ECSS-Q-70-71A rev. 1
18 June 2004

EUROPEAN COOPERATION
ECSS
FOR SPACE STANDARDIZATION

Space product assurance

Data for selection of space materials and processes

ECSS Secretariat
ESA-ESTEC
Requirements & Standards Division
Noordwijk, The Netherlands

Published by:	ESA Publications Division ESTEC, P.O. Box 299, 2200 AG Noordwijk, The Netherlands
ISSN:	1028-396X
Price:	€ 30
Printed in:	The Netherlands

Foreword

This Standard is one of the series of ECSS Standards intended to be applied together for the management, engineering and product assurance in space projects and applications. ECSS is a cooperative effort of the European Space Agency, national space agencies and European industry associations for the purpose of developing and maintaining common standards.

Requirements in this Standard are defined in terms of what shall be accomplished, rather than in terms of how to organize and perform the necessary work. This allows existing organizational structures and methods to be applied where they are effective, and for the structures and methods to evolve as necessary without rewriting the standards.

The formulation of this Standard takes into account the existing ISO 9000 family of documents.

This Standard has been prepared by editing ESA PSS-01-701, reviewed by the ECSS Product Assurance Panel and approved by the ECSS Steering Board.

This revision 1 cancels and replaces ECSS-Q-70-71A, dated 27 February 2004. The revision was made to correct subclause 6.17.6 c. and to implement editorial changes.

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Introduction

The purpose of this Standard is to assist spacecraft and payload designers in their preliminary selection and application of materials and processes by orientating designers and members of project groups towards well-known products that are currently available and that have been used successfully in past spacecraft programmes.

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Scope

General requirements for materials and their associated processes are provided in this Standard along with the environmental requirements for materials application in space.

Annex A (informative) contains guidelines for each class of material used in the declared materials list (DML) in ECSS-Q-70 and factors to be considered for process selection.

Annex B (informative) contains data sheets for materials that can be considered for use in space applications i.e. materials that were used successfully for some applications in space systems and associated equipment. Data sheets contain: property data - either from manufacturers or determined by test, and comments on material application in space conditions. The data sheets are grouped by their DML material class, using the class number, e.g. Class 1: Aluminium and Al-alloys; and Class 10: Adhesives, coatings and varnishes.

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Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this ECSS Standard. For dated references, subsequent amendments to, or revisions of any of these publications do not apply. However, parties to agreements based on this ECSS Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references the latest edition of the publication referred to applies.

ECSS-P-001	Glossary of terms
ECSS-Q-00	Space product assurance — Policy and principles
ECSS-Q-20	Space product assurance — Quality assurance
ECSS-Q-40	Space product assurance — Safety
ECSS-Q-70	Space product assurance — Materials, mechanical parts and processes
ECSS-Q-70-01	Space product assurance — Contamination and cleanliness control
ECSS-Q-70-02	Space product assurance — Thermal vacuum outgassing test for the screening of space materials
ECSS-Q-70-03 [1)]	Space product assurance — Black anodizing of aluminium using inorganic dyes
ECSS-Q-70-04	Space product assurance — Thermal cycling test for the screening of space materials and processes
ECSS-Q-70-05 [1)]	Space product assurance — Detection of organic contamination of surfaces by IR spectroscopy
ECSS-Q-70-06 [1)]	Space product assurance — Particle and UV radiation testing of space materials
ECSS-Q-70-07	Space product assurance — Verification and approval of automatic machine wave soldering
ECSS-Q-70-08	Space product assurance — The manual soldering of high-reliability electrical connections
ECSS-Q-70-09	Space product assurance — Measurement of thermo-optical properties of thermal control materials
ECSS-Q-70-10	Space product assurance — Qualification of printed circuit boards

1) To be published.

ECSS-Q-70-11	Space product assurance — Procurement of printed circuit boards
ECSS-Q-70-13	Space product assurance — Measurement of the peel and pull-off strength of coatings and finishes using pressure-sensitive tapes
ECSS-Q-70-18	Space product assurance — Preparation, assembly and mounting of RF coaxial cables
ECSS-Q-70-20	Space product assurance — Determination of the susceptibility of silver-plated copper wire and cable to "red-plague" corrosion
ECSS-Q-70-21	Space product assurance — Flammability testing for the screening of space materials
ECSS-Q-70-22	Space product assurance — The control of limited shelf-life materials
ECSS-Q-70-25	Space product assurance — The application of the black coating Aeroglaze Z306
ECSS-Q-70-26	Space product assurance — Crimping of high-reliability electrical connections
ECSS-Q-70-28	Space product assurance — The repair and modification of printed circuit board assemblies for space use
ECSS-Q-70-29	Space product assurance — The determination of offgassing products from materials and assembled articles to be used in a manned space vehicle crew compartment
ECSS-Q-70-30	Space product assurance — Wire-wrapping of high-reliability electrical connections
ECSS-Q-70-33	Space product assurance — The application of the thermal control paint PYROLAC PSG 120FD
ECSS-Q-70-34	Space product assurance — The application of the black electrically conductive coating Aeroglaze H322
ECSS-Q-70-35	Space product assurance — The application of the black electrically conductive coating Aeroglaze L300
ECSS-Q-70-36	Space product assurance — Material selection for controlling stress corrosion cracking
ECSS-Q-70-37	Space product assurance — Determination of the susceptibility of metals to stress corrosion cracking
ECSS-Q-70-38 1)	Space product assurance — High-reliability soldering for surface mount and mixed technology printed-circuit boards
ECSS-Q-70-45	Space product assurance — Standard methods for mechanical testing of metallic materials
ECSS-Q-70-46	Space product assurance — Requirements for manufacturing and procurement of threaded fasteners
ECSS-Q-70-50 1)	Space product assurance — Particulate contamination control in clean rooms by particulate fall-out (PFO) measurements
ECSS-Q-70-51 1)	Space product assurance — The termination and splicing of optical fibres, fibre optic cables, cable assembly and installation
ESCC No. 3901	Generic specification for wires and cables, electrical, 600V, low frequency
ESCC No. 3902	Generic specification for cables, coaxial, radio frequency, flexible

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Terms, definitions and abbreviated terms

3.1 Terms and definitions

The following terms and definitions are specific to this Standard in the sense that they are complementary or additional to those contained in ECSS-P-001 and ECSS-Q-70.

3.1.1
adherend
plate adhesively bonded to another plate

3.1.2
B-stage
intermediate stage in the reaction of certain thermosetting resins

3.1.3
coating
material applied to protect or to change the properties of a substrate material or assembly

3.1.4
conformal coating
material applied to protect an electronic assembly

3.1.5
CTE mismatch
difference in coefficient of thermal expansion between two or more materials within a specified temperature change

EXAMPLE Polymer and metals.

3.1.6
cure
changing the properties of a polymer-based material by chemical reaction accomplished by heat or catalyst (or both) and with or without pressure

EXAMPLE Resin, adhesive, or coating.

3.1.7
cure cycle
period with a distinctive time, temperature and pressure profile to obtain specific properties of a polymer-based material

EXAMPLE Resin, adhesive, or coating.

3.1.8
degradation
reduction of material properties (e.g. mechanical, thermal or optical) that can result from deviations in manufacturing or from repeated loading or environmental exposure

3.1.9
flammability
measure of the ease with which a material is set on fire

3.1.10
machining
removal of material in a controlled manner by one or more mechanical, electrical or chemical methods

EXAMPLE Turning, milling, drilling, electro-chemical discharge, and ultrasonic

3.1.11
matrix
material that binds a reinforcement

EXAMPLE Thermoplastic or thermosetting resin in fibre-reinforced composites, and metal alloy in MMCs.

3.1.12
memory alloy
class of metal alloy which, after deformation whilst in one metallurgical state, regains its original shape after heating or cooling through a specific temperature

NOTE Also known as "shape memory" effect.

3.1.13
pot life
length of time a catalysed resin system retains a viscosity low enough to be used in processing

NOTE Also called "working life".

3.1.14
prepreg
woven or unidirectional ply impregnated with a resin, usually advanced to B-stage, ready for lay-up or winding

NOTE Short for "pre-impregnated".

3.1.15
shelf life
stated time period in which the manufacturer guarantees the properties or characteristics of a product for the stated storage conditions

3.1.16
toxic
substances causing serious, acute or chronic effects, even death, when inhaled, swallowed or absorbed through the skin

3.1.17
viscosity
measure of the fluidity of a liquid, in comparison with that of a standard oil, based on the time of outflow through a certain orifice under specified conditions

[ISO/IEC 12207:1995]

3.2 Abbreviated terms

The following abbreviated terms are defined and used within this Standard:

Abbreviation	**Meaning**
ARP	aramid fibre-reinforced plastic
ATC	advanced technical ceramic
ATOX	atomic oxygen
C-C	carbon-carbon composite
CFRP	carbon fibre-reinforced plastic
CMC	ceramic matrix composite
CP	commercial purity
CTE	coefficient of thermal expansion
CVCM	collected volatile condensable materials
DML	declared materials list
DMPL	declared mechanical parts list
DPL	declared process list
EB	electron beam (welding)
EMF	electromotive force
ETFE	ethylene tetrafluoroethylene
FEP	fluorinated ethylene propylene co-polymer
FML	fibre metal laminate
GCMC	glass ceramic matrix composite
GEO	geostationary orbit
GFRP	glass fibre-reinforced plastic (high-performance reinforcement)
GOX	gaseous oxygen
GRP	glass fibre-reinforced plastic ("industrial" grade reinforcement)
HAZ	heat affected zone
HM	high modulus (a grade of carbon fibre)
HT	high strength/high strain (a grade of carbon fibre)
IM	intermediate modulus (a grade of carbon fibre)
ISS	international space station
ITO	indium tin oxide
LEO	low Earth orbit
LOX	liquid oxygen
MIG	metal inert gas
MLI	multi-layer insulation
MMC	metal matrix composite
NRB	nonconformance review board
ODS	oxide dispersion strengthened
OSR	optical solar reflector
PCB	printed circuit board
PTFE	polytetrafluoroethylene
PVC	polyvinylchloride

RH	relative humidity
RML	recovered mass loss
RTM	resin transfer moulding
RTV	room temperature vulcanizing
SCC	stress corrosion cracking
SCEF	stress corrosion evaluation form
SSM	second surface mirror
STS	space transportation system
TFE	tetrafluoroethylene
Tg	glass transition temperature
TIG	Tungsten inert gas
TML	total mass loss
TPS	thermal protection system
UHM	ultra‐high modulus (a grade of carbon fibre)
UTS	ultimate tensile strength (or stress)
UV	ultraviolet
VDA	vacuum deposited aluminium

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Suppliers responsibilities

4.1 Selection of materials

a. Space-proven materials shall be selected at the earliest design stage, the maximum use being made of the materials and processes listed within this Standard. However, the supplier shall be responsible for the selection of materials that are capable of meeting the requirements of his contract.

b. To achieve high reliability and good performance, the use of a material shall be restricted to within its maximum qualified range of physical and mechanical properties.

c. The evaluation of material characteristics shall take into account the mechanical properties of materials processed according to a specified technique and their environmental-stability properties under space conditions, together with mission- or application-specific requirements.

d. All test methods and inspection techniques used to verify material characteristics and final products shall conform to recognized standards and be approved for that purpose.

4.2 Specifications or standards

4.2.1 General

a. The requirements for material specifications or standards are given in ECSS-Q-70. All materials and processes shall be defined by the appropriate standards and procedures.

b. Suppliers shall select ECSS standards, supplemented by: national and international standards and specifications for aerospace materials; agency and appropriate approved “in-house” standards.

4.2.2 Declared materials list (DML)

The supplier shall provide the final customer with a list of materials in order to apply for approval. This list is initiated at the beginning of the design and shall conform to the requirements of ECSS-Q-70.

4.2.3 Declared mechanical parts list (DMPL)

The supplier shall provide the final customer with a list of mechanical parts in order to apply for approval. This list is initiated at the beginning of the design and shall conform to the requirements of ECSS-Q-70.

4.2.4 Declared processes list (DPL)

The supplier shall provide the final customer with a list of materials in order to apply for approval. This list is initiated at the beginning of the design and shall conform to the requirements of ECSS-Q-70.

NOTE Suppliers are responsible for training and certification (to the specified levels conforming to appropriate standards) of their personnel (e.g. welding, soldering and inspection).

4.3 Selection of non-listed or non-proven materials

For materials for which no or insufficient data exists, the supplier shall justify the proposed selection and use, to obtain approval as detailed in ECSS-Q-70.

4.4 Procurement

The Supplier shall be responsible for controlling and ensuring that all materials procured for the project meet the specified requirements. The requirements of procurement and quality assurance or control are defined in the Standards ECSS-Q-70 and ECSS-Q-20, respectively.

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Materials in space applications

5.1 General

This Standard is a short guide to a vast subject. Its purpose is, therefore, limited to presenting basic considerations and examples in order to orientate spacecraft and payload designers in their preliminary selections. Factors which shall be dealt with at the beginning of the design phase are emphasized in order to avoid basic errors which can be very difficult to correct later.

a. The final choice of materials shall be made only after careful evaluation by specialists in the field of space materials in accordance with the product assurance requirements of ECSS-Q-70. This Standard covers materials used for structural and semi-structural applications, electronic and electrical applications, general "engineering" uses and those intended for some more specific applications. Requirements for both manned and unmanned spacecraft are covered.

b. This Standard is concerned mainly with the constraints that are specific to space use, i.e. vacuum and radiation. It is therefore assumed that the designer does his part of the task to ensure that the materials proposed to be used can at least satisfy the more classical constraints of the design, i.e. loads, vibration and high voltage. Material design data shall be generated taking into account the intended service conditions using recognized test and analysis procedures.

c. Material properties shall be compatible with the environments to which they are exposed during both any terrestrial testing prior to launch, and during the mission.

5.2 Mission constraints

5.2.1 Temperature

a. Material properties shall be compatible with the thermal environment to which they are exposed.

b. The passage through transition temperatures, e.g. phase transitions, ductile-brittle transition temperatures for metals, glass transition (Tg) for polymer materials, and environmental factors which affect these properties, such as moisture) shall be taken into account.

5.2.2 Thermal cycling

a. Materials subject to thermal cycling shall be selected such that they are capable of withstanding the induced thermal stresses for the intended service life.

b. Evaluation and testing shall conform to approved procedures, see ECSS-Q-70-04.

5.2.3 Vacuum outgassing

a. All materials intended for use in space systems shall be evaluated to determine their outgassing characteristics.

NOTE The screening process applied depends on the application.

b. Thermal vacuum tests shall conform to approved procedures, see ECSS-Q-70-02.

c. Acceptance criteria shall be defined for recovered mass loss (RML) and collected volatile condensable materials (CVCM).

d. The minimum outgassing requirements are < 1,0 % RML and < 0,1 % CVCM.

5.2.4 Manned environment

a. Safety of human life shall be the overriding consideration during design, manufacture and operation of space systems, including all facilities and ground support systems.

b. All materials intended for use in manned space flight systems shall be subject to product assurance, safety policy and basic specifications whose application shall be mandatory.

c. All materials intended for use in manned space flight systems shall be analysed for hazard and risk potential, both structural and physiological.

5.2.5 Offgassing and toxicity

In a closed environment of a manned spacecraft, contaminants in the atmosphere can be dangerous with respect to toxicity.

a. Spacecraft and associated equipment shall be manufactured from materials and by processes that do not cause an unacceptable hazard to personnel or hardware, either on the ground or in space.

b. For materials intended for the use in manned compartments of spacecraft, offgassing and toxicity analysis shall be performed and the levels agreed with the final customer, see ECSS-Q-70-29.

5.2.6 Bacterial and fungus growth

a. Materials shall not support bacterial or fungus growth.

b. If material properties are degraded by any sterilization process then the extent of the degradation shall be determined and the design and qualification shall accommodate the degraded values.

c. The level of bacterial growth and fungus contamination shall be determined on the final assembled hardware.

d. Organic materials used in the pressurized environment of long-term, manned spacecraft (e.g. ISS) shall be evaluated prior to selection and qualification. Materials that are non-nutrient to fungi shall be selected, except when one of the following criteria is met:

- Materials in crew areas where fungus is visible and can easily be removed.
- Materials used inside environmentally sealed containers with internal container humidity less than 60 % RH at ambient conditions.

- Materials used inside electrical boxes where the temperature is always higher than or equal to the ambient cabin temperature.
- Materials with edge exposure only.
- Materials normally stowed with no risk of condensation in stowage locations.
- Materials used on non-critical off-the-shelf electrical and electronic hardware that is stowed or used in crew areas.
- Fluorocarbon polymers, including ethylene tetrafluoroethylene (ETFE), or silicones.
- Crew clothing items.

NOTE The above rationales can be used when materials neutrient to fungi are selected.

e. When fungus-nutrient materials are used:
- they shall be treated to prevent fungus growth;
- fungus treatment shall not adversely affect the performance or service life of the part or system;
- fungus treatment shall not constitute a health hazard;
- fungus-treated materials shall be protected from environments such that the protective agent does not leach and cause contamination.

f. When fungus-nutrient materials are used and cannot be treated, they shall be identified and all actions required such as inspection, maintenance or replacement shall be specified.

5.2.7 Flammability

a. Evaluation of a material's flammability resistance shall be performed in the hazardous environment envisaged for its use; applicable to:
- unmanned spacecraft launched by space transportation system (STS) when powered on launch;
- manned spacecraft;
- stored equipment;
- payloads or experiments; or
- when specified by the contract.

b. Materials shall be tested according to approved procedures, see ECSS-Q-70-21 and NASA-STD-6001 (for NASA STS payloads).

5.2.8 Radiation

a. All materials on the external surface of a spacecraft (e.g. thermal blankets, thermal insulation systems, thermal paints, transparencies and windows) shall be evaluated to determine that any degradation of properties due to radiation does not affect the specified material performance throughout the entire mission.

b. Evaluation shall include the combined effects of particle radiation and ultraviolet radiation in the normal space environment, along with any mission-specific radiation levels expected.

5.2.9 Electrical charge and discharge

External surfaces of geostationary satellites can be charged to several thousand volts, depending on the environment, electrical properties of materials and surface geometry. Any subsequent discharge can cause malfunction of various subsystems. For materials with large surface areas (e.g. thermal blankets, optical solar reflectors (OSR) and solar arrays) charging shall be controlled, since the discharge amplitude is area dependent.

a. External surfaces of the spacecraft shall have conductive grounding elements.

b. The surface voltage shall not exceed the breakdown voltage of the dielectric.

5.2.10 Lightning strike

a. Provisions shall be made in the design to ensure that the safety and functionality of the vehicle are not compromised by the occurrence of a lightning strike during launch or return.

b. Conductive components (e.g. metal, metallized or coated parts and carbon-fibre reinforced plastics) shall be bonded to the structure, according to approved procedures, to ensure an electrical path.

5.2.11 Chemical (corrosion)

Chemical (corrosion) includes the reaction of metals, glasses, ionic solids, polymeric solids and composites with environments that embrace aqueous and non-aqueous liquids, gases, non-aqueous electrolytes and other non-aqueous solutions, coating systems, adhesion systems and liquid metals.

a. For all materials that come into contact with cleaning fluids and other chemicals it shall be demonstrated that the degradation of properties during their anticipated service-life is acceptable to the performance and integrity requirements.

b. All 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.

c. Metals, metal parts and assemblies shall be evaluated for:

- corrosion effects (such as pitting, crevice, intergranular and impingement) arising from contact with chemicals;
- aqueous environments;
- stress corrosion resistance: see 5.2.12;
- galvanic compatibility: see 5.2.14.

5.2.12 Stress corrosion resistance

Stress corrosion cracking (SCC), defined as the combined action of sustained tensile stress and corrosion, can cause premature failure of metals. SCC ratings were attributed to the major aircraft alloys; based on service experience and testing programmes (ECSS-Q-70-36 and NASA MSFC-STD-3029).

Alloys are rated as:

- high-resistance;
- moderate-resistance;
- low-resistance.

NOTE These ratings are used in Tables 1, 2 and 3 respectively of ECSS-Q-70-36A and within annex A and annex B of this Standard.

a. The metallic components proposed for use in most spacecraft shall be screened to prevent failures resulting from SCC.

b. Materials intended for structural applications shall possess a high resistance to stress corrosion cracking when they are:

- exposed to long-term storage on the ground (terrestrial);
- flown on the space transportation system (STS);

- classified as fracture critical items; or
- parts associated with the fabrication of launch vehicles.

c. Alloys with a high resistance to SCC (i.e. listed in Table 1 of ECSS-Q-70-36A) shall be selected whenever possible for space applications.

d. Alloys with a moderate- or low-resistance to SCC (i.e. Table 2 and Table 3 of ECSS-Q-70-36A) shall be subject to a detailed justification and approval for structural applications and ground use, as described by the stress corrosion evaluation form (SCEF) contained in ECSS-Q-70-36.

e. Alloys with unknown SCC characteristics shall be tested in accordance with the standard method detailed in ECSS-Q-70-37 and shall then be subjected to a SCEF approval if categorized as a class 2 or class 3.

NOTE The ECSS-Q-70-37 method incorporates constant load and alternate immersion in 3,5 % NaCl solution.

5.2.13 Fluid compatibility

Materials can come into contact with liquid oxygen (LOX), gaseous oxygen (GOX) or other reactive fluids or can be exposed to such fluids during an emergency situation.

Materials within the system exposed to hydrogen (liquid or gaseous) shall be evaluated for the effects of hydrogen embrittlement.

NOTE This applies to the selection of materials and processes (e.g. thermal disassociation of water during casting and welding, gas decomposition, pickling, corrosion and galvanic processes such as plating and ion bombardment); storage; assembly and integration and in-service environments, including emergency situations.

a. Materials within the system exposed to liquid oxygen, gaseous oxygen or other reactive fluids, both directly and as a result of a single-point failure shall be compatible with that fluid in their application.

b. The compatibility of materials which are or can come into contact with LOX or GOX shall be evaluated. See NASA-STD-6001 Tests No. 13 and No. 14.

c. If no compatibility data are available, tests shall be performed for reactive fluids other than oxygen. See NASA-STD-6001 Test No. 15.

5.2.14 Galvanic compatibility

a. Galvanic corrosion occurs when two or more dissimilar materials are in direct electrical contact in a corrosive environment.

NOTE This applies to metal-to-metal contact and also metal-to-conductive fibre-reinforced materials (e.g. carbon fibre composites).

b. Galvanic compatibilities shall be selected in accordance with approved lists and procedures in this Standard, see Table 1.

c. Materials not listed in Table 1 shall be evaluated in a flight-simulated configuration using an accelerated environment to be agreed by the customer.

Table 1: Compatible couples for bimetallic contacts

Pure metals and alloys in alphabetical order (including carbon)	Aluminium-Copper alloys	Al (pure), Al-Zinc alloys	Cadmium	Cast iron (austenic)	Chromium	Copper, Brasses	Cupro-Nickel, Al-bronzes, Si-bronzes	Gold, Platinum, Carbon, Rhodium	Gun-metal (CuZn10 alloy), P-bronzes, Sn-bronzes	Magnesium	Nickel, Monel, Inconel, Nickel/Molybdenum-alloys	Silver	Sn-Pb alloys (all), Tin, Lead	Stainless steel 18/8 (300 series)	Stainless steel 13Cr (400 series)	Steel (carbon, low alloy), Cast iron	Titanium and Ti-alloys	Zinc, Beryllium
Aluminium-Copper alloys		1	1	3	3	3	3	3	3	2	2	3	1	2	2	3	2	2
Al (pure) Al-Zinc alloys			1	3	3	3	3	3	3	2	3	3	2	3	3	3	3	2
Cadmium				2	2	2	2	2	2	1	2	2	0	1	1	2	2	2
Cast iron (austenic)					1	1	1	2	1	3	1	2	1	1	1	2	1	3
Chromium						1	0	0	1	3	1	0	2	0	0	2	0	3
Copper, Brasses							0	2	0	3	1	1	2	1	1	3	0	3
Cupro-Nickel Al-bronzes Si-bronzes								2	0	3	1	1	2	2	1	3	0	3
Gold Platinum, Carbon Rhodium									2	3	2	0	3	0	1	3	0	3
Gun-metal(CuZn10 alloy) P-bronzes Sn-bronzes										3	1	1	1	0	0	3	0	3
Magnesium											3	3	2	3	3	3	3	3
Nickel Monel Inconel Nickel/Molybdenum-alloys												2	2	1	0	2	1	3
Silver													3	0	0	3	0	3
Sn-Pb alloys (all) Tin, Lead														1	1	1	3	1
Stainless steel 18/8 (300 series)															1	3	0	3
Stainless steel 13Cr (400 series)																3	0	3
Steel (carbon, low alloy) Cast iron																	0	3
Titanium and Ti-alloys																		3
Zinc Beryllium																		

Key:

0 – Can be used without restriction.

1 – Can be used in a non-controlled environment (e.g. assembly area and general non-clean room environment).

2 – Can be used in a clean room environment.

3 – Needs specific measures to avoid galvanic corrosion when these combinations are selected.

5.2.15 Atomic oxygen

Spacecraft in low Earth orbit (LEO) altitudes (200 km to 700 km) are exposed to a flux of atomic oxygen (ATOX). The flux level varies with altitude, velocity vector and solar activity. Fluence levels vary with the duration of exposure.

a. All materials considered for use on the external surfaces of spacecraft intended for LEO altitudes shall be evaluated for:

— resistance to ATOX for their intended operational life;

— evaluated for the combined effects of the LEO environment (ATOX, solar UV radiation, ionizing radiation, plasma, vacuum, thermal cycling and contamination). See also 5.2.16.

b. Test procedures shall be subject to the approval of the final customer.

5.2.16 Micrometeoroids and debris

Low-energy impacts, depending on the velocity, angle of impact and mass, can result in plastic deformation of metal surfaces and delamination within composites. The effects of high-energy impacts (velocities of several km/s) are largely mass-related: low masses produce surface pitting and erosion, high masses can cause catastrophic damage to the material.

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

b. Analysis and test procedures shall be subject to the approval of the final customer.

5.2.17 Moisture absorption and desorption

Polymer-based materials are susceptible to moisture absorption during storage and processing. This is then released under vacuum levels experienced in space. Desorption can produce dimensional changes and induce stresses.

a. Moisture absorption susceptibility shall be evaluated as part of material selection.

b. Precautions shall be taken to avoid moisture being absorbed by susceptible materials during processing and storage.

c. The relative humidity and temperature of manufacturing and storage environments shall be controlled and monitored.

5.3 Information on materials

There are thousands of materials on the market which were never tested for space use. Guidance is given only to a restricted number of materials on which enough tests were conducted to allow some statement to be made. Owing to the present demand for "clean" satellites, the first screen applied is a mass-loss and contamination test, such as the "Micro VCM", (ECSS-Q-70-02).

NOTE Requirements for cleanliness and contamination control are given in ECSS-Q-70-01.

To complete the evaluation, suitable UV- and particulate radiation resistance tests are available and are applied to all the materials that are exposed to space radiation. Moreover, materials for manned projects are tested for flammability, odour and toxicity.

The citation of names of products and manufacturers does not by itself constitute a recommendation or approval. Unless otherwise stated, it merely indicates materials that were submitted to such preliminary tests and are suitable for further testing in support of an approval process. Even when data on a material are sufficient, quality-control tests should be run on each new batch before use, except where a continuous good record leads to confidence in the material's consistency.

NOTE A collection of data appears in ESA RD-01, ESA RD-02 and NASA RP 1124 (some data in these documents are obsolete).

Both European and American materials are identified. Inevitably, many are of US origin. Wherever possible, the examples given are European-made materials or those from the USA which are readily available on the European market.

Annex A of this Standard provides a general discussion of each class of material with respect to:

- Use in spacecraft: brief non-exhaustive account of some typical uses.
- Main categories: chemical nature and aspects of the various products which can be useful in spacecraft manufacture.
- Processing and assembly: mention of the main fabrication methods involved.
- Precautions: some points to be considered when designing with this class of material or for specific materials.
- Hazardous or precluded: self explanatory.
- Effects of space environment: summary of the possible damage mechanisms under vacuum, radiation, thermal stresses and atomic oxygen.
- Some representative products: a short list of products that were sufficiently tested or for which sufficient flight experience were accumulated to enable designers to recommend them as first choice. The list refers either to a generic class of product or to individual materials that have a data sheet in annex B.

  NOTE The citation of product names and manufacturers does not by itself constitute a recommendation or approval.

Annex B provides data sheets for materials that are either:

- capable of satisfying a wide range of design applications;
- mature in their technology and suitable for a range of flight hardware;
- predicted to have a significant utilization in present and future programmes;
- characterized by a sufficient test or use history; or
- available from suppliers or manufacturers whose previous performance indicates that they are capable of providing products of the specified quality.

  NOTE This is not an exhaustive list: industrial users and manufacturers are invited to comment on the existing sheets and to submit new or updated sheets for materials they recommend for inclusion in later issues.

A material may be removed from this list for any of the following reasons:

- material is obsolete;
- adequate sources are no longer available;
- material is replaced by a functionally similar but improved material;
- inherent reliability quality problems were experienced;
- more accessible sources were found (e.g. in Europe) for the same (or similar) material.

  NOTE Materials that are known to be hazardous for certain applications or are prohibited for use in certain spacecraft applications are cited.

Materials are classed within this Standard according to those used in the declared materials list (DML), see ECSS-Q-70.

NOTE See annex A for general information on material selection and space uses.

See annex B for materials data sheets.

Requirements for each class of material are listed in the following subclauses. See also clause 6, Processes.

5.4 Classes of materials

5.4.1 Class 1: Aluminium and Al-alloys

a. Maximum use shall be made of alloys, heat treatments and coatings that minimize susceptibility to general corrosion, pitting, intergranular and stress corrosion cracking.

b. All residual stresses that can cumulatively reach design-stress levels shall be evaluated.

c. Corrosion shall be considered during the whole manufacture and prelaunch phase; electrolytic couples shall be avoided.

d. Selection of alloys shall conform to the requirements for controlling failure by stress corrosion cracking.

   1. In ECSS-Q-70-36A, those alloys listed in Table 1 should be used for space application. For alloys listed in Tables 2 and 3 a detailed justification for use shall be provided, e.g. the submission of a SCEF.
   2. Coating or plating on a ranked susceptible material does not imply a higher SCC rating than the base alloy alone. A detailed justification shall also be provided.

e. Wrought heat-treatable products shall be mechanically stress relieved (TX5X or TX5XX tempers) whenever possible.

f. Wrought alloys 5456, 5083 and 5086 shall be used only in controlled tempers (H111,H112, H116, H117, H323, H343) for resistance to SCC and exfoliation.

g. Long-term manned structures, such as ISS, shall not use aluminium alloys 2024-T6, 7079-T6 and 7178-T6 in structural applications.

h. Long-term manned structures, such as ISS, shall not use aluminium alloys 5083-H32, 5083-H38, 5086-H34, 5086-H38, 5456-H32 and 5456-H38 in applications where the temperature exceeds 66 °C.

5.4.2 Class 2: Copper and Cu-alloys

a. Maximum use shall be made of alloys, heat treatments and coatings which minimize susceptibility to general corrosion, pitting, intergranular and stress corrosion cracking.

b. In electronic assemblies, wires made of high-purity copper or copper alloy shall be used.

c. In electronic assemblies, bronze terminals are preferred.

d. In electronic assemblies, brass terminals shall not be employed unless they are correctly plated with a 3 μm to 10 μm barrier layer of copper.

   NOTE Nickel is also acceptable but it is magnetic and can have poor solderability.

e. In electronic assembly operations, the correct selection and use of process materials (e.g. approved solders and fluxes for space hardware and solvents) shall conform to the requirements of ECSS-Q-70-08.

f. Copper coatings shall not be used on external surfaces exposed to atomic oxygen in low Earth orbit.

5.4.3 Class 3: Nickel and Ni-alloys

The effect of alloying element depletion at the surface of superalloys in high-temperature oxidizing environments shall be evaluated when thin sheet is used.

5.4.4 Class 4: Titanium and Ti-alloys

a. Maximum use shall be made of alloys, heat treatments and coatings which minimize susceptibility to general corrosion, pitting, intergranular and stress corrosion cracking.

b. Avoid the uptake of hydrogen during processes such as welding and heat treatment, in order to prevent embrittlement caused by hydrides.

c. All residual stresses that can cumulatively reach design-stress levels shall be evaluated.

d. Corrosion shall be considered during the whole manufacture and prelaunch phase; electrolytic couples shall be avoided.

e. Selection of alloys shall conform to the requirements for controlling failure by stress corrosion cracking.

1. In ECSS-Q-70-36A, those alloys listed in Table 1 should be used for space application. For alloys listed in Tables 2 and 3 a detailed justification for use shall be provided, e.g. the submission of a SCEF.
2. Coating or plating on a ranked susceptible material does not imply a higher SCC rating than the base alloy alone. A detailed justification shall also be provided.

f. Titanium alloys whose hardenability is limited by section size shall not be used in dimensions which exceed their specific limits.

g. Structural applications using titanium shall be designed to avoid fretting.

h. In long-term, manned structures titanium shall not be used with liquid oxygen (LOX) or gaseous oxygen (GOX) at a pressure (or with air at oxygen partial pressure) exceeding 34,5 kPa.

5.4.5 Class 5: Steels

a. Heat treated steel with ultimate tensile strengths above 1 250 MPa shall be approved for each application by the customer.

ISS requirements state that these materials shall not be used.

b. All carbon and low alloy high strength steels with ultimate tensile strengths greater than 1 250 MPa shall be evaluated for stress corrosion cracking in conformance with ECSS-Q-70-36 requirements.

c. All high-strength ($\geq$ 1 250 MPa UTS) heat treated parts which are acid cleaned, plated or exposed to other hydrogen-producing processes shall be subjected to a baking procedure that shall be agreed with the customer.

Both temperature and time shall be stated for baking processes.

d. Tempers of precipitation hardening steels that are susceptible to stress corrosion and hydrogen embrittlement shall be avoided.

e. Designs using precipitation hardening steels shall ensure that controlled processing procedures are used for these steels and processing and procurement records shall be maintained for reference as appropriate.

5.4.6 Class 6: Stainless steels

a. Unstabilized austenitic steels shall not be used at temperatures of 370 °C or above.

b. Caution shall be exercised when using 400-series stainless steels to minimize hydrogen embrittlement, corrosion and stress corrosion cracking.

5.4.7 Class 7: Filler materials: welding, brazing and soldering

a. The selection of alloys to be welded and the selection of process techniques shall be in accordance with national or international aerospace specifications and standards, see also subclause 6.7.

b. The fusion zone and the unmelted heat affected zone of a weld shall be accessible for inspection.

c. All critical and highly stressed welds shall undergo 100 % radiographic inspection in accordance with approved specifications that shall be stated on the engineering drawing.

d. The suitability of the equipment, processes, welding supplies and supplementary treatments specified shall be demonstrated through qualification testing of welded specimens representing the materials and joint configuration of production parts.

e. The selection of brazing alloys and brazing techniques shall be in accordance with national or international aerospace specifications and standards.

f. The effect of the brazing process on the strength of the parent (base) metal shall be considered in structural designs.

g. Subsequent fusion welding in the vicinity of brazed joints or other operations involving high temperatures that can affect the brazed joint shall be prohibited.

h. Soldered joints shall not be used for structural applications unless approved by the final customer.

