ascent conditions). In this respect, silicones and silicates are best.

- Atomic oxygen in low Earth orbit attacks paints. Those with a silicone and perfluorinated base seem better. Silicate bases are resistant.

# Lubricants/1

## Use in spacecraft

- All moving parts under vacuum, either “one shot” or constantly operating items, shall be lubricated.

## Main categories

- Basic oils are hydrocarbons, silicones, diesters, polyglycols and fluorinated compounds.
- Besides these “wet” lubricants, many “dry” types find a use in spacecraft. These are:
  - *laminar inorganic substances, such as $MoS_2$ and $WSe_2$*

## Processing and assembly

- Application of oil or grease is straightforward. Dry lubricants are more difficult to apply and some processes are proprietary. In the case of metals, chemical and electrochemical plating can be used, as well as vacuum deposition.

# Lubricants/2

## Precautions

- The main problem is to ensure that the lubricant stays where it is useful and does not migrate to places where it is not wanted.
- Graphite is not a lubricant in vacuum, but an abrasive (it can be used in combination with other lubricating materials such as silver or $MoS_2$).

Hints, Tips & Techniques

Graphite in space

## Effects of space environment

- Vacuum effects are mainly the evaporation of oils and “dry-off” of greases. Surface “cleaning” due to vacuum encourages oils to creep out of their location; this is particularly so with silicones.
- Under radiation, oils have a tendency to evolve gases or corrosive products, to foam or to gel, but this needs rather high doses. Dry lubricants are quite resistant to all types of radiation.
- Normally, friction generates higher temperatures in space than on the ground for the same part: this is due to the difficulty of eliminating heat under vacuum
- Atomic oxygen can degrade $MoS_2$ and similar solid lubricants which are exposed to it.

# Potting compounds, sealants and foams/1

## Use in spacecraft

- Potting compounds and sealants have various uses in spacecraft: electrical and mechanical insulation, damping, sealing and thermal coupling.

## Main categories

- Three main chemical groups of polymers predominate: epoxies, silicones and polyurethanes. These exist as hardened potting compounds, sealants, foams, and syntatic foams (containing micro-balloons).

## Processing and assembly

- The assembly to be sealed or potted is first cleaned. Sometimes a surface treatment (for example etching of PTFE parts) or a primer application is necessary.

## Precautions

- Many potting compounds create quite high temperatures and pressures during curing, and damage to potted components can occur unless some countermeasure is taken. Some catalysts used in potting compounds and sealants have corrosive effects on metals (for example dibutyl-tin-dilaurate on copper). Most of them are in one way or another harmful to man and safety precautions are necessary.

# Potting compounds, sealants and foams/2

**Hazardous or precluded**

- The present trend in space systems is to avoid potting as far as possible and to use conformal coatings in preference. Most of the flexible potting compounds and sealants outgas too much to be useful in space. “Open cell” foams shall not be used, since they do not protect the potted items against corrosion in the atmosphere.

**Effects of space environment**

- Vacuum exposure of potting and sealant materials leads to problems analogous to those of conformal coatings. Closed-cell foams contain gases ($CO_2$ or freon), which normally take a very long time to evolve even under space vacuum.
- Radiation exposure of potting and sealant materials is normally minimal, since they are mostly used inside modules.
- Temperature effects shall be considered. On the low side, potting and sealants shrink and become more rigid. On the high side, chemical degradation can occur, particularly around power-dissipation component. Silicones have the best high-temperature properties.
- Thermal cycling due to the switching on and off of equipment can lead to cracking and debonding.

# Reinforced plastics/1

## General

- Reinforced plastics - defined as a reinforcing material, normally a fibre, in a polymer matrix can be grouped as those used for:
  - *structural applications;*
  - *electronic uses.*
- The reinforced plastics within each group have very different mechanical and physical properties dictated by the fibre reinforcement (material and form), the reinforcement content and orientation and the polymer matrix used to support the reinforcement fibres.
- The design and verification of fibre-reinforced composite materials used for structural applications shall conform to the requirements from clause 4 of ECSS-E-ST-32-08.

# Reinforced plastics/2

## Use in spacecraft

- Applications for reinforced plastics in structural and semi-structural uses include:
  - *honeycomb facings,*
  - *antennas, trays,*
  - *structural members,*
  - *fairings,*
  - *spacecraft skin,*
  - *solar cell substrate.*

- The reinforcement phase in polymer matrix composites can be grouped as:
  - *long, continuous fibres, unidirectional or woven,*
  - *short (discontinuous) fibres, sometimes "chopped" to a specific length or as felts and mats, or*
  - *powders and other forms of fillers.*
  - *Carbon -- grouped by their dominating mechanical properties: ultra-high modulus (UHM), high modulus (HM), intermediate modulus (IM), high strength/high strain (HT) or standard modulus.*
  - *Aromatic polyamide fibres (aramid).*
  - *Glass -- high-performance grades.*
  - *Boron*

# Reinforced plastics/3

## Processing and assembly

- Structural materials are normally supplied as semi-processed forms, the most common of which is “prepreg”,
- Prepregs are limited-life items and therefore strict control of their transport, storage, shelf and working life (also called “out-life”), and of the working environment shall be applied.
- Except where semi-finished products are bought and machined to shape, the processing methods used are an integral part of producing the actual composite material, i.e. the material and the finished part are created at the same time.
- For electronic PCBs, the basic insulation board uses woven glass-reinforced dielectric material. Types G10, G11, FR4, FR5 and polyimide are preferred.
- Procurement of electronic PCBs shall be in conformance with requirements from clause 5 to clause 7 of ECSS-Q-ST-70-11.

# Reinforced plastics/4

## Precautions

- Most reinforced plastics are anisotropic in all their properties.
- In high-performance structural composites the fibre selection controls the mechanical performance (strength or stiffness) and the resin selection.
- The main problems in processing are to ensure as far as possible the absence of voids, to maintain the reinforcement in good mechanical condition
- Assembly methods are of prime importance. Reinforced plastics are sensitive to stress-raisers created by classical fasteners, and hence adhesive bonding is preferred.
- In galvanic couples, carbon-fibre composites usually behave as the cathode causing the metal or coating (often a metal) to corrode.

Hints, Tips & Techniques

Moisture effects

## Hazardous or precluded

- Polyester laminates are not generally suitable for space uses. Some reinforcements appearing in ground electronics, such as cotton and paper, also shall be rejected.
- Composite materials made with polyester containing styrene shall not be used.
- Natural reinforcing materials (e.g. Cotton and paper) shall not be used for electronic composite laminates.

# Reinforced plastics/5

## Effects of space environment

Thermosetting plastics are in general quite stable under space conditions if the comments already made are borne in mind when they are selected.

- Vacuum can lead to outgassing. This does not generally degrade the properties of the polymer, but can raise corona or contamination problems in the vicinity.
- Radiation at levels existing in space is unimportant. In fact, there are some structural reasons for using reinforced organic materials to replace metals where Bremsstrahlung is a problem, i.e. around sensitive electronics.
- Thermal effects are most noticeable, especially problems raised by the thermal anisotropy of most reinforced plastics (expansion varies with the direction).
- Microcracks are formed in thermal cycling which could jeopardise long term properties. The temperature range within which reinforced plastics can be used is similar to that for adhesives of the same chemical nature
- Atomic oxygen etches classical reinforced plastics and can cause damage to thin structures. Since resin is generally etched more quickly than fibres, fibre fragments can be released and contaminate the environment.