NOTE Long-term, manned structures (e.g. ISS) do not permit soldering in structural applications.

i. Solders, process materials and procedures for electrical and electronic assembly shall conform to the requirements of ECSS-Q-70-08 and ECSS-Q-70-38.

5.4.8 Class 8: Miscellaneous metallic materials

a. Magnesium alloys shall not be used except in areas where minimal exposure to corrosive environments can be ensured and protection systems can be maintained with ease and reliability.

b. Magnesium alloys shall not be used in primary flight control systems, for landing gear wheels, for primary structures, or in other areas subject to wear, abuse, foreign object damage, abrasion, erosion or at any location where fluid or moisture entrapment is possible.

c. Beryllium and beryllium alloys shall be restricted to applications in which their properties offer definite performance and cost advantages over other materials.

d. The ability of beryllium parts to provide reliable service and predictable life shall be demonstrated by pre-production tests under simulated service conditions, including any expected corrosive environments.

e. The design of beryllium parts shall take into consideration the material's low impact resistance, notch sensitivity, its anisotropy and sensitivity to surface finish requirements.

f. National or international safety regulations shall be followed when manufacturing and handling beryllium products.

g. In long-term, manned structures (e.g. ISS) beryllium shall not be used for primary structural applications without the prior approval of the customer.

NOTE Beryllium can be used as an alloying constituent up to a maximum of 4 % by weight.

h. The application of refractory alloys shall be subject to approval by the customer.

i. The use of devices containing mercury or compounds of mercury shall be prohibited for installed equipment and for use during fabrication of flight structures and subsystems.

j. Cadmium and zinc coatings shall not be used.

NOTE ISS requirements prohibit the use of cadmium in any vacuum environments or in crew environments (pressurized) at temperatures above 100 °C.

k. Silver, copper and osmium coatings shall not be used on external surfaces of space systems exposed to atomic oxygen in low Earth orbit.

l. Platings of cadmium, zinc and tin grow whiskers both in air and under vacuum:

- Cadmium and zinc shall be excluded from all spacecraft and ground‐support equipment.
- Electroplated and electroless‐coated tin shall be reflowed to avoid whisker growth (see also Note under 6.17.6 c.).

m. In the soldering of electronic assemblies, silver‐ and gold‐plated terminals on PCBs shall have restricted use.

n. Soldering directly to gold finishes on conductors shall not be used. Approved de‐golding procedures shall be used.

o. RF circuits requiring gold finishes can have their conductors selectively plated to provide a tin‐lead finish for soldering.

p. Porous platings shall be sealed.

q. The selection of a superalloy for a given application shall be based on tests of the material in simulated in‐service environments.

r. Foreign material which contains sulphur (e.g. oils, grease and cutting lubricants) shall be removed from superalloys prior to heat treatment or high‐temperature service.

s. The effect of alloying element depletion in superalloys at the surface in a high‐temperature oxidizing environment shall be evaluated when thin sheet is used.

5.4.9 Class 9: Optical materials

a. Optical glasses shall be chosen in accordance with the mission requirements.

b. Organic glasses shall not be used in high‐precision equipment.

c. An assembly incorporating optical materials shall take into account the difference in thermal expansion coefficients between the optical material and its mounting.

d. Optical glasses shall be assessed for their resistance to ionizing radiation, particle and UV radiation.

e. Glasses shall not be used in structural applications without the prior approval of the customer.

In structural applications, glasses shall be considered to be in the same class as ceramics and the requirements stated for ceramics shall apply: see subclause 5.4.20.

5.4.10 Class 10: Adhesives, coatings and varnishes

Adhesives within this class include those used in structural and non‐structural applications, see A.10.

See also the ECSS‐E‐30 series of standards for structural applications.

a. For polymer-based materials (thermosetting and thermoplastic), a clear definition of all the design constraints (e.g. short-term loading, long-term loading, cyclic loading, impact loading, design life and critical dimensional tolerances) shall be established.

b. A structural design analysis shall be performed on all parts incorporating polymer-based materials, taking into account the visco-elastic nature of the chosen material.

c. Structural adhesive bonds in honeycomb panels shall attach the facings rigidly to the core to allow loads to be transmitted from one face to another.

d. For polymer-based materials (thermosetting and thermoplastic), part design shall be accomplished by using good engineering practice for the chosen material and processing method.

e. For polymer-based materials (thermosetting and thermoplastic), prototypes shall be produced and tested to qualify the design.

f. For polymer-based materials (thermosetting and thermoplastic), environmental exposure (e.g. flammability requirements, electrical requirements, normal use temperature, abnormal use temperature excursions, chemical exposure and humidity levels) shall be considered.

g. All components of adhesives, coatings and varnishes (e.g. base polymer compound, hardeners and catalysts) that are identified as having a limited shelf-life shall be controlled in conformance with the requirements of ECSS-Q-70-22.

h. National or international safety procedures shall be implemented and controlled for the handling of materials known to be flammable or have health-related effects on operators.

i. Adhesives, coatings and varnishes shall be physically and chemically compatible with the component parts of the finished assembly, i.e. the adherends for adhesives, substrates and any other parts, such as materials used in the insulation or bodies of electronic components for coatings.

j. Adhesives, coatings and varnishes shall be capable of accommodating dimensional changes resulting from temperature excursions without causing damage to the adhesive bond, or to other parts of the assembly (e.g. electronic PCBs); i.e. an assessment of the mismatch of thermal expansion coefficients between adherends and adhesive and substrates and coatings shall conform to the requirements of ECSS-Q-70-04.

k. When reductions in the performance of bonded joints are found as a result of thermal cycling, these should be fully characterized within the normal evaluation and verification process.

l. Applications of thick coatings that can result in damage (high residual stresses, high temperatures during cure) to the coated items shall be evaluated by testing.

m. The selection of alkyd-, polyester- or polysulphide-type coatings shall be avoided whenever possible and is subject to the approval of the final customer.

n. Any compound that contains or liberates corrosive media (acetic acid, ammonia, amines, hydrochloric and other acids) that can attack adjacent parts of the assembly shall be used with care.

o. Adhesives that need atmospheric moisture as part of the curing process shall not be used for large bond areas between non-porous surfaces.

p. Coatings and varnishes containing solvents (thinners) shall be subjected to an approved baking process prior to curing.

q. Adhesives, coatings and varnishes that are sensitive to moisture contamination shall only be used in controlled-humidity environments.

r. A controlled low‐pressure debubbling process shall be used for coatings and varnishes to ensure that a void‐free protective layer is produced.

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

5.4.11 Class 11: Adhesive tapes

a. Tapes having a polyvinylchloride backing shall not be used in spacecraft.

b. All release agents present on the surface of tapes shall be removed.

c. The adherent surface or surfaces shall be clean and dry prior to the application of the tape.

d. An even pressure shall be used on the tape during its application.

e. Suitable controls shall be taken to ensure that the tape is not damaged during its application.

f. To enable the correct evacuation of trapped air bubbles underneath adhesive tape, perforated tapes should be used. If the perforated tapes are not used then the process of tape application shall be documented correctly so that subsequent exposure to the space environment does not impair the function of the tape.

g. Surfaces that have had tapes removed for reworking reasons shall be carefully cleaned after the tape is removed.

NOTE Silicone adhesives can leave a residue which prevents adhesion of other systems onto that surface.

h. Velcro®‐type tapes shall not shed hooks or felt during assembly or disassembly.

i. Conductive adhesive tapes shall be tested to ensure that the specified conductivity and adhesion are maintained at temperature extremes.

5.4.12 Class 12: Paints and inks

a. All components of paints (e.g. base, hardeners and catalysts) that are identified as having a limited shelf‐life shall be controlled in conformance with the requirements of ECSS‐Q‐70‐22.

b. Contamination of painted surfaces shall be prevented.

NOTE For non‐moisture curing paints, environmental control applies.

c. Painted surfaces shall be protected from mechanical damage (e.g. scratches and chips).

d. National and international standards for safety equipment for operatives and the collection and disposal of waste shall be implemented and controlled.

5.4.13 Class 13: Lubricants

a. All moving parts, both “one‐shot” and constantly moving, under vacuum conditions shall be lubricated.

b. Designs for lubricated items shall ensure that the lubricant is contained and cannot leak or otherwise migrate and contaminate associated parts.

c. “Dry” lubricated items shall be designed such that wear or loss of adhesion to the parts’ surface does not occur.

d. Lubricants shall only be applied to clean surfaces.

e. Lubricated items shall be protected from contamination (e.g. dust and dirt).

f. “Wet” lubricants (liquids and greases) and thermally conductive compounds shall be contained by a seal around the area concerned.

g. Except for specific grades, oils and greases shall not be directly exposed to the space environment.

h. Graphite alone shall not be used under vacuum.

i. Thin metal films shall be paired with the rubbing part to prevent cold welding.

j. The long-term performance of lubricants shall be considered during their selection for long-term deployed systems.

k. Lubricants containing chloro-fluoro compositions shall not be used with aluminium or magnesium if shear stresses can be imposed.

5.4.14 Class 14: Potting compounds, sealants and foams

a. All components of potting compounds and sealants (e.g. base, hardeners and catalysts) that are identified as having a limited shelf-life shall be controlled in conformance with the requirements of ECSS-Q-70-22.

b. Polysulphide potting material shall not be used.

c. Non-metallic foams with an open-cell structure shall not be used.

d. Products with excessive shrinkage or those that produce high exothermic temperatures during curing shall be evaluated before use.

e. Surface treatments (e.g. etching and priming) shall be used in accordance with approved process procedures on components and assemblies to ensure proper adhesion between the component and the potting compound or sealant.

f. Pre-coating shall be used, when necessary, on parts and assemblies to ensure proper adhesion between the part and the potting compound or sealant and reduce residual stresses created during curing.

g. Air bubbles shall be removed using an approved debubbling procedure during the application of the potting compound, however, true foam products shall not be debubbled.

h. All filler materials used in potting compounds shall be submitted to a drying procedure prior to use and shall be stored in a dry conditions until and during mixing.

i. The viscosity of the applied material shall be sufficiently low to permit acceptable flow in intricate devices.

j. Cure procedures shall be carefully evaluated such that the temperatures and pressures created during curing process do not damage the potting compound or the parts being potted.

k. All potting, coating and sealing materials used successively shall be evaluated for compatibility.

NOTE Some chemical or atmospheric constituents can affect those of another material.

l. Catalysts and hardeners shall be evaluated for their compatibility with any metals present in the assembly.

5.4.15 Class 15: Reinforced plastics

a. The design and verification of fibre-reinforced composite materials used for structural applications shall conform to the requirements of the ECSS-E-30-series of standards.

b. Prepregs and thermosetting resin-systems (e.g. base, hardeners and catalysts) that are identified as having a limited shelf-life shall be controlled in conformance with the requirements of ECSS-Q-70-22.

c. Composite materials made with polyester containing styrene shall not be used.

d. The individual stages of all processing shall be controlled and monitored in accordance with approved quality control and inspection procedures.

NOTE These can include, for example, correct lay-up of plies, no or low void content, absence of defects, absence of contamination, results of test coupons and non-destructive evaluation.

e. Curing schedules shall be monitored to ensure that all parameters conform to those identified as acceptable during the product development evaluation stage.

f. Natural reinforcing materials (cotton and paper) shall not be used for electronic composite laminates, i.e. printed circuit boards.

g. Electronic PCBs shall conform to the requirements of ECSS-Q-70-10.

5.4.16 Class 16: Rubbers and elastomers

a. Designs using rubber and elastomeric materials shall be evaluated for: “set” under stress; effects of cyclic stress; environmental resistance; chemical resistance.

b. Polysulphide materials shall not be used in the space environment.

c. Chlorinated materials shall not be used in space environments.

d. Silicone materials shall not be used in pressurized systems requiring low gas permeability.

e. Rubbers and elastomers containing plasticisers or extending oils shall not be used under vacuum.

f. The leaching of filler materials shall be evaluated with respect to their potential hazard to associated equipment.

g. Material depolymerization due to vacuum exposure shall be evaluated.

h. Outgassing and contamination shall be evaluated for each material formulation using approved test procedures, see ECSS-Q-70-02.

i. Materials that liberate corrosive media shall be evaluated for the effects on metals.

j. Materials that liberate acetic acid shall be evaluated before use.

k. 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, working fluids, lubricants and operating media (as a minimum) and any application- or mission-specific requirements.

l. The cure date of rubbers and elastomers shall be identified within associated documentation, and also preferably on the part.

5.4.17 Class 17: Thermoplastics

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

b. The choice of material shall be subject to the approval by the final customer.

c. Anisotropic characteristics of plastic films shall be considered during design.

d. Processing methods shall take into account the softening temperature of thermoplastics.

e. PTFE shall be avoided in applications requiring creep resistance.

f. Thermoplastics that retain residual stresses after processing shall be subject to an approved thermal stress-relief process.

g. The release of additives in plastics under vacuum shall be evaluated for their effect on the material performance and contamination risk.

h. Materials that absorb and release water shall be evaluated with respect to the effect on the performance of the material and for contamination risk.

i. Neither PVC bulk materials nor PVC plastic films shall be used in space applications.

j. Cellulose and acetate materials in the form of films shall not be used in space applications.

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

l. Polyvinyl acetate shall not be used in space applications.

m. Polyvinyl butyrate shall not be used in space applications.

n. Multi-layer systems shall be vented to eliminate internal overpressure.

o. Multi-layer systems shall be baked to an approved process prior to integration into the spacecraft.

5.4.18 Class 18: Thermoset plastics

a. Structural design of components using thermosetting resins, e.g. fibre-reinforced composites, shall conform to the requirements of the ECSS-E-30-series of standards.

b. Thermosetting plastics shall be evaluated for the effects of service conditions.

c. Curing processes shall be evaluated by means of a preliminary test programme using thermal-analysis equipment.

d. The selection of thermo-setting resins shall be subject to the approval of the final customer.

e. Thermo-setting resin systems (e.g. base, hardeners and catalysts) that are identified as having a limited shelf-life shall be controlled in conformance with the requirements of ECSS-Q-70-22.

f. Resin systems used in PCBs for space hardware shall be qualified in accordance with ECSS-Q-70-10.

g. Polyester resins shall not be used for space applications.

h. Polyimide or polybenzimide resins which retain low-volatility solvents in the cured item shall not be used for space applications.

5.4.19 Class 19: Wires and cables

a. Electrical wires and cables (600V, low frequency) shall be procured according to the requirements of ESA/SCC Generic specification No. 3901.

b. Coaxial cables (radio frequency, flexible) shall be procured according to ESA/SCC Generic specification No. 3902.

c. The materials for coaxial cable assembly shall be selected according to ECSS-Q-70-18.

5.4.20 Class 20: Miscellaneous non-metallic materials

a. Ceramics and glass, except as fibres, shall not be used in a structural application without the prior approval of the final customer.

b. Structural applications of ceramic and glass materials shall be based on careful selection criteria and agreed with the final customer.

c. Engineering data used to justify the selection and demonstrate the strength of ceramics and glasses for structural uses shall be subject to review and approval by the final customer.

d. National or international standards relating to the occupation health of operatives working with ceramic powders, fibres and associated processes resulting in exposure to debris shall be implemented and strictly controlled.

e. All applications using advanced composite materials based on ceramic, carbon and glass compositions shall be reviewed and approved by the final customer.

f. Products containing asbestos shall not be used.

g. Ceramics used in electrical and electronic applications shall conform to the requirements of standards regarding their electrical or thermal characteristics.

h. Printed circuit boards shall be procured according to ECSS‐Q‐70‐11.

6 Processes

6.1 General

Processes are grouped within this Standard according to those used in the declared process list (DPL), see ECSS-Q-70.

NOTE See subclause 5.4 for classes of materials and annex A for general information on material selection and space uses. See annex B for material data sheets.

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.

International or national aerospace standards and specifications are normally applied to processes.

Materials used for electrical and electronic applications are covered in this Standard. The ECSS-Q-70-series of standards provides precise requirements for each process.

a. Processes using limited-life materials shall conform to the requirements of ECSS-Q-70-22.

b. Operators performing electrical harness assembly and electronic soldering processes shall be trained and certified in conformance with the requirements of the relevant standard.

c. All trained operators shall be certified and their certification reassessed every two years.

d. All training and certification shall only be performed at a school authorized by the final customer.

e. National or international 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.

6.2 Group 1: Adhesive bonding

6.2.1 General

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.

6.2.2 Structural

a. Surfaces to be bonded shall be cleaned and prepared by a surface treatment process (e.g. abrasion and chemical etching) under strict control. Prepared surfaces shall be protected from contaminants. During the bonding process, the adhesive cure cycle shall be controlled. For guidelines on structural adhesive bonding see ECSS-E-30-05.

b. Good toughness and peel strength are applicable characteristics for structural adhesives. Bonded primary structural joints shall demonstrate cohesive failure modes in shear.

   NOTE This is valid for metal-to-metal joints but not for CFRP structures.

c. An insert system consists of a removable threaded fastener and a fixture that is embedded into the honeycomb structure using a potting compound. The general processing steps for installing inserts include: machining the honeycomb panel, normally using specific tools; potting the insert; curing the potting material. For guidelines on the use of inserts see ECSS-E-30-06.

6.2.3 Electrical

Materials and processes used in electrical bonding or grounding shall meet the requirements of this Standard.

6.3 Group 2: Composite manufacture

a. 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 ECSS-E-30-04 for information on composite manufacture.

b. Tooling materials shall be carefully selected to ensure thermal-expansion matching between the composite over the processing temperatures.

6.4 Group 3: Encapsulation and moulding

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

b. In electronic assemblies, the use of potting (encapsulation) shall be generally restricted to minimize weight and allow rework or repair. See subclause 6.2 for potting of inserts.

c. Conformal coating shall be used in preference to potting.

6.5 Group 4: Painting and coating

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

b. 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.

c. Processes developed for certain types of paints shall be implemented and controlled in conformance with the relevant ECSS-series standards.

NOTE 1 The application of some commercial products is covered by the following standards:

ECSS-Q-70-25: Aeroglaze Z306
ECSS-Q-70-34: Aeroglaze H332
ECSS-Q-70-35: Aeroglaze L300

d. 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.

e. Contamination of painted surfaces shall be prevented because they are difficult to clean.

NOTE For non-moisture curing paints environmental control applies (see ECSS-Q-70-01).

f. National and international standards for safety equipment for operators and the collection and disposal of waste shall be implemented and controlled.

6.6 Group 5: 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.

a. All cleaning materials and processes shall be stated and controlled.

b. Selection and use of solvents shall be carefully controlled to ensure that they do not degrade the base material or that of adjacent parts, for example, polymer materials adjacent to metals.

c. Cleaning processes shall not degrade the base material, any applied surface coating or finishes (e.g. paint and varnish); or that of adjacent parts (e.g. submerging in solvent baths and use of ultrasonic cleaning).

d. Cleaning processes shall be used to remove all chemical residues produced during manufacture and assembly (e.g. cutting oils and dye-penetrants).

e. Foreign materials containing sulphur (e.g. oils, grease and cutting lubricants) shall be removed from superalloys prior to heat treatment or high-temperature service.

f. 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.

g. Surfaces that have had tapes applied for temporary reasons shall be carefully cleaned after the tape is removed (see 5.4.11 g.).

h. National and international standards for safety equipment for operators and the collection and disposal of waste shall be implemented and controlled.

i. For electronic assemblies, only approved solvents and cleaning processes that conform to the requirements of ECSS-Q-70-08 shall be used.

6.7 Group 6: Welding and brazing

6.7.1 Welding

a. In the aerospace industry the following welding techniques shall be considered:

- tungsten inert gas (TIG);
- metal inert gas (MIG);

- plasma-arc welding;
- electron beam welding (EB);
- resistance welding (induction, spot, seam);
- diffusion welding;
- laser welding; and
- friction stir welding.

b. 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.

c. Welding processes shall be selected to provide
   - the specified weld quality;
   - the minimum weld energy input;
   - protection from contamination.

d. The suitability of the equipment, the welding process documentation (including process variants), the filler material (if used) and any supplementary treatments shall be demonstrated through qualification testing of welded specimens representing the materials and the joint configuration of production parts.

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

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

g. Welded assemblies of corrosion resistant steels shall be heat treated after welding, except for stabilized steels or low carbon grades.

h. The selection of alloys to be welded and the selection of process techniques shall be in accordance with national or international aerospace specification and standards.

i. Personnel, equipment and procedures used for welding shall be certified for their capability to produce welds and weld repairs.

j. The contractor shall provide the necessary training and qualification requirements to certify each operator and the applicable welding equipment for specific welding tasks.

k. The weld repair process and inspection shall be performed only under nonconformance review board (NRB) approval and qualified to the same level of assurance as the primary process specification drawing requirement, using the same inspection technique that found the original defect and by all other methods of examination that were originally specified for the affected part. The results are subject to review by the final customer upon request.

6.7.2 Brazing

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.

a. Brazing processes shall be evaluated regarding the effect on the parent metal.

b. Subsequent fusion welding in the vicinity of the brazed joint shall be avoided.

c. Brazing operations shall be carried out by fully trained operators, working to fully documented and approved brazing procedures.

6.8 Group 7: Crimping and wire-wrapping

6.8.1 Crimping

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-70-26.

6.8.2 Wire wrapping

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

6.9 Group 8: Soldering

a. Soldered joints shall not be used for structural applications without the prior approval of the final customer.

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

6.10 Group 9: Surface treatments

6.10.1 General

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. See also subclause 6.5.

Some surface treatments are also included in other processes, e.g. preparation prior to painting and adhesive bonding to improve adhesion. These can include a proprietary “chemical” process such as anodizing or alodining or the application of a primer.

a. As surface treatments can influence the mechanical and environmental durability of a part, surface treatments shall be specified, e.g. composition and thickness.

b. Processes and materials shall not degrade the substrate and result in loss of performance or integrity.

c. The surface finish shall be free from defects and shall not be stained or discoloured.

d. Coatings and substrates shall be evaluated for, example, CTE mismatches.

6.10.2 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.

NOTE Not all grades of an alloy can be anodized successfully.

Depending on the precise process, anodizing can produce:

- hard anodized wear resistant and durable surfaces;
- coloured surfaces (either functional or decorative), e.g. black for optical properties;
- pretreatment process prior to adhesive bonding or painting.

NOTE Specifications for aerospace anodizing processes are available (often of American origin), but bath constituents and process conditions tend to vary between organizations.

Anodizing processes to thin foils (e.g. honeycomb cores) shall be applied cautiously, e.g. to avoid perforation, and complete removal of process chemicals in complex parts.

a. Anodized layers shall be sealed and shall be continuous when used as the final surface finish of a part.

b. Anodized surfaces for pretreatment (bonding or painting) need not be sealed.

c. Process conditions (bath constituents, temperature and time) shall be implemented and controlled.

6.10.3 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. See also annex E for general considerations for corrosion protection and electrical bonding.

NOTE Non-metal oxide films may sometimes be used.

Chemical conversion processes include:

- Chromating (mixed metal-chromium oxide film) providing good corrosion resistance and pretreatment for subsequently applied organic coatings. For example, alodine and iridite are non-electrolytic, immersion-type processes that are used on aluminium surfaces. These coatings have a thickness of less than 1 μm and are electrically conductive.
- Phosphating is used as a pretreatment prior to painting on ferrous materials.

a. Chemical conversion layers shall be sealed and shall be continuous when used as the final surface finish of a part.

b. Chemical conversion surfaces for pretreatment (bonding or painting) need not be sealed.

c. Control of process conditions (bath constituents, temperature and time) shall be implemented and controlled.

6.11 Group 10: Plating

a. Process conditions and environments shall be specified and strictly controlled during all stages of plating, i.e. during preparation, application, inspection or testing, and storage.

b. Porous platings shall not be used as they fail to provide adequate corrosion protection and can act as sources of contamination.

NOTE Plated layers of less than 1 μm thickness tend to be porous.

c. An approved post-plating baking process shall be applied to materials with known or suspected susceptibility to hydrogen embrittlement.

d. In electronic assemblies, brass terminals shall have a barrier layer plating to prevent diffusion and surface oxidation of zinc, prior to applying a tin-lead coating. See ECSS-Q-70-08.

e. In electronic assemblies, approved processes shall be used for the removal of certain platings, e.g. tin, silver and gold. See ECSS-Q-70-08.

6.12 Group 11: Machining

Numerous different machining operations are used for aerospace materials. International or national aerospace standards and specifications are normally applied.

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. For guidelines on machining composites, see ECSS-E-30-04.

a. Machining (e.g. drilling or grinding) of martensitic steel hardened to ≥1 250 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.

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

c. The collection and disposal of dust and debris produced during the processing of beryllium and beryllium-copper alloys shall conform to national or international specifications.

6.13 Group 12: Metal forming

6.13.1 General

Numerous different forming operations are used for aerospace materials. International or national aerospace standards and specifications are normally applied.

NOTE 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.

Specialized techniques used in the manufacture of certain spacecraft parts include:

- superplastic forming, e.g. panel sections and tanks;
- "gatorising": forging with superplastic materials, e.g. integral turbine blades or discs;
- explosive forming, e.g. tanks and sections.

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.

6.13.2 Forging

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

a. Forging techniques shall be used that produce an internal grain-flow pattern such that the direction of flow is essentially parallel to principal stresses.

b. Evaluation of flow patterns, including test data shall be submitted as part of the approval procedure for forged components.

6.13.3 Sheet metal

All forming processes for sheet metals involve plastic deformation of the material. Processing techniques are either conducted "cold", or "warm or hot".

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. High-strength materials are difficult to form to complex shapes by cold forming, and can be done “warm or hot”.

NOTE Forming is often followed by a final heat-treatment to restore the mechanical properties of the finished part.

a. Forming processes shall respect the minimum bend radii for the specific alloy and condition (heat-treatment or temper).

b. Annealing processes shall be carefully selected to avoid degradation of the material.

c. Hot forming temperatures and soak times shall be selected to avoid segregation effects at grain boundaries or liquation of low melting point alloy constituents, either during heating the material or as a result of localized “over-heating” during forming.

6.13.4 Superplastic forming

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

- microstructure: 1 μm to 5 μm grain size and stable at process temperature;
- plastic deformation in the range of 100 % to 1 500 % typically, without fracture;
- heated to at least 50 % of the melting temperature (in K);
- relatively low forming stresses;
- low deformation rate.

NOTE Commercial superplastic alloys include those based on aluminium, titanium, copper, nickel, stainless- and carbon-steels.

Depending on the metal alloy, superplastic forming can be combined with diffusion bonding to create finished parts, such as struts, cylinders and integrally stiffened panels.

See ECSS‐E‐30‐04 for superplastic forming processes.

6.13.5 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.

Safety procedures shall be applied for the storage and handling of explosives.

6.14 Group 13: Heat treatment

a. Heat treatment of metals and alloys shall conform to national or international specifications for aerospace applications.

b. Heat treatment procedures that are not included in any national or international specifications shall be approved by the customer prior to their use.

c. Processes shall be selected and controlled to avoid the dezincification of brasses.

d. Superalloys shall be cleaned to remove all foreign materials containing sulphur (e.g. oils, grease and cutting lubricants) prior to heat treatment.

6.15 Group 14: Special fabrication

This group covers processes developed specifically for the programme.

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

6.16 Group 15: 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-70-02.
- Engraving of painted, plated or coated parts shall be avoided.
- Stamping resulting in stress-raisers shall be avoided.

6.17 Group 16: Miscellaneous processes

6.17.1 Casting

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

6.17.2 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 also ECSS-E-30-07.

6.17.3 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 required, or expected, to internal or adjacent parts of the structure. For guidelines on riveted joints in composites, see ECSS-E-30-04.

6.17.4 Printed circuit and flexible circuit boards

Fabrication processes and controls used in rigid and flexible printed circuit boards shall conform to the requirements of ECSS-Q-70-10 and ECSS-Q-70-11.

6.17.5 Printed circuit assemblies

Fabrication processes and controls used in staking and conformal coating of printed circuit boards and electronic assemblies shall conform to the requirements of ECSS-Q-70-08 and ECSS-Q-70-38.

6.17.6 Wire and cable assemblies

The general requirements for spacecraft insulated electrical conductors are described by the ESCC standards for qualification approval, procurement, including lot acceptance testing, and delivery of wires and cables.

a. Silver-plated copper strands are the preferred conductors. These are suitable for soldering and crimping.

b. Nickel- and tin-coated copper strands can also be used but they shall possess a good solderability after ageing, as described by the generic specification.

   NOTE Nickel is magnetic and cannot be used for all applications.

c. Pure tin-coated wires and wire strands do not give rise to the growth of tin whiskers and this shall not restrict their usage. Other tin-plated finishes (electroplated) shall be either re-flowed or excluded.

NOTE Pure tin on wires is produced by immersing the wire into liquid tin (this does not promote whisker growth).

d. Silver-plated wires shall be tested to the Anthony and Brown test in accordance with the wire generic specification and ECSS-Q-70-20. The individual wire specification shall be consulted for other requirements such as accelerated ageing, cut-through resistance, flammability.

e. The following shall be assembled or installed in conformance with the requirements of ECSS-Q-70-08:

- electrical connectors;
- interconnecting cables, harness and wiring;
- solder splice.

f. Solder sleeves shall not be used in flight hardware due to their retention of solder flux and inspection difficulties.

6.17.7 Fibre optic assemblies

Fabrication processes and controls shall be established for terminations, joining fibre optic cable assemblies and their installation in accordance with the requirements of ECSS-Q-70-51.

6.18 Group 17: 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.

a. Training programmes shall be developed, maintained and implemented for all inspection personnel.

b. Inspection personnel shall be trained to appropriate, recognized standards.

c. All trained personnel shall be certified and their certification reassessed every two years.

d. All training and certification shall only be performed at a school authorized by the final customer.

e. Retraining shall be applied in the event of a new inspection procedure, modification to an existing inspection procedure or a change of the equipment used.

f. Records shall be maintained of the training and certification status of all inspection personnel.

g. Inspection equipment shall be regularly maintained and calibrated using approved methods to recognized standards.

h. Records shall be maintained for the calibration of equipment.

Annex A (informative)

Classes of materials

A.1 Aluminium and Al- alloys

A.1.1 General

Aluminium alloys are some of the basic building materials of existing spacecraft and appear in many subsystems. Only a few specific points of special interest for the spacecraft designer are considered here, since the general aspects of aluminium alloy assemblies are already well known in the similar field of aeronautical design.

NOTE See clause 5 for material requirements and clause 6 for process-related requirements.

A.1.2 Use in spacecraft

Light alloys based on aluminium are used in:

- primary and secondary structures;
- plumbing;
- plating in many applications (e.g. electronics, thermal control and corrosion protection);
- aluminized layers on other materials (see subclauses A.11 (adhesive tapes) and A.17 (plastic film));
- fillers in other materials to provide electrical or thermal conductivity.

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

- Additions of lithium to increase mechanical performance and decrease density. Li-additions are often lower than other "conventional" alloying elements, so Al-Li alloys can 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).

For guidelines on these materials, see ECSS-E-30-04.

A.1.3 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 optimize 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 product forms are available: foil, sheet, plate, profiles, sections and casting stock.

Many aluminium alloys exhibit excellent corrosion resistance in all standard tempers. However, the higher-strength alloys, which are of primary interest in aerospace applications, shall be used with caution. In structural applications preference should be given to alloys, heat treatments and coatings which minimize susceptibility to general corrosion, pitting, intergranular and stress corrosion cracking. Some alloys are clad with thin layers of pure aluminium to improve corrosion performance.

A.1.4 Processing and assembly

All classical methods find a use: shaping and forming processes (for example, wrought products produced by rolling, extrusion, forging and cast products) and joining by, for example, welding, brazing, riveting, bolting or adhesive bonding.

NOTE Not all alloys are weldable. Most high-strength alloys cannot be brazed.

a. Space use does not raise special problems in this respect; except that processes shall be extremely reliable. Aircraft industry standards are normally followed.

b. Processing of metals gives rise to residual stresses that can cumulatively reach design-stress levels, particularly as regards fatigue phenomena. Such stresses shall be checked.

A.1.5 Precautions

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

This point should be taken into account in specifications and checked after processing. Brittle intermetallic compounds can form by diffusion during thermal operations (heat-treatment, welding). They can be avoided by correct choice of alloy, heat-treatments used and by suitable thermal conditions during joining operations. International or national aerospace specifications for the heat treatment of aluminium alloys are used.

Residual stresses from processing (forming and heat-treatments), machining, assembly (improper tolerances during fit-up, over-torquing, press-fits, high-interference fasteners and welding), operational use, storage and transportation need evaluation to ensure that the as-designed stresses are not exceeded. Cumulative residual stresses also have an important influence on stress corrosion resistance.

a. Corrosion shall be considered during the whole manufacture and prelaunch phase; electrolytic couples (see Table 1 of this Standard) 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).

b. The metallic components proposed for use in most spacecraft shall be screened to prevent failures resulting from SCC. Such metal-alloy selection shall in particular be applied during the design phases of all spacecraft making use of the Space Shuttle, items intended for long-term storage prior to launch, highly stresses structures, all parts used or associated with the fabrication of, for example, launch vehicles.

c. 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-70-36). Also, because conventional processes are designed to optimize 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. Consequently, wrought heat-treatable aluminium products specified for use in the fabrication of hardware should be mechanically stress-relieved (TX5X or TX5XX temper designations) whenever possible.

   SCC ratings were attributed to the major aircraft alloys; these are based on service experience and testing programmes.

   NOTE See ECSS-Q-70-36 and NASA MSFC-STD-3029.

d. Three ratings of alloys were chosen: high-resistance, moderate-resistance and low-resistance to SCC (these are listed in Tables 1, 2 and 3 respectively of ECSS-Q-70-36A). The alloys listed in Table 1 should be used for space applications. For alloys listed in Table 2 or 3 a detailed justification for space use shall be provided, demonstrating that SCC testing according to the standard method detailed in ECSS-Q-70-37 has taken place. (Method incorporates constant load and alternate immersion in 3,5 % NaCl solution).

   NOTE All of the Al-Li alloys known at present are very sensitive to SCC (Table 3).

e. Machining and assembly methods can leave residues of chemicals (particularly cutting oils and dye penetrants). Methods of cleaning shall be applied and design shall prevent inaccessible “contaminant traps”.

A.1.6 Hazardous and precluded

Certain alloys and tempers are unsuitable for structural applications in long-term, manned structures, such as the 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 need specific tempers to provide resistance to stress corrosion cracking and exfoliation.

a. Porous platings (corrosion protection) and aluminized layers shall not be used, because they fail to provide adequate protection and can act as sources for contamination (see also subclauses A.11 (adhesive tapes) and A.17 (plastic film)).

b. Electrolytic couples shall be avoided or corrected by a suitable insulation between the metals concerned.

c. Bare metal-to-metal contact shall be avoided in any moveable part.

A.1.7 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 % should not be used for applications where temperatures can exceed 66 °C.
- Atomic oxygen in low Earth orbit (LEO) does not degrade aluminium alloys.

A.1.8 Some representative products

There are many European manufacturers of conventional aluminium and its alloys. Procurement to internationally recognized specifications is preferred, such as ISO, MIL Specs, B.S., SAE., DIN or AFNOR specifications.

The materials listed in Table A-1 (from ECSS-Q-70-36), can be considered.

Table A-1: Aluminium alloys with high resistance to stress corrosion cracking

Aluminium alloys			
Wrought[1,2]		Cast	
Alloy	**Condition**	**Alloy[3]**	**Condition**
1000 series	All	355.0, C355.0	T6
2011	T8	356.0, A356.0	All
2024, rod bar	T8	357.0	All
2219	T6, T8	B358.0 (Tens-50)	All
(E) 2419	T8	359.0	All
(E) 2618	T6, T8	380.0, A380.0	As cast
3000 series	All	514.0 (214)	As cast[5]
5000 series	All[4,5]	518.0 (218)	As cast[5]
6000 series	All	535.0 (Almag 35)	As cast[5]
(E) 7020	T6[6]	A712.0, C712.0	As cast
7049	T73		
7149	T73		
7050	T73		
7075	T73		
7475	T73		

1. Mechanical stress relieved (TX5X or TX5XX) where possible.
2. Including weldments of the weldable alloys.
3. The former designation is shown in parentheses when significantly different.
4. High magnesium content alloys 5456, 5083 and 5086 should be used only in controlled tempers (H111, H112, H116, H117, H323, H343) for resistance to stress corrosion cracking and exfoliation.
5. Alloys with magnesium content greater than 3,0 % should not be used for high-temperature application, 66 °C (150 °F) and above.
6. Excluding weldments.

(E) ESA classification - not in NASA MSFC-STD-3029.

A.2 Copper and Cu-alloys

A.2.1 General

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

NOTE See clause 5 for material requirements and clause 6 for process-related requirements.

A.2.2 Use in spacecraft

The main applications for copper are in electrical and electronic subsystems (wiring, terminals in soldered assemblies) and plating (e.g. electronics, thermal control and corrosion protection). Copper is also used as a metallizing coating (see A.17) and as an additive in other materials (see subclause A.13).

A.2.3 Main categories

Copper materials are generally grouped as follows:

- 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. Alloys form two groups: one with less than 1 % Be content and the other with approximately 2 % Be. Cobalt and nickel additions (present for heat treatment purposes) tend to vary inversely with Be content. These alloys, depending on their condition, offer combined mechanical performance and electrical conductivity for electrical and electronic applications (e.g. 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, see ECSS-E-30-04.

A.2.4 Processing and assembly

In electronic assembly operations, copper wires are soldered to terminals (either manually or automatically). The correct selection and use of process materials (e.g. approved solders and fluxes for space hardware and solvents) is a controlling factor in making reliable soldered connections - see also subclause A.7 and ECSS-Q-70-08.

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

A.2.5 Precautions

Heating brass in an oxidizing atmosphere or under corrosive conditions can cause dezincification of the alloy (loss of zinc from the exposed surface layer). This alters the surface properties and reduces fatigue and bending resistance.

Cold worked brass alloys are sensitive to stress corrosion cracking. Annealing heat treatments are used to remove the cold work, but care shall be taken to avoid any dezincification.

Natural atmospheres containing the pollutants sulphur dioxide, oxides of nitrogen and ammonia are reported to cause stress corrosion cracking of some copper alloys. Chlorides present in marine atmospheres can cause stress corrosion problems, but to a lesser extent than the above pollutants, indicating that industrial areas are probably more aggressive to copper-based alloys than marine sites. Many copper alloys containing over 20 % zinc are susceptible to SCC even in the presence of alloying additions that normally impart resistance to stress corrosion.

In electronic assemblies, terminals fabricated from bronze should be used. Brass terminals need 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.

A.2.6 Hazardous and precluded

- The toxicity of copper-beryllium alloys (less than 4 % Be) is not known.
- Copper shall not be used on the external surfaces of spacecraft in LEO. Copper shows discoloration under atomic oxygen attack.
- Brass (Cu-Zn alloys) used in electronic connections shall be plated with a barrier layer to prevent zinc diffusion to the surface (see ECSS-Q-70-08).

A.2.7 Effects of space environment

- Vacuum presents no special problem for copper-based materials, although copper-zinc alloys are generally plated – see subclause A.8. 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.

A.2.8 Some representative products

The materials listed in Table A-2 (from ECSS-Q-70-36), can be considered.

Table A-2: Copper alloys with high resistance to stress corrosion cracking

Copper Alloy	
CDA no.[1]	**Condition (% cold rolled)[2]**
110	37
170	AT, HT[3,4]
172	AT, HT[3,4]
194	37
195	90
230	40
422	37
443	10
510	37
521	37
619	40 (9 % B phase)
619	40 (95 % B phase)
688	40
706	50
725	50, annealed
280, 524, 606, 632, 655, 704, 710	0
715, (E) 917, (E) 937	0

1. Copper Development Association alloy number.
2. Maximum per cent cold rolled for which stress corrosion-cracking data are available.
3. AT - annealed and precipitation hardened.
4. HT - work hardened and precipitation hardened.

(E) ESA classification - not in NASA MSFC-STD-3029.

A.3 Nickel and Ni-alloys

A.3.1 General

As a family, the Ni-based alloys are used in many engineering fields for their corrosion resistance and high-temperature performance. Some alloys are used in electrical applications (e.g. heating elements). The magnetic characteristics of certain alloys are utilized in transformer components. A few alloys have controlled-expansion and constant-modulus properties (bimetals, thermostats, glass sealing, precision equipment). Others were 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.

NOTE 1 Ni-alloys are often known by trade names, rather than by their specification code numbers.

NOTE 2 See clause 5 for material requirements and clause 6 for process-related requirements.

A.3.2 Use in spacecraft

Nickel plating appears in many applications (e.g. electronics, thermal control and corrosion protection).

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” can be used as actuators.

A.3.3 Main categories

Nickel-based materials can be grouped by principal alloying additions. However, alloys within one composition grouping can be used in more than one general application group. For example: the majority of nickel-iron-chromium alloys in the Inconel and Incoloy series are now applied to elevated-temperature service, except two which are primarily used for their corrosion resistance.

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).

The resistance of Ni-alloys to a particular corrosive media largely depends on the composition.

- Ni-Mo-Fe alloys, often with additions of Cr: resistance to high acid concentrations, retained at high-temperatures.

  NOTE These are also used in high-temperature structural applications.

- Ni-Cr-Mo-Cu alloys: resistance to strong mineral acids, many fluorine compounds, sea water – often used as castings.
- Ni-Fe-Cr: Inconel 625 – resistance to inorganic and organic acid solutions, alkaline solutions, chloride ion stress corrosion, especially sea-water; Inconel 825 – resistance to strong mineral acids, reducing and oxidizing, sulphuric and phosphoric acids at all concentrations to boiling point.
- Ni-Cu (with about 30 % Cu): resistance to water and sea-water, non-oxidizing acids and alkalis, many salts and organic acids. Lower resistance to oxidizing acids.

Heat-resistant alloys tend to form two, not entirely independent, groups. They were developed to:

- resist corrosive attack imposed by the service conditions – hot corrosion;
- resist deformation and fracture under the imposed service stresses and temperatures – creep resistant or “super alloys”.

Almost all heat-resistant Ni-alloys are developments of the basic 80Ni – 20Cr composition. Modifications to this include variations in the Cr content and the addition of other alloying elements. Ni-Fe-Cr (usually with 15 %–25 % Cr) alloys are used at service temperatures up to about 1 100 °C in oxidizing, carburizing, sulphidizing environments and also are resistant to other forms of chemical attack. Under thermal cycling, the protective oxide layer can crack and spall.

Creep-resistant alloys (nickel-based superalloys) probably have the most complex compositions of any engineering alloys and have similarly complex microstructures. The alloying additions are designed to exploit many “microstructural engineering” techniques, such as phase stabilization, precipitation hardening, dispersion strengthening, grain-boundary pinning and solid-solution strengthening as well as give corrosion resistance. Alloying increases the strength and temperature capability but reduces the processability (since the alloys are specifically designed to resist deformation at temperature). This limits the product forms available. Sheet and complex forgings can only be made in lower-alloy variants and their temperature resistance is correspondingly lower.

Creep-resistant alloys can be grouped by application:

- Turbine blades: Alloy selection is normally made on creep and corrosion and oxidation requirements, but toughness and fatigue resistance are also important factors. The alloying combinations dictate the overall performance (strength, hot-corrosion and oxidation resistance). For severe, complex service environments overlay coatings are applied. These are generally proprietary mixtures of metals or ceramic powders. Casting now predominates as the manufacturing process, as it allows complex integral features (e.g. cooling channels), over forging or machining from wrought materials.
- Discs: Alloy selection is based on combined mechanical performance (creep and high-cycle fatigue, crack propagation and fracture toughness) at the service temperature. Alloys with a high iron content tend to have lower service temperatures, but conventional Ni-based superalloys can operate at higher temperatures. The properties obtained in discs (forgings) vary with the precise disc geometry and size. Strict control of the microstructure produced in the final item is essential in highly alloyed materials.
- Sheet alloys: Mechanical performance at service temperature (and conditions) is determined by composition and the strengthening mechanism used. Commercially available alloys can be solid solution strengthened, precipitation hardened or oxide dispersion strengthened (ODS). Sheet alloys are readily weldable, with the exception of ODS alloys (where heating destroys the dispersion) and Rene 41, which is prone to cracking in the heat affected zone.

Nickel-based superalloys possess good combinations of high-temperature mechanical properties and oxidation resistance up to approximately 550 °C. Many of these alloys also have excellent cryogenic temperature properties.

Continued alloy development has produced materials specifically designed for processing in particular ways: directional solidification and single-crystal castings; powder metallurgy and associated consolidation techniques. These materials optimize mechanical properties in selected directions, and so increase creep resistance in the dominant direction experienced in service.

Magnetic alloys generally have a high magnetic permeability in low or moderate strength magnetising fields, or exhibit particular magnetic hysterisis characteristics. The resulting magnetic properties depend on careful control of specialized processing methods. They are mainly used in telecommunications or for electronic transformer components. Pure nickel and some high nickel content-Co alloys have magnetorestrictive characteristics used in transducers. Ni-Fe alloys containing about 30 % Ni and nickel-30 % copper alloys have permeabilities that vary rapidly with temperature at “normal” temperatures and find uses in temperature compensation devices.

With careful control of composition and processing techniques, the thermal expansion coefficient of some Ni-Fe alloys can be low or be matched to the CTE of non-metallic materials such as glasses and ceramics. Some alloys can, by composition modifications, be strengthened, making them suitable for load-bearing applications. Uses include vacuum equipment, metrology and chronometry. 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 to ensure stability during changes of temperature.

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), they return to the original shape. The cold deformation produces microstructural phase changes which accommodate the reshaping without permanent material flow. On heating these microstructural changes are reversed and the shape returns to the original. Applications include temperature sensitive actuators, fixing and gripping devices (often in inaccessible locations).

A.3.4 Processing and 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, e.g. hot isostatic pressing, can be used for the consolidation (porosity elimination) of cast components. All processes should be strictly controlled and the specifications applied to aircraft and other critical industry applications (power generation) are used.

A.3.5 Precautions

In electronic assemblies, brass terminals can be plated with a barrier layer of nickel provided that its magnetic properties are acceptable in the final assembly.

NOTE Nickel can have poor solderability compared with copper platings.

The precise operating environment shall be carefully evaluated to ensure that the correct alloy is selected (e.g. resistance to a particular chemical at service temperatures; combined temperature, hot-corrosion and oxidation resistance; electrical and magnetic requirements or constraints).

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. Depletion of alloying elements in precipitation hardening superalloys can occur in high-temperature oxidizing environments. This is especially important for thin materials, since a slight depletion effect can represent a considerable proportion of the effective material cross-section.

A full evaluation of service conditions and interfacial effects (e.g. thermal mismatch and diffusion) shall be carried out when selecting and using coatings for oxidation or corrosion resistance. Barrier, ceramic-type coatings can crack and spall during thermal cycling and elements of metal coatings can diffuse into the substrate at prolonged elevated temperatures.

As a class, alloys with a high nickel content are resistant to stress corrosion cracking. Alloys that were evaluated are listed as high-resistance (see A.3.8). For non-listed alloys a SCC evaluation shall be optained prior to use.

A.3.6 Hazardous or precluded

Alloys with a high nickel content are susceptible to sulphur embrittlement. Sulphur is a common constituent of industrial oils, greases and cutting lubricants, so careful cleaning of components is necessary prior to heat-treatments or prior to use in high-temperature environments.

A.3.7 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 that can remove or disrupt oxide layers.
- Radiation at the levels 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.

A.3.8 Some representative products

Ni-alloys are often known by their trade names, rather than by their specification code numbers. They form a family of materials that have developed over the last 70-odd years and been modified to enhance certain properties over others. Consequently there exist the main trademarked suppliers products, but many variants of these are available under different proprietary names. The following list is not comprehensive of all that is available across Europe.

- Corrosion resistant alloys: Monel, Inconel, Incoloy, Corronel from INCO Group; Hastelloy from Cabot Corp.; Nirolium from Bonar Langley Alloys.
- High-temperature alloys: Nimonic, Inconel and Inconel from INCO Group; other suppliers often incorporate the INCO alloy number in their own proprietary name. Superalloy suppliers include: Hastelloy, Haynes from Cabot Corp.; Inconel, Incoloy, Inco from International Nickel Co.; MarM from Martin Marietta; Udimet from Special Metals; Nimonic, Ninocast from INCO Group.
- Electrical alloys: Monel, Brightray, Ferry from INCO Group; Nichrome, Tophet, Chromel, Alumel from British Driver Harris; Pyromic, Telconstan from Telcon Metals; Constantan from I.T.T.
- Magnetic alloys: Mumetal, Radiometal from Telcon Metals; Permalloy from I.T.T.; Nilomag, JAE metal from INCO Group.
- Controlled-expansion alloys: Nilo from INCO Group; Invar, Telcoseal from Telcon Metals; Therlo from British Driver Harris.
- Controlled-modulus alloys: Ni-Span from INCO Group; Elinvar from Telcon Metals.
- Fastener fabricators and suppliers include:
  - Blanc Aero (F);
  - Kamax (D);
  - Linread (UK).

An additional supplier is Aubert and Duval (F).

Nickel alloys that were evaluated and shown to have a high resistance to stress corrosion cracking are listed in Table A-3 (from ECSS-Q-70-36).

Table A-3: Nickel alloys with a high resistance to stress corrosion cracking

Nickel Alloy	Condition
Hastelloy C	All
Hastelloy X	All
Incoloy 800	All
Incoloy 901	All
Incoloy 903	All
Inconel 600[1]	Annealed
Inconel 625	Annealed
Inconel 718[1]	All
Inconel X-750	All
Monel K-500	All
MP35N	All
Ni-Span-C 902	All
Rene 41	All
Unitemp 212	All
Waspaloy	All
1. Including weldments	

A.4 Titanium and Ti-alloys

A.4.1 General

Titanium and Ti-alloys are generally chosen for their mechanical properties, temperature resistance 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.

NOTE See clause 5 for material requirements and clause 6 for process-related requirements.

A.4.2 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 can find specialized uses as actuators.

Titanium alloys are preferred for contact with CFRP due to their low CTE and matched galvanic corrosion properties.

A.4.3 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 are available.

A.4.4 Processing and 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. The filler material also needs careful selection to avoid potential hydrogen embrittlement problems: the use of CP filler wire to join CP alloys parts is possible, but CP filler for alloy parent parts shall not be used.

Some metals and processing chemicals can degrade the properties of titanium alloys by inducing stress corrosion or hydrogen embrittlement or by reducing fracture toughness. See A.4.6.

A.4.5 Precautions

The properties of titanium alloys are strongly dependent on their previous thermal 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.

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 (e.g. 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.

a. Corrosion shall be considered during the whole manufacture and prelaunch phase (see Table 1 of this standard); 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).

b. The metallic components proposed for use in most spacecraft shall be screened to prevent failures resulting from SCC. Three ratings of alloys were chosen: high-resistance, moderate-resistance and low-resistance to SCC (these are listed in Tables 1, 2 and 3 respectively of ECSS-Q-70-36A). The alloys listed in Table 1 should be used for space applications. For alloys listed in Table 2 or 3 a detailed justification for space use shall be provided, demonstrating that SCC testing according to the standard method detailed in ECSS-Q-70-37 was done. (Method incorporates constant load and alternate immersion in 3,5 % NaCl solution).

A.4.6 Hazardous or precluded

Titanium alloys can be susceptible to hydrogen-embrittlement and are generally unsuitable for hydrogen-containing atmospheres.

Care shall be exercised to ensure that cleaning fluids 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.

A.4.7 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.

A.4.8 Some representative products

There are several European sources of conventional titanium alloys, e.g. Timet (previously Imperial Metal Industries - IMI (UK); Tital (D), Ugine Kuhlmann (F).

Sources of high-reliability fasteners include: Blanc Aero (F); Fairchild Fasteners Europe Hildesheim (D); Linread (UK).

Procurement to internationally recognized specifications is recommended, e.g. ISO, MIL Specs, B.S., SAE., DIN or AFNOR specifications.

The materials listed in Table A-4 (from ECSS-Q-70-36), can be considered.

Table A-4: Titanium alloys with high resistance to stress corrosion cracking

Miscellaneous Alloy (wrought)	Condition
Titanium, 3Al-2.5V	All
Titanium, 6AI-4V	All
Titanium, 13V-11Cr-3AI	All
(E) Titanium OMI 685, IMI 829	All
(E) ESA classification - not in NASA MSFC-STD-3029.	

A.5 Steels

A.5.1 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 can be considered for use in space and any precautions that shall be taken for their application.

NOTE See clause 5 for material requirements and clause 6 for process-related requirements.

A.5.2 Use in spacecraft

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

A.5.3 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. This results from excess Mn used for deoxidation and desulphurization during smelting. Impurity levels (e.g. phosphorus and sulphur) depend mainly on the smelting and melting processes used, although increased use of remelted scrap metal can introduce other problem elements such as copper. 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 % C–0,3 % C) to medium-carbon steels (0,3 % C–0,6 %C) are used for various "engineering" components, whereas high-carbon steels (0,6 % C–0,9 %C) are used for applications requiring hardness and wear resistance.

Alloying additions to plain carbon steels produce a wide range of alloy steels with improved performance. Alloying effects can be microstructure-related: for example, control of transformation effects, control of grain size, carbide precipitation; process-related: workability, heat-treatment, hardenability and weldability; corrosion-related: forming adherent oxide films on the surface (see also subclause A.6). Depending on the level of additions, some elements have effect on all of these.

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 and processability) strengths rarely exceed 1 250 MPa. The exceptions are 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 1 250 MPa, 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 %). These alloys have a number of benefits: very high tensile strengths (1 175 MPa to 2 450 MPa); high toughness which remains good at low temperatures; weldability; ease of heat-treatment and machinability. Low-strength maraging steels have better resistance to stress corrosion than low alloy steels. However, fatigue and wear resistance tend to be lower than low alloy steels. They are also high-cost materials.

A.5.4 Processing and 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 (e.g. machining, welding and fastening). Care shall be taken with some alloys that the processing does not degrade the microstructure, hence properties. Heat treatments can 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 and thread rolling). Aircraft specifications for heat-treatments and processing are used.

High-strength martensitic steels (UTS ≥1 225 MPa) shall be carefully machined using carbide-tipped tools and other techniques to ensure that the formation of an untempered martensitic structure does not occur on surfaces.

A.5.5 Precautions

Carbon and low-alloy steels with ultimate tensile strengths below 1 225 MPa (180 ksi) are generally resistant to stress corrosion cracking. For applications where the primary loading is compressive or low tensile or with a history of satisfactory performance, materials with UTS ≥1 225 MPa can be accepted providing that their stress corrosion properties were approved.

Some steels have a ductile-brittle transformation which, depending on the alloy composition, can occur within the normal service conditions for some space components. Specifications normally include a value for the impact energy.

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. Some strong acids can be handled by low-carbon steels (mild steel), although a careful evaluation of the concentration ranges is needed. Alkaline solutions have a slow corrosion rate (owing to a passivation-effect), but corrosion rates are fairly high in hot, high alkali concentrations. 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, although Cr-levels can promote pitting in some conditions. Stress corrosion cracking occurs in steels in hot (>40 °C approx.) caustic solutions and in some other chemical solutions (ammonia, nitrate, hydrogen-sulphide containing). Higher strength steels are also prone to SCC in seawater and other chloride solutions.

High-strength steels are susceptible to hydrogen embrittlement resulting from hydrogen pick-up during plating and pickling processes (or excessive cathodic protection). Such problems in parts are normally alleviated by a post-process baking procedure.

A.5.6 Hazardous or precluded

Platings on steels commonly used in terrestrial applications for improved corrosion resistance can be unsuitable for space. These include zinc, cadmium or other volatile metals – see subclause A.8.

A.5.7 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.
- 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.

A.5.8 Some representative products

European suppliers provide a wide range of steels, all of which are denoted by national and international specifications and standards, including series specifically for aerospace grade materials.

Steels that were evaluated and shown to have a high resistance to stress corrosion cracking are listed in Table A–5 (from ECSS–Q–70–36).

Table A-5: Steel alloys with high resistance to stress corrosion cracking

Steel	Condition
Carbon steel (1000 series)	Below 1 225 MPa (180 ksi) UTS
Low alloy steel (e.g. 4130 and 4340)	Below 1 225 MPa (180 ksi) UTS[1]
(E) D6AC, H-11	Below 1 450 MPa (210 ksi) UTS
Music wire (ASTM 228)	Cold drawn
HY-80 steel	Quenched and tempered
HY-130 steel	Quenched and tempered
HY-140 steel	Quenched and tempered
1095 spring steel	Quenched and tempered
Nitronic 33[2]	All

1. A small number of laboratory failures of specimens cut from plate more than 2 inches thick were observed at 75 % yield, even within this ultimate strength range. The use of thick plate is generally avoided in a corrosive environment when sustained tensile stress in the short transverse direction is expected.
2. Including weldments.

(E) ESA classification not in NASA MSFC-STD-3029.

A.6 Stainless steels

A.6.1 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 can be considered for use in space and introduces precautions for their application.

NOTE See clause 5 for material requirements and clause 6 for process-related requirements.

A.6.2 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.

A.6.3 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. Stainless steels are normally grouped by their metallurgical structure:

- austenitic: derived from the basic 18 Cr/8 Ni compositions (300-series), or higher strength versions in which some of the Ni-content was replaced by nitrogen and manganese (200-series). There are a large number of variants that were developed to provide resistance to specific environments or to enhance particular mechanical properties, including creep resistance. Strength is increased by cold-working and properties are retained at low temperatures.
- ferritic: 400-series materials contain between 11 % Cr–30 % Cr and a maximum of 0,1 %C. Other elements are used to improve processability (welding) or environmental resistance (pitting and crevice corrosion; high-temperature scaling). Low interstitial grades control carbon and nitrogen to below 0,03 %.

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 (>1 400 MPa).
- 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). Nitrogen additions provide high strengths (cold-working) and better as-welded corrosion resistance than non nitrogen-containing 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.

A.6.4 Processing and assembly

Most conventional processing techniques are applied to steels (e.g. machining, welding and fastening). Care shall be taken 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 (localized 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.

A.6.5 Precautions

Alloys have generally been developed to have maximum corrosion resistance to specific environments. Careful evaluation of the service conditions is needed for successful alloy selection.

Chromium within the alloy can react with carbon and form localized Cr-depleted areas and brittle compounds, normally at grain boundaries. This effect is known as “sensitization” and can have serious consequences for corrosion resistance, especially stress corrosion cracking. “Stabilized” stainless steels have alloying additions (Ti, Mo, Nb) specifically to “tie-up” carbon as carbides and so prevent sensitization (also known as weld decay). Unstabilized, austenitic steels have a service temperature limit of 370 °C. With the exception of stabilized or low-carbon grades (e.g. 321, 347, 316L, 304L), welded assemblies need solution treatment and quenching after welding.

Austenitic stainless steels can suffer stress corrosion cracking in chloride environments and they can be prone to pitting, crevice corrosion and weld decay unless composition, heat-treatment and service conditions are carefully controlled.

Austenitic stainless steels of the 300-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 shall be cleaned carefully prior to operation in service. Heat treatment can thicken the oxide film to produce scale or deplete the subscale metal of chromium. Welding spatter and flux residues can promote localized corrosion. Embedded carbon-rich materials from machining can react with chromium at high temperatures. Cleaning processes are normally chemical pickling using various combinations of acids, the residues of which also have to be removed thoroughly. Some grades can be susceptible to hydrogen embrittlement resulting from hydrogen pick-up during pickling processes.

A.6.6 Hazardous or precluded

Alloys prone to sensitization need careful consideration of their stress corrosion characteristics and service at elevated temperatures.

A.6.7 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 that 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.

A.6.8 Some representative products

European suppliers provide a wide range of stainless steels, all of which are denoted by national and international specifications and standards, including series specifically for aerospace grade materials.

Stainless steels that were evaluated and shown to have a high resistance to stress corrosion cracking are listed in Table A-6 (from ECSS-Q-70-36).

Fastener fabricators or suppliers include:

- Blanc Aero (F);
- Fairchild Fasteners Europe (D);
- Linread (UK).

Table A-6: Stainless steels with high resistance to stress corrosion cracking

Stainless Steel	Condition
300 series stainless steel (unsensitized)[1]	All
400 series Ferritec stainless steel (404, 430, 431, 444, etc.)	All
21-6-9 stainless steel	All
Carpenter 20 Cb stainless steel	All
Carpenter 20 Cb-3 stainless steel	All
A286 stainless steel	All
AM350 stainless steel	SCT 1000[2] and above
AM355 stainless steel	SCT 1000 and above
Almar 362 stainless steel	H1000[3] and above
Custom 455 stainless steel	H1000 and above
15-5 PH stainless steel	H1000 and above
PH 14-8 Mo stainless steel	CH900 and SRH950 and above[4,5].
PH 15-7 Mo stainless steel	CH900
17-7 PH stainless steel	CH900
(E) Maraging steel MARVAL X12	All

1. Including weldments of 304L, 316L, 321 and 347.
2. SCT 1000 = sub-zero cooling and tempering at 538 °C (1 000 °F).
3. HI 000 hardened above 538 °C (1 000 °F).
4. CH900 cold worked and aged at 480 °C (900 °F).
5. SRH950 = solution treated and tempered at 510 °C (950 °F).

(E) ESA classification not in NASA MSFC-STD-3029.

A.7 Filler materials: welding, brazing and soldering

A.7.1 General

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

NOTE See clause 5 for material requirements and clause 6 for process-related requirements.

A.7.2 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 should be used instead of soldering when stronger joints and an increase in temperature resistance is specified. 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.

A.7.3 Main categories

There are a large number of welding filler materials available. Forms (e.g. wires and rod) vary depending on the welding technique used. Selection of the correct filler rod is largely dictated by the metals being joined, notably alloy composition. 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 (e.g. solvents and cleaning baths), were subject to intense evaluation, see Table A-7 and Table A-8 (from ECSS-Q-70-08).

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

Table A-7: Guide to choice of solder-types for space use

	Melting Range (°C)		
Solder Type	**Solidus**	**Liquidus**	**Uses**
63 tin solder (eutectic)	183	183	Soldering PCBs where temperature limitations are critical and in applications where an extremely short melting range is specified.
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 or cable harnesses or terminal connections and for coating or pre-tinning metals.
96 tin silver (eutectic)	221	221	Can be used for special applications such as soldering terminal posts. It shall be used for the assembly of semi-rigid cables (ECSS-Q-70-18).

Table A-8: Approved solder compositions for space use

Composition		Designation			
		63 tin solder (eutectic)	62 tin silver-loaded solder	60 tin solder	96 tin silver solder (eutectic)
Tin (Sn)	Min %	62,5	61,5	59,5	remainder
	Max %	63,5	62,5	61,5	
Lead (Pb)	Max %	remainder	remainder	remainder	0,10
Antimony (Sb)	Max %	0,05	0,05	0,05	0,12
Silver (Ag)	Min %	-	1,8	-	3,5
	Max %	-	2,2	-	4,0
Bismuth (Bi)	Max %	0,10	0,10	0,10	0,10
Copper (Cu)	Max %	0,05	0,05	0,05	0,05
Iron (Fe)	Max %	0,02	0,02	0,02	0,02
Aluminium (Al)	Max %	0,001	0,001	0,001	0,001
Zinc (Zn)	Max %	0,001	0,001	0,001	0,001
Arsenic (As)	Max %	0,03	0,03	0,03	0,03
Cadmium (Cd)	Max %	0,002	0,002	0,002	0,002
Others	Max %	0,08	0,08	0,08	0,08

A.7.4 Processing and assembly

Aircraft standards and specifications are normally applied. Other critical industry sectors (e.g. nuclear and power-generation) can offer guidance on specialist materials.

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

A.7.5 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 shall be considered.

Not all "industrial" welding techniques can be used on all materials. The choice of welding process is largely dictated by the metal composition, although the component itself and the ease of producing an acceptable weld are important, as is the correct selection of the filler material. For some alloys preheating can be used to reduce thermal-distortion effects and post-weld thermal treatments to recover mechanical or environmental resistance properties.

The correct selection of parent materials and weld methods requires consideration of all factors that affect operational capability of the parts concerned. Welding procedures are selected on their ability to provide the specified weld quality, minimum weld energy input and protection of the heated metal from contamination.

Comments specific to the welding of particular materials are included in the section on that material class; see also subclause A.8.

For some filler materials additional qualitative analysis or non-destructive testing can be carried out (e.g. Ni-based filler rod) to ensure that the correct filler metal is used on each specific critical part.

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 can 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 shall also be cleaned from components. Common soldering fluxes, their application and use are detailed in ECSS-Q-70-08.

A.7.6 Hazardous or 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 shall be applied.

A.7.7 Effects of space environment

See corresponding subclause on base materials for comments.

A.7.8 Some representative products

There are numerous suppliers of welding and brazing consumables (e.g. fillers and fluxes) in Europe. Solder alloys can be procured from J.L. Goslar GmbH (D).

A.8 Miscellaneous metallic materials

A.8.1 General

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

NOTE See clause 5 for material requirements and clause 6 for process-related requirements

A.8.2 Use in spacecraft

Light alloys based on magnesium and beryllium are used in some primary and secondary structures.

Plating appears in many applications (e.g. electronics, thermal control and corrosion protection) and calls mainly for silver and gold.

“Memory alloys” based on titanium and nickel can find uses as actuators: see subclause A.3.

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.

See ECSS-E-30-04.

A.8.3 Main categories

Miscellaneous metals include, but are not limited to:

- magnesium alloys;
- beryllium and Be-alloys (see subclause A.2 for Be-Cu alloys);
- refractory alloys;
- superalloys, which as a group include cobalt-, iron- or nickel-based alloys (see subclause A.3 for Ni-based superalloys);
- mercury;

- plating materials: e.g. cadmium, zinc, tin, gold, silver and osmium.

  NOTE This subclause also includes comments on metal-based materials that are either prohibited or can be used cautiously for space applications.

A.8.4 Processing and assembly

Magnesium alloys are available as wrought forms or for casting. Care shall be taken in storing magnesium alloys due to their tendency to corrode. Machining shall be performed with special precautions to prevent ignition and burning of swarf.

Sophisticated techniques and rigorous safety procedures shall be applied during processing of beryllium to avoid the formation and release of beryllium oxide, metal particles and compounds which are toxic. Consequently, the majority of beryllium components and structures are produced by companies dedicated to working with these materials.

Superalloys are processed following recognized aerospace procedures or other appropriate industry standards.

Specialist methods for processing refractory metals and alloys are applied.

During processes when metals with known or suspected toxicity problems are involved, appropriate safety equipment shall be used for operatives and appropriate procedures followed for collection and disposal of waste. See A.8.5 and A.8.6.

A.8.5 Precautions

The metallic components proposed for use in most spacecraft shall be screened to prevent failures resulting from SCC. Three alloy ratings were derived: high-resistance, moderate-resistance and low-resistance to SCC (these are listed in Tables 1, 2 and 3 respectively of ECSS‐Q‐70‐36A). The alloys listed in Table 1 should be used for space applications. For alloys listed in Table 2 or 3 a detailed justification for space use shall be provided, demonstrating that SCC testing according to the standard method detailed in ECSS‐Q‐70‐37 took place (method incorporates constant load and alternate immersion in 3,5 % NaCl solution).

- Magnesium alloys

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

- Beryllium and Be-alloys

  Beryllium is used in its pure form, but is both brittle and difficult to fabricate as well as being fairly toxic. This metal is produced by powder metallurgy involving hot isostatic processing and component parts should be initially rough machined, heat treated to remove major residual stresses and then fine machined. A final chemical etching treatment should be performed to remove 0,1 mm from the surface of machined parts. This generally removes mechanical damage such as subsurface microcracks and deformation twins.

  Beryllium and Beryllium oxide dust and vapours are toxic: special precautions shall be taken when work is done on this material.

- 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.

  NOTE Cadmium in NiCd batteries is acceptable.

- Osmium oxide is toxic: special precautions shall be taken when work is done on this material.

A.8.6 Hazardous or 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.

Specialized safety equipment and procedures for the collection and disposal of dust and debris shall be used 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.

A.8.7 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 can form conductive deposits on insulators or opaque deposits on optical components. Oxide layers slow down the process of evaporation when they are thick enough and not cracked. 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. It is particularly intense for pairs of cubic-lattice metals which alloy readily (see A.13).
- 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).

A.8.8 Some representative products

European sources of beryllium are: SAGEM (F), Royal Ordnance Factory (UK), Heraeus (D), Brush Wellman (UK and D); Superalloys: Aubert and Duval (F)

Magnesium alloys: Magnesium Elektron (UK).

Procurement to internationally recognized specifications is recommended, such as ISO, MIL Specs, B.S., SAE., DIN or AFNOR specifications.

The materials listed in Table A–9 (from ECSS–Q–70–36), can be considered.

Table A-9: Miscellaneous alloys with high resistance to stress corrosion cracking

Miscellaneous alloy (wrought)	Condition
Beryllium, S-200C	Annealed
HS 25 (L605)	All
HS 188	All
Magnesium, M1A	All
Magnesium, LA141	Stabilized
Magnesium, LAZ933 (no longer commerially available)	All

A.9 Optical materials

A.9.1 General

The classical meaning of the word "glass" is extended in this Standard to cover "organic glass" and some crystalline optical materials.

NOTE See clause 5 for material requirements and clause 6 for process-related requirements.

A.9.2 Use in spacecraft

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

See also subclause A.20 for glasses and oxide ceramics used as electrical insulators.

A.9.3 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.