# Rubbers and elastomers/1

## Use in spacecraft

There are many applications throughout a vehicle for rubber compounds, e.g. mechanical damping systems, seals and gaskets, electrical insulation, membranes, and bladders for fluids.

## Main categories

The most useful for space applications are based on polybutadiene, polychloroprene, polyurethanes, acrylics, nitrile, ethylene-propylenes, silicones and fluorinated polymers. They appear, for example, as moulded parts, films, coated textiles, extruded insulation, sleeves and shrinkable items. It is practically impossible to obtain details from the manufacturers of the formulations they sell. For critical applications it is sometimes better to use a special formulation tailored to the use with the help of a local compounder.

## Processing and assembly

The user is usually not concerned with rubber processing. This operation is rather complicated and calls for specialized equipment.

## Precautions

Rubbers, depending on their nature and composition and on the type of environmental exposure, have a tendency to "set" under stress, i.e. to suffer a non-reversible deformation, which should be taken into account. Cyclic stresses produce heat in rubber structures; this can lead to thermal degradation. Some rubber mixtures contain products that are corrosive to certain metals.

# Rubbers and elastomers/2

**Designs using rubber and elastomeric materials shall be evaluated for:**

- "set" under stress
- effects of cyclic stress
- environmental resistance
- chemical resistance.

**Rubbers and elastomers used in long-life, manned structures (e.g. ISS) shall be evaluated for their**

- long-term resistance to ageing
- low temperature
- ozone
- heat-ageing
- polymer reversion – loss of cross-linking due to over-vulcanisation
- working fluids
- lubricants and operating media (as a minimum)
- any application- or mission-specific requirements.

**The following materials shall not be used**

- Polysulphide materials
- Chlorinated materials
- Silicone materials in pressurized systems requiring low gas permeability.
- Rubbers and elastomers containing plasticisers or extending oils under vacuum.

# Rubbers and elastomers/3

## Effects of space environment

- Vacuum exposure provokes outgassing, which is particularly due to volatile additives, but also to depolymerization of the base polymer. Both these phenomena lead to a change in mechanical and physical properties of rubber items. The risk of contamination in the vicinity is also high. Outgassing and contamination shall be measured for each formulation: results cannot be generalized safely to a full series, except perhaps in the case of perfluorinated rubbers, which are safe, and for the silicone rubbers, which become generally acceptable only after a long post-cure at 250 ºC.

TABLE IX. – TYPICAL IONIZING RADIATION EFFECTS ON ELASTOMERS

| Elastomer | 25% Damage dose, rad (C) | Predominant effect |
|---|---|---|
| Fluorocarbon | $10^6$ | Chain scission; gas evolution |
| Butyl | $4 \times 10^6$ | Cis-tran isomerization; chain scission |
| Silicone | $4 \times 10^6$ | Usually cross linking |
| Neoprene | $6 \times 10^6$ | Cross linking |
| Nitrile | $7 \times 10^6$ | Cross linking |
| Styrene | $1 \times 10^7$ | Cross linking |
| Natural rubber | $2.5 \times 10^7$ | Cross linking |
| Urethane | $4.3 \times 10^7$ | Chain scission |

- Radiation attacks rubber either by hardening it (cross-linking) or by softening it to form a viscous material. Most common rubbers cannot be used if the ionizing radiation is more than a few Mrad. Polyurethanes and fluorinated rubbers can go up to 10 Mrad. Uses inside the spacecraft are not limited by these features, but care shall be taken in the selection of external applications, particularly because of the added action of solar UV.
- The temperature range for useful rubber properties is rather narrow, from -100 ºC for the best low-temperature silicones to 300 ºC for short exposure of fluorinated rubbers. At low temperature, one observes hardening, stiffening and eventually crazing and crushing. High temperatures provoke decomposition. Some boron-based experimental rubbers exist now for temperatures up to 400 ºC. The temperature resistance is lessened in the presence of incompatible fluids.

# Thermoplastics/1

## Use in spacecraft

*Plastic films appear in:*

- electronic circuitry as insulation, dielectrics and bases for printed wiring;
- multi-layer insulations(MLI)used for thermal-control purposes: basic components;
- inflatable and erectile devices: e.g. "structural" applications;
- flexible second-surface mirrors (solar reflectors).

*Thermoplastics, either plain or reinforced, find multiple uses in spacecraft, including:*

- electrical insulators,
- gaskets,
- small mechanical parts,
- lacing and tie devices,
- sleeves and tubing.

## Main categories

- The main film-forming polymers used are: polyolefins, polyester, fluorinated plastics, polyimides, polycarbonates and acetals. Composite laminated films are commercially available. Uncoloured films are transparent or translucent white to yellow, but dyed and pigmented grades exist in any shade. Classical plastic additives are used in films: plasticisers, antioxidants, antistatic agents.
- Fillers are sometimes used as well as other additives such as antioxidants, plasticizers,UV stabilizers and processing aids.

## Processing and assembly

Films can be cut to size and tailored to intricate shapes. Attachment is made by glueing, sewing or welding (heat sealing, ultrasonic welding), though not all methods are applicable to any one type of film.

# Thermoplastics/2

Structural designs using thermoplastic composite materials shall conform to the requirements of the **ECSS-E-ST-30-series of standards**.

**Thermoplastics** shall be evaluated for the effects of service conditions.

**Polyamide films** shall be evaluated for moisture-related effects.

**The following thermoplastics shall not be used**

- ❑ Neither PVC bulk materials nor PVC plastic films
- ❑ Cellulose and acetate materials in the form of films
- ❑ Polyvinyl acetate
- ❑ Polyvinyl butyrate
- ❑ PTFE when requiring creep resistance.

**For polymer-based materials, environmental exposure shall be assessed.**

*NOTE* *Examples of environmental exposure are:*

- flammability requirements
- electrical requirements
- normal use temperature
- abnormal use temperature excursions
- chemical exposure and humidity levels.

... MORE

# Thermoplastics/3

## Effects of space environment

- Vacuum tends to extract additives from plastics, the consequence of which is a degradation of the properties that were stabilized by the additives (increase in rigidity and fragility when a plasticiser is lost, for example). Plastic films tend to stiffen as a result.

- Radiation: Both UV and particle, can modify plastic materials. The result is frequently discoloration accompanied by evolution of gas and hardening. UV damage is generally limited to a very thin surface layer and can be disregarded when optical properties are not a concern. Radiation is quite damaging for thin polymer films exposed to the total space environment.

- Temperature: High temperatures soften thermoplastics and degrade polymer films. Most plastics harden significantly and become brittle at temperatures lower than their "glass-transition temperature". Fluorinated polymers and polyimides can be used over awide range of temperatures from cryogenic to more than 200 ºC. Thermal cycling can be damaging to some metallized films where tiny metal flakes can loosen and contaminate the vicinity.

- Atomic oxygen attacks thermoplastics and affects polymer films with a carbon/hydrogen skeleton. Protection layers such as SiOx or ITO can be applied in most cases. FEP is sensitive to the combination of ATOX and UV light.

...MORE

# Thermoset plastics/1

## General

- Synthetic polymers are formed by addition or condensation polymerization. The length of the polymer chains, usually measured by molecular weight, has a very significant effect on the performance properties and a profound effect on processibility.

## Use in spacecraft

- Thermosetting resins can be used without any reinforcement as bulk plastics or as foams.
- Fibre-reinforced plastics normally use a thermosetting matrix to support the fibres and allow load-transfer. These can be structural or semi-structural parts.
- A further use for composites is as electronic circuit board substrate materials

# Thermoset plastics/2

## Processing and assembly

- Mixed resins have a limited “pot life” and shall be used before the viscosity increases during cure. Debubbling processes are used to remove air bubbles introduced during mixing or pouring

## Effects of space environment

- Before using thermosetting plastics, a full evaluation of the effects of the service conditions shall be performed. Polyester resins shall not be used for space applications.
- Vacuum can lead to outgassing. This does not generally degrade the properties of the plastic, but can raise corona or contamination problems in its vicinity.
- Radiation at levels existing in space is unimportant.
- Thermal expansion can be quite large in unreinforced plastics. Cracks are formed in thermal cycling which could jeopardize long-term properties.
- Atomic oxygen etches thermosetting plastics. Fragments can be released which contaminate the environment.

TABLE VII. – TYPICAL EFFECTS OF IONIZING RADIAT[ION]
ON THE THERMOSETTING PLASTICS

| Material | Parameter | Dose, rad (C) | Effects |
|---|---|---|---|
| Unfilled phenolic | Tensile and impact strength | $5 \times 10^7$ | Slight reduction |
| | | $3 \times 10^8$ | 50% reduction |
| Epoxy | Flexural strength | $10^8$ | ≥80% of original when cured with aromatic agents; 50% to 80% of original when cured with aliphatic curing agents |
| | | $10^9$ | 50% to 80% of original when cured with aromatic agents; <10% of original, when cured with aliphatics |
| Phenol-formaldehyde with asbestos filler | Tensile strength | $3.9 \times 10^9$ | 25% reduction |
| Polyurethane foam sandwich construction | Ultimate flexural strength; flatwise compressive strength | $10^9$ | No changes observed |

Hints, Tips & Techniques

[Thermoset plastics or PCBs](Thermoset plastics or PCBs)

# Wires and cables

General requirements for **wires and cables** shall be in conformance with requirements from ESCC Generic Specifications **3901, 3902 and 3903**.

- The materials for coaxial cable assembly shall be selected in conformance with requirements from clause 5 of ECSS-Q-ST-70-18.

- For wires with insulating material made of PTFE or other non-treated fluorocarbons, the supplier shall demonstrate that workmanship avoids cold flow.

  *NOTES* *Examples of good practices are controlled bend radii, no contact with sharp objects, wire fixation rules.*

  *The use of irradiated ETFE-Ethylenetetrafluroethylene (TEFZEL) wires with improved characteristics against cold flow is preferred.*

**Hints, Tips & Techniques** Cold-flow of teflon

# Miscellaneous non-metallic materials/1

## General

- This covers ceramic-type materials used for space engineering applications.

  These materials are generally known as advanced technical ceramics (ATCs): a term that encompasses a wide range of material types used in engineering applications for mechanical, electrical or thermal characteristics or some combination thereof. It also covers "Functional" ceramics, e.g. piezoelectric.

## Use in spacecraft

- Structural uses of ceramics are largely limited to those applications where extreme service temperatures or aggressive environmental conditions preclude the use of any other material (e.g. re-entry surfaces of manned or reusable space vehicles). Ceramics and glasses are used in electrical and electronic equipment subassemblies (electrical insulators).

## Precautions

- The brittle characteristics of ceramics and glasses, along with the scarcity of reliable characterization of their properties and in-service performance mean that they are not among the routine structural materials applied to spacecraft.

## Hazardous or precluded

- Specialist safety equipment and procedures shall be applied when operators are working with ceramic fibres and fine powders or processing methods that produce dust and debris.

# Miscellaneous non-metallic materials/2

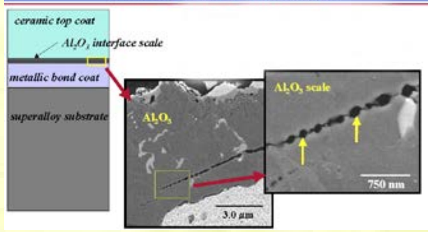
## Effects of space environment

- Vacuum can provoke outgassing of residual processing-related materials or moisture. For fibrous materials a baking process prior to assembly shall be performed. Application of coatings also includes a baking out process. Shaped ceramic parts are often sealed (glazed) to prevent outgassing.
- Radiation at the levels experienced in space, does not affect the characteristics of ceramics.
- Temperature: Ceramics are selected for their high-temperature and service environment resistance. Aggressive environments can attack some ceramics.
- Thermal-cycling can promote cracking in solid shapes and coatings. Differences in CTE between the substrate and the applied coating can promote cracking and spalling of the coating.
- Atomic oxygen: there is no evidence that ceramics are susceptible to ATOX.

TABLE X. – TYPICAL TEST RESULTS OF RADIATION EFFECTS ON CERAMICS

| Material | Property | Fluence for appreciable change | Effects |
|---|---|---|---|
| BeO | Density | $10^{19}$ n/cm$^2$ (E > 1 keV) | Decreases $10^{-2}$% to $10^{-1}$% |
| | Thermal conductivity | $10^{19}$ n/cm$^2$ (E > 1 keV) | Large decrease; to ⅓ initial value by $10^{20}$ n/cm$^2$ |
| | Modulus of elasticity | $5 \times 10^{19}$ n/cm$^2$ (E > 1 keV) | Decreases by as much as 50% |
| | Compressive strength | $10^{19}$ n/cm$^2$ (E > 1 keV) | Substantial decrease with increasing dose |
| | Mechanical integrity | $10^{20}$ n/cm$^2$ (E > 1 keV) | Cracking; powdering by $10^{21}$ n/cm$^2$ |
| $Al_2O_3$ | Density | $10^{19}$ n/cm$^2$ (E > 1 keV) | Decreases about 1% by $6 \times 10^{20}$ n/cm$^2$ |
| | Thermal conductivity | $10^{19}$ n/cm$^2$ (E > 1 keV) | Decreases to less than ½ initial value |
| | Thermal conductivity | Co-60 gammas; $10^6$ rad ($Al_2O_3$) | Decreases to 50% of initial value by $3 \times 10^6$ n/cm$^2$ |
| MgO | Thermal conductivity | $3 \times 10^{19}$ n/cm$^2$ (E > 1 keV) | Decreases 40% |
| $B_4C$ | Mechanical integrity | $10^{20}$ thermal n/cm$^2$ | Cracking and eventual disintegration |

**Failure mechanisms in ceramic coatings and thin films are poorly understood**



# SUMMARY

# EFFECTS OF SPACE ENVIRONMENT

# Effects of space environment -Vacuum

- Vacuum presents no special problems to metals, however there are some exceptions
- copper-zinc alloys are generally plated
- Fretting is a particular concern for titanium alloys.
- Vacuum affects volatile metals, such as cadmium and zinc
- All metals in contact under vacuum conditions or in inert gas have a tendency to cold weld. This phenomenon is enhanced by mechanical rubbing or any other process which can remove oxide layers.
- Vacuum exposure of polymer materials results in outgassing due mainly to solvent residues
- Vacuum exposure of potting and sealant materials leads to problems analogous to those of conformal coatings
- Thermosetting plastics are in general quite stable in vacuum can lead to outgassing, but can raise corona or contamination problems in the vicinity
- A baking process prior to assembly is sometimes helpful

# Effects of space environment - Radiation

- Radiation of reinforced plastics at levels existing in space is unimportant for metals, reinforced plastics, thermoset plastics and ceramics.
- Particle radiation at the level encountered in space is not harmful for adhesives, which are in any case protected by the items (adherends) they are bonding. Only coatings on satellite surfaces experience exposure to radiation, often combined with UV. UV radiation can darken optical adhesives. In this regard silicones are superior to epoxies. UV and particle radiation can both increase the outgassing rate of adhesives.
- Radiation is the most damaging environmental factor for paints used on the exterior of spacecraft. Particles and UV tend to embrittle paint layers. Their main effect, however, is the degradation of optical properties
- Under radiation, oils have a tendency to evolve gases or corrosive products, to foam or to gel, but this needs rather high doses. Dry lubricants are quite resistant to all types of radiation.
- Radiation exposure of potting and sealant materials is normally minimal, since they are mostly used inside modules.
- Radiation attacks rubber either by hardening it (cross-linking) or by softening it to form a viscous material.
- Radiation: Both UV and particle, can modify plastic materials. The result is frequently discoloration accompanied by evolution of gas and hardening.