A.9.4 Processing

Inorganic glass parts are mainly assembled by means of flanges and gaskets or adhesives. Glass-to-metal welds are possible. Assembly shall be rigid enough to provide accurate alignment but shall also be designed to cope with thermal expansion and provide suitable damping.

Organic glasses are easily machined: this operation can be performed on inorganic glasses by using special techniques (e.g. ultrasonic machining).

A.9.5 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.

Assembly methods are the most important points in the design of parts containing glass and particular attention shall be given to matching the thermal expansion coefficient of the optical material with that of its mounting.

A.9.6 Hazardous or precluded

a. Canada Balsam and other similar products shall not be used in the assembly, since they are liable to produce contaminants.

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

A.9.7 Effects of space environment

- Vacuum exposure does not affect inorganic glasses or most organic glasses. The main danger comes from bonding agents, optical coupling agents and other assembly materials which can contaminate the optics by yielding condensable products. A contaminated optic is, in general, very difficult to clean.
- Radiation is the most harmful factor to be considered for glasses. Some inorganic glasses are damaged by doses of the order of 10 Gray of ionizing radiation (1 Gray = 1 J kg^{-1} of absorbed energy): the damage is a loss of transparency in certain wavelength ranges due to colour-centre formation. UV is less harmful, at least for inorganic glasses. Particle radiation can also distort the shape of optical elements. 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.
- Temperature: Thermal shock can lead to fracture in inorganic glasses. Also, distortion can be noted in precision optics when the assembly is not designed to compensate correctly for the low expansion of these glasses and the high expansion of metal mountings. Organic glasses soften at quite low temperature (80 °C to 100 °C frequently) and have rather high expansion coefficients.
- Atomic oxygen can attack organic glasses.

A.9.8 Some representative products

In the case of inorganic glasses pure silica should be used. This is sold by many European firms under many different trade names, for example:

- ULTRASIL, SUPRASIL, HERASIL from HERAEUS (D);
- PURSIL, TETRASIL from QUARTZ and SILICE (F);
- SPECTROSIL, VITREOSIL from THERMAL SYNDICATE (UK).

Optical glasses are mainly designated by reference numbers from manufacturers like SCHOTT (D), CORNING (USA) and PILKINGTON (UK).

For solar-cell covers, the main sources are still OCLI (USA) and PILKINGTON (UK). Some are manufactured with an electrically conductive surface such as ITO by the same manufacturers.

Optical solar reflectors (OSR) based on silica/silver/inconel or silica/aluminium are manufactured by OCLI. PILKINGTON produces OSR’s based on cerium glass/silver-nickel-chrome.

Filters are made by BALZERS (CH), SCHOTT (D), ASTRIUM SAS (F), M.T.O. (F), BARR and STROUD (UK) and THALES (UK).

Organic glasses based on acrylic and methacrylic polymers are well known: PLEXIGLAS from ROHM and HAAS (D), PERSPEX from ICI (UK). Polycarbonates like MAKROLON (BAYER, D) can also be considered as well as several polystyrene grades.

A.10 Adhesives, coatings and varnishes

A.10.1 General

Information and specific requirements are given for polymer-based adhesives (structural and non-structural), coatings and varnishes. For ceramic-type adhesives and applied coatings, see subclause A.20.

NOTE See clause 5 for material requirements and clause 6 for process-related requirements.

A.10.2 Use in spacecraft

Structural adhesives appear where high load-bearing capability is needed, e.g. in the face-to-core bond of honeycombs. They are characterized by having high strength and modulus; good toughness and peel strength are important factors for structural adhesive bonds. See ECSS-E-30-05 for guidelines on structural adhesives.

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. Some ensure good thermal contact and low stress concentration at the joint, but such assemblies are difficult to take apart after fabrication. Electrically conductive adhesives find a use as grounding points for conductive surfaces.

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).

See also subclause A.12 for coatings used for thermal-control purposes; subclause A.8 for metallic coatings; subclause A.20 for ceramic-type coatings and adhesives.

A.10.3 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. Some have to be kept cold until used; others are prepared by mixing two or more components just before application. They can contain fillers or be clear and transparent. Adhesives are in general quite complex (and proprietary) formulations, and appear on the market under many trade names; it is frequently difficult to determine their basic chemical nature from the manufacturer’s data. Anything can be bonded with adhesives, but no adhesive exists that can effectively bond everything.
- 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. Some are crystal clear, while some contain organic dye (mainly for quality control in the application). There are also products containing fillers. From the mechanical point of view, all grades are found from quite rigid to elastic products. As in the case of adhesives, coatings are frequently proprietary mixtures, the composition of which is difficult to trace.
- Some adhesive coatings have quite different properties above or below their Tg. This shall be carefully considered during selection for a particular application.

A.10.4 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. Typical examples in the cases of structural adhesives are:
  - Low temperature (50 °C) and pressure (2 kg/cm^2) for epoxy/amines.
  - High temperature (150 °C) and low pressure for epoxy/anhydrides.
  - High temperature and high pressure (5 kg/cm^2 to 20 kg/cm^2) for phenolics.
  - Very high temperature (250 °C) and high pressure for polyimides.

- 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. Some of these adhesives are quite sensitive to contaminants, the presence of which sometimes prevents correct curing.

- 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 (air drying or forced air drying). Solvent retention frequently occurs and tends to increase as the square of the film thickness, it is reduced by a high-temperature bake. High viscosity sometimes creates flow problems which can be corrected by the use of thixotropic agents.

A.10.5 Precautions

a. 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 (see ECSS-Q-70-22). They frequently have a short "pot-life" or "working life" after their component parts are mixed or brought to activation temperature.

b. The adhesive shall be physically and chemically compatible with the component parts to be bonded:

   - Physically, the adhesive shall attach itself to the two surfaces to be bonded and in general this needs special pretreatment (cleaning, etching, priming). The adhesive shall also be capable of accommodating dimensional changes in the bonded surfaces (expansion-coefficient matching).

   - Chemically, the adhesive shall not be corrosive to the adherents used (corrosion action is frequently due to hardeners).

c. Many adhesives or curing agents are harmful to human beings and care in their handling is necessary.

d. Adhesive bonding is in general quite sensitive to small changes in the process. This can lead to considerable variations in performance if strict control is not exercised. Moisture, either contained in the constituents, condensed on the adherends or in the atmosphere, can impair the cure of some adhesives (epoxies for example): humidity shall therefore be controlled. Atmospheric carbon dioxide can react with some curing agents and affect the properties of the cured product.

e. The storage, shelf life and pot life of coatings and varnishes shall be controlled in the same way as for adhesives. When the purpose of varnishes and coatings is to protect or insulate the underlying item, care shall be taken to produce a continuous and adherent layer. Adhesion can be promoted by the use of suitable surface treatments (e.g. when a conformal coating shall adhere to Teflon insulation) and priming. Debubbling under low pressure with careful control of the process aids the formation of an intact protective surface.

f. The proportion of catalyst, the temperature of the applied coating or varnish product and of the substrate, along with the topography and orientation of the substrate shall all be controlled. Thick coatings can generate mechanical stresses and fairly high temperatures during their cure, and any damaging effects of these on the item to be protected shall be assessed by testing. Coatings cured at high temperature contain residual stresses at lower temperatures. Some catalysts also give rise to corrosion problems with certain metals (copper, silver). Corrosion appears also where impurities (solder flux, moisture) are trapped in voids or cracks in the coating. Finally, thinners as well as base compounds can be toxic or flammable.

Material selection factors for conformal coatings are detailed in ESA SP1173 and are dependent on electrical requirements and anticipated service environment: dielectric constant, insulation resistance and corona suppression; and processing-related factors such as cure temperature and exothermic heat of reaction.

A.10.6 Hazardous or precluded

a. Many adhesives on the market are solutions or emulsions. Although these products can be excellent for their intended terrestrial use, they shall not be applied to space vehicles since they are potential outgassers. It shall be ensured that adhesives are quoted "100 % solid".

b. Structural adhesives for which the maximum temperature of use is low (60 °C to 70 °C) are likely to evolve contaminants at quite low temperature under vacuum (epoxy/amine). Adhesives which need atmospheric moisture to cure shall not be used in confined areas (large bonds between nonporous surfaces).

c. Most coatings and varnishes which rely only on solvent evaporation to harden (solvent types, e.g. cellulose varnishes or dispersions, e.g. acrylics) are not suitable for space applications. These products are most likely to be profuse outgassers even after long drying periods. Solvent elimination is an exponential function of absolute temperature (Arrhenius equation) and is inversely proportional to the square of the coating's thickness. Other coatings, containing solvent as a thinner but relying on a subsequent curing reaction to harden, should be avoided.

NOTE It is sometimes difficult to attain the specified viscosity without using a solvent.

d. Solvents sometimes attack insulation in the device to be coated. Alkyd and polyester are in general not good enough for space use. Polysulphides, which are unstable in a thermal-vacuum environment, should also be avoided.

e. Coatings and varnishes usually present very large surfaces to the space environment, this makes them particularly dangerous when not well chosen.

A.10.7 Effects of space environment

- Exposure of adhesives to vacuum provokes outgassing. The major components which outgass are unreacted compounds, low-molecular-weight constituents and the bi-products from chemical reactions. As the exposed surface is small (only the bondline), outgassing rates can be quite low. Effects of vacuum alone on the bond integrity are normally not observed, but some of the evolved constituents can be condensable and can create a contamination danger in a spacecraft ("coating" of electrical or optical components). Many epoxies are acceptable from an outgassing point of view, but are rather sensitive to humidity conditions at the time of curing. "Modified" epoxies, particularly the flexible ones, can have outgassing rate. Nearly all RTV silicones are known to be contaminant, but some manufacturers have developed special compounds for space use. All coatings and varnishes outgas. This is particularly noticeable for types containing solvent. This phenomenon can sometimes be reduced by extended curing at high temperature and under vacuum, but such a method is not very practical and is not always successful. Atmospheric gases trapped within cracks and voids in the coating can leak out under vacuum and produce pressures in the "corona range". Cracks formed under vacuum can fill with outgassing products up to the same pressures. These two phenomena lead to troubles when high electric field strengths are present during spacecraft equipment operation.
- 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; see comments for UV. Insulating varnishes used inside "black boxes" are well protected against particle fluxes.

- 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. UV radiation and proton fluxes are the main factors and can cause darkening and hardening of coatings and increase the outgassing rate. Insulating varnishes used in "black boxes" are not subjected to UV.
- High temperature degrades adhesives. For long-term exposure polyimide can be used up to more than 300 °C; the best epoxies are normally limited to 170 °C. Phenolics and silicones lie between. High temperature accelerates outgassing. Silicone-type coatings and varnishes are recommended for high temperatures. For very high temperatures, "ladder-polymers", such as polyimide or polybenzimide, are the only possible candidates. When flammability is a property to be considered, silicone materials should be chosen in preference to polyurethane coatings.
- Low temperature stiffens adhesives and causes brittle bonds. Some polyurethane adhesives are still useful at very low temperatures (cryogenic). A similar effect is seen with coatings which tend to harden, shrink and crack.
- 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. Thick layers of rigid adhesives are prone to high stresses. Coatings and varnishes experience thermal-cycling due to shadow-sunlight passage or to variable internal heat sources caused by switching equipment on and off. Mismatch of expansion coefficients between coating and coated items gives rise to high stresses and eventually to cracks. Thermal insulation by the coating can lead to overheating of high-power components, particularly in vacuum.
- 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.

A.10.8 Some representative products

Adhesives that can be considered are (see annex B – Data sheets):

- Araldite AV 138,
- DC 6-1104,
- DC93500,
- Eccobond Solder 56C,
- Redux 312,
- RTV 566,
- RTV S 691,
- RTV S 695,
- Scotch Weld EC 2216,
- Solithane 113.

Coatings and varnishes that can be considered are (see annex B – Data sheets):

- DC 93500,
- MAPSIL 213,
- RTV S 695,
- Uralene 5750.

A.11 Adhesive tapes

A.11.1 General

Tapes can be an integral part of a flight assembly or be used as a temporary aid during the assembly of parts.

NOTE See clause 5 for material requirements and clause 6 for process-related requirements.

A.11.2 Use in spacecraft

In existing satellites, adhesive tapes are used mainly in the thermal-control subsystems. They function either as thermal-control surfaces themselves or are used in assembling thermal blankets. They can also be used in electrical insulators. Such tapes can be used extensively during qualification tests as a means of attaching sensors and temporary wiring to the spacecraft. Adhesive tapes are easy to handle, can be cut to size and used to make patterns. They can be removed easily after temporary use.

Some conductive adhesive tapes are used for electrical grounding.

A.11.3 Main categories

The backing of adhesive tapes can be made from polyester, polyimide, polyolefin, fluorinated polymers, fibreglass cloth, metal sheet, metallized (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 (e.g. tackifiers and plasticisers), and the composition is normally proprietary. Basic rubber-like polymers used are, for example, natural rubber, acrylates, acrylic rubbers, silicones and butyl.

Adhesive tapes are sold in rolls of different widths with or without an intermediate liner. Some can be heat or solvent activated. Thermosetting adhesive tapes also exist. Transfer tapes (2 adhesive sides), supported or unsupported, find extensive use in the bonding of metallized films.

A.11.4 Processing and assembly

The processing and use of adhesive tapes appear to be extremely simple; cut to size and apply. One should, however, ensure that the adherent surface is clean enough, that the application pressure is even and that the tape surface is not damaged during the application. Sometimes tapes shall be perforated all over their surfaces; this allows evacuation of trapped or generated gas bubbles under vacuum (particularly with metal-backed tapes).

A.11.5 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. Cleaning solvents can accidentally damage the adhesive or the tape, or be absorbed into them and diffuse out when vacuum exposure takes place. The top face of some adhesive tapes is coated with a release agent that can discolour during subsequent vacuum or UV exposure – this should be removed.

A.11.6 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. Tape of unknown origin shall not be used.

A.11.7 Effects of space environment

- Vacuum exposure can draw products out of the backing when it is a polymer and also out of the adhesive. When the tape is applied, outgassing takes place through the backing by diffusion when it is permeable and also through the bond line. Outgassing products and entrapped air can lift the tape or bubble it unless the tape is perforated. Adhesives mainly generate condensable products which are dangerous contaminants for optics and electronics. The release of such products, which are frequently plasticisers or tackifiers, can harden the adhesive layer and render it inoperative. Practically each new type of tape shall be tested for outgassing: present results do not allow a generalized statement to be made regarding safe tapes for space application, but acrylic adhesives seem to be the better choice.
- 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. The best choice for UV resistance is polyimide or fluorinated resins. When the backing is metallized on the side of the incident light, optical properties are quite stable. Metals are not affected, although discoloration can occur when they are coated with a protective varnish. Radiation has a tendency to harden polymers and render them brittle. Dimensional stability of polymer tapes is frequently poor under space conditions.
- High temperatures up to 200 °C can be sustained by polyimide, silicone and PTFE tapes with suitable adhesives (silicone). Metal and glass tapes are limited by the properties of the adhesive to similar temperatures.
- 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.

A.11.8 Some representative products

Materials which can be considered (see also annex B):

- Eccoshield PST-CA,
- Scotchtape No. 5,
- Scotchtape No. 60,
- Scotchtape No. 425,
- Scotchtape No. 850 silver,
- Scotchtape Y966.

A.12 Paints and inks

A.12.1 General

Most commercial paints are unsuitable for use in space. Painted materials or structures present a large surface area to environmental conditions. Only with careful selection, application and control of processes can paints fulfil the specified function.

NOTE See clause 5 for material requirements and clause 6 for process-related requirements.

A.12.2 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.

A.12.3 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 (ZnO), titanium dioxide (TiO_2), zinc orthotitanate (Zn_2TiO_4) and zirconium dioxide (ZrO_2) are the most common);
- 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. Some, which are based on metal or carbon pigments, can be used when a α/ε ratio close to one is acceptable. Electrically conductive white paints are based on semi-conductive pigments; their stability in the space environment has now been assessed in some cases. Paints normally contain several proprietary components intended to give them good application properties. They come in the form of one-part or two-part, rather viscous liquids. They are brought to the right viscosity by mixtures of solvents. Solvent-free paints also exist.

A.12.4 Processing and assembly

Hardening of the paint layer is due first to the evaporation of the solvents followed by some chemical reaction producing an insoluble film; the reaction can be catalysed by the atmosphere (oxygen or moisture) in one-part paints or by an added catalyst in two-part systems.

Processing generally needs mixing: application of one or more coats by brush or by spray with intermediate partial drying; final drying and curing at room temperature or in an oven. Inorganic paints are more difficult to apply and good adhesion is difficult to obtain.

A.12.5 Precautions

a. Paints with limited shelf-lives shall be stored under controlled conditions and meet the requirements of ECSS-Q-70-22. Pot life shall also be controlled. Special pretreatment shall be carried out of the item to be painted (e.g. cleaning, abrading and priming, as for adhesives, coatings or varnishes) to achieve good adhesion of the paint coating. Paints tend to remain sticky for a long time and should not be applied in dusty atmospheres. Paint layers are fragile and can be damaged by abrasion and shocks.

b. Contamination by oils and chemicals shall be avoided since the cleaning of a painted item is a difficult operation: this is particularly acute for inorganic-base paints.

A.12.6 Hazardous or precluded

It is very difficult to find a good “space” paint, particularly a white one, in view of the different requirements of mechanical resistance, space environment stability and outgassing. This normally results in the recommendation of rather lengthy and difficult cure schedules and extreme cleanliness precautions during and after application.

Most of the solvents used in paints are toxic or flammable.

A.12.7 Effects of space environment

- Vacuum exposure of paints results in high outgassing due mainly to solvent residues (which are reduced by a baking process) and also condensable products. The only way to reduce this inconvenience is to prescribe extremely long and difficult cure processes, sometimes under vacuum. Even in this case, only very few of the commercial paints can qualify. The method is in any case frequently impracticable since the painted items cannot resist the cure temperature if they contain electronic or other sensitive devices. During the outgassing period, paint layers harden and become more brittle, but the main risk is contamination of optics and electronics in the vicinity (see also subclause A.10). Inorganic paints are generally less contaminating, since they evolve mainly water.

- 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: emittance of paints is in general stable under radiation. Some black paints bleach slightly under the combined effects of vacuum, particles and UV. These factors are very dangerous for white paints, which undergo a drastic increase in absorptance. This effect can be studied only by measurements under vacuum, since atmospheric gases can bleach the defects created in the paint. The increase in absorptance is due to changes in both pigment and binder. In the former, colour centres are created which absorb at specific wavelengths; in the latter the absorptance edge of the UV side is moved towards longer wavelengths and sometimes new bands appear.

  Inorganic-based white paints (silicate binder) are more stable than those with an organic base, and some of them are quite good from the optical-properties point of view. The stability of white paint under radiation depends to a large extent on the physico-chemical purity of the pigment used.

- High temperature degrades paints (“smoking” under ascent conditions). In this respect, silicones and silicates are best. Heat can be beneficial in accelerating the bleaching of certain colour centres in pigments, but normally increases the yellowing of binders. Thermal cycling can cause deterioration in paints that are not flexible enough to cope with the substrate’s dimensional changes: flaking, blistering, cracking can occur. Paints with inorganic binders are rather sensitive in this respect.
- Atomic oxygen in low Earth orbit attacks paints. Those with a silicone and perfluorinated base seem better. Silicate bases are resistant.

A.12.8 Some representative products

No commercial white paint is perfectly satisfactory for space use, since most of them outgas too much or are unstable under radiation. The situation is a bit less critical for black paints. Many commercial paints were flown but with moderate success. Many space paints, and particularly white, are not commercial items and are prepared in-house or under contract by spacecraft builders. Materials which can be considered are (see also annex B):

Black paint:

- Aeroglaze H332 (former Chemglaze),
- Aeroglaze L300 (former Chemglaze),
- Aeroglaze Z306 (former Chemglaze),
- Acheson Electrodag 501,
- MAP-PU1,
- MAP-PUK.

White paint:

- S13GP:6N/LO-1,
- MAP-SG 121 FD,
- MAP-PCBE,
- MAP-PSB.

Silver loaded paint:

- Acheson Electrodag 503

A.13 Lubricants

A.13.1 General

The majority of lubricants are used to minimize friction and wear between contacting, moving surfaces and can be in the form of "dry" (solids) or "wet" (liquids or semi-solid greases). Some perform a combined role of lubrication and thermal coupling.

NOTE See clause 5 for material requirements and clause 6 for process-related requirements.

A.13.2 Use in spacecraft

All moving parts under vacuum, either "one shot" or constantly operating items, shall be lubricated. These include mechanisms and slip rings of deployable and orientable solar panels, bearings of rotating antennae, mechanisms of orientable experiments, deployment systems and active thermal control louvres. Moving parts appear also in pressurized systems where the situation is more or less similar to that of conventional ground use. An additional use for greases and compounds is the thermal coupling of boxes and structural elements.

A.13.3 Main categories

Basic oils are hydrocarbons, silicones, diesters, polyglycols and fluorinated compounds. Commercial products normally contain several additives to improve their lubricating properties. Greases are based on the same oils thickened with organic or inorganic gelling agents (metal soaps, silica, arylurea, indanthrene blue). "Compounds" are high-molecular-weight organics which do not need any gelling agent to make them semi-solid. Besides these "wet" lubricants, many "dry" types find a use in spacecraft. These are:

- laminar inorganic substances, such as MoS_2 and WSe_2, which are applied by burnishing, molecular sputtering or as an inorganic or resin-bound curing compound;
- self-lubricating polymers, such as polyamide, Teflon or polyimide, sometimes reinforced or modified by a filler (copper powder, MoS_2 or carbon fibres).

A.13.4 Processing and assembly

Application of oil or grease is straightforward; except on bearings where a porous retainer (phenolic, polyamide) is used; in this case the retainer is first solvent extracted, then vacuum impregnated (in 100 Pa vacuum range) by dipping in the oil used to make the grease. 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.

Molecular compounds such as MoS_2, which are rather sensitive to heat, can be sputtered (ion-sputtering, RF-sputtering). Simple burnishing is also used. When binders are used in combination with MoS_2, the application process resembles that of curing a paint, and the items to be lubricated should have increased clearance to compensate for the lubricant thickness. In any case, new lubricants should be "run-in" before operational use is commenced. Particles given off during running-in shall be removed by a stream of clean dry air.

A.13.5 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. Wet lubricants can disappear by evaporation or creep. Dry lubricants are destroyed by wear or by lack of adhesion to the substrate. Replenishment is possible with wet lubricants (e.g. from a sintered reservoir). Oil lubrication is basically hydrodynamic and does not operate in low-speed devices or under high loads. When the lubricant has disappeared, mating parts weld readily in vacuum. Moreover, the evolved residues create a danger of contamination in the vicinity.

Lubricants shall be applied only on clean surfaces, and lubricated items shall be protected from dust and dirt. Some lubricants intended for use under vacuum are degraded by running in normal atmosphere (lead for example) or by humidity (some silicate combinations). When lubricants are used in devices which should be electrically conducting, problems of electrical noise appear and wear can be increased at high current density. Thermally conductive compounds used at interfaces are prone to creep: they shall be kept in place by a suitable seal placed around the area concerned.

A.13.6 Hazardous or precluded

Oils and greases, except certain special grades, shall never be exposed directly to space conditions: labyrinth seals should be applied and the “exhaust pipe” should always be far away from sensitive satellite parts. 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). Ester-type oils can develop corrosivity under high radiation: this occurs rarely in space. Nylon absorbs considerable amounts of water, which are released subsequently in vacuum; because of this, its dimensional stability is not good. Sintered nylon, however, can be vacuum impregnated with oil to serve as a reservoir.

A.13.7 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. Wet lubricants are also liable to contaminate optical and electrical parts under vacuum. Some dry lubricants (particularly the resin-bound types) also evolve contaminating substances. Thin metal films shall be paired with the rubbing part in order to avoid as far as possible the tendency to cold weld: a good criterion is to avoid pairing materials which alloy readily. Cold welding is particularly intense for pairs of cubic-lattice metals.
- Under radiation, oils have a tendency to evolve gases or corrosive products, to foam or to gel, but this needs rather high doses (over 10 Mrad in general) which are not normally encountered in space except for very special applications. Greases show the same damage, but at a lower rate since they are partly protected by their gelling agents. Dry lubricants are quite resistant to all types of radiation. In any case, lubricants are normally screened from high radiation doses by the mechanical parts to which they are applied.
- The main temperature effect is to encourage evaporation of wet lubricants. Temperatures high enough to degrade lubricants should not be encountered in correctly designed parts and, in any case, lubricants are more stable in space, owing to the absence of oxidation. 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 (no convective cooling, no conductance through atmosphere). Wet lubricants allow better cooling than dry lubricants, but the gain is minimal in comparison with the other dangers already mentioned.
- Atomic oxygen can degrade MoS_2 and similar solid lubricants which are exposed to it.

A.13.8 Some representative products

In sealed instruments (or semi-sealed when contamination is not a problem), many oils can be considered:

- Silicones (e.g. Dow Corning (USA), General Electric (USA), Wacker (D), Rhone-Poulenc (France) and ICI (UK));
- Diesters (e.g. Lehigh (USA) and Kluber (D));
- Fluorocarbon (DuPont (USA));
- Greases based on the above-mentioned oils also exist.

For direct space exposure, very few non-contaminating silicone oils, greases or compounds exist; solid lubricants are also useful materials for direct exposure to space.

The following materials, for which some data sheets are included, can be considered:

- Apiezon L,
- Bray cote 601,
- DC 340,
- Everlube 620C,
- Fomblin Z25,
- Kinel 5518,
- MAPLUB SH050,
- MAPLUB PF100a,
- MAPSIL 210,
- PTFE,
- Tio-lube 460.

A.14 Potting compounds, sealants and foams

A.14.1 General

Within this Standard, the generic name “potting compounds” applies to all types of products which can be applied in bulk fluid form and subsequently become relatively rigid; including sealants.

NOTE See clause 5 for material requirements and clause 6 for process-related requirements.

A.14.2 Use in spacecraft

Potting compounds and sealants have various uses in spacecraft: electrical and mechanical insulation, damping, sealing and thermal coupling. They appear in practically all subsystems.

A.14.3 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). Pigments, fillers and dyes are often added to these organic materials.

All these products vary from soft and elastic to hard and rigid. Specific gravity is from 0,1 for some foams to more than 2 for bulk-filled resins. Syntactic foams are between 0,5 and 0,8. Before the hardening (curing) process, potting compounds are liquids, pastes or even powders. Some cure by atmospheric exposure (one-part systems), others by the addition of a catalyst (two-part systems).

A.14.4 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. Two‐part potting compounds need mixing in the specified proportions. Application is by pouring into open or closed moulds, caulking or smearing.

To avoid the formation of bubbles, it is frequently necessary to pour small quantities, de‐gas under low vacuum (a few Pa), pour again, and so on.

True foam products foam and rise in place (the "debubbling" operation is not applicable). When closed moulds are used, the quantity of initial product shall be carefully calculated to produce the specified final volume and density. Moulds equipped with overflow vents are also used. The hardening of potting compounds shall be done under a certain cure schedule, which can be as simple as a few hours exposure at room temperature. Sometimes a simple heat treatment is necessary. In other cases, post‐curing under vacuum is required. When curing is by atmospheric moisture, the curing time depends on the accessibility of air; thick samples need a longer time. Foams are cured simultaneously with the rising process, and the rate of both should be matched to produce the specified density, implying good control of the curing‐temperature profile. When fillers are used, they shall be carefully dried and shall be kept dry until and during mixing.

A.14.5 Precautions

Many potting compounds create quite high temperatures and pressures during curing, and damage to potted components can occur unless some countermeasure is taken: use of low‐temperature, long‐duration cure profiles, use of either a flexibilizer as a component of the potting or of a pre‐coat on the device, and special design aimed at limiting stresses induced by curing were employed. Pre‐coating the device can be essential to obtain good adhesion to all components. When different potting materials or coatings are used successively, it is necessary to ensure that they are "compatible": some components of one mixture can have a deleterious effect on the curing of the other (the same effect can be found with atmospheric components: water vapour, for example).

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. The need for correct debubbling procedures is stressed above. The viscosity of the mixture to be poured should be low enough to permit a good flow in intricate devices. Most potting compounds and sealants have a limited shelf life and pot life depending on the conditions of storage and use.

Except when special fillers are used, potting compounds and sealants have a rather low thermal conductivity and overheating of enclosed parts can occur in powered devices.

A.14.6 Hazardous or precluded

The present trend in space systems is to avoid potting as far as possible and to use conformal coatings in preference. This leads to weight savings and ease of repair, but diminishes the protection against mechanical stresses.

Most of the flexible potting compounds and sealants outgas too much to be useful in space. Polysulphide potting compounds are not stable enough under space environment. Products that shrink severely or are highly exothermic during curing shall be avoided. "Open cell" foams shall not be used, since they do not protect the potted items against corrosion in the atmosphere.

A.14.7 Effects of space environment

- Vacuum exposure of potting and sealant materials leads to problems analogous to those of conformal coatings (see subclause A.10), i.e. contamination of the vicinity and possibility of corona effect due to release of gases in cracks and voids when these products are used in the presence of strong electrical fields.

  Closed-cell foams contain gases (CO_2 or freon), which normally take a very long time to evolve even under space vacuum: some foams can be considered for space insulation up to 5 kV.

  Contamination of the vicinity by potting materials is sometimes diminished by a postcure under vacuum or by an "egg-shell" varnish applied as a thin layer over the potted module.
- 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, their damping ability gets worse and internal stresses rise, particularly in potting cured at high temperatures. On the high side, chemical degradation can occur, particularly around power-dissipation component. Silicones have the best high-temperature properties (class 180). Thermal cycling due to the switching on and off of equipment can lead to cracking and debonding.

A.14.8 Some representative products

Some epoxies, polyurethanes and silicones can be considered for potting as well as conformal coating or adhesion (see also subclause A.10).

The following materials, for which data sheets are included, can be considered:

- Araldite CY205,
- Epikote 828/Versamite 140,
- RTV 566,
- RTV S691,
- Solithane 113,
- Stycast 1090,
- Stycast 2850FT.

A.15 Reinforced plastics

A.15.1 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.

See ECSS-E-30-04.

NOTE See clause 5 for material requirements and clause 6 for process-related requirements.

A.15.2 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.

For guidelines on structural uses of fibre-reinforced plastics, see ECSS-E-30-04.

The substrate materials of electronic printed-circuit boards are made from reinforced plastics; equipment housing can be composite rather than metal.

A.15.3 Main categories

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.

Other forms of reinforcement, such as whiskers and metal wires, are normally used in composites with a metal matrix phase (see also aluminium-, magnesium-based alloys in subclause A.8). Natural materials (cotton and paper) - used for some composites for electronic laminates - are unacceptable for space applications.

Common commercial materials for continuous reinforcing fibres used in structural applications are:

- 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.

  NOTE Some overlap exists between categories, especially for IM grades which are often selected for strength and strain, rather than stiffness.

- Aromatic polyamide fibres (aramid).
- Glass - high-performance grades.
- Boron (to a lesser extent) – these have a larger cross-section than the other fibres (normally known as "filaments"). There are two types: boron deposited onto thin tungsten wires, or onto a carbon fibre substrate.

These fibre-types offer the high-strength and high-modulus properties necessary for structural applications. Glass fibres are usually used for their electrical characteristics, e.g. dielectric, rather than mechanical performance alone. Carbon fibres are conductive, whereas aramid fibres are not. Other polymer-based fibres were proposed, but were not generally evaluated for space.

Discontinuous fibres are also available from the same materials (except boron) for non-structural uses.

NOTE The use of asbestos is discontinued because of its carcinogenic nature.

Reinforcements are rarely supplied as "raw" fibres (other than to companies making pre-impregnated sheet or tapes and doing winding of filaments). The normal forms are yarns or "tows" (containing specified numbers of filaments) or are woven into fabrics of various styles (e.g. plain and satin); felts and mats (of various types) are also available. Yarns and fabrics containing a mixture of reinforcing materials are also available, e.g. carbon/aramid hybrids. For thermoplastic composites, hybrids of carbon or aramid reinforcement combined with a high-performance thermoplastic fibre were commercialized to some extent.

Fibres for a particular resin system normally have a specific surface treatment to ensure good bonding to the matrix. The interface characteristics are crucial to achieve load-transfer between matrix and fibre. Fibres for a particular resin system are normally treated with an appropriate size to ensure good bonding to the matrix.

The polymer-matrix phase is usually a thermosetting resin, mainly: epoxies, cyanate esters, phenolics, bismaleimides, polyimides.

See also subclause A.18.

NOTE Polyimides are really thermoplastic ladder polymers, but are included here.

For structural applications, the most common resins are epoxies and cyanate esters (of various formulations). Higher temperature applications use polyimide and bismaleimide; specialist requirements (e.g. flame-retardant properties) need other resins (e.g. phenolics). A limited number of high-performance thermoplastics were evaluated and commercialised, but to a much smaller extent than thermoset resins.

Reinforced plastics can be supplied as semi-finished items ready for machining to shape (such as, flat laminates and profiles of various simple shapes, e.g. box sections, angles and tubes).

Structural materials are normally supplied as semi-processed forms, the most common of which is “prepreg”, i.e. reinforcement sheet or tape already impregnated with partially cured resin (B-stage). These materials are specifically designed to be sticky (tack) to aid assembly. Prepregs are supplied on a support (backing-sheet) usually as rolls, but sometimes as flat sheets.

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.

A.15.4 Processing and assembly

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. Unlike metals, which can be subjected to a number of processes to achieve the finished part, once a composite material is produced there are no opportunities to “rework” it to optimize properties, i.e. the properties are “designed-in” at the processing stage. This is why designing for composites is totally different to that of metals, see ECSS-E-30 Part 8 and ECSS-E-30-04.

Structural components are produced from “prepreg” sheets (plies) or tapes. In continuous fibre prepregs, all the fibres are aligned in one direction (as denoted on the packaging and on the backing-sheet). Depending on the weave style, the principal fibre direction can be denoted for fabrics.

Tooling materials shall be carefully selected to ensure thermal-expansion matching between the composite and the tool over the processing temperatures. Low CTE materials, such as cast iron, certain other metals, ceramics, graphite and composite material tools are used.

Thermoset prepreg processing involves the following:

- Tool preparation: e.g. cleaning and applying any materials to release the finished composite from the tooling.
- Cutting prepreg to size.

- Removing the backing‐sheet.

  NOTE Backing sheets are present only as a handling aid; they are normally plastics films chosen for their "ease‐of‐removal" characteristics. Their complete removal is critical – any backing‐sheet left in consolidated composites means that the plies do not bond together and the properties are seriously impaired.

- Laying up of the plies in the correct order and in the correct direction: by placing cut plies on top of one another (manually or automatically). Tapes are sometimes "wound" around formers (tools) or wrapped around an existing part (overwrapping). Some designs use a mixture of continuous fibre plies and fabric plies; others can use different types of fabrics.

  NOTE The fibre direction dictates the final mechanical performance of the final composite material or part.