# Effects of space environment - Temperature

- Temperature problems on metals and alloys are similar to those encountered in technologies other than space, but are complicated by the difficulty of achieving good thermal contact in vacuum and the absence of any convective cooling.
- Thermal shock can lead to fracture in inorganic glasses. Organic glasses soften at quite low temperature (80 ºC to 100 ºC frequently) and have rather high expansion coefficients.
- High temperature degrades adhesives. Polyimide can be used up to more than 300 ºC; the best epoxies are normally limited to 170 ºC. Low temperature stiffens adhesives and causes brittle bonds.
- Low temperatures stiffen the adhesive and backing. Polyimide and Teflon based tapes can still be used as well as metal.
- High temperature degrades paints ("smoking" under ascent conditions). In this respect, silicones and silicates are best.
- Temperature effects shall be considered. On the low side, potting and sealants shrink and become more rigid. On the high side, chemical degradation can occur, particularly around power-dissipation component.
- Thermal effects are most noticeable, especially problems raised by the thermal anisotropy of most reinforced plastics.
- The temperature range for useful rubber properties is rather narrow, from -100 ºC for the best low-temperature silicones to 300 ºC for short exposure of fluorinated rubbers.
- Thermal expansion can be quite large in unreinforced plastics.
- Temperature: Ceramics are selected for their high-temperature and service environment resistance

# Effects of space environment – Thermal Cycling

- Thermal cycling leads to failure of the adhesive bond when the expansion coefficients of the adherents and adhesives are not matched and when the adhesive is not flexible enough to cope with the strain.
- Thermal cycling on pressure-sensitive adhesives is in general not a problem since these are quite flexible except at low temperatures.
- Thermal cycling on potting material due to the switching on and off of equipment can lead to cracking and debonding.
- Microcracks in reinforced plastics are formed in thermal cycling which could jeopardise long term properties.
- Thermal-cycling can promote cracking in solid shapes and coatings. Differences in CTE between the substrate and the applied coating can promote cracking and spalling of the coating.

# Effects of space environment – Atomic Oxygen

- Atomic oxygen in low earth orbit does not degrade metals and alloys except for the following: silver, osmium and to some extend copper.
- Atomic oxygen can attack organic glasses.
- Atomic oxygen is only applicable to adhesives (such as those on solar-cell and panel assemblies) which can be attacked. Exposed coatings are susceptible: silicones are resistant.
- Atomic oxygen in low orbit can attack polymer tapes.
- Atomic oxygen in low Earth orbit attacks paints. Those with a silicone and perfluorinated base seem better. Silicate bases are resistant.
- Atomic oxygen can degrade $MoS_2$ and similar solid lubricants which are exposed to it.
- Atomic oxygen etches classical reinforced plastics and can cause damage to thin structures. Since resin is generally etched more quickly than fibres, fibre fragments can be released and contaminate the environment.
- Atomic oxygen attacks thermoplastics and affects polymer films with a carbon/hydrogen skeleton. Protection layers such as SiOx or ITO can be applied in most cases. FEP is sensitive to the combination of ATOX and UV light.
- Atomic oxygen etches thermosetting plastics. Fragments can be released which contaminate the environment.
- Atomic oxygen: there is no evidence that ceramics are susceptible to ATOX.

# Limited Shelf Life Materials

## ECSS-Q-ST-70-22C: The control of limited life materials

- Material applications involving a chemical reaction or a physical process can have final properties that are sensitive to the exact composition of the reactants, in other words the final properties can vary with the reactants' age and storage conditions.

- Shelf life is defined as the time during which a material can be processed to produce final properties with consistently stable parameters.

- Limited shelf life items shall be clearly identified and handled to avoid the possibility of over-aged material being used.

# Control of material life

**Procurement Documentation**

- Date of manufacture, required storage conditions, shelf life of products

**Identification**

- Clearly identified with date of manufacture, shelf life…
- Quantities split from a batch shall be fully traceable to that batch (same date and life indications)

**Storage**

- Stored in a nominal clean area (22 +/- 3 °C) and 55 +/-10 %RH unless otherwise specified by manufacturer or supplier.
- A wide range of pre-impregnated composites, adhesives etc requires storage at lower temperature to preserve shelf lives.

**Hints, Tips & Techniques**

Shelf Life of Organic Materials

# Shelf Life Assessment

**Stated by Manufacture/Supplier**

- acceptance of liability?

**Basics Rules**

- incoming inspection
  - *get shelf life/certification*
  - *measure properties*
    - *properties according to procurement specifications*
    - *relevant to the application*

**Handling**

- decant materials
- minimize openings of container

**critical applications**

- reduce shelf life

**low temperature materials**

- effects of RT on materials stored at low temperature
  - *record time at RT*
  - *allow time to reach RT*

# Extension of shelf-life ( Re-certification)


- Re-certification is permitted on condition that a material that has exceeded its shelf life shall be submitted to the relevant tests, and if successful, the material shall be given an extension of shelf life equal to half the initial shelf life.
- Re-certification may be performed one further time on a case by case basis, depending on the product, application, storage and user experience. This second extension of shelf life shall be half of the first extension.
- Ensure that its properties are still within the limits, taking into account tolerances.
- Choice of properties to be measured
  - *based on a combination of*
    - *final application*
    - *processing.*
- Re-testing shall include properties specified in the procurement specification or performed during incoming inspection.

# Acceptance criteria in case of Re-certification testing

## Examples

- Properties related to individual components and curing process
  - *Molecular weight distribution*
  - *Molecular structure (IR)*
  - *degree of cure*
  - *cure exotherm and glass transition temperature*
  - *measurement of pot life*
  - *measurement of resin flow characteristics*
  - *Measurement of degree of tackiness*

- Properties related to the material application
  - *Adhesive (e.g. lap shear testing), coatings (peel and pull strength)*
  - *Conformal coatings (hardness, adhesion),*
  - *Potting compounds (hardness, electrical or thermal characteristics)*
  - *Fibre-reinforced materials resin/fibre/void content, mechanical properties (tensile strength or flexural strength).*

# Part 3 - Processes

# Processes used in Aerospace Engineering

Most aerospace engineering processes are used in the manufacture and assembly of spacecrafts. Some processes are described which can be considered to be variations of an approved process but which can have a profound affect on the material performance or integrity of an assembly.