- An interim consolidation: used during the lay‐up stage, by applying a pressure to remove air trapped between plies. For thick sections a vacuum‐assisted debulking process can be utilized.
- Preparation for curing: depending on the process used, other materials are applied to the lay‐up (e.g. release films, vacuum‐bagging consumables). Peel‐plies are "disposable layers" that are used on areas of the lay‐up that need protection from contamination during processing, or areas to be adhesive bonded or have a coating applied.
- Curing: needs heat and pressure applied for a specific time (resin‐dependent: see subclause A.18) and, normally, to a defined cure schedule for the part (heating and cooling rates; hold‐at‐temperature called "dwell time"; when pressure is applied and released).

  NOTE Thermoplastic composites are not cured, but they are consolidated under a temperature or pressure cycle. The other process steps are appropriate. After producing the composite, reheating and forming processes can be used to shape the laminate (e.g. press‐ and vacuum‐moulding techniques).

Composite items can also be produced from an individual resin system (base, hardener, catalyst) and combined with a reinforcing agent during the process. There are several different methods: hand‐layup or wet‐layup; filament winding; near‐net shape processes – such as resin transfer moulding (RTM). Some processes do not allow high‐reinforcement contents to be obtained, i.e. the resin content is comparatively high. These processes are not normally used for structural components needing optimized mechanical properties for a low weight.

For electronic PCBs, the basic insulation board uses woven glass‐reinforced dielectric material. Types G10, G11, FR4, FR5 and polyimide are preferred. Compressed layers with organic fillers shall be avoided.

A.15.5 Precautions

Most reinforced plastics are anisotropic in all their properties. Design criteria used shall take this fact into account. It is frequently possible to reduce anisotropy by using multidirectional reinforcement, but this is done at the cost of a reduction in overall strength or an increase in weight. Reinforced plastics generally retain internal stresses after moulding. These can be relieved by thermal treatment at sub‐zero temperatures.

In high‐performance structural composites the fibre selection controls the mechanical performance (strength or stiffness) and the resin selection. The resin and associated cure processes largely determine the environmental resistance, e.g. service‐temperature; constraints on dimensional tolerances and durability.

Cure schedules or cycles are carefully studied by means of a preliminary test programme during the design and prototyping stage to ensure full and proper consolidation (sufficient resin flow; that the cure is complete; that no thermal degradation of the resin occurs) in order to obtain a final product with optimum properties.

Thermal-analysis equipment can be used to assist in developing appropriate cure schedules.

The main problems in processing are to ensure as far as possible the absence of voids, to maintain the reinforcement in good mechanical condition (high-strength fibres are quite sensitive to surface defects created by handling), and to achieve a good bonding at the fibre interface (use of coupling agent or pretreatment of the fibres).

Assembly methods are of prime importance. Reinforced plastics are sensitive to stress-raisers created by classical fasteners, and hence adhesive bonding is preferred. For guidelines on structural adhesive bonding see ECSS-E-30-05.

Where mechanical fastening is needed to attach composite parts to other parts of the structure, special fasteners offering a large load-transfer area are used: inserts (a removable threaded fastener and its fixture - normally light-alloy - embedded and potted into the panel) are used for assembly of honeycomb panels. For guidelines on the design with inserts see ECSS-E-30-06.

Failure of reinforced plastics occurs frequently at the fibre or matrix interface. This type of failure can be accelerated by some terrestrial environments (e.g. high humidity). Carbon-reinforced resins generally show water absorption or desorption associated with dimensional changes. Low moisture-expansion resin formulations were introduced.

Galvanic coupling is a consideration for carbon-fibre reinforced composites when they are attached to metals or have a coating applied to act either as a moisture barrier, as ATOX protection or for optical properties. In galvanic couples, carbon-fibre composites usually behave as the cathode causing the metal or coating (often a metal) to corrode.

A.15.6 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.

Polyimide or polybenzimide resins are applied to prepregs with the use of a low-volatility solvent, traces of which can stay in the cured item: this sometimes renders them unsuitable. All designs directly translated from classical metal design concepts shall be avoided: designers working with new products shall revise their usual way of thinking.

A.15.7 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 (see subclause A.10).
- 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.

A.15.8 Some representative products

High-performance reinforcing fibres are generally known by their trade names. There are a number of European sources; many products have an American or Japanese origin or link. In addition to the large companies, there are a number of independent weavers, providing fabric reinforcements of various styles. The following list of sources is by no means a comprehensive list of what is available. See also ECSS-E-30-04 for information on carbon fibre-reinforced plastics (CFRP), aramid fibre-reinforced plastics (ARP) and glass fibre-reinforced plastics (GFRP) and other non-standard materials.

NOTE GFRP is used to denote composites using high-performance glass reinforcements, whereas GRP usually refers to other more “industrial” grades.

Carbon fibres:

- Akzo Fortafil - USA,
- Amoco - USA,
- Enka AG (Akzo) - Europe,
- Hercules - USA,
- Mitsubishi Chemical Corp. - Japan,
- R.K. Carbon Fibres - Europe,
- Sigri GmbH - Europe,
- Soficar SA (Toray Industries Inc.) - Europe,
- Tenax - Europe,
- Toho Rayon Co. Ltd - Japan,
- Toray Industries Inc. – Japan,
- Zoltek - USA.

Aramid fibres:

- Primary sources:
  - Kevlar - DuPont de Nemours (USA and Europe),
  - Twaron - Akzo Fibers and Polymers Div. (Enka AG) - Europe.
- Others:
  - SAPEM -Anglo-Soviet Materials Ltd. - Russia,
  - Schappe SA - France,
  - Teijin Ltd. - Japan,
  - Toray Industries Inc. - Japan.

Boron fibres:

- Composites Incorporated - USA,
- Textron Speciality Materials - USA,

- Glass fibres (high-performance grades S-, R-, D-glass and TE-grade):
  - Owens Corning - USA and Europe,
  - Nitto Boseki Co. Ltd. - Japan,
  - Vetrotex St. Gobain - France.

Thermosetting prepreg materials (various fibre reinforcements or resin combinations).

Main suppliers of aerospace materials with product ranges available in Europe, include:

- ACG - UK,
- AIK - Germany,
- Bryte - USA,
- Cytec Engineered Materials - USA,
- FiberCote -USA,
- Hexcel - USA,
- Structil - France,
- YLA - USA.

See also subclause A.18 for resins

Thermoplastics for fibre-reinforced plastics:

- PEEK (polyetheretherketone): Victrex - UK,
- PES (polyethersulphone): Victrex - UK,
- UDEL (polysulfone): Union Carbide - USA,
- ULTEM (polyetherimide): General Electric -USA.

See also subclause A.17.

PCBs used in space hardware shall be qualified in accordance with ECSS-Q-70-10.

NOTE A list of qualified manufacturers is maintained by the QM Division, ESTEC.

A.16 Rubbers and elastomers

A.16.1 General

Only vulcanized-rubber items which are extruded or moulded in their final shape are covered in this section. For some other rubber-compound applications where there is either no cure or a cure-in-place application (like RTV rubbers), see subclauses A.11 (adhesive tapes) and A.14 (potting compounds, sealants and foams).

NOTE See clause 5 for material requirements and clause 6 for process-related requirements.

A.16.2 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.

A.16.3 Main categories

Commercial "rubbers" contain not only one or more rubber polymers, but many, for example, additives, fillers and pigments. 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.

A.16.4 Processing and assembly

Except in the case mentioned above, the user is not concerned with rubber processing. This operation is rather complicated and calls for specialized equipment. It consists in hot-mixing rubber polymers with, for example, pigments, fillers, reinforcing agents, antioxidants and vulcanizing agent, followed by shaping (extrusion, moulding) and curing. All the steps are quite sensitive to processing variables and shall be carefully controlled. On the other hand, the use of finished or semi-finished items is normally straightforward and only the bonding of the rubber to other materials or to itself is a possible problem.

A.16.5 Precautions

Under the same generic name, for example “butyl”, an immense number of different formulations can exist. The identification of a rubber product is difficult, but should nevertheless be made carefully.

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.

Most rubbers are quite sensitive to chemical attack by gas, liquids and solvents. Tables of chemical resistance should be consulted.

Some rubbers have a limited life time in air, this shall be considered if long duration storage is involved.

A.16.6 Hazardous or precluded

Polysulphide rubbers are not stable enough in the space environment. Chlorinated rubbers are marginal in outgassing. In many types of use, the choice is dictated not by the space environment, but by the compatibility with some fluid or gas (e.g. membranes and bladders). Silicones shall not to be used for low gas permeability (pressurized systems). Rubbers containing, for example, plasticisers and extending oils, are unstable in vacuum and shall be excluded. Fillers may be leached out by a fluid and clog small apertures (e.g. the pores of a catalyst).

A.16.7 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 °C.
- 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 °C for the best low-temperature silicones to 300 °C 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 °C. The temperature resistance is lessened in the presence of incompatible fluids.

A.16.8 Some representative products

As for plastics, raw products and some semi-finished items are produced by large companies, but there are many relatively small compounders manufacturing catalogue or "on-demand" items. The following materials, for which data sheets are provided, can be considered:

- Eccoshield SV-R,
- Vibrachoc VHDS,
- Viton B910.

A.17 Thermoplastics

A.17.1 General

This subclause A.17 covers thermoplastic materials used in films, non-adhesive tapes and foils, plus either unreinforced or reinforced "bulk" materials.

See also subclause A.9 for optical plastics, and subclause A.13 for self-lubricating products.

NOTE See clause 5 for material requirements and clause 6 for process-related requirements.

A.17.2 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.

A.17.3 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.

Film surfaces can be modified by chemical treatment and by metallization. The latter use mainly vacuum-deposited aluminium, silver, gold or copper.

Films are sold in rolls or sheets. Thickness varies from a few micrometres upwards. Thicknesses of less than 5 μm to 7 μm are generally difficult to procure in large quantities.

Commercial thermoplastics are extremely numerous. Most of them can find some space use, for example, polyamides, acetal, polyolefins, polycarbonate, acrylics, polystyrene, fluorinated resins and polyphenylene oxide. Some are hard and brittle, others are tough; some are flexible and soft. Pure products vary from transparently clear to translucent white or light yellow, but most of them can be dyed or pigmented. Fillers are sometimes used as well as other additives such as antioxidants, plasticizers, UV stabilizers and processing aids. Reinforced thermoplastics based on glass fibres or chopped carbon fibres are commercially available. Many types of thermoplastics appear as textile items. Shrinkable plastics exist on the market, as well as foamed plastics.

High-performance thermoplastics, with continuous fibre-reinforcement, were promoted for structural applications, see subclause A.15.

A.17.4 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; for example, plain polyester or polyimide cannot be heat-sealed, but some laminated composites can.

Operations such as, moulding, extrusion and textile processing are generally done by specialized firms, and aerospace users are mainly concerned with semi-finished or finished items. Most plastics can be machined and assembled by classical techniques; adhesive bonding is one of the most versatile; welding is sometimes possible. The processing of reinforced thermoplastics is very similar to that of light metals.

A.17.5 Precautions

Thermoplastics soften at rather low temperatures (from about 80 °C for polystyrene to more than 300 °C for polytetrafluoroethylene – PTFE). This should be kept in mind during processing. Thermoplastics are sometimes quite sensitive to chemicals or solvents: tables of chemical resistance should be consulted, particularly when devising cleaning methods.

Films are more or less fragile with respect to tearing, cutting, puncturing or folding, particularly in thin gauges. Anisotropy is frequent, the properties in one direction (the extrusion direction) being quite different from those in the perpendicular direction; this shall be considered in the design. The dimensional stability of plastic films in severe environments is not very good. They can be stabilized by a suitable thermal treatment. Static charges can develop on most plastic films (unless they are specially treated or metallized).

a. Sensitivity to chemicals and solvents is similar to that of the base plastic, but attack is rather rapid, owing to high surface or volume ratio. Metallized films are sensitive to abrasion, since the metal layer is extremely thin. Cleaning is not recommended and contamination shall therefore be avoided. Electrical grounding of metallized films is difficult; contacts are very sensitive to corrosion in the terrestrial environment. Most plastic films are flammable. Absorption of water by some plastic films can drastically change their electrical properties.

b. The dimensional stability of many thermoplastics is inferior to that of conventional metals: many fluorinated resins have a tendency to creep under load; polyamide plastics absorb water in normal atmospheres and shrink under dry conditions. Tough plastics can retain internal stresses after machining or forming operations, and this renders some stress-relieving thermal-treatment necessary (polycarbonate, acetal). Thermal conductivity of plastics is low; this shall be taken into account in the design and during processing. Most current plastics are flammable, but some exceptions exist (fluorinated), and self-extinguishing grades of conventional types can be found. Filled thermoplastics are generally more stable thermally and mechanically than plain grades. Further improvement is given by reinforcement, which permits the design of small, precise mechanical parts.

A.17.6 Hazardous or precluded

a. Additives commonly used in plastics can be detrimental in space applications; particularly plasticizers that have a tendency to evaporate in space vacuum. Many commercial films contain volatile additives (plasticizers and antistatic agents) and shall not be used in space.

b. Polyvinylchloride (PVC), cellulose and acetates are not stable enough under vacuum and shall not be used (particularly in electrical insulation). The same is true of polyvinylacetate and butyrate. Polyamide films absorb water in normal atmospheres and desorb it in vacuum with dimensional changes and are therefore of limited use. Many polyamides are dangerous because they absorb water and shrink under vacuum; they should be excluded.

A.17.7 Effects of space environment

Physico-chemical degradation of plastic films is similar to that of bulk plastics, but the overall effects can be different owing to the particular aspects of films: thinness, need for flexibility, frequent need for stable optical properties.

- 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.

  There is also a great risk of contamination by evolved products, which are generally quite high-boiling-point chemicals. The exposed surface areas of plastics films are often large, consequently contamination dangers are high. Polyimides, TFE, FEP and polyterephthalates are generally safe in this respect. Multi-layer systems shall be properly vented to eliminate internal overpressure; these tend to accumulate large amounts of contaminants during handling and shall be baked under vacuum before integration into a spacecraft.

  In general, “pure” plastics, with the exception of PVC, polyamides, polyvinyl acetates and butyrates, are fairly safe to use, but it is difficult to assess this “purity”, since manufacturers tend to “improve” their products by adding chemicals. In addition it frequently happens that that processing aids or miscellaneous impurities stay absorbed in commercial plastics. The electrical insulation properties of these plastics, which tend to absorb water, are improved by the drying action of a vacuum.

- Radiation: Both UV and particle, can modify plastic materials. The result is frequently discoloration accompanied by evolution of gas and hardening. Some fluorinated plastics are rather sensitive to particle radiation (PTFE is limited to 1 Mrad) and shall not be used in such a way that it is fully exposed to space. However, a minimal amount of shielding reduces doses to acceptable levels. Other plastics are far more resistant and are not significantly modified by particle fluxes encountered in space, particularly the filled or reinforced grades. 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. The primary effects are generally deformation, embrittlement and discoloration, which in turn affect the mechanical integrity and the thermal equilibrium of the devices concerned. TFE is very sensitive to particle radiation; polyterephthalates are damaged by solar UV. The best choice is FEP or polyimides (the latter being normally yellow). Radiation effects are frequently increased by impurities and oxidation consecutive to processing.

- Temperature: High temperatures soften thermoplastics and degrade polymer films. The low thermal conductivity of "bulk" thermoplastics makes it difficult to eliminate heat except when a suitable filler is present (metal powder for example). Most plastics harden significantly and become brittle at temperatures lower than their "glass-transition temperature". Fluorinated polymers and polyimides can be used over a wide range of temperatures from cryogenic to more than 200 °C. 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 SiO_x or ITO can be applied in most cases. FEP is sensitive to the combination of ATOX and UV light.

A.17.8 Some representative products

It is impossible to cite all the trade names in this enormous domain. Big European chemical firms are engaged in producing most of the thermoplastics that can be used in aerospace vehicles, including:

- BASF, Bayer, Huels, Dynamit-Nobel and Hoechst in Germany;
- ICI in UK;
- Aquitaine-Organico, Kuhlmann, Rhone-Poulenc in France;
- Montecatini-Edson in Italy.

The following materials can be considered (see annex B for data sheets):

- Hostaform C9020,
- Makrolon GV30,
- PTFE,
- Succofit,
- Super Gude Space PT,
- Thermofit RT850.

Also the following film materials (see annex B for data sheets):

- Kapton H,
- FEP,
- Makrofol N,
- PET,
- Sheldahl G401500,
- Sheldahl G400900,
- Sheldahl G410620.

A.18 Thermoset plastics

A.18.1 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.

A.18.2 Use in spacecraft

Thermosetting resins can be used without any reinforcement as bulk plastics or as foams.

For other uses see also subclauses A.10 (adhesives, coatings and varnishes) and A.14 (potting compounds, sealants and 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, see subclause A.15.

A.18.3 Main categories

Polymer resins used are mainly epoxies, cyanates, phenolics, polyesters, bismaleimides, polyimides, silicones, diallylphthalate and diphenyloxide.

NOTE Polyimides are really thermoplastic ladder polymers, but are included here by analogy.

A.18.4 Processing and assembly

With the exception of one-part resin systems, the component parts of the thermosetting polymers (base, hardener, catalyst) shall be accurately measured and thoroughly mixed. 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 (except resin types for foams); see subclause A.14.

The cure process temperature depends on the formulation (base polymer type, modifying agents used, one-part or two-part systems – hardener and catalyst used), e.g. epoxies (RT; 50 °C to 150 °C); phenolics (150 °C); polyimides (250 °C).

A.18.5 Precautions

The curing schedule shall be carefully studied by means of a preliminary test programme. (Thermal-analysis equipment shall be used for these tests).

Exothermic reactions occur during curing that can raise the temperature of the resin excessively and degrade the polymer and its resultant characteristics. The amount of resin mixed at any one time (pot size/volume) shall be defined precisely and can limit the production of parts with thick sections.

Thermosetting resins, especially unfilled materials, are prone to shrinkage during cure. This shall be taken into account during the design stage, for example, final dimensions of specified component; sharp features that increase residual stresses and cause cracking; and combining thin and thick sections.

Parts produced from resins are normally cast into moulds. The thermal expansion characteristics of the resin and mould need consideration. Mould surfaces are normally pre-treated with "mould-release" agents to aid removal of the finished part. The choice of mould-release agent is all important to prevent potential contamination problems.

A major problem in processing is to ensure that the finished part is, as far as possible, free of voids.

A.18.6 Hazardous or precluded

Polyester resins are not generally suitable for space uses.

Polyimide or polybenzimide resins containing low-volatility solvents (to ensure flow) can retain traces of them in the cured item which subsequently outgas in vacuum: this can render them unsuitable.

A.18.7 Effects of space environment

Before using thermosetting plastics, a full evaluation of the effects of the service conditions shall be performed. In general, they are quite stable under space conditions provided that selection criteria were fully assessed.

- 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.

A.18.8 Some representative products

There are many large manufacturers on the European market, some of them having a link with the USA. There are also small firms making commercial resins. Some names can be cited, but the following list is far from complete:

- Epoxy resins:
  - Araldite, Vantico, Switzerland,
  - Bakelite - Germany,
  - Epikote (or Epon), Shell, The Netherlands (Shell, USA).
- Phenolic, melamine and silicones:
  - Chemical and Insulating Ltd., UK (Hitco, USA),
  - Dynamit-Nobel, Germany,
  - Kuhlmann, France (Wyandotte, USA),
  - M.A.S., Italy (Synthane, USA).
- Polyimide: Rhône-Poulenc, France (trade name Kerimid).

PCBs used in space hardware shall be qualified in accordance with ECSS-Q-70-10. A list of qualified manufacturers is maintained by TOS-QM Division, ESTEC.

For other uses, the following materials can be considered (see annex B for data sheets):

- Araldite CT205,
- Cycon C 69/MH-S,
- Epikote 828,
- Rexolite 1422.

A.19 Wires and cables

Wires and cables shall be procured according to the requirements in ESCC generic specifications 3901 and 3902.

A.20 Miscellaneous non-metallic materials

A.20.1 General

This subclause A.20 covers non-metallic materials that do not fall in any other DML material class, i.e. it does not include thermosetting or thermoplastic type polymer-based materials, but does cover ceramic-type materials used for space engineering applications.

NOTE 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, but can include materials for optical applications. (See also subclause A.9).

A.20.2 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).

Ceramic coatings can be applied selectively to parts to improve resistance to hot, aggressive environments such as those within propulsion systems.

Ceramic-based adhesives can be used for very high-temperature applications (~ 1 000 °C) normally for the assembly of ceramics.

Thermal insulation ceramic-based products can be applied to structures and also used in payload experiments (e.g. oven and furnace linings).

Ceramics and glasses are used in electrical and electronic equipment subassemblies (electrical insulators); within the manufacture of electronic components (capacitors; packaging for integrated circuits); and in sensing and measuring devices (transducers).

A.20.3 Main categories

Ceramics normally have complex compositions based on one or more oxide, nitride or carbide and often contain glassy constituents. Ceramic-type materials – characterized by their hard, brittle nature – can be in the form of:

- Shapes and engineered parts – often of one type of ceramic and used in applications requiring very high-temperature resistance or electrical characteristics. Most ceramics are electrically insulative, but some are conductive or are used for a particular electrical property, e.g. piezoelectric materials.
- Fibres – (oxides and silicates) used for thermal insulation purposes that are often in the form of blankets: this excludes fibres used for reinforcements for other materials, e.g. polymer-matrix composites; metal-matrix composites (MMCs); fillers in thermosetting products and thermoplastics.

  NOTE The use of asbestos is discontinued because of its carcinogenic nature.
- Coatings – applied to selected parts of components to provide a thermal barrier between the environment (localized high-heat flux) and the underlying material (metal). Excluded from this group are coatings that form on component surfaces as a result of a specific processing method: anodizing, chemical conversion, diffusion, heat-treatments (e.g. carburizing and nitriding).

A further group of ceramic-type materials are the carbon – (C–C) or ceramic-matrix composites (CMCs) and ceramic variants containing glass (GCMCs). These are finding applications as structural components on the re-entry surfaces of reusable launch vehicles (e.g. panels and flaps), and as specialist high temperature fasteners for their assembly and attachment. Such applications are known as “passive thermal protection systems (TPS)”.

NOTE Active TPS systems are ablative coatings.

C–C and CMCs are only used for applications when the design requirements, performance and economical factors justify their selection. See ECSS‐E‐30‐04 for information on current materials, design and applications for C–C and CMCs.

A.20.4 Processing and assembly

Within the ceramics industry, processing methods include using slurry and powder forms of raw materials to create a shape, followed by drying and high-temperature firing to consolidate the product form. Owing to their extreme hardness and brittleness, most shaped engineering products are produced to the final shape. Some grades of ceramics are “machinable” but this is usually limited to cutting product forms to the specified dimensions or making holes for attachments. In general, extreme care is needed when handling brittle materials to prevent cracking, and the use of diamond or other ceramic tools is advised.

Processing of fibre-based products used for thermal insulation is normally restricted to cutting to shape and attaching the "blanket" to the structure. Some blankets can be "moulded" to a take a shape. Some thermal insulation materials are supplied as blocks or bricks that can be shaped to the specified form by machining (e.g. oven and furnace linings for experimental payloads).

A.20.5 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. The exception is re-entry surfaces on reusable, manned space vehicles for which intensive evaluation studies are necessary, with the final customer reviewing and approving the various design stages.

An evaluation shall be made of the characteristics of ceramics used as insulators in electrical and electronic applications. Many ceramics have a relatively high porosity which makes their potential as contaminant traps a concern; glazed materials effectively seal the surface.

A.20.6 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. Some materials and their common forms are known to provoke respiratory problems; this is a growing subject for legislation worldwide.

The use of asbestos is discontinued because of its carcinogenic nature.

A.20.7 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.

A.20.8 Some representative products

There are many sources of advanced technical ceramics within Europe (from raw products, standard shapes or forms to finished components). There are also small firms making specific components. Some names can be cited, but the following list is far from complete:

- Aluminium Pechiney (F),
- Céramiques et Composites (F),
- CeramTec [Hoechst] (D),
- Degussa (UK),
- Friatec AG (D),
- H.C. Starck (D),

- Le Carbone Lorraine (F),
- Morgan (UK),
- SGL Carbon Group (D),
- Sintec (D).

Annex B (informative)

Material data sheets — Introduction[2)]

B.1 Identification of data sheets

Materials are first identified by material classes used for the declared materials list (DML) from ECSS-Q-70; see Table B-1.

Table B-1: Material classes

Class	Material
1	Aluminium and Al-alloys
2	Copper and Cu-alloys
3	Nickel and Ni-alloys
4	Titanium and Ti-alloys
5	Steels
6	Stainless steels
7	Filler materials: welding, brazing, soldering
8	Miscellaneous metallic materials
9	Optical materials
10	Adhesives, coatings, varnishes
11	Adhesive tapes
12	Paints and inks
13	Lubricants
14	Potting compounds, sealants, foams
15	Reinforced plastics
16	Rubbers and elastomers
17	Thermoplastics (inc. non-adhesive tapes and foils [MLI])
18	Thermoset plastics
19	Wires and cables
20	Miscellaneous non-metallic materials (e.g. ceramics)

[2)] **Disclaimer**
All reasonable steps were taken to ensure that the data given herein are correct. It is the responsibility of the users to assess the validity of the data. The authors cannot accept responsibility for the data presented or its usage.

Within each material class, each data sheet is numbered.

For example:

Code: **B 1 - 5**

FIRST DIGIT Class number for material group (i.e. 1 = Aluminium and Al- alloys)

SECOND DIGIT Sequential number within material class

NOTE An index which cross-references product name or identification to data sheet numbers is given in annex D.

B.2 Material description

The name designations are selected from industrial standards, established trade names or manufacturer product codes. The precise characteristics are defined in the applicable specification, which is also referenced.

B.3 Product

Describes the type of material, its composition and the manufacturer's details for procurement purposes. European contact points are given where possible.

NOTE 1 Some products are available from several European sources, e.g. metal alloys.

NOTE 2 The citation of products and manufacturers does not by itself constitute a recommendation or approval.

B.4 Experience and availability

Details the current development status, a ranking of cost (high, medium, low), an indication of lot reproducibility (for metals, this includes some of the relevant internationally recognized specifications), and a ranking of space experience (extensive, high, medium, low).

B.5 General properties

Contains data on material physical, mechanical, thermal, electrical and optical properties. The properties given for any class of material can vary depending on its main use, e.g. tear strengths for films. All properties given are typical values at normal ambient conditions (unless otherwise stated). The origin of data is also given, e.g. from manufacturers, from tests to the stated standards. Where possible, properties are given in standard SI units to allow comparison between different but similar products.

a. Data shall not be used for design or specification purposes, but only as a screening parameter.

b. Properties defined by the manufacturer shall be studied in conjunction with the manufacturer's catalogue or data.

B.6 Properties relevant to space use

Properties relevant to space use are those tested by recognized test agencies and in most cases are covered by the ECSS-Q-70-XX series of documents.

NOTE Information (test data) available in industry can be submitted to the ECSS Secretariat for inclusion in updated data sheets in order to expand the information on material properties relevant to space use.

B.7 Special recommendations

Information is given about a material concerning, for example, any special processes, treatments, precautions, application and limited behaviour of material for certain environmental conditions.

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Annex C (informative)

Material data sheets

C.1 Aluminium and Al-alloys

C.1.1 Aluminium (ISO Al 99.5)

PRODUCT

Type	Metal Alloy	
Chemical Composition	99,5 % Al	
Manufacturer	Corus 30 Millbank London SW1 4WY UK	Tel: 0800 008 400 Fax: Email: customer-services@corusgroup.com www.corusgroup.com
	Aluminium Pechiney Usine de Mercus 09400 Mercus Garrabet France	Tel: +33 (0)5 61 02 42 00 Fax: +33 (0)5 61 02 42 01 Email: www.aluminium-pechiney.com
	Corus Metallversteib Deutschland Kennedydamm 17 D-40476 Düsseldorf Germany	Tel: +49 211 4926-0 Fax: +49 211 4926-282 Email:

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Very Low
Lot Reproducibility	AA 1050, BS 1B, AFNOR A5, DIN Al 99.5
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	2,71	@ Room Temperature
Ultimate Tensile Strength	75 MPa to 146 MPa	@ Room Temperature
Proof Stress (0,2 %)	55 MPa to 133 MPa	@ Room Temperature
Elongation at Break	25 %	@ Room Temperature
Thermal Expansion Coefficient	24×10^{-6} °C^{-1}	@ Room Temperature
Thermal Conductivity	230 W m^{-1} °C^{-1}	@ Room Temperature
Electrical Resistivity	$0,028 \times 10^{-6}$ Ω m	@ Room Temperature

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Corrosion	Excellent resistance to atmospheric corrosion. For more severe environments, part can be either: • Chromated • Chromated and painted • Sulphuric anodized, or • Chromic anodized. • See also annex E.	
Stress Corrosion	High resistance.	

SPECIAL RECOMMENDATIONS

-

C.1.2 Aluminium-copper alloy (ISO AlCu4Mg1)

PRODUCT

Type	Metal Alloy	
Chemical Composition	4,5 % Cu, 1,5 % Mg, 0,6 % Mn, Rem. Al	
Manufacturer	Corus 30 Millbank London SW1 4WY UK	Tel: 0800 008 400 Fax: Email: customer-services@corusgroup.com www.corusgroup.com
	Aluminium Pechiney Usine de Mercus 09400 Mercus Garrabet France	Tel: +33 (0)5 61 02 42 00 Fax: +33 (0)5 61 02 42 01 Email: www.aluminium-pechiney.com
	Corus Metallversteib Deutschland Kennedydamm 17 D-40476 Düsseldorf Germany	Tel: +49 211 4926-0 Fax: +49 211 4926-282 Email:

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Very Low
Lot Reproducibility	BS L97, BS L98, AFNOR A-U4G1, DIN 1725, AA 2024
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	2,77	@ Room Temperature
Ultimate Tensile Strength	385 MPa to 495 MPa	@ Room Temperature
Proof Stress (0,2 %)	260MPa to 470 MPa	@ Room Temperature
Elongation at Break	3 % to 16 %	@ Room Temperature
Thermal Conductivity	150 W m^{-1} $^{o}C^{-1}$ to 180 W m^{-1} $^{o}C^{-1}$	@ Room Temperature
Thermal Expansion Coefficient	22×10^{-6} $^{o}C^{-1}$ to 24×10^{-6} $^{o}C^{-1}$	@ Room Temperature
Electrical Resistivity	$8{,}9 \times 10^{-8}$ Ω m	@ Room Temperature

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Corrosion	Relatively poor resistance to atmospheric corrosion and should always be anodized or chromated and painted. See also annex E.	
Stress Corrosion	Only limited forms and temper conditions have high resistance to stress corrosion cracking. (Refer to ECSS-Q-70-36 for approval of this alloy). Furthermore, only rod and bar forms in the T8 condition have a high resistance. Plate, extrusions and forgings have moderate to low resistance.	

SPECIAL RECOMMENDATIONS

- For precipitation hardened parts, heating above the precipitation temperature can result in susceptibility to intergranular and stress corrosion.
- The room-temperature-aged conditions can become susceptible to intergranular corrosion if the alloy is heated above 65 °C.

C.1.3 Aluminium-magnesium alloy (ISO AlMg2)

PRODUCT

Type	Metal Alloy	
Chemical Composition	1,7 % to 2,4 % Mg, Rem. Al	
Manufacturer	Corus 30 Millbank London SW1 4WY UK	Tel: 0800 008 400 Fax: Email: customer-services@corusgroup.com www.corusgroup.com
	Aluminium Pechiney Usine de Mercus 09400 Mercus Garrabet France	Tel: +33 (0)5 61 02 42 00 Fax: +33 (0)5 61 02 42 01 Email: www.aluminium-pechiney.com
	Corus Metallversteib Deutschland Kennedydamm 17 D-40476 Düsseldorf Germany	Tel: +49 211 4926-0 Fax: +49 211 4926-282 Email:

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Very Low
Lot Reproducibility	AA 5052, AFNOR A-2,5C, WkStnr 3.3523
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	2,69	@ Room Temperature
Ultimate Tensile Strength	180 MPa to 250 MPa	@ Room Temperature
Proof Stress (0,2 %)	87 MPa to 190 MPa	@ Room Temperature
Elongation at Break	16 %	@ Room Temperature
Thermal Conductivity	155 W m $^{-1}$ $^{o}C^{-1}$	@ Room Temperature
Thermal Expansion Coefficient	24×10^{-6} $^{o}C^{-1}$	@ Room Temperature
Electrical Resistivity	$4,7 \times 10^{-8}$ Ω m	@ Room Temperature

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Corrosion	Very good resistance to atmospheric corrosion. For more severe environments, part can be either: ● Chromated ● Chromated and painted ● Sulphuric anodized, or ● Chromic anodized. ● See also annex E.	
Stress Corrosion	High resistance.	

SPECIAL RECOMMENDATIONS

-

C.1.4 Aluminium-magnesium-silicon alloy (ISO AlMgSi)

PRODUCT

Type	Metal Alloy	
Chemical Composition	0,4 % to 0,9 % Mg, 0,3 % to 0,7 % Si, Rem. Al	
Manufacturer	Corus 30 Millbank London SW1 4WY UK	Tel: 0800 008 400 Fax: Email: customer-services@corusgroup.com www.corusgroup.com
	Aluminium Pechiney Usine de Mercus 09400 Mercus Garrabet France	Tel: +33 (0)5 61 02 42 00 Fax: +33 (0)5 61 02 42 01 Email: www.aluminium-pechiney.com
	Corus Metallversteib Deutschland Kennedydamm 17 D-40476 Düsseldorf Germany	Tel: +49 211 4926-0 Fax: +49 211 4926-282 Email:

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Very Low
Lot Reproducibility	BS H9, AFNOR A-GS, DIN 1746, AA 6063
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	2,70	@ Room Temperature
Ultimate Tensile Strength	155 MPa to 210 MPa	@ Room Temperature
Proof Stress (0,2 %)	90 MPa to 180 MPa	@ Room Temperature
Elongation at Break	8 % to 14 %	@ Room Temperature
Thermal Conductivity	197 to 201 W m $^{-1}$ °C $^{-1}$	@ Room Temperature
Thermal Expansion Coefficient	23×10^{-6} °C $^{-1}$	@ Room Temperature
Electrical Resistivity	$3{,}4 \times 10^{-8}\ \Omega$ m	@ Room Temperature

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Corrosion	Moderate resistance to atmospheric corrosion. Generally, one of the following treatments will be required: • Chromating, • Chromating and painting, • Sulphuric anodizing, or • Chromic anodizing. • See also annex E.	
Stress Corrosion	High resistance.	

SPECIAL RECOMMENDATIONS

-

C.1.5 Aluminium-zinc alloy 7075

PRODUCT

Type	Metal Alloy	
Chemical Composition	5,6 % Zn, 2,5 % Mg, 1,6 % Cu, 0,3 % Cr, Rem. Al	
Manufacturer	Corus 30 Millbank London SW1 4WY UK	Tel: 0800 008 400 Fax: Email: customer-services@corusgroup.com www.corusgroup.com
	Aluminium Pechiney Usine de Mercus 09400 Mercus Garrabet France	Tel: +33 (0)5 61 02 42 00 Fax: +33 (0)5 61 02 42 01 Email: www.aluminium-pechiney.com
	Corus Metallversteib Deutschland Kennedydamm 17 D-40476 Düsseldorf Germany	Tel: +49 211 4926-0 Fax: +49 211 4926-282 Email:

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Very Low
Lot Reproducibility	DTD 5074A, AFNOR A-Z5GU, WkStnr. 3.4364, AA 7075
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	2,80	@ Room Temperature
Ultimate Tensile Strength	400 MPa to 650 MPa	@ Room Temperature
Proof Stress (0,2 %)	340 MPa to 595 MPa	@ Room Temperature
Elongation at Break	3 % to 8 %	@ Room Temperature
Thermal Conductivity	134 W m $^{-1}$ ^{o}C $^{-1}$	@ Room Temperature
Thermal Expansion Coefficient	22×10^{-6} ^{o}C $^{-1}$	@ Room Temperature
Electrical Resistivity	$8{,}9 \times 10^{-8}$ Ω m	@ Room Temperature

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Corrosion	Poor resistance to atmospheric corrosion and should always be protected. Although anodizing is possible, the degree of protection it affords is not as great as with other Aluminium alloys, so painting is the recommended treatment. See also annex E.	
Stress Corrosion	In some tempers it has moderate to low resistance. (Refer to ECSS-Q-70-36 for approval of this alloy.) Furthermore, in the T6 condition, it is susceptible to stress corrosion. However, this can be overcome by application of the T73 treatment (overaging), which provides a high resistance to stress corrosion.	

SPECIAL RECOMMENDATIONS

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C.1.6 Aluminium alloy 2618 (T851)

PRODUCT

Type	Metal Alloy
Chemical Composition	Si 0,1-0,25, Fe 0,9-1,3, Cu 1,9-2,7, Mg 1,3-1,8, Zn 0,1, Ni 0,9-1,2, Ti 0,04-0,1, Others: Each 0,05 Total 0,15, Rem. Al

Manufacturer	Pechiney Rhenalu Issoire	Tel: +33 4 73 55 51 60 / 4 73 55 50 29
	BP42	Fax:
	F-63501 Issoire Cedex	Email: frederic_breda@pechiney.com
	France	www.pechiney.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Low
Lot Reproducibility	USA: AA2618; European (ISO): AlCu2Mg1.5Fe1Ni1; France: A-U2GN; Germany: AlCu2Mg2Ni; LW3.1924; UK: H16; DTD717A, 724, 731A, 731B; 745A, 5084A, 5014A
Space Experience	-

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	2,76	
Ultimate Tensile Strength	441 MPa	(Typical) AA Data
Proof Stress (0,2 %)	372 MPa	(Typical) AA Data
Elongation at Break	10 %	(Typical) AA Data

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Stress Corrosion	Resistant (ECSS-Q-70-36) Tempers T6 and T8 are considered to be Table 1 alloys (“Alloys with high resistance to SCC”). See also annex E.	

SPECIAL RECOMMENDATIONS

-

C.1.7 Aluminium-copper-manganese alloy 2219 (ISO AlCu6Mn)

PRODUCT

Type	Metal Alloy	
Chemical Composition	Cu 5,8 % to 6,8 %, Mn 0,2 % to 0,4 %, Rem. Al	
Manufacturer	Several: e.g. Pechiney Rhenalu Issoire BP42 F-63501 Issoire Cedex France	Tel: +33 4 73 55 51 60 / 4 73 55 50 29 Fax: Email: frederic_breda@pechiney.com www.pechiney.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Low
Lot Reproducibility	AA2219, EN573 AW-2219, DTD 5504A, A-U6MT
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	**Typical Value** (depending on heat treatment)	**Remarks**
Specific Gravity	2,84	
Ultimate Tensile Strength	172 MPa to 476 MPa	@ Room Temperature
Yield Strength	70 MPa to 395 MPa	@ Room Temperature
Elongation at Break	7 % to 20 %	@ Room Temperature
Thermal Conductivity	116 W m^{-1}°C^{-1} to 170 W m^{-1} °C^{-1}	@ Room Temperature
Thermal Expansion Coefficient	$22{,}3 \times 10^{-6}$ °C^{-1}	@ Room Temperature
Electrical Resistivity	$3{,}9 \times 10^{-8}$ Ω m to $6{,}2 \times 10^{-8}$ Ω m	@ Room Temperature

PROPERTIES RELEVANT TO SPACE USE

Nature	**Typical Value**	**Type of Test**
Corrosion	Relatively poor resistance to corrosion. Protective finish always required. See also annex E.	
Stress Corrosion	Resistant (refer to ECSS-Q-70-36). Tempers: T6 and T8 are considered to be Table 1 alloys (“Alloys with high resistance to SCC”).	

SPECIAL RECOMMENDATIONS

- Solution treatment temperatures should be closely controlled as higher temperatures can cause solid solution grain boundary melting or eutectic melting which cannot be repaired by subsequent heat treatment.
- The alloy can be satisfactorily welded by fusion and resistance welding techniques.
- Reheat-treatment of clad material should be done carefully because copper tends to diffuse through the cladding layer to the surface, decreasing corrosion resistance.

C.2 Copper and Cu-alloys

C.2.1 Copper (oxygen-free high-conductivity; OFHC)

PRODUCT

Type	Metal Alloy	
Chemical Composition	99,95 % Cu	
Manufacturer	Thomas Bolton Copper Products Bolton House, Froghall, Stoke on Trent, ST10 2HF Staffordshire, UK	Tel: + 44 (0)1538 757700 Fax: + 44 (0)1538 757701 Email: www.thomasbolton.co.uk

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Very Low
Lot Reproducibility	ASTM B152 OF, BS 2870 C103, AFNOR 53-100, DIN 1708
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	8,9	@ Room Temperature
Ultimate Tensile Strength	220 MPa to 450 MPa	@ Room Temperature
Proof Stress (0,2 %)	45 MPa to 320 MPa	@ Room Temperature
Elongation at Break	5 % to 50 %	@ Room Temperature
Thermal Conductivity	394 W m $^{-1}$ $^{o}C^{-1}$	@ Room Temperature
Thermal Expansion Coefficient	$17{,}7 \times 10^{-6}$ $^{o}C^{-1}$	@ Room Temperature
Electrical Resistivity	$1{,}7 \times 10^{-8}$ Ω m	@ Room Temperature

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Corrosion	Copper corrodes if sulphur is present, forming the familiar green surface patina which inhibits further corrosion.	

SPECIAL RECOMMENDATIONS

-

C.2.2 Beryllium‐copper (CDA 170)

PRODUCT

Type	Metal Alloy
Chemical Composition	1,8 % Be, 0,3 % Co + Ni, Rem. Cu
Manufacturer	NGK BERYLCO UK Ltd. UNIT ”E” Houston Park, Montford street, Salford M5 2RP UK

Tel: +44 (0)161 745 7162
Fax: +44 (0)161 745 7520
Email: enquiries@ngkberylco.co.uk
www.ngkberylco.co.uk/europe.htm

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Low
Lot Reproducibility	ASTM B194, BS 2870, BS 2873, CB101
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	8,25	@ Room Temperature
Ultimate Tensile Strength	460 MPa to 1 500 MPa	@ Room Temperature
Proof Stress (0,2 %)	125 MPa to 1 100 MPa	@ Room Temperature
Elongation at Break	2 % to 50 %	@ Room Temperature
Thermal Conductivity	84 W m^{-1} $^{o}C^{-1}$ to 150 W m^{-1} $^{o}C^{-1}$	@ Room Temperature
Thermal Expansion Coefficient	17×10^{-6} $^{o}C^{-1}$	@ Room Temperature

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Corrosion	Generally good.	
Stress Corrosion	High resistance only when solution treated/work hardened, then precipitation hardened.	

SPECIAL RECOMMENDATIONS

- The alloy is age‐hardenable and the heat treatment is as follows:
  - solution treat 760 ^{o}C ‐ 820 ^{o}C – Water Quench
  - age 315 ^{o}C ‐ 350 ^{o}C – Air Cool
- Solution treatment can be from 10 min to 30 min for light materials (i.e. wire or strip), extending up to several hours for bulky castings. Precipitation hardening normally requires 2 hours at 310 °C or 30 min at 350 °C.
- Fabrication methods involving either welding, brazing or high temperature soldering should be performed whilst the alloy is in the soft condition and then followed by the solution and ageing treatments.

C.2.3 Brass (α-β) leaded

PRODUCT

Type	Metal Alloy	
Chemical Composition	40 % Zn, 2 % Pb, Rem. Cu	
Manufacturer	H. Rollet & Co. Ltd. 105 – 107 Fore Street, Hertford Hertfordshire SG14 1AS, UK	Tel: +44 (0)1992 500818 Fax: +44 (0)1992 509905 Email: www.hrollet.co.uk

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Very Low
Lot Reproducibility	ASTM B1224/2, BS 2870 CZ120, CuZn40Pb2
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	8,4	@ Room Temperature
Ultimate Tensile Strength	350 MPa to 460 MPa	@ Room Temperature
Proof Stress (0,2 %)	100 MPa to 390 MPa	@ Room Temperature
Elongation at Break	20 % to 45 %	@ Room Temperature
Thermal Conductivity	117 W m $^{-1}$ °C $^{-1}$	@ Room Temperature
Thermal Expansion Coefficient	20,9 × 10^{-6} °C $^{-1}$	@ Room Temperature

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Atmospheric Corrosion	Thew resistance to atmospheric corrosion is fair. The material is generally plated for protection.	
Stress Corrosion	The resistance to stress corrosion is low (see notes).	

SPECIAL RECOMMENDATIONS

- When this material is used for PCB terminals (machined), there shall be a Copper or Nickel diffusion barrier (3 μm) between the solder coating and the brass,(see ECSS-Q-70-08). For swaged terminals, the lead-free variety should be used.
- Resistance to stress corrosion is low when the material is 50 % cold rolled. Furthermore, it should not be used in stressed conditions. See ECSS-Q-70-36 for alternative copper alloys with high resistance to stress corrosion.

C.2.4 Phosphor bronze (CDA 510)

PRODUCT

Type	Metal Alloy	
Chemical Composition	5 % Sn, 0,2 %P, Rem. Cu	
Manufacturer	Thomas Bolton Copper Products Bolton House, Froghall, Stoke on Trent, ST10 2HF Staffordshire, UK	Tel: + 44 (0)1538 757700 Fax: + 44 (0)1538 757701 Email: www.thomasbolton.co.uk

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Very Low
Lot Reproducibility	ASTM B103A, BS 2870 PB102, AFNOR UE5P, DIN 1733
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	8,85	@ Room Temperature
Ultimate Tensile Strength	320 MPa to 770 MPa	@ Room Temperature
Proof Stress (0,2 %)	110 MPa to 690 MPa	@ Room Temperature
Elongation at Break	3 % to 60 %	@ Room Temperature
Thermal Conductivity	75 W m^{-1} $^{o}C^{-1}$	@ Room Temperature
Thermal Expansion Coefficient	$17,9 \times 10^{-6}$ $^{o}C^{-1}$	@ Room Temperature

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Atmospheric Corrosion	Good up to 700 ^{o}C.	
Stress Corrosion	High resistance.	

SPECIAL RECOMMENDATIONS

-

C.3 Nickel and Ni-alloys

C.3.1 MP35N

PRODUCT

Type	Nickel-Cobalt Alloy	
Chemical Composition	35 % Co, 35 % Ni, 20 % Cr, 10 % Mo, 0,15 % Fe.	
Manufacturer	SPS Technologies 301 Highland Avenue, Jenkintown, PA 19046 USA	Tel: +1 215-572-3718 Fax: +1 215-572-3193 Email: mdonoghue@spstech.com www.spstech.com

EXPERIENCE and AVAILABILITY

Development Status	-
Cost Range	-
Lot Reproducibility	-
Space Experience	-

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	8,43	
Ultimate Tensile Strength	1 274 MPa to 1 685 MPa	
Reduction of Area at Break	60 % - 70 %	
Thermal Expansion Coefficient	$12{,}8 \times 10^{-6}$ °C^{-1}	21 °C to 93 °C

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Stress Corrosion	ECSS-Q-70-36A, Table 1, (“Alloys with high resistance to SCC”)	

SPECIAL RECOMMENDATIONS

Material for high-strength fasteners.

C.4 Titanium and Ti-alloys

C.4.1 Timetal 35A (IMI 115)

PRODUCT

Type	Metal Alloy	
Chemical Composition	Commercially Pure Titanium	
Manufacturer	Timet PO Box 704, Witton Birmingham B6 7UR UK	Tel: +44 121 356‐1155 Fax: +44 121 356‐5413 Email: EuroSales@timet.com www.timet.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Low to Medium
Lot Reproducibility	ASTM B265, BS TA1, AFNOR T35, Werk. No. 3.7024
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	4,51	@ Room Temperature
Ultimate Tensile Strength	369 MPa	@ Room Temperature
Proof Stress (0,2 %)	246 MPa	@ Room Temperature
Elongation at Break	35 %	@ Room Temperature
Thermal Expansion Coefficient	$7,6 \times 10^{-6}\ {}^{o}C^{-1}$	@ Room Temperature
Thermal Conductivity	$16\ W\ m^{-1}\ {}^{o}C^{-1}$	@ Room Temperature
Electrical Resistivity	$48 \times 10^{-8}\ \Omega\ m$	@ Room Temperature

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Corrosion	Exceptional resistance to corrosion by oxidizing media up to 700 ^{o}C.	

SPECIAL RECOMMENDATIONS

- Methyl alcohol should not be used in the pressure testing of tanks since failure can occur due to stress corrosion cracking.
- Should have very low interstitial content (i.e. oxygen, hydrogen, nitrogen) to avoid, for example, hydrogen embrittlement. This is particularly important when there is a need for welding or heat testing.

C.4.2 Ti 6Al 4V (IMI 318)

PRODUCT

Type	Metal Alloy
Chemical Composition	6 % Al, 4 % V, Rem. Ti

Manufacturer Timet
PO Box 704, Witton
Birmingham B6 7UR
UK
Tel: +44 121 356-1155
Fax: +44 121 356-5413
Email: EuroSales@timet.com
www.timet.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Low to Medium
Lot Reproducibility	AMS 4911; 4928, BS TA10; 11, AFNOR TA6V, Werk. No. 3.7164
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	4,42	@ Room Temperature
Ultimate Tensile Strength	924 MPa to 1 155 MPa	@ Room Temperature
Proof Stress (0,2 %)	847 MPa to 1 078 MPa	@ Room Temperature
Elongation at Break	10 % to 12 %	@ Room Temperature
Thermal Expansion Coefficient	$7{,}9 \times 10^{-6}$ °C $^{-1}$	@ Room Temperature
Thermal Conductivity	6 W m $^{-1}$ °C $^{-1}$	@ Room Temperature
Electrical Resistivity	$1{,}68 \times 10^{-6}$ Ω m	@ Room Temperature

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Corrosion/Thermal	Oxidation resistant with retention of useful strength and creep resistance up to 500 °C. Strong affinity for H_2 (above 130 °C), N_2 (above 800 °C) and O_2 (above 700 °C), which cause embrittlement.	
Stress Corrosion	High resistance (see note).	

SPECIAL RECOMMENDATIONS

- Alloy possesses poor notch sensitivity characteristics, so considerable care should be taken to avoid the presence of stress raisers.
- Methyl alcohol should not be used in the pressure testing of tanks since failure can occur due to stress corrosion cracking.

C.4.3 Ti 4Al 4Mo - Si (IMI 550)

PRODUCT

Type	Metal Alloy
Chemical Composition	4 % Al, 4 % Mo, 2 % Sn, 0,5 % Si Rem. Ti

Manufacturer	Timet	Tel: +44 121 356-1155
	PO Box 704, Witton	Fax: +44 121 356-5413
	Birmingham B6 7UR	Email: EuroSales@timet.com
	UK	www.timet.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Low to Medium
Lot Reproducibility	BS TA45 to TA51, AFNOR TA4DE, Werk. No. 3.7185, CEN Ti P68
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	4,60	@ Room Temperature
Ultimate Tensile Strength	1 062 MPa to 1 210 MPa	@ Room Temperature
Proof Stress (0,2 %)	970 MPa to 1 109 MPa	@ Room Temperature
Elongation at Break	12 %	@ Room Temperature
Thermal Expansion Coefficient	$8{,}8 \times 10^{-6}\ {}^{\circ}C^{-1}$	@ Room Temperature
Thermal Conductivity	$8\ W\ m^{-1}\ {}^{\circ}C^{-1}$	@ Room Temperature
Electrical Resistivity	$1{,}59 \times 10^{-6}\ \Omega\ m$	@ Room Temperature

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Corrosion/Thermal	Oxidation resistant with retention of useful strength and creep resistance up to 500 °C. Strong affinity for H_2 (above 130 °C), N_2 (above 800 °C) and O_2 (above 700 °C), which cause embrittlement.	
Stress Corrosion	High resistance (see note).	

SPECIAL RECOMMENDATIONS

- Alloy possesses poor notch sensitivity characteristics, so considerable care should be taken to avoid the presence of stress raisers.
- Methyl alcohol should not be used in the pressure testing of tanks since failure can occur due to stress corrosion cracking.

C.5 Steels

C.5.1 Marval X12

PRODUCT

Type	Metal Alloy	
Chemical Composition	<0,001 % C, 8,9 % Ni, 12,05 % Cr, 1,99 % Mo, 0,68 % Al, 0,06 %Si, 0,33Ti, 0,03 % Mn, Rem Fe.	
Manufacturer	Aubert and Duval Tour Maine Montparnasse 33, avenue du Maine F-75755 Paris Cedex 15 France	Tel: +33 (0)1 44 10 24 00 Fax: +33 (0)1 44 10 24 01 Email: dircom@aubertduval.fr www.aubertduval.fr

EXPERIENCE and AVAILABILITY

Development Status	Commercial product
Cost Range	Medium
Lot Reproducibility	Good
Space Experience	Limited

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Ultimate Tensile Strength	1 539 MPa	
Proof Stress (0,2 %)	1 512 MPa	
Elongation at Break	15 %	

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Stress Corrosion	ECSS-Q-70-36A, Table 1, (“Alloys with high resistance to SCC”)	

SPECIAL RECOMMENDATIONS

High-strength fasteners in corrosive environment.

C.6 Stainless steels

C.6.1 Stainless steel A286

PRODUCT

Type	Metal Alloy
Chemical Composition	25 % Ni, 15 % Cr, 2 % Ti, 1,5 % Mn, 1,3 % Mo, 0,3 % V, Rem. Fe
Manufacturer	Maher Ltd Edward Street, Sheffield S3 7GD UK Tel: +44 (0)114 290 9200 Fax: +44 (0)114 290 9290 Email: www.maher.co.uk

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Medium
Lot Reproducibility	Werk. No. 1.4980, Z6 NCT 25/15
Space Experience	Extensive

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	7,92	@ Room Temperature
Ultimate Tensile Strength	1 007 MPa	@ Room Temperature
Proof Stress (0,2 %)	690 MPa	@ Room Temperature
Elongation at Break	25 %	@ Room Temperature
Thermal Expansion Coefficient	$18,5 \times 10^{-6}$ $^{o}C^{-1}$	@ Room Temperature
Thermal Conductivity	23,7 W m^{-1} $^{o}C^{-1}$	@ Room Temperature

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Atmospheric Corrosion	High resistance up to 700 ^{o}C.	
Stress Corrosion	High resistance.	

SPECIAL RECOMMENDATIONS

Suitable for fasteners.

C.6.2 Stainless steel AISI 304L

PRODUCT

Type	Metal Alloy
Chemical Composition	8 % to 12 % Ni, 18 % to 20 % Cr, 2 % Mn max, 1 % Si max, 0,03 % C max, Rem. Fe
Manufacturer	Many European suppliers.

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Low
Lot Reproducibility	AMS 5647, DIN 1.4306, ISO 4954 X2CrNi1810E, B.S. 304 S 12
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	8,0	@ Room Temperature
Ultimate Tensile Strength	564 MPa	@ Room Temperature
Proof Stress (0,2 %)	210 MPa	@ Room Temperature
Elongation at Break	58 %	@ Room Temperature
Thermal Conductivity	16,2 W m^{-1} $°C^{-1}$	@ Room Temperature
Thermal Expansion Coefficient	$17,3 \times 10^{-6}$ $°C^{-1}$	@ Room Temperature
Electrical Resistivity	$7,2 \times 10^{-7}$ Ω m	@ Room Temperature

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Corrosion	High resistance.	
Stress Corrosion	High resistance (refer to ECSS-Q-70-36).	

SPECIAL RECOMMENDATIONS

- AISI 304L is the low carbon version of AISI 304 (0,08 %C) which can be susceptible to intergranular corrosion in certain corrosive media after it is welded or otherwise heated at temperatures between 430 and 860 °C.
- For welded applications avoid the unstabilized, higher carbon, versions.

C.6.3 Stainless steel AISI 316L

PRODUCT

Type	Metal Alloy
Chemical Composition	12 % Ni, 17 % Cr, 2,5 % Mo, 2 % Mn, 1 % Si, 0,03 % C max, Rem. Fe
Manufacturer	Many European suppliers.

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Low
Lot Reproducibility	ISO 4954 X2CrNiMo17133E, UNS S31603
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	8,0	@ Room Temperature
Ultimate Tensile Strength	560 MPa	@ Room Temperature
Proof Stress (0,2 %)	290 MPa	@ Room Temperature
Elongation at Break	50 %	@ Room Temperature, varies with thickness.
Thermal Conductivity	16 W m $^{-1}$ °C $^{-1}$	@ Room Temperature
Thermal Expansion Coefficient	$17{,}2 \times 10^{-6}$ °C $^{-1}$	RT to 200 °C
Electrical Resistivity	$0{,}74 \times 10^{-6}$ Ω m	@ Room Temperature

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Corrosion	High resistance.	
Stress Corrosion	High resistance (refer to ECSS-Q-70-36).	

SPECIAL RECOMMENDATIONS

- AISI 316L is the low carbon version of AISI 316 (0,08 %C) which can be susceptible to intergranular corrosion in certain corrosive media after it is welded or otherwise heated at temperatures between 430 and 860 °C.
- For welded applications avoid the unstabilized, higher carbon, versions.

C.7 Filler materials: welding, brazing and soldering

C.7.1 Soft solder, Sn60 (space quality)

PRODUCT

Type	Metal Alloy; Wire, Bar and Flux-cored Wire
Chemical Composition	60 % Sn, 40 % Pb
Manufacturer	JL Goslar GmbH Postfach 2129, D-38611 Goslar Deutschland Tel: +49 (0) 5321 / 754-332 Fax: +49 (0) 5321 / 754-333 Email: h.walk@jlgoslar.de www.jlgoslar.de

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Low
Lot Reproducibility	ECSS-Q-70-08 / 1999: 60 Tin Solder, EN 29453 / 1993: S-Sn60 Pb40 E
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	8,5	@ Room Temperature
Ultimate Tensile Strength	39 MPa	@ Room Temperature
Proof Stress (0,2 %)	28 MPa	@ Room Temperature
Elongation at Break	52 %	@ Room Temperature
Thermal Expansion Coefficient	$16{,}0 \times 10^{-6}\ ^{o}C^{-1}$	@ Room Temperature

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	Suitable for extensive periods at +80 °C or short periods to a maximum of +120 °C.	

SPECIAL RECOMMENDATIONS

- Recommended for pre-tinning of component leads (see ECSS-Q-70-08) and can be used for soldering stranded wire.
- For assembly of components on printed circuit boards use type 63 Sn.

C.7.2 Soft solder, Sn63 (space quality)

PRODUCT

Type	Metal Alloy; Wire, Bar and Flux-cored Wire	
Chemical Composition	63 % Sn, 37 % Pb	
Manufacturer	JL Goslar GmbH Postfach 2129, D-38611 Goslar Deutschland	Tel: +49 (0) 5321 / 754-332 Fax: +49 (0) 5321 / 754-333 Email: h.walk@jlgoslar.de www.jlgoslar.de

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Low
Lot Reproducibility	ECSS-Q-70-08 / 1999: 63 Tin Solder, EN 29453 / 1993: S-Sn63 Pb37 E
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	8,5	@ Room Temperature
Ultimate Tensile Strength	47 MPa	@ Room Temperature
Proof Stress (0,2 %)	35 MPa	@ Room Temperature
Elongation at Break	46 %	@ Room Temperature
Thermal Expansion Coefficient	$16{,}0 \times 10^{-6}$ °C $^{-1}$	@ Room Temperature

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	Suitable for extensive periods at +80 °C or short periods to a maximum of +120 °C.	
Thermal Cycling	Test programme showed no electrical failures after 1 000 cycles.	Joints made to ECSS-Q-70-08 requirements; -60 °C to +80 °C under vacuum with ΔT of 10 °C/min.

SPECIAL RECOMMENDATIONS

- Mandatory for the assembly of components on printed circuit boards (ECSS-Q-70-08).

C.7.3 Soft solder, silver-loaded (space quality)

PRODUCT

Type	Metal Alloy; Wire, Bar and Flux-cored Wire
Chemical Composition	62 % Sn, 2 % Ag, Rem. Pb

Manufacturer	JL Goslar GmbH Postfach 2129, D-38611 Goslar Deutschland	Tel: +49 (0) 5321 / 754-332 Fax: +49 (0) 5321 / 754-333 Email: h.walk@jlgoslar.de www.jlgoslar.de

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Low
Lot Reproducibility	ECSS-Q-70-08 / 1999: 62 Tin Silver-loaded Solder, EN 29453 / 1993: S-Sn62 Pb36 Ag2
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	8,5	@ Room Temperature
Ultimate Tensile Strength	63 MPa	@ Room Temperature
Proof Stress (0,2 %)	52 MPa	@ Room Temperature
Elongation at Break	46 %	@ Room Temperature
Thermal Expansion Coefficient	$16{,}0 \times 10^{-6}$ $^{\circ}C^{-1}$	@ Room Temperature

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	Suitable for extensive periods at +80 °C or short periods to a maximum of +120 °C.	

SPECIAL RECOMMENDATIONS

- Not generally recommended for spacecraft use. Only used to prevent scavenging (dissolution) effect when soldering to silver-plated surface (e.g. silver plated or painted components, silver wire).

C.7.4 Tin-silver eutectic solder, (space quality)

PRODUCT

Type	Metal Alloy; Wire, Bar and Flux-cored Wire	
Chemical Composition	96 % Sn, 4 % Ag	
Manufacturer	JL Goslar GmbH Postfach 2129, D-38611 Goslar Deutschland	Tel: +49 (0) 5321 / 754-332 Fax: +49 (0) 5321 / 754-333 Email: h.walk@jlgoslar.de www.jlgoslar.de

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Medium
Lot Reproducibility	ECSS-Q-70-08 / 1999: 96 Tin Silver Solder (Eutectic), EN 29453 / 1993: S-Sn96 Ag4
Space Experience	Limited

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	10,4	
Ultimate Tensile Strength	36 MPa	@ Room Temperature
Elongation at Break	31 %	@ Room Temperature
Thermal Expansion Coefficient	$20 \times 10^{-6}\ ^{o}C^{-1}$	@ Room Temperature
Electrical Resistivity	$1{,}23 \times 10^{-6}\ \Omega\ m$	@ Room Temperature

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	Suitable for extensive periods at +120 ^{o}C or short periods to a maximum of +150 ^{o}C.	

SPECIAL RECOMMENDATIONS

- Is suitable for special applications, such as solder attachment of terminal posts to one side of a printed circuit board (ECSS-Q-70-08) and for assembly of connectors to semi-rigid cables.

C.8 Miscellaneous metallic materials

C.8.1 Magnesium-aluminium-zinc alloy

PRODUCT

Type	Metal Alloy
Chemical Composition	8,5 % Al, 0,5 % Zn, Rem. Mg

Manufacturer
Magnesium Elektron
PO Box 23, Swinton
Manchester M27 8DD
UK
Tel: + 44 (0)161 911 1000
Fax: + 44 (0)161 911 1010
Email:
www.magnesium-elektron.com/

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Low
Lot Reproducibility	ASTM AZ80; AZ85, DIN 1729, MgAl8Zn
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	1,80	@ Room Temperature
Ultimate Tensile Strength	235 MPa to 330 MPa	@ Room Temperature
Proof Stress (0,2 %)	150 MPa to 227 MPa	@ Room Temperature
Elongation at Break	2 % to 9 %	@ Room Temperature
Thermal Conductivity	90 W m $^{-1}$ °C $^{-1}$	@ Room Temperature
Thermal Expansion Coefficient	26×10^{-6} °C $^{-1}$ to 27×10^{-6} °C $^{-1}$	@ Room Temperature
Electrical Resistivity	$1,4 \times 10^{-7}$ Ω m	@ Room Temperature

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Corrosion	Has poor resistance to atmospheric corrosion and should always be protected.	
Stress Corrosion	Is prone to stress corrosion cracking in air, fresh water, sea water and salt solutions. Not suitable for structural applications, see ECSS-Q-70-36.	
Temperature Range	Maximum application temperature is 150 °C.	

SPECIAL RECOMMENDATIONS

- The part should be Lanolin covered or oiled at all times during machining and prior to protective treatments so as to avoid corrosion.
- Protective treatments can be either:
  - Anodizing and painting, or
  - Chromating and painting.
- The part should never make direct contact with other metals. Magnesium is more electrochemically negative than all other commonly used metals and will therefore be sacrificially corroded in any electrochemical cell that is created.

C.8.2 Magnesium-aluminium-zinc-manganese alloy

PRODUCT

Type	Metal Alloy
Chemical Composition	3 % Al, 1 % Zn, 0,2 %Mn, Rem. Mg

Manufacturer	Magnesium Elektron	Tel: + 44 (0)161 911 1000
	PO Box 23, Swinton	Fax: + 44 (0)161 911 1010
	Manchester M27 8DD	Email:
	UK	www.magnesium-elektron.com/

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Low
Lot Reproducibility	ASTM AZ31B, BS 111, DIN 1729, MgAl3Zn
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	1,78	@ Room Temperature
Ultimate Tensile Strength	220 MPa to 275 MPa	@ Room Temperature
Proof Stress (0,2 %)	105 MPa to 200 MPa	@ Room Temperature
Elongation at Break	4 % to 12 %	@ Room Temperature
Thermal Conductivity	84 W m^{-1} $^{o}C^{-1}$	@ Room Temperature
Thermal Expansion Coefficient	26×10^{-6} $^{o}C^{-1}$ to 27×10^{-6} $^{o}C^{-1}$	@ Room Temperature
Electrical Resistivity	$9,2 \times 10^{-7}$ Ω m	@ Room Temperature

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Corrosion	Has poor resistance to atmospheric corrosion and should always be protected. Protective treatment can be either anodizing or chromating <u>and</u> painting.	
Stress Corrosion	Is prone to stress corrosion cracking in air, fresh water, sea water and salt solutions. Not suitable for structural applications. For high stress applications, see ECSS-Q-70-36.	
Temperature Range	Maximum application temperature is 150 ^{o}C.	

SPECIAL RECOMMENDATIONS

- The part should be Lanolin covered or oiled at all times during machining and prior to protective treatments so as to avoid corrosion.
- Protective treatments can be either:
  - Anodizing <u>and</u> painting, or
  - Chromating <u>and</u> painting.
- The part should never make direct contact with other metals. Magnesium is more electrochemically negative than all other commonly used metals and will therefore be sacrificially corroded in any electrochemical cell that is created.

C.9 Optical materials

(None at present)

C.10 Adhesives, coatings and varnishes

C.10.1 Araldite AV138/HV998 (100/40 pbw)

PRODUCT

Type	2-part adhesive paste
Chemical Composition	Epoxy

Manufacturer	Vantico Ltd. Duxford, Cambridge CB2 4QA UK	Tel: +44 (0)1223 832121 Fax: +44 (0)1223 493230 Email: info@vantico.com www.vantico.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Low
Lot Reproducibility	Unknown
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Pot Life	30 min	@ 23 °C
Tensile Strength	43 MPa	@ 40 °C
Fatigue Strength	$>10^7$ cycles	@ 25 % Max. Strength
Thermal Expansion Coefficient	67×10^{-6} °C $^{-1}$	Between 18 °C and 93 °C
Thermal Conductivity	0,35 W m $^{-1}$ °C $^{-1}$	@ 30 °C
Volume Resistivity	$1{,}9 \times 10^{13}$ Ω m	@ 22 °C
Glass Transition Temperature	66 °C	T.M.A.

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	Up to 120 °C.	Long term.
Toxicity/Offgassing	Pass	NASA-STD-6001
Outgassing	TML = 0,84 %, RML =0,57 %, CVCM = 0,02 %	ECSS-Q-70-02
Flammability	Pass 24,5 % O_2	NASA-STD-6001

SPECIAL RECOMMENDATIONS

- Mixing ratio 100 parts AV138 to 40 parts HV998 by weight.
- Sensitivity to water absorption by the catalyst before use. This can degrade outgassing and mechanical properties.
- Does not pass odour test with cure at RT; passes with cure at 65 °C.
- Recommended cure time: 48 hours at room temperature.
- AV138M is newer version of AV138.

C.10.2 CV-1144-0

PRODUCT

Type	Controlled volatility RTV silicone atomic oxygen overcoat	
Chemical Composition	Dimethyl Diphenyl Silicone Polymer	
Manufacturer	Nusil Technology 1050 Cindy Lane, Carpinteria, CA 93013 USA	Tel: +1 805 684 8780 Fax: +1 805 566 990 Email: steveb@nusil.com www.nusil.com
European Agent	NuSil Technology-Europe 2740, route des Cretes BP 325 06906 Sophia Antipolis Cedex France	Tel: +33 (0) 4 92 96 93 31 Fax: +33 (0) 4 92 96 06 37 Email: nusil.sophia@nusil.com www.nusil.com

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	High
Lot Reproducibility	Good
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Appearance	Clear, elastomer	
Viscosity	(265±50) cps	Manufacturer's Data
Refractive Index	1,43±0,05	Manufacturer's Data
Non-volatile Content	(60±2) %	Manufacturer's Data
Shelf Life	6 Months	@ 25 °C, Refrigeration can extend shelf life.

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	-115 °C to +232 °C.	Manufacturer's Data
Outgassing	TML = 0,30 %, RML =0,25 %, CVCM = 0,01 %	ECSS-Q-70-02

SPECIAL RECOMMENDATIONS

- CV-1144-0 is normally self bonding.
- If more adhesion is required, Nusil silicone primers should be used: SP-120, SP-124 or SP-133.
- Cure times at 25 °C and 50 % RH:
  - Tack-free time – 1 hour.
  - Time to handling – 24 hours.