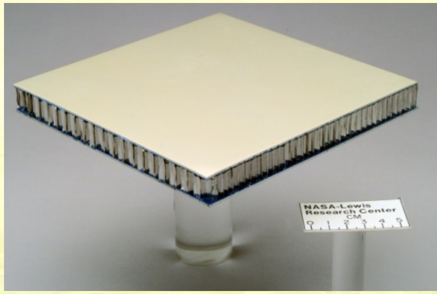
**Processes shall be chosen from already verified processes**

- processes covered by space agencies or other governmental organization certification for identical conditions of use;
- processes for which satisfactory evaluation and verification results are obtained on samples representative of the application with a sufficient margin as regards conditions of use;
- processes already used by the same supplier for other space programmes in the same conditions of use.

The ECSS-Q-ST-70-series of standards provides precise requirements for each process.

- *Processes using limited-life materials shall conform to the requirements of ECSS-Q-ST-70-22.*
- *Operators shall be trained for all processes. Inspectors shall be trained and certified for all processes. Certification shall be reassessed at least every two years.*
- *All training and certification shall only be performed at a school or by certified instructors in conformance with customer requirements*
- *standards relating to the occupational health of operators working with processes resulting in exposure to vapours, dust or debris shall be implemented under strict control.*

# Adhesive bonding



Process conditions and environments shall be specified and strictly controlled during all stages of adhesive bonding, i.e. during preparation, application, curing or drying, inspection or testing and storage.

**Surface Preparation:**

- ❑ Surfaces to be bonded shall be cleaned and prepared by a surface treatment process. (e.g. abrasion and chemical etching)
- ❑ Prepared surfaces shall be protected from contaminants.
- ❑ Prepared surfaces shall be stored in controlled environment.

**Good toughness and peel strength** are applicable characteristics for structural adhesives.

- ❑ Therefore the supplier shall demonstrate that the bonded primary structural joints show cohesive failure modes in shear testing.

For guidelines on structural adhesive bonding see **ECSS-E-HB-32-21**

# Composite manufacture

- Process conditions and environments shall be specified and strictly controlled during all stages of composite manufacture
  - *i.e. storage and handling of raw materials, during preparation, application, curing, inspection or testing and storage of finished parts.*
  - *See also ECSS-E-HB-32-20 and ECSS-E-ST-08C*

- Tooling materials shall be selected to ensure thermal-expansion matching between the composite over the processing temperatures.
  - *The rigidity of the tooling is also an important parameter.*

**Hints, Tips & Techniques**

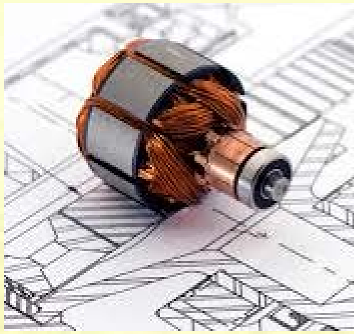
Composite design allowables

Composite materials - laminates

Final integration of RUAG Payload Fairings in Emmen, Switzerland. Photo: RUAG Space

# Encapsulation and moulding

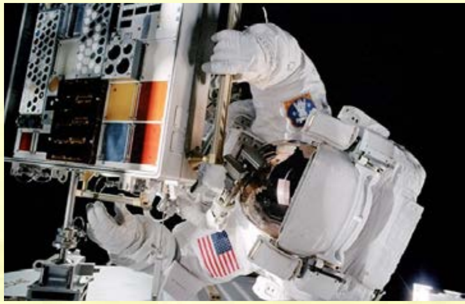
- Process conditions and environments shall be specified and controlled during all stages of encapsulation, moulding and varnishing.
  - *i.e. during preparation, application, curing or drying, inspection or testing and storage.*



- In electronic assemblies, when potting is used for encapsulation it shall allow rework or repair.
- In electronic assemblies conformal coating shall be used on populated boards.

# Painting and coating

A satellite with a passive thermal control system mainly uses thermal coatings and paints to maintain temperatures within safe operating limits. Satellite coatings, exposed to harsh space environments such as ultraviolet (UV) radiation and atomic oxygen (AO), undergo physical damage and thermal degradation.



**ECSS-Q-ST-70-31C: Application of paints on space hardware**

- *Pretreatment processes (e.g. cleaning, abrasion and priming) for the surfaces to be painted shall be selected and controlled to ensure acceptable adhesion of the paint to the substrate.*
  - *Phosphating, used as a pre-treatment prior to painting on ferrous materials.*
- *Painting shall be carried out in a controlled environment that has equipment for the control and removal of dust, solvents and chemical vapours released during processing.*
- *Contamination of painted surfaces shall be prevented because they are difficult to clean.*
- *Anodized surfaces for pre-treatment of painting shall not be sealed.*

**Hints, Tips & Techniques** Painting

# Cleaning

**Cleaning processes** are applied at various stages throughout the sequence of manufacturing processes, e.g. remove of cutting oils, fluxes used for joining processes, removal of inspection media (e.g. gels and dyes); fingerprints, dust and debris.

**To help insure a low contamination level on flight hardware**, particular attention must be given to the state of cleanliness of the cleaning solvents and the implements that are used. Quite often a solvent that is used for cleaning becomes a source of contamination.

- ❑ Cleaning processes shall not degrade the base material, any applied surface coating or finishes (e.g. paint and varnish); or that of adjacent parts
- ❑ Cleaning processes shall be used to remove all chemical residues produced during manufacture and assembly (e.g. cutting oils and dye-penetrants).
- ❑ Foreign materials containing sulphur (e.g. oils, grease and cutting lubricants) shall be removed from superalloys prior to heat treatment or high-temperature service.
- ❑ The use of cleaning fluids and other chemicals that are detrimental to the performance of titanium or titanium alloy parts shall not come in contact with these metals.
- ❑ Surfaces that have had tapes applied for temporary reasons shall be carefully cleaned after the tape is removed
- ❑ For electronic assemblies, only approved solvents and cleaning processes that conform to the requirements of ECSS-Q-ST-70-08 shall be used.

**Hints, Tips & Techniques** Cleaning of Flight Cable Assemblies

# Welding and brazing

**In the aerospace industry the following welding techniques shall be considered:**

- tungsten inert gas (TIG);
- resistance welding (induction, spot, seam);
- metal inert gas (MIG);
- diffusion welding;
- plasma-arc welding;
- laser welding;
- electron beam welding (EB);
- friction stir welding

Hints, Tips & Techniques

Titanium welding

Welding techniques acceptable to aerospace engineering shall be selected with due consideration of:

- the parent metals to be joined;
- the effect of the welding process on material properties in the fusion zone, heat affected zone and parent metal;
- the filler material.

**Each operator** shall be trained and certified along with the applicable welding equipment for specific welding tasks.

**In long-term, manned structures**, alloyed titanium shall be welded using alloy weld filler wire and not commercially pure (CP) filler wire.

**Brazing** usually refers to joining with alloys of copper, silver and zinc. It is used where stronger joints or an increase in heat resistance is specified compared with soldered joints.

# Crimping/1

Fabrication processes and controls used in crimping of electrical terminations, terminal lugs, splices and two-piece shield termination rings shall conform to the requirements of ECSS-Q-ST-70-26.

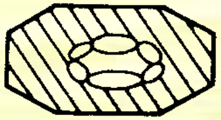


*Figure 1 - Confined irregular-octagon crimp (compactive)*

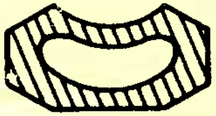


*Figure 2 - Dimpled confined octagon crimp (compactive)*

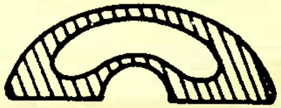
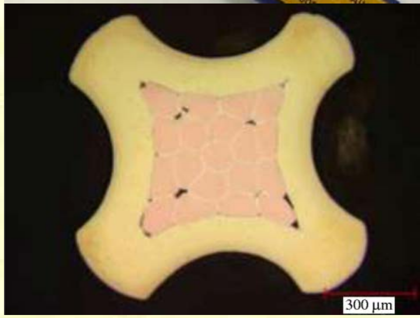


*Figure 4 - Semicircular one- or two-indent crimp (dispersive)*



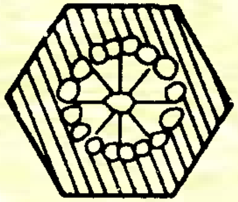



*Figure 3 - Regular-hexagon crimp (compactive)*

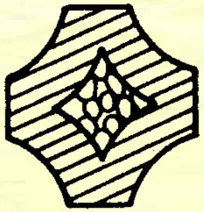
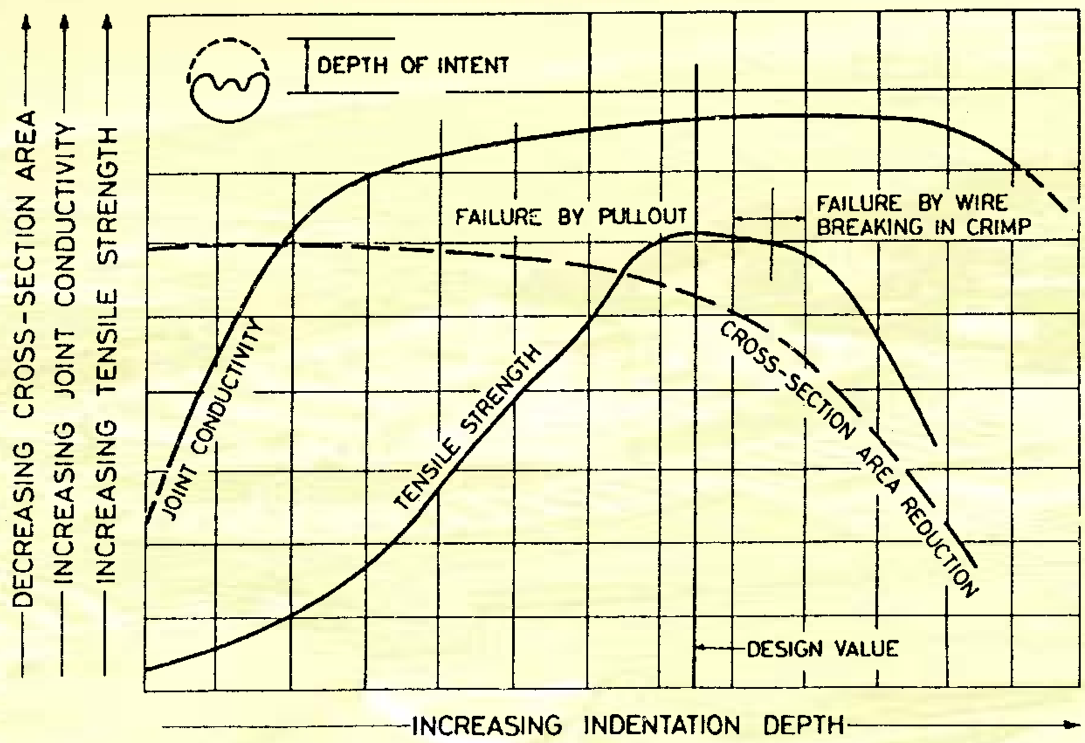


*Figure 5 - Four-indent crimp (dispersive)*

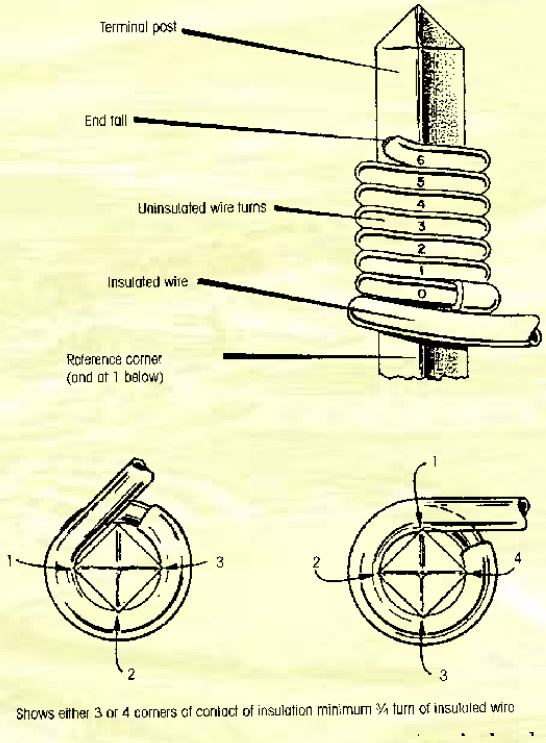
# Crimping/2

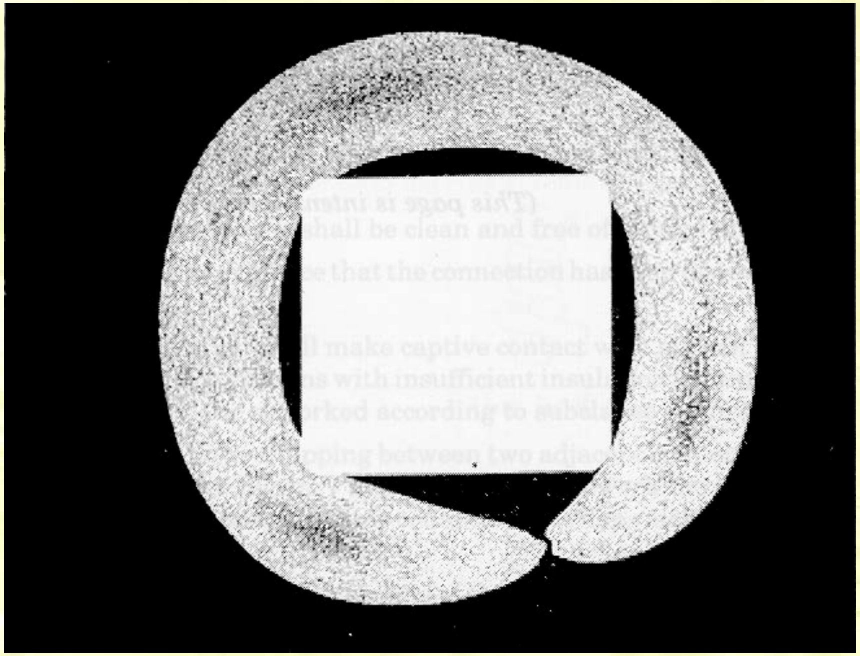



Typical plots showing variation in crimp termination characteristics with increasing indentation depth

# Wire-wrapping

Fabrication processes and controls used in wire wrapped electrical connections shall conform to the requirements of ECSS-Q-ST-70-30.



Satisfactory wire wrap cross-section of copper alloy wire wrapped onto a 0.64 mm square terminal post

# Soldering/1

Fabrication processes and controls used in soldering of electrical connections shall conform to the requirements of ECSS-Q-ST-70-08.