C.10.3 CV-1152

PRODUCT

Type	Controlled volatility RTV silicone conformal coating	
Chemical Composition	Dimethyl Diphenyl Silicone Polymer	
Manufacturer	Nusil Technology 1050 Cindy Lane, Carpinteria, CA 93013 USA	Tel: +1 805 684 8780 Fax: +1 805 566 990 Email: steveb@nusil.com www.nusil.com
European Agent	NuSil Technology-Europe 2740, route des Cretes BP 325 06906 Sophia Antipolis Cedex France	Tel: +33 (0) 4 92 96 93 31 Fax: +33 (0) 4 92 96 06 37 Email: nusil.sophia@nusil.com www.nusil.com

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	High
Lot Reproducibility	Good
Space Experience	Extensive

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	1,01	@ 25 °C, Manufacturer's Data
Appearance	Clear, elastomer	
Viscosity	6 200 cps	Manufacturer's Data
Refractive Index	1,43±0,005	Manufacturer's Data
Dielectric Strength	19,7 kV/mm	Manufacturer's Data
Volume Resistivity	1×10^{17} Ω m	Manufacturer's Data
Shelf Life	6 Months	@ 25 °C, Refrigeration can extend shelf life.

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	-115 °C to +260 °C.	Manufacturer's Data
Outgassing	TML = 0,18 %, RML =0,15 %, CVCM = 0,00 %	ECSS-Q-70-02
Toxicity/Offgassing	Pass	NASA-STD-6001
Flammability	Pass (24,5 % O_2)	NASA-STD-6001

SPECIAL RECOMMENDATIONS

- If more adhesion is required, NuSil silicone primers should be used: SP-120, SP-124 or SP-133.
- Cure times at 25 °C and 50 % RH:
  - Tack-free time – 1 hour.
  - Set-up - 24 hours.
  - Time to handling – 7 days.

C.10.4 CV-2640

PRODUCT

Type	Controlled volatility electrically-conductive RTV silicone for EMI and RF shielding
Chemical Composition	Phenyl Silicone - Carbon

Manufacturer	Nusil Technology 1150 Mark Avenue, Carpinteria, CA 93013 USA	Tel: +1 805 684 8780 Fax: +1 805 566 990 Email: steveb@nusil.com www.nusil.com
European Agent	Polymer Systems Technology Ltd. Unit 6, First Floor, Vernon Bldg, Westbourne St, High Wycombe UK	Tel: +44 (0)1494 446610 Fax: +44 (0)1494 528611 Email: Poly.systechltd@btinternet.com

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	High
Lot Reproducibility	Good
Space Experience	Limited

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	1,25±0,05	@ 25 °C
Appearance	Black, elastomer	
Pot Life	1 hour minimum	
Viscosity	100 000±20 000 cps	Manufacturer's Data
Hardness	50 minimum	Durometer, Type A
Tensile Strength	0,5 MPa minimum	Manufacturer's Data
Elongation	25 % minimum	Manufacturer's Data
Volume Resistivity	0,1 Ω m maximum	Manufacturer's Data
Shelf Life	6 Months	@ 25 °C, Refrigeration can extend shelf life.

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	-115 °C to +260 °C.	Manufacturer's Data
Outgassing	TML = 0,19 %, RML =0,17 %, CVCM = 0,00 %	ECSS-Q-70-02
Thermal Cycling	Pass	ECSS-Q-70-04

SPECIAL RECOMMENDATIONS

- A primer can be required in some bonding applications. Nusil CF1-135 Silicone primer should be used.
- Base should be mixed thoroughly before use to dissipate filler.
- Cure times at 25 °C:
  - 24 hours to handle carefully.
  - 7 days to cure fully.

C.10.5 D.C. 93500

PRODUCT

Type	Two-part adhesive, potting, coating.	
Chemical Composition	Silicone	
Manufacturer	N.V. Dow Corning Parc Industriél, Zone C B-7180 Senette Belgium	Tel: +32-64-88 80 00 Fax: +32-64-88 84 01 Email: www.dowcorning.com

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	Very High
Lot Reproducibility	Excellent
Space Experience	Extensive

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	**Typical Value** (standard version)	**Remarks**
Specific Gravity	1,08	@ 25 °C
Viscosity	8 400 cps	@ 25 °C
Pot Life	2 hours	@ 25 °C
Hardness	40	Shore A
Tensile Strength	7 MPa	ASTM D412 Die C
Thermal Expansion Coefficient	300×10^{-6} °C $^{-1}$	Manufacturer's Data
Thermal Conductivity	0,146 W m^{-1} °C $^{-1}$	Manufacturer's Data
Electrical Resistivity (volume)	$6{,}9 \times 10^{12}\ \Omega$ m	ASTM D257
Dielectric Constant	2,75	ASTM D150 (100 Hz)
Loss Factor	0,001 1	ASTM D150 (100 Hz)
Dielectric Strength	14,8 kV mm^{-1}	ASTM D149
Optical Transmission	97,5 %	Solar cell measurement
Shelf Life	24 Months	Manufacturer's Data
Glass Transition Temperature	-84 °C	TMA
Specific Heat	0,867 J g^{-1} °C $^{-1}$	@ 0 °C

PROPERTIES RELEVANT TO SPACE USE

Nature	**Typical Value**	**Type of Test**
Temperature Range	-65 °C to +200 °C.	Long Term
Outgassing	TML = 0,30 %, RML =0,28 %, CVCM = 0,03 %	ECSS-Q-70-02
Thermal Cycling	Pass	ECSS-Q-70-04
Oxygen Index	49,5	ECSS-Q-70-21
Ionizing Radiation	200Mrad (Co60 source)	Manufacturer's Data
Flammability	Pass (24,5 % O_2): tested as coating on FR4 PCB	NASA-STD-6001

SPECIAL RECOMMENDATIONS

- Recommended cure: 7 days at room temperature.
- DC 93500 can be filled with silica for thixotropy and with silver powder for electrical conductance. In these cases, a high temperature cure is necessary (24 hours @ 80 °C).
- Where high adhesion is required, use a primer: DC 1200 (red) or DC 92023 (clear).
- Sensitive to contamination, particularly when cured in thin layers.
- Three commercial versions are available: DC 93500 (thixotropic), DC 93500 (high viscosity) and DC 93500 (low viscosity).

C.10.6 Eccobond "solder" 56C

PRODUCT

Type	Electrically-conductive adhesive paste.
Chemical Composition	Epoxy – Silver-loaded.

Manufacturer Emerson & Cumming
Nijerheidsstraat 7,
B-2260 Westerlo
Belgium
Tel: +32 14 56 25 00
Fax: +32 14 56 25 01
Email:
www.emersoncuming.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	High
Lot Reproducibility	Excellent
Space Experience	Extensive

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Shear Strength	5,65 MPa	Manufacturer's Data
Thermal Expansion Coefficient	36×10^{-6} °C $^{-1}$	Manufacturer's Data
Thermal Conductivity	5,8 W m^{-1} °C $^{-1}$	Manufacturer's Data
Electrical Resistivity (volume)	2×10^{-6} Ω m	Manufacturer's Data

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	-60 °C to +175 °C.	Manufacturer's Data
Outgassing	TML = 0,30 %, RML =0,20 %, CVCM = 0,02 %	ECSS-Q-70-02
Flammability	Pass (23,8 % O_2)	NASA-STD-6001
Toxicity/Offgassing	Pass	NASA-STD-6001

SPECIAL RECOMMENDATIONS

- Recommended proportions are: 100 pbw resin + 2,5 pbw catalyst 9.
- Recommended cure is 16 hours at 50 °C.
- Peel strength of this adhesive is low. Cycling to sub-zero temperatures can be detrimental.
- Electrical bonds made with this adhesive to metals having a different EMF are likely to degrade in a humid environment, particularly if the metal layers are thin (e.g. vacuum deposits).
- Different catalysts are available which affect the properties, including temperature range and processing recommendations. Space experience with catalysts 9 and 11 is available.

C.10.7 MAPSIL 213

PRODUCT

Type	Encapsulating resin (2-part) or transparent conformal coating (3-part), electrically insulating.
Chemical Composition	Elastomeric Silicone

Manufacturer	Société MAP S.A.	Tel: +33 (0)5 34 01 27 00
	Z.I. rue Clément Ader,	Fax: +33 (0)5 61 60 28 77
	F-09100 Pamiers	Email: map@map-coatings.com
	France	www.map-coatings.com

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	Medium
Lot Reproducibility	Good
Space Experience	Fair

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Electrical Surface Resistance	$>10^{12}\,\Omega$	Manufacturer's Data, depends on coating thickness
Electrical Volume Resistance	$>10^{12}\,\Omega m$	Manufacturer's Data, depends on coating thickness
Shelf Life	6 Months	Manufacturer's Data

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Outgassing	TML = 0,30 %, RML =0,27 %, CVCM = 0,04 %	ECSS-Q-70-02
Temperature Range	-100 °C to +200 °C.	

SPECIAL RECOMMENDATIONS

- Room temperature (with activator). Cured by heating.
- Fully evaluated for application by ESA-ESTEC (QM division).

C.10.8 RTV S 691

PRODUCT

Type	Two-part, room-temperature-vulcanizing adhesive.	
Chemical Composition	Silicone, Filled.	
Manufacturer	Wacker-Chemie GmbH Johannes-Hess-Str. 24, D-84489 Burghausen Germany	Tel: +49-86 77-83-20 04 Fax: +49-86 77-83-55 91 Email: www.wacker.de

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	Very High
Lot Reproducibility	Good
Space Experience	Extensive

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Pot Life	90 min to 110 min	Up to 2 000 cps viscosity
Initial Viscosity	180 cps to 260 cps	
Specific Gravity	1,41 to 1,43	
Hardness	50 Shore A to 60 Shore A	DIN 53505
Tensile Strength	4 MPa to 6 MPa	DIN 53504
Tear Strength	4 Nmm $^{-1}$ to 6 Nmm $^{-1}$	ASTM D624B
Thermal Expansion Coefficient	200×10^{-6} °C $^{-1}$	T > -105 °C
	400×10^{-6} °C $^{-1}$	T < -105 °C
Thermal Conductivity	0,39 W m^{-1} °C^{-1}	
Volume Resistance	10^{12} Ω m	DIN 53482 (100V, 1min)
Brittleness Temperature	-105 °C	
Shelf Life	12 Months (room temperature)	Manufacturer’s Data
Glass Transition Temperature	-111 °C	TMA

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	-180 °C to +200 °C.	
Outgassing	TML = 0,35 %, RML =0,35 %, CVCM = 0,07 %	ECSS-Q-70-02
Thermal Cycling	Pass	ECSS-Q-70-04
Toxicity/Offgassing	Fails	NASA-STD-6001
Flammability	Burnt	NASA-STD-6001

SPECIAL RECOMMENDATIONS

- Recommended proportions are 90 pbw A to 10 pbw B. Thorough mixing is necessary.
- Cure: 7 days at room temperature.
- Quality control test according to ECSS-Q-70-02 should be done.
- Use with primer Wacker G 790 for better adhesion.
- Offgassing can be reduced to an acceptable level by curing at 65 °C.

C.10.9 RTV S 695

PRODUCT

Type	Two-part, room-temperature-vulcanizing adhesive.	
Chemical Composition	Silicone.	
Manufacturer	Wacker-Chemie GmbH Johannes-Hess-Str. 24, D-84489 Burghausen Germany	Tel: +49-86 77-83-20 04 Fax: +49-86 77-83-55 91 Email: www.wacker.de

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	Very High
Lot Reproducibility	Good
Space Experience	Fair

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Pot Life	8 hours (@ 23 °C)	Manufacturer's Data
Initial Viscosity	66 cps	Manufacturer's Data
Hardness	12 (@ 23 °C)	Manufacturer's Data
Shear Strength	0,7 MPa (@ 23 °C)	Manufacturer's Data
Shear Modulus	0,2 MPa (@ 23 °C)	Manufacturer's Data
Thermal Expansion Coefficient	320×10^{-6} °C^{-1}	23 °C to 100 °C
	76×10^{-6} °C^{-1}	-180 °C to -140 °C
Thermal Conductivity	0,21 W m^{-1} °C^{-1}	@ 93,5 °C
Brittleness Temperature	-110 °C	Manufacturer's Data
Shelf Life	12 Months (room temperature)	Manufacturer's Data
Glass Transition Temperature	-110 °C	TMA
Refractive Index (η_0)	1,424 to 1,428	Manufacturer's Data (@ 25 °C)

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	-180 °C to +200 °C.	
Outgassing	TML = 0,05 %, RML =0,04 %, CVCM = 0,01 %	ECSS-Q-70-02
Thermal Cycling	Pass	ECSS-Q-70-04
UV Resistance	Similar to that of DC 93500	
Flammability	Self Extinguishing	NASA-STD-6001 21 % O_2
	Burnt	NASA-STD-6001 24,5 % O_2

SPECIAL RECOMMENDATIONS

- Recommended proportions are 90 pbw A to 10 pbw B. Thorough mixing is necessary.
- Cure: 7 days at room temperature.
- Mechanical resistance of this adhesive is low. Its use is mainly for optical purposes; a typical application being as a solar-cell cover-glass adhesive.

C.10.10 MAP ATOX 41B

PRODUCT

Type	Varnish for printed circuits, conformal coating.	
Chemical Composition	Elastomeric Silicone	
Manufacturer	Société MAP S.A. Z.I. rue Clément Ader, F-09100 Pamiers France	Tel: +33 (0)5 34 01 27 00 Fax: +33 (0)5 61 60 28 77 Email: map@map-coatings.com www.map-coatings.com

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	Medium
Lot Reproducibility	Good
Space Experience	Fair

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Resistance to Atomic Oxygen	$\Delta\alpha_s = +0{,}017$, $\Delta e = +0{,}15\ \mu m$	$2{,}8 \times 10^{20}$ atoms/cm^2, on aluminized Kapton.
Resistance to UV	$\Delta\alpha_s = +0{,}05$	1 000 esh

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Outgassing	TML = 0,28 %, RML =0,28 %, CVCM = 0,086 %	ECSS-Q-70-02
Temperature Range	-100 °C to +200 °C.	

SPECIAL RECOMMENDATIONS

-

C.10.11 MAPSIL 213B

PRODUCT

Type	Encapsulating resin (2-part) or transparent conformal coating (2-part), electrically insulating.
Chemical Composition	Elastomeric Silicone

Manufacturer	Société MAP S.A. Z.I. rue Clément Ader, F-09100 Pamiers France	Tel: +33 (0)5 34 01 27 00 Fax: +33 (0)5 61 60 28 77 Email: map@map-coatings.com www.map-coatings.com

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	Medium
Lot Reproducibility	Good
Space Experience	Fair

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Electrical Surface Resistance	$>10^{12}\ \Omega$	Manufacturer's Data, depends on coating thickness
Electrical Volume Resistance	$>10^{12}\ \Omega m$	Manufacturer's Data, depends on coating thickness
Shelf Life	6 Months	Manufacturer's Data

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	-100 °C to +200 °C.	
Outgassing	TML = 0,30 %, RML =0,27 %, CVCM = 0,04 %	ECSS-Q-70-02

SPECIAL RECOMMENDATIONS

- Mapsil 213B was developed from Mapsil 213 with a new catalyst allowing optical transparency and preventing some components like Kovar from electrochemical corrosion.

C.10.12 MAP S2

PRODUCT

Type	Matt-black, Conductive, Thermal-control paint	
Chemical Composition	Purified Elastomeric Silicone, Black Carbon Pigment	
Manufacturer	Société MAP S.A. Z.I. rue Clément Ader, F-09100 Pamiers France	Tel: +33 (0)5 34 01 27 00 Fax: +33 (0)5 61 60 28 77 Email: map@map-coatings.com www.map-coatings.com

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	Medium
Lot Reproducibility	Good
Space Experience	Fair

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Typical Thickness: S2 Paint	30 µm to 50 µm	Manufacturer's Data
Electrical Surface Resistance	1 kΩ to 50 kΩ	Manufacturer's Data
Solar Absorptance	$\alpha_s \leq 0{,}97 \pm 0{,}01$	ECSS-Q-70-09, depends on topcoat thickness
Normal IR Emittance	$0{,}89 \pm 0{,}04$	ECSS-Q-70-09, Manufacturer's Data
Shelf Life	6 Months at 6 °C	Manufacturer's Data

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Outgassing	RML = 0,27 %, CVCM = 0,00 %, TWL = 0,56 %	ECSS-Q-70-02
Thermal Cycling	Pass	200 cycles 10^{-4} Pa (-150 °C to +100 °C)
Resistance to Atomic Oxygen	$\Delta\alpha_s$ = 0,00, Δe= -0,09 µm	Dose 2×10^{20} atoms/cm^2 Manufacturer's Data

SPECIAL RECOMMENDATIONS

- Room temperature curing.
- Manufacturer's Data

C.10.13 Scotchweld EC 2216 (5 pbw base / 7 pbw accelerator)

PRODUCT

Type	2-part structural adhesive.
Chemical Composition	Modified Epoxy

Manufacturer	3M Belgium	Tel: +32 (0)2 722 51 11
	Hermes Laan, 7,	Fax: +32 (0)2 720 02 25
	B-1831 Diegem	Email:
	Belgium	www.3m.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Medium
Lot Reproducibility	Fair
Space Experience	Extensive

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Pot Life	90 min	Manufacturer's Data
Tensile Shear Strength	21,3 MPa	@ 24 °C
Tensile Peel Strength	3,6 Nmm^{-1}	@ 24 °C
Specific Heat	1,34 $J\ g^{-1}\ °C^{-1}$	@ 0 °C
Glass Transition Temperature	11,8 °C	TMA
Thermal Expansion Coefficient	$45 \times 10^{-6}\ °C^{-1}$	-100 °C to 0 °C
	$182 \times 10^{-6}\ °C^{-1}$	40 °C to 100 °C

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	-50 °C to 80 °C.	Long term.
Toxicity/Offgassing	Pass	NASA-STD-6001
Outgassing	TML = 1,42 %, RML =0,75 %, CVCM = 0,01 %	ECSS-Q-70-02
Flammability	Pass	NASA-STD-6001

SPECIAL RECOMMENDATIONS

- The accelerator (catalyst) is sensitive to atmospheric humidity and CO_2. Minimal exposure to atmosphere is recommended during storage and mixing.
- Recommended cure is 2 hours at 70 °C.
- Quality control test by micro-VCM method (ECSS-Q-70-02) should be done.

C.10.14 Epo-tek 930

PRODUCT

Type	Thermally-conductive adhesive.	
Chemical Composition	2-part Epoxy, Boron nitride filled.	
Manufacturer	Epotek 14 Fortune Drive Billerica, MA 01821 USA	Tel: +1 978 667 3805 Fax: +1 978 663 9782 Email: www.epotek.com
Epotek - Belgium / Luxembourg / Netherlands	Gentec Benelux Chaussee de Louvain, 270 B-1410 Waterloo Belgium	Tel: +32 2-351-1800 Fax: +32 2-351-1962 Email: info@gentec.be www.gentec.be

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Medium
Lot Reproducibility	Unknown
Space Experience	Little

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Thermal Conductivity	4,1 W m^{-1} $°C^{-1}$	
Thermal Expansion	4×10^{-5} K^{-1}	

PROPERTIES RELEVANT TO SPACE USE

-

SPECIAL RECOMMENDATIONS

Thermally conductive adhesive for stacking of surface-mount packages (ESA STM-265).

C.11 Adhesive tapes and films

C.11.1 REDUX 312

PRODUCT

Type	Adhesive film, structural, unsupported.	
Chemical Composition	Epoxy, modified.	
Manufacturer	Hexcel Composites Ltd. Duxford, Cambridge CB2 4QD UK	Tel: +44 (0)1223 833 141 Fax: www.hexcel.com www.hexcelcomposites.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Medium
Lot Reproducibility	Good
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Mass per Unit Area	300 gm^{-2}	Manufacturer's Data
Tensile Shear Strength	43 MPa	Manufacturer's Data (@ 24 °C)
Tensile Peel Strength	48,6 N cm^{-1}	Manufacturer's Data (@ 24 °C)
Flatwise Tensile Strength	9,1 MPa	Manufacturer's Data (@ 24 °C)
Shelf Life	3 Months	Manufacturer's Data (@ 24 °C)
	12 Months	Manufacturer's Data (@ -18 °C)

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	-55 °C to +120 °C.	Long Term
Outgassing	TML = 1,1 %, RML =0,4 %, CVCM = 0,05 %	ECSS-Q-70-02
Flammability	Fail (21 % O_2)	NASA-STD-6001

SPECIAL RECOMMENDATIONS

- Recommended cure is 90 minutes at 120 °C or 60 minutes at 130 °C.
- A lighter version of the film exists under the name 312L (150 gm^{-2}) and 312UL (100 gm^{-2}).
- The same adhesive exists as supported film under the name 312/5 (knitted Nylon carrier).
- Primer REDUX 112 can be used with this adhesive.
- Where high temperatures (175 °C, short term) are expected, REDUX 319 should be used.
- Quality control test according to ECSS-Q-70-02 should be done.

C.11.2 Scotch tape no. 5

PRODUCT

Type	Adhesive tape, thermosetting, transparent.	
Chemical Composition	Polyester/Acrylic.	
Manufacturer	3M Belgium Hermes Laan, 7, B-1831 Diegem Belgium	Tel: +32 (0)2 722 51 11 Fax: +32 (0)2 720 02 25 Email: www.3m.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Low
Lot Reproducibility	Good
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Thickness	63 μm	Manufacturer's Data
Tensile Strength	45 N m^{-1}	Manufacturer's Data
Peel Strength	3,9 N cm^{-1}	Manufacturer's Data
Insulating Resistance	>10^6 MΩ	Manufacturer's Data
Dielectric Strength	6 000 V	Manufacturer's Data

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	Up to 130 °C.	Long Term
Outgassing	TML = 0,9 %, RML =0,7 %, CVCM = 0,08 %	ECSS-Q-70-02
Offgassing/Toxicity	Pass	NASA-STD-6001
Flammability	Pass (23,8 % O_2)	NASA-STD-6001

SPECIAL RECOMMENDATIONS

- Adhesion and solvent resistance are enhanced by a thermal treatment of 3 hours at 120 °C or 1 hour at 150 °C.

C.11.3 Scotch tape no. 60

PRODUCT

Type	Adhesive tape, thermosetting.
Chemical Composition	PTFE/Silicone.

Manufacturer 3M Belgium
Hermes Laan, 7,
B-1831 Diegem
Belgium
Tel: +32 (0)2 722 51 11
Fax: +32 (0)2 720 02 25
Email:
www.3m.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	-
Lot Reproducibility	Good
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Thickness	88 µm	Manufacturer's Data
Tensile Strength	35 N m^{-1}	Manufacturer's Data
Peel Strength	3,3 N cm^{-1}	Manufacturer's Data
Insulating Resistance	$>10^6$ MΩ	Manufacturer's Data
Dielectric Strength	9 000 V	Manufacturer's Data

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	Up to 180 °C.	Long Term
Outgassing	TML = 0,45 %, RML =0,4 %, CVCM = 0,1 %	ECSS-Q-70-02

SPECIAL RECOMMENDATIONS

- This tape shall be cured for 3 hours at 260 °C in order to develop its full adhesion. This treatment also reduces contaminants (CVCM), which is marginal.

C.11.4 Scotch tape no. 425

PRODUCT

Type	Adhesive tape.	
Chemical Composition	Aluminium/Acrylic.	
Manufacturer	3M Belgium Hermes Laan, 7, B-1831 Diegem Belgium	Tel: +32 (0)2 722 51 11 Fax: +32 (0)2 720 02 25 Email: www.3m.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Low
Lot Reproducibility	Very Good
Space Experience	Extensive

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Thickness	130 μm	Manufacturer's Data
Tensile Strength	7 N m^{-1}	Manufacturer's Data
Peel Strength	53 N cm^{-1}	Manufacturer's Data
Solar Absorptance	0,25	ECSS-Q-70-09
Hemispherical Emittance	0,035	ECSS-Q-70-09

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	-54 °C to +149 °C.	Manufacturer's Data, Long Term
Outgassing	TML = 0,20 %, RML =0,12 %, CVCM = 0,02 %	ECSS-Q-70-02
Thermal Cycling	Pass	ECSS-Q-70-04

SPECIAL RECOMMENDATIONS

- This tape shall be carefully and firmly applied with a roller to avoid a crinkled surface.
- Tape shall be regularly perforated to facilitate outgassing and avoid air bubbles.
- A lighter version of the same tape exists under the name Scotch Tape No. 431 (90 μm).

C.11.5 Scotch tape no. 850 silver

PRODUCT

Type	Adhesive tape.
Chemical Composition	Polyester/Aluminized/Acrylic.

Manufacturer

3M Belgium
Hermes Laan, 7,
B-1831 Diegem
Belgium
Tel: +32 (0)2 722 51 11
Fax: +32 (0)2 720 02 25
Email:
www.3m.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Low
Lot Reproducibility	Fair
Space Experience	Extensive

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Thickness	50 µm	Manufacturer's Data
Tensile Strength	3,8 N m^{-1}	Manufacturer's Data
Peel Strength	35 N cm^{-1}	Manufacturer's Data
Solar Absorptance	0,135	ECSS-Q-70-09
Hemispherical Emittance	0,63	ECSS-Q-70-09

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	-50 °C to +150 °C.	Manufacturer's Data, Long Term
Outgassing	TML = 0,6 %, RML =0,3 %, CVCM = 0,03 %	ECSS-Q-70-02
Thermal Cycling	Pass	ECSS-Q-70-04

SPECIAL RECOMMENDATIONS

- A "lined" version of the same tape is available under the name Scotch Tape No. 852.
- Tape 850 is also available in a transparent version and in different colours. Only silver is proven for space use.

C.11.6 Scotch tape Y 966

PRODUCT

Type	Adhesive transfer tape.
Chemical Composition	Acrylic.

Manufacturer 3M Belgium
Hermes Laan, 7,
B-1831 Diegem
Belgium
Tel: +32 (0)2 722 51 11
Fax: +32 (0)2 720 02 25
Email:
www.3m.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product (High performance version of Scotch Tape 467)
Cost Range	Low
Lot Reproducibility	Fair
Space Experience	Fair

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Thickness	50 μm	Manufacturer's Data
Tensile Strength	3 N m^{-1}	Manufacturer's Data (@ 160 °C; Test piece: 1,27 × 7,65 cm)
Peel Strength	1,8 N cm^{-1}	Manufacturer's Data (90° peel)
Creep	3 000 min	Under 3 Ncm^{-2} (Test piece: 1,27 × 7,65 cm^2)

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	-40 °C to +150 °C.	Manufacturer's Data, Long Term
Outgassing	TML = 0,93 %, RML =0,37 %, CVCM = 0,01 %	ECSS-Q-70-02
Thermal Cycling	Pass	ECSS-Q-70-04
Offgassing/Toxicity	Pass	NASA-STD-6001

SPECIAL RECOMMENDATIONS

- Recommended as a replacement for Scotch Tape 467 (same basic properties, but better temperature and solvent resistance).
- When used to bond fragile materials such as Second Surface Mirrors (SSM), the tape shall be applied first on the structure side. The liner is then removed and a suitable shape SSM bonded. If tape is already applied to the back of the SSM (as in some Sheldahl products), the liner shall be removed with the utmost care so as to avoid stresses on the SSM.
- Availability in Europe is limited when purchased quantity is very small. Maximum width is 122 cm.
- Not to be used when peel forces are applied.
- Peel strength at temperatures below -40 °C goes to zero.

C.12 Paints and inks

C.12.1 Aeroglaze H322 (formerly Chemglaze)

PRODUCT

Type	Heat-activated, Electrically-conductive, Matt-black Coating	
Chemical Composition	Polyurethane	
Manufacturer	Lord Corporation 111 Lord Drive P.O.Box 8012 Cary, NC 27512-8012, USA	Tel: +1 919 468 5979 Fax: 1 919 469 5777 Email: www.lordcorp.com
Europe	Lord Corporation (Europe) Ltd. Barton Dock Rd. Stretford, Manchester M32 0ZH UK	Tel: +44 (0)161 865 8048 Fax:+ 44 (0)161 865 0096 Email: www.lordcorp.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Low
Lot Reproducibility	Fair
Space Experience	Extensive

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Solid Content	25 %	Manufacturer's Data
Viscosity	500 cps	Manufacturer's Data
Electrical Surface Resistance	5 kΩ	@ 1V, nonconductive substrate
Solar Absorptance	0,95	ECSS-Q-70-09
Hemisperical Emittance	0,85	ECSS-Q-70-09
Shelf Life	6 Months	20°C

PROPERTIES RELEVANT TO SPACE USE (Effects of or on environment)

Nature	Typical Value	Type of Test
Flammability	Pass 21 % O_2. (on 1mm thick Aluminium foil).	NASA-STD-6001
Outgassing	TML = 1,6 %, RML = 0,9 %, CVCM = 0,04 %	ECSS-Q-70-02
UV/Particle Effects	$\Delta\alpha_s$ = -0,025	3 Years/OTS spec.
Thermal Cycling	Pass	ECSS-Q-70-04

SPECIAL RECOMMENDATIONS

- Recommended cure: 15 minutes at 125 °C after last layer + post cure 50 Hours at 100 °C (Specification ECSS-Q-70-34).
- Primer: Lesonol 01-66050 can be used for increased adhesion.
- This paint (like most others) is not recommended for use in badly vented places where high electrical fields are present in the vicinity (corona risk).
- Quality control tests according to ECSS-Q-70-02 are recommended.
- Difficult to procure in Europe.

C.12.2 Aeroglaze L300 (formerly Chemglaze)

PRODUCT

Type	Low-temperature-curing, Electrically-conductive, Matt-black Paint	
Chemical Composition	Polyurethane	
Manufacturer	Lord Corporation 111 Lord Drive P.O.Box 8012 Cary, NC 27512-8012, USA	Tel: +1 919 468 5979 Fax: 1 919 469 5777 Email: www.lordcorp.com
Europe	Lord Corporation (Europe) Ltd. Barton Dock Rd. Stretford, Manchester M32 0ZH UK	Tel: +44 (0)161 865 8048 Fax:+ 44 (0)161 865 0096 Email: www.lordcorp.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Low
Lot Reproducibility	Good
Space Experience	Fair

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Solid Content	22 %	Manufacturer's Data
Viscosity	400 cps	Manufacturer's Data
Electrical Surface Resistance	3 kΩ	@ 1V, nonconductive substrate
Solar Absorptance	0,955	ECSS-Q-70-09
Hemisperical Emittance	0,85	ECSS-Q-70-09
Shelf Life	6 Months	20 °C

PROPERTIES RELEVANT TO SPACE USE (Effects of or on environment)

Nature	Typical Value	Type of Test
Flammability	Pass 21 % O_2. (on 1mm thick Aluminium foil).	NASA-STD-6001
Outgassing	TML = 1,7 %, RML = 0,9 %, CVCM = 0,04 %	ECSS-Q-70-02
Thermal Cycling	Pass	ECSS-Q-70-04

SPECIAL RECOMMENDATIONS

- Recommended cure: 16 hours at 65 °C after last layer of paint has been applied ECSS-Q-70-35.
- This paint (like most others) is not recommended for use in badly vented places where high electrical fields are present in the vicinity (corona risk).
- Quality control tests by micro-VCM (ECSS-Q-70-02) are recommended.
- Flammability test on 1 mm thick Aluminium substrate in 21 % O_2. Material burns when applied to 7,6 μm Kapton. Configuration test mandatory.
- Use with Pyrolac P123 Primer for better adhesion.
- Difficult to procure in Europe.

C.12.3 Aeroglaze Z606 (formerly Chemglaze)

PRODUCT

Type	Flat back, Flexible, One-part Paint	
Chemical Composition	Polyurethane	
Manufacturer	Lord Corporation 111 Lord Drive P.O.Box 8012 Cary, NC 27512-8012, USA	Tel: +1 919 468 5979 Fax: 1 919 469 5777 Email: www.lordcorp.com
Europe	Lord Corporation (Europe) Ltd. Barton Dock Rd. Stretford, Manchester M32 0ZH UK	Tel: +44 (0)161 865 8048 Fax:+ 44 (0)161 865 0096 Email: www.lordcorp.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Low
Lot Reproducibility	Good
Space Experience	Extensive

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Solid Content	26 % to 29 % (pbw)	Manufacturer's Data
Viscosity	150 cps	Manufacturer's Data
Solar Absorptance	0,95	ECSS-Q-70-09
Hemisperical Emittance	0,90	ECSS-Q-70-09
Shelf Life	1 Year	20 °C

PROPERTIES RELEVANT TO SPACE USE (Effects of or on environment)

Nature	Typical Value	Type of Test
Flammability	Pass 24,5 % O_2. (on 1mm thick Aluminium foil).	NASA-STD-6001
Outgassing	TML = 1,5 %, RML = 0,6 %, CVCM = 0,03 %	ECSS-Q-70-02
UV/Particle Effects	$\Delta\alpha = 0$	7 Years/OTS spec.
Thermal Cycling	Pass	ECSS-Q-70-04
Offgassing/Toxicity	Pass	NASA-STD-6001

SPECIAL RECOMMENDATIONS

- Cuvertin 306 made by Henkel (Germany) generally shows higher TML/CVCM.
- This paint (like most others) is not recommended for use in badly vented places where high electrical fields are present in the vicinity (corona risk).
- Coating to be applied according to ECSS-Q-70-25 with use of Pyrolac P123 Primer.
- Quality control tests by micro-VCM (ECSS-Q-70-02) are recommended.
- Flammability test on 1mm thick Aluminium substrate in 24,5 % O_2. Material burns when applied to other substrates, e.g. Kapton. Configuration test mandatory.
- This paint has been shown to contaminate space hardware returned from space. This is probably due to processing aids based on silicones.

C.12.4 Electrodag 501

PRODUCT

Type	Electrically conductive black paint.	
Chemical Composition	Fluorinated binder.	
Manufacturer	Acheson Colloiden Postbus 1 NL-9697 ZG Scheemda The Netherlands	Tel: +31 597 59 13 03 Fax: +31 597 59 25 52 Email: www.achesonindustries.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Low
Lot Reproducibility	-
Space Experience	Limited

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Solid Content	14,7 %	Manufacturer's Data
Areal Weight	30 gm^{-1} for layer 20 μm thick	
Viscosity	800±200 cps, No. 2 spindle at 20 rpm Brookfield	Manufacturer's Data
Surface Resistivity	1 000 Ω for 25 μm thickness	Manufacturer's Data
Volume Resistivity	0,025 4 Ω m	Manufacturer's Data
Temperature Range	-40 °C to >260 °C *	Manufacturer's Data
Service Temperature	275 °C *	* Withstands 400 °C for short periods
Shelf Life	6 Months	
Solar Absorptance	0,965	ECSS-Q-70-09
Normal Emittance	0,829	ECSS-Q-70-09

PROPERTIES RELEVANT TO SPACE USE (Effects of or on environment)

Nature	Typical Value	Type of Test
Outgassing	TML = 0,86 %, RML = 0,44 %, CVCM = 0,00 %	ECSS-Q-70-02
Thermal Cycling	Pass	ECSS-Q-70-04
Radiation	$\Delta\alpha s$ = 0,01	5 years GEO
Flammability	Pass (21 % O_2.) Kapton substrate.	NASA-STD-6001

SPECIAL RECOMMENDATIONS

Each lot of this paint shall be checked for its normal emittance value, since large variations have been observed in this parameter, which is not systematically controlled by the manufacturer.