## solder flux

- rosin-based
  - *pretinning: mildly activated (fully activated in cases of poor solderability)*
  - *assembly: pure rosin flux*
- water-soluble acid flux
  - *only for pretinning when rosin-based fluxes are inadequate. (immediate cleaning after use is required)*

## solder alloy

- 63 tin solder (63 Sn, 37 Pb)
- 62 tin silver-loaded solder (62 Sn, 2 Ag, 36 Pb)
- 60 tin solder (60 Sn, 40 Pb)
- 96 tin silver solder (96 Sn, 4 Ag)
- 75 Indium lead (75 In, 25 Pb) – smd only
- 70 Indium lead (70 In, 30 Pb) – smd only
- 10 tin lead (10 Sn, 90 Pb)

# Soldering/2

| Solder type | Melting range (°C) | | Uses |
|---|---|---|---|
| | Solidus | Liquidus | |
| 63 tin solder (eutectic) | 183 | 183 | Soldering printed circuit boards where temperature limitations are critical and in applications with an extremely short melting range. Preferred solder for surface mount devices. |
| 62 tin silver loaded | 179 | 190 | Soldering of terminations having silver and or silver palladium metallization. This solder composition decreases the scavenging of silver surfaces. |
| 60 tin solder | 183 | 188 | Soldering electrical wire/cable harnesses or terminal connections and for coating or pretinning metals. |
| 96 tin silver (eutectic) | 221 | 221 | Can be used for special applications, such as soldering terminal posts. |
| 75 indium lead | 145 | 162 | Special solder used for low temperature soldering process when soldering gold and gold-plated finishes. Can be used for cryogenic applications. |
| 70 indium lead | 165 | 175 | For use when soldering gold and gold-plated finishes when impractical to degold. |
| 10 tin lead | 268 | 290 | For use in step-soldering operations, to avoid reflow of initial solder on making the second joint (limited to connections internal to devices). |

# Surface treatments

**Surfaces of materials are often treated for the following reasons:**

- To improve properties, e.g. nitriding, carburising and shot-peening.
- To increase resistance to an environment, e.g. corrosion,moisture- and diffusion barriers, high-temperature and ATOX.
- To provide particular characteristics, e.g. thermo-optical properties.

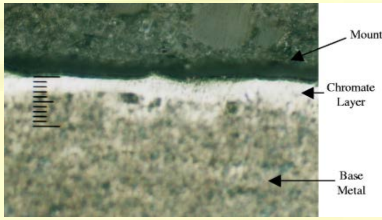
Some surface treatments are also included in other processes, e.g. preparation prior to painting and adhesive bonding to improve adhesion.

## Anodizing

- Anodizing is an electrolytic process for thickening and stabilizing the inherent oxide films on metal substrates. Anodizing is widely used on aluminium alloys and can be applied to magnesium and titanium. The anodized layer is electrically non-conductive.

Hints, Tips & Techniques

Quality of anodic coatings



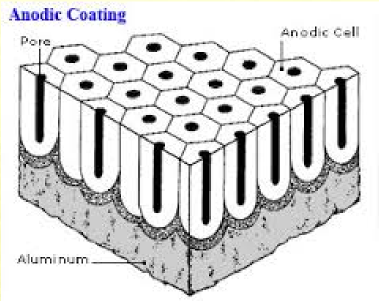

## Chemical conversion

- Chemical conversion processes involve the absorption of a protective metal oxide film into an existing oxide film. The resulting surface finish can be electrically conductive or non-conductive.

# Plating/1

**Thick coatings:**

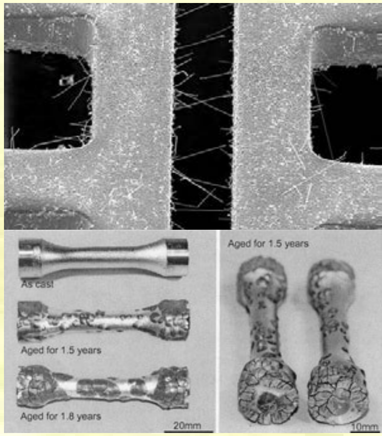
Coatings with such a thickness that the properties of the substrate do not significantly influence the coating properties. The thickness is generally above approximately 125 µm




- Platings with open porosity shall not be used.
- Platings with open porosity shall be sealed.
  - *Porous platings fail to provide adequate corrosion protection and can act as sources of contamination. E.g. Silver plated copper wires*
  - *Plated layers of less than 1 µm thickness tend to be porous.*
- Plating of terminals used in electronic assemblies, shall satisfy the requirements from clause 5 to clause 15 of ECSS-Q-ST-70-08.
- All platings shall be blister tested by baking during a minimum of 30 minutes at a maximum temperature seen in production or qualification phases.
- An approved post-plating baking process shall be applied to materials with known or suspected susceptibility to hydrogen embrittlement.

# Plating/2

- If Nickel plated copper strands are used the supplier shall demonstrate that solderability after ageing
- Tin-plated finishes electroplated other than pure tin-coated wires shall be either re-flowed or excluded.
- Pure tin finish with more than 97 % purity shall not be used.
  - *This is due to the possibility of whisker growth and transformation to grey tin powder at low temperatures.*
- Silver and osmium coatings shall not be used on external surfaces of space systems exposed to atomic oxygen in low Earth orbit.
- Cadmium and zinc shall not be used as surface treatment for flight hardware.



# Machining

Numerous different machining operations are used for aerospace materials.

Special tools and processes are applied to the machining of composites (laminates and honeycomb panels) to prevent damage to the materials (e.g. delamination, break-out on the backface and distortion of the core) that degrade the material integrity.

- ❑ Machining (e.g. drilling or grinding) of martensitic steel hardened to ≥1250 MPa UTS shall be avoided. When machining cannot be avoided, carbide-tipped tooling and other techniques necessary to avoid formation of untempered martensite shall be used.

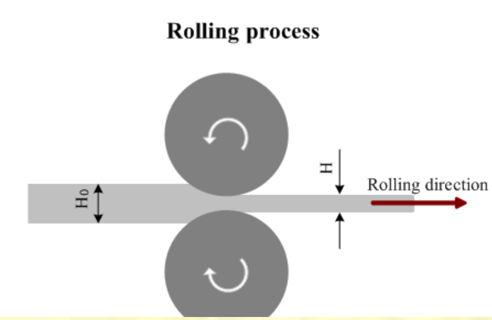

- ❑ Appropriate safety equipment shall be provided for operators processing beryllium and beryllium-copper alloys.

# Metal forming/1

Although forming processes are applied to metallic-, polymer-based and ceramic-type materials, this applies only to metal forming.

Metal forming processes generally form two main groups:

- “Warm” or “hot”: rolling, forming, various forging techniques.
- “Cold”:
  - *primary forming by various sheet metal techniques, e.g. deep drawing and bending, or*
  - *finishing operations, e.g. cold forging and cold rolling.*




Process selection is influenced by the material to be formed, its specific composition and mechanical properties plus the requirements of the finished formed part, e.g. shape, size, strength and appearance.

# Metal forming/2

**Forging**

- The mechanical properties are optimum in the direction of material flow during forging.

**Sheet metal**

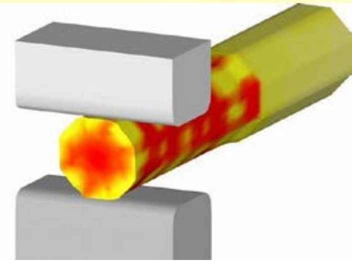
- The amount of deformation possible without fracture is linked to the material ductility. For materials which harden as a result of cold working normally an annealing process shall be applied to achieve the final shape without cracking or fracture. Forming is often followed by a final heat-treatment to restore the mechanical properties of the finished part.

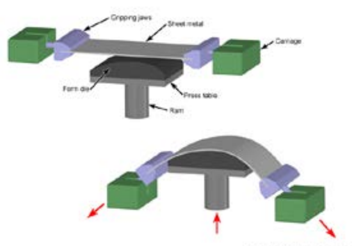
**Superplastic forming**

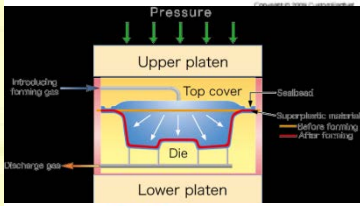
- Superplastic forming processes can only be applied to specific grades of materials designed to behave superplastically

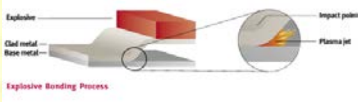
**Explosive forming**

- Explosive forming is a rapid process for producing small quantities of large, fairly simply-shaped parts. It is applied to materials retaining acceptable ductility at high plastic deformation rates.
- Explosive forming is also used as a cladding process and for joining dissimilar metals that cannot be joined effectively by any other means.

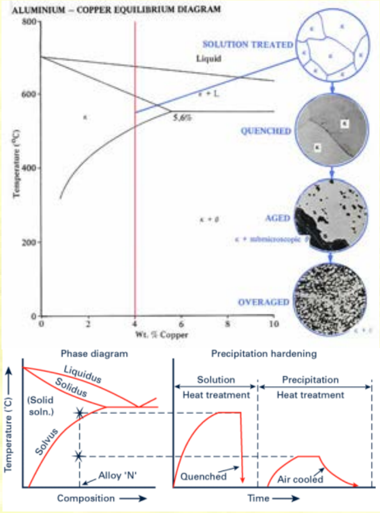






# Heat treatment




Heat treatment involves the use of heating or cooling, normally to extreme temperatures, to achieve a desired result such as hardening or softening of a material. Proper heat treating requires precise control over temperature, time held at a certain temperature and cooling rate. Heat Treatment is used not only for increasing the strength of materials but also to improve machining, formability and ductility to enhance the characteristics for manufacturability.

It involves treatments such as annealing, normalizing, stress relieving, aging, quenching, tempering and hardening

- ❑ Heat treatment of metals and alloys shall conform to national or international specifications for aerospace applications.
- ❑ Heat treatment procedures that are not included in any national or international specifications shall be approved by the customer prior to their use.
- ❑ Processes shall be selected and controlled to avoid the dezincification of brasses.
- ❑ Superalloys shall be cleaned to remove all foreign materials containing sulphur (e.g. oils, grease and cutting lubricants) prior to heat treatment.

**Hints, Tips & Techniques** Some definitions

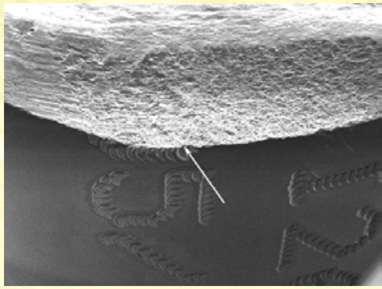
# Special fabrication

Special fabrication: processes developed specifically for the programme

- Each process shall conform to the requirements of ECSS-Q-ST-70.

# Marking

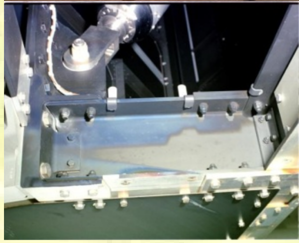
- Marking of spacecraft piece parts for identification purposes shall not result in the degradation of any mechanical or surface characteristics.

**For example**:

- *Solvents in inks should not attack substrates.*
- *Inks shall have low outgassing properties, see ECSS-Q-ST-70-02.*
- *Engraving of painted, plated or coated parts shall be avoided.*
- *Stamping resulting in stress-raisers shall be avoided.*

# Miscellaneous processes



## Casting

- Quality control and inspection procedures of all process related factors influencing the performance and integrity of castings shall be implemented and controlled to all of them.
  - *Many process-related factors influence the performance and integrity of castings, for example, inclusions, gas bubbles and porosity, shrinkage.*

## Bolted joints

- Bolts offer the greatest strength for mechanical fastened joints, providing that they are not over-tightened and no damage occurs during assembly. For guidelines on the design of bolted joints, see ECSS-E-HB-32-23.

## Riveted joints

- Riveted joints are permanent and are normally sealed against the environment. Disassembly can only be done by drilling out the rivets. Consequently, riveted joints cannot be used where access is used, or expected, to internal or adjacent parts of the structure. For guidelines on riveted joints in composites, see ECSS-E-HB-32-20.

## Rigid, flexible and rigid-flex printed circuit boards

- clause 5 to clause 9 of ECSS-Q-ST-70-10 and from clause 5 to clause 7 of ECSS-Q-ST-70-11.

## Printed circuit assemblies

- clause 5 to clause 15 of ECSS-Q-ST-70-08, from clause 5 of ECSS-Q-ST-70-07 and from clause 5 to clause 16 of ECSS-Q-ST-70-38 and clause 4 of ECSS-Q-ST-70-28.

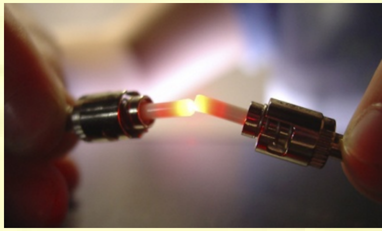
# Miscellaneous processes

## Wire and cable assemblies

- Tin-plated finishes electroplated other than pure tin-coated wires shall be either re-flowed or excluded.
  - *Pure tin on wires is produced by immersing the wire into liquid tin (this does not promote whisker growth).*
- Silver-plated wires shall be procured in conformance with requirements from the ESCC Generic Specification 3901.
  - *Silver-plated copper strands are the preferred conductors. These are suitable for soldering and crimping.*
- Solder sleeves shall not be used in flight hardware due to their retention of solder flux and inspection difficulties.

## Fibre optic assemblies

- Fabrication processes and controls shall be established for terminations, joining fibre optic cable assemblies and their installation and submitted to the customer for approval.
  - *ECSS-Q-TM-70-51 contains guidelines*



# Inspection Procedures

- Many different inspection procedures are employed for spacecraft materials and processes are numerous and varied. They are used at all stages of the manufacturing process and form part of the overall quality assurance plan.

- A full and comprehensive evaluation shall be performed of the material, the part, classification of defects and establishing their acceptance and rejection criteria, in order to inspection procedures.

  *NOTE: The ability to inspect a part is a critical part of the design development.*

- Some inspection procedures can be relatively straightforward, e.g. visual inspection by unaided eye; whereas others are complex and need equipment that is regularly maintained and calibrated to recognized, approved standards, e.g. eddy current and ultrasonic.

# Bibliography

**The following sources were used to compile the M&P course:**

- ECSS-Q-ST-70 series of standards
- ECSS-E-ST-32-08
- Spacematdb.com (Space Materials DataBase)
- ESMAT website (www.esmat.esa.int)
- NASA Materials Engineering Branch Tips
- Google for pictures

# END