C.12.5 Electrodag 503

PRODUCT

Type	Electrically conductive silver paint.	
Chemical Composition	Fluorocarbon binder/silver pigment.	
Manufacturer	Acheson Colloiden Postbus 1 NL-9697 ZG Scheemda The Netherlands	Tel: +31 597 59 13 03 Fax: +31 597 59 25 52 Email: www.achesonindustries.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	High
Lot Reproducibility	-
Space Experience	Limited

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Solid Content	62 %	Manufacturer's Data
Viscosity	(1 200±300) cps, No. 2 spindle at 20 rpm Brookfield	Manufacturer's Data
Surface Resistivity	0,05 Ω for 25 μm thickness	Manufacturer's Data
Volume Resistivity	127×10^{-8} Ω m	Manufacturer's Data
Temperature Range	-40 °C to >260 °C	Manufacturer's Data
Service Temperature	275 °C	Manufacturer's Data
Shelf Life	6 Months	Manufacturer's Data
Solar Absorptance	0,370	ECSS-Q-70-09
Normal Emittance	0,440	ECSS-Q-70-09
Specific Heat	0,295 J g^{-1} $°C^{-1}$	0 °C

PROPERTIES RELEVANT TO SPACE USE (Effects of or on environment)

Nature	Typical Value	Type of Test
Outgassing	TML = 0,22 %, RML = 0,21 %, CVCM = 0,06 %	ECSS-Q-70-02

SPECIAL RECOMMENDATIONS

In atomic oxygen environment the silver pigment is attacked.

C.12.6 MAP – PCBE

PRODUCT

Type	Matt-white, Conductive, Thermal-control Paint	
Chemical Composition	Silicone/Metallic Base, Encapsulated Zinc-Oxide Pigment	
Manufacturer	Société MAP S.A. Z.I. rue Clément Ader, F-09100 Pamiers France	Tel: +33 (0)5 34 01 27 00 Fax: +33 (0)5 61 60 28 77 Email: map@map-coatings.com www.map-coatings.com

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	Medium
Lot Reproducibility	Good
Space Experience	Fair

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Thickness		
Base	40 μm to 80 μm	Manufacturer's Data
Topcoat	50 μm to 90 μm	Manufacturer's Data
Surface Resistance	< 1 000 Ω	Manufacturer's Data
Solar Absorptance	α_p <= 0,27 ±0,04	ECSS-Q-70-09, depends on topcoat thickness.
Normal IR Emittance	0,88±0,04 -20 °C	ECSS-Q-70-09
	0,77±0,03 at -183 °C	Manufacturer's Data
Shelf Life	6 Months at 20 °C	Manufacturer's Data

PROPERTIES RELEVANT TO SPACE USE (Effects of or on environment)

Nature	Typical Value	Type of Test
Outgassing	RML= 0,43 %, CVCM= 0,08 %	ECSS-Q-70-02
Thermal Cycling	Pass	200 cycles 10^{-4} Pa (-170 °C; +130 °C)
UV Radiation	$\Delta\alpha_s$ = 0,00	1 000 esh
UV + e^- + p^+	$\Delta\alpha_s$ = +0,08/50 μm thickness	1 year in GEO

SPECIAL RECOMMENDATIONS

- Room temperature curing.
- See manufacturer's data.

C.12.7 MAP – PSB

PRODUCT

Type	Matt-white, Thermal-control Paint
Chemical Composition	Potassium Silicate/Zinc Orthophosphate

Manufacturer Société MAP S.A.
Z.I. rue Clément Ader,
F-09100 Pamiers
France
Tel: +33 (0)5 34 01 27 00
Fax: +33 (0)5 61 60 28 77
Email: map@map-coatings.com
www.map-coatings.com

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	Medium
Lot Reproducibility	Good
Space Experience	Fair

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	**Typical Value**	**Remarks**
Thickness	130 μm to 150 μm	Manufacturer's Data
Solar Absorptance	0,14±0,02 (Aluminium substrate, coating 150 μm thick)	ECSS-Q-70-09, depends on topcoat thickness.
Hemisperical Emittance	0,88	ECSS-Q-70-09
Normal Emittance	0,90±0,04	ECSS-Q-70-09
Shelf Life	1 Month	Manufacturer's Data

PROPERTIES RELEVANT TO SPACE USE (Effects of or on environment)

Nature	**Typical Value**	**Type of Test**
Outgassing	TML= 3,04 %, RML= 0,04 %, CVCM= 0,00 %	ECSS-Q-70-02
Thermal Cycling	Pass	200 cycles 10^{-4} Pa (-150 °C; +100 °C)
UV Radiation	$\Delta\alpha_s$ = +0,03 $\Delta\varepsilon$ = +0,00	1 500 esh @ 40 °C
UV + e^- + p^+	$\Delta\alpha_s$ = +0,25 $\Delta\varepsilon$ = +0,00	2,5 years GEO
Atomic Oxygen	Δe = +0,12 μm, $\Delta\alpha_s$ = +0,01, $\Delta\varepsilon$ = 0,00	2×10^{20} atoms cm^{-2}
Induced Surface Potential:		
+18 °C	25 V	1nA cm^{-2}, 15 keV
+18 °C	50 V	5nA cm^{-2}, 20 keV
-150 °C	900 V	1nA cm^{-2}, 20 keV

SPECIAL RECOMMENDATIONS

- Room temperature curing.
- This paint is usable directly on aluminium substrates without any chemical treatment.
- The high value of TML is due to water.

C.12.8 MAP – PU1

PRODUCT

Type	Matt-black, non-conductive, Thermal-control Paint
Chemical Composition	Binder: Polyurethane, Solvent: Aromatics and aliphatic, Pigment: Carbon black
Manufacturer	Société MAP S.A. Z.I. rue Clément Ader, F-09100 Pamiers France Tel: +33 (0)5 34 01 27 00 Fax: +33 (0)5 61 60 28 77 Email: map@map-coatings.com www.map-coatings.com

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	Medium
Lot Reproducibility	Good
Space Experience	Fair

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Thickness	50 μm to 60 μm	Manufacturer's Data
Solar Absorptance	0,96±0,04	Manufacturer's Data
Hemisperical Emittance	0,89	ECSS-Q-70-09
Normal Emittance	0,88±0,04	Manufacturer's Data
Shelf Life	6 Months in original unopened container between 5 °C to 20 °C away from humidity	Manufacturer's Data

PROPERTIES RELEVANT TO SPACE USE (Effects of or on environment)

Nature	Typical Value	Type of Test
Resistance to Atomic Oxygen	$\Delta\alpha_s$ = +0,00, Δe = -0,22 μm	$2{,}8 \times 10^{20}$ atoms/cm^2

SPECIAL RECOMMENDATIONS

- Manufacturer's Data.

C.12.9 MAP – SG121FD

PRODUCT

Type	Matt-black, Thermal-control Paint
Chemical Composition	Silicone-Zinc Oxide
Manufacturer	Société MAP S.A. Z.I. rue Clément Ader, F-09100 Pamiers France Tel: +33 (0)5 34 01 27 00 Fax: +33 (0)5 61 60 28 77 Email: map@map-coatings.com www.map-coatings.com

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	Medium
Lot Reproducibility	Good
Space Experience	In progress

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Thickness	100 µm to 120 µm	Manufacturer's Data
Solar Absorptance	α_s <= 0,17 ±0,02 α_p <= 0,22 ±0,04	ECSS-Q-70-09, depends on topcoat thickness
Normal Emittance	0,88±0,04	ECSS-Q-70-09
Shelf Life	6 Months	Manufacturer's Data

PROPERTIES RELEVANT TO SPACE USE (Effects of or on environment)

Nature	Typical Value	Type of Test
Outgassing	TML= 1,30 %, RML= 0,28 %, CVCM= 0,08 %	ECSS-Q-70-02 (with PSI or PSW primer)
Thermal Cycling	Pass	200 cycles 10^{-4} Pa (-170 °C; +130 °C).
UV Radiation	$\Delta\alpha_s$ = 0,02	1 300 esh at 40 °C
UV + e^- + p^+	$\Delta\alpha_s$ = +0,08	1 year in GEO N/S
ATOX	$\Delta\alpha_e$ = 0,00 µm $\Delta\alpha_s$ = +0,01	$2,10^{20}$ atoms/cm^2
Induced surface potential (Volts)	0 0	1 nA/cm^2 15 keV 5 nA/cm^2 20 keV

SPECIAL RECOMMENDATIONS

- Room temperature curing.
- It is mandatory to use PSI or PSW primer.

C.12.10 MAP – PUK

PRODUCT

Type	Matt-black, conductive, Thermal-control Paint
Chemical Composition	Binder: Polyurethane, Pigment: Carbon black, Solvent: Aromatics and aliphatic

Manufacturer	Société MAP S.A. Z.I. rue Clément Ader, F-09100 Pamiers France	Tel: +33 (0)5 34 01 27 00 Fax: +33 (0)5 61 60 28 77 Email: map@map-coatings.com www.map-coatings.com

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	Medium
Lot Reproducibility	Good
Space Experience	Fair

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Thickness	50 μm to 70 μm.	Manufacturer's Data
Electrical surface resistance	400 kΩ to 1000 kΩ	Manufacturer's Data
Solar Absorptance	$0{,}97 \pm 0{,}04$	Manufacturer's Data
Normal Emittance	$0{,}91 \pm 0{,}03$	Manufacturer's Data
Shelf Life	6 Months in original unopened container between 5 °C to 20 °C away from humidity	Manufacturer's Data

PROPERTIES RELEVANT TO SPACE USE (Effects of or on environment)

Nature	Typical Value	Type of Test
Outgassing (with Phosmap 11 primer)	TML= 1,50 %, RML= 0,88 %, CVCM= 0,00 %	ECSS-Q-70-02 (with Phosmat 11 primer)
Outgasing (withou primer)	TML= 1,00 %, RML= 0,52 %, CVCM= 0,00 %	ECSS-Q-70-02 (without primer)
Thermal cycling	71 cycles at 10^{-4} Pa at -170 °C to +130 °C	

SPECIAL RECOMMENDATIONS

- Final curing 4 hours at 70 °C.
- Manufacturer's Data.
- Any further sticking on the paint being absolutely forbidden, masked areas must be provided for sticking.

C.12.11 S13GP: 6N/LO-1

PRODUCT

Type	Matt-white Paint, 2-part.	
Chemical Composition	Silicone, Zinc Oxide, Potassium Silicate.	
Manufacturer	IITRI 10 West 35th Street Chicago, IL 60616 USA	Tel: +1 312 567 4000 Fax: Email: contact@iitri.org www.iitri.com

EXPERIENCE and AVAILABILITY

Development Status	Pilot Scale
Cost Range	High
Lot Reproducibility	Excellent
Space Experience	Extensive

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Solids Content	20 %	Manufacturer's Data
Solar Absorptance	0,18	ECSS-Q-70-09
Hemisperical Emittance	0,90	ECSS-Q-70-09
Shelf Life	6 Months	@ -18 °C

PROPERTIES RELEVANT TO SPACE USE (Effects of or on environment)

Nature	Typical Value	Type of Test
Outgassing	TML=0,5 %, RML=0,15 %, CVCM= 0,01 % to 0,04 %	ECSS-Q-70-02
Thermal Cycling	Pass	ECSS-Q-70-04
UV/Particle Effects	$\Delta\alpha_s$ = 0,2 to 0,25	7 years to 10 years in GEO

SPECIAL RECOMMENDATIONS

- Recommended proportions: 100 pbw paint + 1 pbw catalyst + diluent as needed.
- Cure at room temperature.
- Shall be used with primers Dow Corning DC 1200, General Electric SS 4044 or SS 4155 for better adhesion. Avoid primers containing dyes. For non-metallic substrates use A 1100.
- When the paint is applied to a high α_s substrate, a layer thickness of at least 200 μm is required if low final absorbtance is required.
- S13GLO-1 is out of trade. The latest and more stable version is S13GP: 6N/LO-1.

C.13 Lubricants

C.13.1 Apiezon L

PRODUCT

Type	Grease Lubricant.	
Chemical Composition	Hydrocarbon.	
Manufacturer	Apiezon Products, M + I Materials Ltd. PO Box 136 Manchester M60 1AN UK	Tel: +44 (0)161 875 4313 Fax: Email: tech@apiezon.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	High
Lot Reproducibility	Good
Space Experience	Limited

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	0,896	@ 20 °C
Melting Point	47 °C	Manufacturer's Data
Viscosity	766 cps	@ 50 °C
Thermal Expansion Coefficient	760×10^{-6} °C-1	Manufacturer's Data
Thermal Conductivity	0,2 W m^{-1} °C^{-1}	Manufacturer's Data
Heat of Fusion	63 J g^{-1}	Manufacturer's Data
Volume Resistivity	12×10^{14} Ωm	Manufacturer's Data
Dielectric Strength	28,7 kV/mm	Manufacturer's Data

PROPERTIES RELEVANT TO SPACE USE (Effects of or on environment)

Nature	Typical Value	Type of Test
Temperature Range	Around room temperature	
Outgassing	TML = 0,13 %, RML = 0,12 %, CVCM = 0,04 %	ECSS-Q-70-02

SPECIAL RECOMMENDATIONS

- A derived product, Apiezon AP100, contains PTFE additive for superior anti-seize properties.
- Does not pass odour test.

C.13.2 Fomblin Z25

PRODUCT

Type	Oil	
Chemical Composition	Perfluoralkylether	
Manufacturer	Ausimont Deutschland GmbH Parsevalstrasse, 6 D-06749 Bitterfeld Germany	Tel: +49 3493 79 0 Fax: +49 3493 79 102 Email: service@ausimont.de www.ausimont.de

EXPERIENCE and AVAILABILITY

Development Status	Available as raw stock Z; Limited laboratory production of Z25 available from ESTEC.
Cost Range	High
Lot Reproducibility	Good
Space Experience	Limited in Europe; wider in USA as Bray Micronic 815Z

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Kinematic Viscosity	(250±50) cps	@ 20 °C
	(140±30) cps	@ 38 °C
	(45±10) cps	@ 99 °C
ASTM Slope	(0,30±0,3)	
Viscosity Index	(360±10)	
Extrapolated Vapour Pressure	$< 5 \times 10^{-10}$ Pa	@ 20 °C
	$(5\pm4)\times 10^{-7}$ Pa	@ 93,3 °C
	$(5\pm4) \times 10^{-4}$ Pa	@ 204,4 °C
Pour Point	(-60 ±10(°C	
Specific Gravity	1,85±0,05	
Volatility Los	<0,1 %	149 °C – 22 h
Interfacial Tension	(40±5) mN/m	ASTM D971
Average Molecular Weight	15 000	

PROPERTIES RELEVANT TO SPACE USE (Effects of or on environment)

Nature	Typical Value	Type of Test
Outgassing	TML = 0,06 %, RML = 0,05 %, CVCM = 0,01 %	ECSS-Q-70-02

SPECIAL RECOMMENDATIONS

- Can show some undesirable reaction to metal surfaces after long-term operation.
- Any long-term use should be discussed with the European Space Tribology Laboratory (ESTL) before the design is finalised.

C.13.3 Mapsil 210

PRODUCT

Type	Thermally conductive grease.	
Chemical Composition	Silicone / Metallic Oxides.	
Manufacturer	Société MAP S.A. Z.I. Rue Clément ADER F-09100 PAMIERS France	Tel: +33 (0)5 34 01 27 00 Fax: +33 (0)5 61 60 28 77 Email: map@map-coatings.com www.map-coatings.com

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	High
Lot Reproducibility	Good
Space Experience	Limited

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Solid Content	100 % approx.	Manufacturer's Data
Thermal Conductivity	~ 0,41 W m^{-1} K^{-1}	Manufacturer's Data
Shelf Life	6 Months	@ 5 °C to 25 °C in original closed package.

PROPERTIES RELEVANT TO SPACE USE (Effects of or on environment)

Nature	Typical Value	Type of Test
Outgassing	TML = 0,06 %, RML = 0,03 %, CVCM = 0,01 %	ECSS-Q-70-02

SPECIAL RECOMMENDATIONS

- Can be used for thermally conductive interfaces.

C.14 Potting compounds, sealants and foams

C.14.1 CV-1142

PRODUCT

Type	Non-corrosive, controlled-volatility RTV silicone adhesive sealant.
Chemical Composition	Phenyl Silicone.

Manufacturer	Nusil Technology 1050 Cindy Lane, Carpinteria, CA 93013 USA	Tel: +1 805 684 8780 Fax: +1 805 566 990 Email: steveb@nusil.com www.nusil.com
European Agent	NuSil Technology-Europe 2740 route des Cretes, BP 325 06906 Sophia Antipolis Cedex France	Tel: +33-4 92 96 93 31 Fax: +33-4 92 96 06 37 Email: nusil.sophia@nusil.com www.nusil.com

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	High
Lot Reproducibility	Good
Space Experience	High

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Appearance	Translucent elastomer	
Consistency	Non-slump, 35 gpm, extrusion rate	Manufacturer's Data
Specific Gravity	1,10±0,02	25 °C, Manufacturer's Data
Hardness	45	Manufacturer's Data, Durometer, Type A
Tensile Strength	4,5 MPa	Manufacturer's Data
Elongation	350 %	Manufacturer's Data
Refractive Index	1,43±0,05	Manufacturer's Data
Dielectric Strength	19,7 kV/mm	Manufacturer's Data
Volume Resistivity	$1 \times 10^{17}\ \Omega$ m	Manufacturer's Data
Shelf Life	6 Months	25 °C. Refrigeration can extend shelf life.

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Outgassing	TML = 0,41 %, RML = 0,31 %, CVCM = 0,01 %	ECSS-Q-70-02
Temperature Range	-115 °C to 260 °C	Manufacturer's Data

SPECIAL RECOMMENDATIONS

- This product can be provided in white or black colour, differnet viscosities and pot life.
- If more adhesion is required, NuSil silicone primers should be used: SP-120, SP-124 or SP-133.
- Cure time at 25 °C and 50 % RH:
  - Tack-free time – 30 min.
  - Full cure – 7 days.
- Thick sections can require extended cure times.

C.14.2 CV-1500

PRODUCT

Type	Controlled-volatility electrically-conductive RTV silicone adhesive sealant.	
Chemical Composition	Phenyl Silicone Polymer - Carbon.	
Manufacturer	Nusil Technology 1050 Cindy Lane, Carpinteria, CA 93013 USA	Tel: +1 805 684 8780 Fax: +1 805 566 990 Email: steveb@nusil.com www.nusil.com
European Agent	NuSil Technology-Europe 2740 route des Cretes, BP 325 06906 Sophia Antipolis Cedex France	Tel: +33-4 92 96 93 31 Fax: +33-4 92 96 06 37 Email: nusil.sophia@nusil.com www.nusil.com

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	High
Lot Reproducibility	Good
Space Experience	Limited

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Appearance	Black elastomer	
Consistency	Non-slump	Manufacturer's Data
Specific Gravity	1,24	25 °C, Manufacturer's Data
Hardness	70	Manufacturer's Data, Durometer, Type A
Tensile Strength	3,5 MPa	Manufacturer's Data
Elongation	30 %	Manufacturer's Data
Refractive Index	1,41±0,05	Manufacturer's Data
Dielectric Strenght	19,7 kV/mm	Manufacturer's Data
Volume Resistivity	150 Ω m	Manufacturer's Data
Shelf Life	6 Months	25 °C. Refrigeration can extend shelf life.

PROPERTIES RELEVANT TO SPACE USE (Effects of or on environment)

Nature	Typical Value	Type of Test
Outgassing	TML = 0,29 %, RML = 0,25 %, CVCM = 0,02 %	ECSS-Q-70-02
Temperature Range	-115 °C to 260 °C	Manufacturer's Data
Thermal Cycling	Pass	ECSS-Q-70-04

SPECIAL RECOMMENDATIONS

- If more adhesion is required, NuSil silicone primer should be used: SP-120, SP 124 or SP-133.
- Cure time at 25 °C and 50 % RH:
  - Tack-free time – 30 min.
  - Full cure – 7 days.
- Thick sections can require extended cure times.

C.14.3 CV-2500

PRODUCT

Type	Controlled-volatility RTV silicone: Optically clear adhesive.	
Chemical Composition	Dimethyl Silicone Polimer.	
Manufacturer	Nusil Technology 1050 Cindy Lane, Carpinteria, CA 93013 USA	Tel: +1 805 684 8780 Fax: +1 805 566 990 Email: steveb@nusil.com www.nusil.com
European Agent	NuSil Technology-Europe 2740 route des Cretes, BP 325 06906 Sophia Antipolis Cedex France	Tel: +33-4 92 96 93 31 Fax: +33-4 92 96 06 37 Email: nusil.sophia@nusil.com www.nusil.com

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	High
Lot Reproducibility	Good
Space Experience	High

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Appearance	Optically clear elastomer	
Viscosity	8 000 cps	Manufacturer's Data
Specific Gravity	1,04	25 °C
Hardness	50	Durometer, Type A
Tensile Strength	6,9 MPa	Manufacturer's Data
Elongation	150 %	Manufacturer's Data
Dielectric Strength	21,7 kV/mm	Manufacturer's Data
Volume Resistivity	1×10^{13} Ω m	Manufacturer's Data
Refractive Index	1,41	Manufacturer's Data
Shelf Life	6 Months	25 °C. Refrigeration can extend shelf life.

PROPERTIES RELEVANT TO SPACE USE (Effects of or on environment)

Nature	Typical Value	Type of Test
Outgassing	TML = 0,16 %, RML = 0,16 %, CVCM = 0,01 %	ECSS-Q-70-02
Temperature Range	-65 °C to 232 °C	Manufacturer's Data
Thermal Cycling	Pass	ECSS-Q-70-04

SPECIAL RECOMMENDATIONS

- This product can be provided in whit or black colour and different viscosities.
- If more adhesion is required, NuSil silicone primers should be used: CF1-135 or CF6-135.
- Cure times at 25 °C: between 4 and 7 days.
- Cure time can be reduced with elevated temperature

C.14.4 CV-2566

PRODUCT

Type	Controlled-volatility RTV silicone adhesive, coating, sealing, potting.	
Chemical Composition	Diphenyl Dimethyl Silicone Polymer.	
Manufacturer	Nusil Technology 1050 Cindy Lane, Carpinteria, CA 93013 USA	Tel: +1 805 684 8780 Fax: +1 805 566 990 Email: steveb@nusil.com www.nusil.com
European Agent	NuSil Technology-Europe 2740 route des Cretes, BP 325 06906 Sophia Antipolis Cedex France	Tel: +33-4 92 96 93 31 Fax: +33-4 92 96 06 37 Email: nusil.sophia@nusil.com www.nusil.com

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	High
Lot Reproducibility	Good
Space Experience	High

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Appearance	Red, elastomer	
Pot Life	60 min minimum	
Viscosity	40 000cps	Manufacturer's Data
Specific Gravity	1,5	25 °C
Hardness	55	Manufacturer's Data, Durometer, Type A
Tensile Strength	5,9 MPa	Manufacturer's Data
Elongation	175 %	Manufacturer's Data
Dielectric Strength	19,7 kV/mm	Manufacturer's Data
Volume Resistivity	1×10^{17} Ω m	Manufacturer's Data
Shelf Life	6 Months	25 °C. Refrigeration can extend shelf life.

PROPERTIES RELEVANT TO SPACE USE (Effects of or on environment)

Nature	Typical Value	Type of Test
Temperature Range	-115 °C to 260 °C	Manufacturer's Data
Outgassing	TML = 0,40 %, RML = 0,28 %, CVCM = 0,01 %	ECSS-Q-70-02
Thermal Cycling	Pass	ECSS-Q-70-04

SPECIAL RECOMMENDATIONS

- This product can be provided with different viscosities and pot life.
- If more adhesion is required, NuSil silicone primers should be used: SP-120, SP-124 or SP-133.
- Cure time at 25 °C at 50 % RH:
  - Set up: 24 hours.
  - Full cure – 7 days.

C.14.5 D.C. 6-1104

PRODUCT

Type	One-part adhesive, sealant.
Chemical Composition	Silicone

Manufacturer N.V. Dow Corning
Parc Industriel, Zone C
B-7180 Senette
Belgium
Tel: +32-64-88 80 00
Fax: +32-64-88 84 01
Email: www.dowcorning.com

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	Very High
Lot Reproducibility	Excellent
Space Experience	Extensive

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	1,12	@ 25 °C
Hardness	38	Shore A
Tensile Strength	6 MPa	
Shelf Life	12 Months	
Thermal Expansion Coefficient	387×10^{-6} °C $^{-1}$	10 °C to 90 °C - TMA
Glass Transition Temperature	-117 °C	TMA
Specific Heat	1,56 J g^{-1} °C $^{-1}$	@ 0 °C

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	-65 °C to +150 °C.	Long Term
Outgassing	TML = 0,18 %, RML = 0,14 %, CVCM = 0,03 %	ECSS-Q-70-02
Thermal Cycling	Pass	ECSS-Q-70-04
Flammability	Pass (23,8 % O_2)	NASA-STD-6001
Toxicity/Offgassing	Pass	NASA-STD-6001

SPECIAL RECOMMENDATIONS

- Recommended cure: 7 days at room temperature.
- This product cures with air moisture and should not be used to bond large nonporous items.
- This product does not evolve corrosive products during cure.

C.14.6 D.C. 340

PRODUCT

Type	Heat-transfer compound.	
Chemical Composition	Silicone compound, filled	
Manufacturer	N.V. Dow Corning Parc Industriel, Zone C B-7180 Senette Belgium	Tel: +32-64-88 80 00 Fax: +32-64-88 84 01 Email: www.dowcorning.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Low
Lot Reproducibility	Good
Space Experience	Fair

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	2,3	Manufacturer's Data
Penetration (Worked)	260	ASTM D217
Thermal Conductivity	0,55 W m^{-1} $^{o}C^{-1}$	Manufacturer's Data

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Outgassing	TML = 0,33 %, RML =0,31 %, CVCM = 0,11 %	ECSS-Q-70-02

SPECIAL RECOMMENDATIONS

- This product is only tolerated in small quantities and shall be fully sealed around with an approved sealant to prevent creep.

C.14.7 Eccosorb AN

PRODUCT

Type	Flexible-foam microwave absorber.	
Chemical Composition	Loaded Polyurethane.	
Manufacturer	Emerson & Cumming Microwave Products Nijverheidsstraat 7, B-2260 Westerlo Belgium	Tel: +32 14 56 25 00 Fax: +32 14 56 25 01 Email: www.emersoncuming.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Medium
Lot Reproducibility	Variable
Space Experience	Fair

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Frequency Range	455 MHz	Manufacturer's Data
Mass per Unit Area	0,05 g cm $^{-2}$ to 1 g cm $^{-2}$	Manufacturer's Data

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	150 °C max.	Manufacturer's Data
Outgassing	TML = 1,30 %, RML =0,4 %, CVCM = 0,04 %	ECSS-Q-70-02 (after cleaning*)
Flammability	No ignition	NASA-STD-6001

SPECIAL RECOMMENDATIONS

* Cleaning process according to ESA PSS-01-727 compulsory.

C.14.8 Epikote 828 + Versamid 140

PRODUCT

Type	Two-part potting resin.	
Chemical Composition	Epoxy, aromatic amine cured.	
Manufacturer	Resolution Europe B.V. P.O. Box 606, 3190 AN Hoogvliet Rt The Netherlands	Tel: +31-10-431 7111 Fax: +31-10-431 4649 www.resins-versatics.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Very Low
Lot Reproducibility	Good
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	1,2	Manufacturer's Data
Viscosity (at 20 °C)	32 000 cps	Manufacturer's Data
Pot Life (at 25 °C)	8 hours	Manufacturer's Data
Tensile Strength	92 MPa	at 25 °C
Hardness	105	Rockwell M
Thermal Expansion Coefficient	51×10^{-6} °C^{-1}	-50 °C to +50 °C
Resistivity (volume)	2×10^{5} Ω cm	ASTM D257 at 23 °C
Dielectric Constant	3,9	at 23 °C 1 kHz
Loss Factor	0,02	at 23 °C 1 kHz

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	up to +130 °C	Manufacturer's Data
Outgassing	TML = 0,6 %, RML =0,3 %, CVCM = 0,02 %	ECSS-Q-70-02
Water absorption	0,67 %	24 hours in boiling water

SPECIAL RECOMMENDATIONS

- Cure 2 hours at 75 °C + 2 hours at 135 °C.
- Different fillers may be used, alumina, silica, glass microballoons to adjust the properties to the usage. These fillers must be carefully dried before mixing.
- Quality control test to ECSS-Q-70-02 recommended.

C.14.9 RTV 566

PRODUCT

Type	Two-part, adhesive, sealant, potting.	
Chemical Composition	Silicone (methyl, phenyl).	
Manufacturer	GE Silicones 260 Hudson River Rd, Waterford, New York 12188, USA	Tel: +1 518 237 3330 Email: www.gesilicones.com
Europe	GE Silicones Europe PO Box 117 NL-4600 Bergen op Zoom The Netherlands	Tel: +31 16429 3882 Fax: +31 16429 1819 Email: www.gesilicones.com
Europe	Europewide free telephone number: +800 4321 1000	

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	Very High
Lot Reproducibility	Good
Space Experience	Extensive

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	1,51	Manufacturer's Data
Viscosity	42 700 cps	Manufacturer's Data
Pot Life	30 min	
Tensile Strength	6,6 MPa	Manufacturer's Data
Tear Strength	7,9 N/mm	ASTM die B
Hardness	61 minimum	Shore A
Thermal Expansion Coefficient	200×10^{-6} °C $^{-1}$	
Thermal Conductivity	0,3 W m^{-1} °C $^{-1}$	
Resistivity (volume)	10^{13} Ω m	
Dielectric Constant	4,2	@ 60 Hz.
Loss Factor	0,006	@ 60 Hz.
Dielectric Strength	19,7 kV/mm	
Solar Absorbtance	0,65	ECSS-Q-70-09
Shelf Life	4 Months	Manufacturer's Data

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	-115 °C to 315 °C max.	Manufacturer's Data
Outgassing	TML = 0,27 %, RML =0,23 %, CVCM = 0,03 %	ECSS-Q-70-02
Thermal Cycling	Pass	ECSS-Q-70-04
Oxygen Index	23,6 % (0,5 mm thick)	ECSS-Q-70-21
Offgassing/Toxicity	Pass	NASA-STD-6001

SPECIAL RECOMMENDATIONS

- Recommended proportions: 100 pbw part A, 0,2 pbw part B. Thorough mixing is necessary.
- Cure 7 days at room temperature.
- For superior adhesion, use primer DC 1200 (Dow Corning) or SS 4155 (General Electric).
- Can be made electrically conductive with Cho-Bond 1029B: 250 pbw for 100 pbw RTV 566.
- RTV 567, a non-filled version of 566, is very difficult to procure in Europe.

C.14.10 Solithane 113/C 113-300 (100/73 pbw)

PRODUCT

Type	Two-part, soft, transparent, potting, conformal coating, bonding agent.
Chemical Composition	Polyurethane.

Manufacturer	Uniroyal Chemical Company Inc. (Crompton Corporation) 214 West Ruby Avenue, Gastonia NC 28053, USA	Tel: +1 704 864-3411 Fax: +1 704 864-4079 Email: bob_marionneaux@cromptoncorp.com www.cromptoncorp.com
(Previously)	Thiokol Chemical Corp. Trenton, NJ, USA	

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Low
Lot Reproducibility	Excellent
Space Experience	Extensive

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	1,073	
Viscosity	20 000 cps	@ 27 °C
Pot Life	3 hours	@ 27 °C
Hardness	55 to 60	
Tensile Strength	2,85 MPa	Manufacturer's Data
Glass Transition Temperature	-10 °C	Thermal expansion measurement
Dielectric Constant	4,2	@ 27 °C, 1kHz
Dissipation Factor	0,162	@ 27 °C, 1kHz
Dielectric Strength	14,9 kV/mm	@ 27 °C
Volume Resistivity	$2{,}5 \times 10^{12}$ Ω m	@ 27 °C
Thermal Expansion Coefficient	126×10^{-6} °C $^{-1}$	-55 °C to -15 °C
	238×10^{-6} °C $^{-1}$	0 °C to 70 °C

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	-60 °C to 120 °C max.	Long Term
Outgassing	TML = 0,37 %, RML = 0,21 %, CVCM = 0,01 %	ECSS-Q-70-02
Thermal Cycling	Pass	ECSS-Q-70-04
Ionizing Radiation	10 Mrad	Manufacturer's Data
Oxygen Index	24,7	ECSS-Q-70-21
Flammability	Fail (21 % O_2)	NASA-STD-6001

SPECIAL RECOMMENDATIONS

- Recommended cures: 7 days at room temperature, or 24 hours at 70 °C.
- Compositions other than the one detailed here are possible. Large amounts of experimental data on them exists and is available on demand.
- Not resistant to solar UV radiation.
- Owing to flammability risk, not to be used as a conformal coating in manned spacecraft unless a fire-resistant overcoating is used. Its acceptability as an adhesive will depend on the configuration.
- Possible use as a screw-locking compound.
- Possible use as an ink with suitable addition of pigments and solvents.
- Possible use as a conductive coating when filled with silver powder.
- Flammability highly dependent on coating thickness. Configuration flammability tests required.

C.14.11 Stycast 1090

PRODUCT

Type	Syntactic casting, potting, foam, 2-part.	
Chemical Composition	Epoxy.	
Manufacturer	Emerson & Cumming Nijverheidsstraat 7, B-2260 Westerlo Belgium	Tel: +32 14 56 25 00 Fax: +32 14 56 25 01 Email: www.emersoncuming.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Medium
Lot Reproducibility	Excellent
Space Experience	Extensive

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	0,88	Manufacturer's Data
Viscosity (before reaction)	30 000 cps	Manufacturer's Data
Pot Life	30 min	Manufacturer's Data
Hardness	82	Shore D
Compressive Modulus	25 MPa	Manufacturer's Data
Thermal Expansion Coefficient	40×10^{-6} °C $^{-1}$	Manufacturer's Data
Thermal Conductivity	0,167 W m^{-1} °C $^{-1}$	Manufacturer's Data
Dielectric Constant	3,9	@ 60 Hz.
Loss Factor	0,02	@ 60 Hz.
Dielectric Strength	14,8 kV/mm	Manufacturer's Data
Electrical Resistivity (volume)	10^{10} Ω m	Manufacturer's Data

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	-75 °C to +200 °C.	Manufacturer's Data
Outgassing	TML = 0,75 %, RML =0,35 %, CVCM = 0,06 %	ECSS-Q-70-02
Toxicity/Offgassing	Pass	NASA-STD-6001
Water Absorption	0,4 %	24 hours @ 25 °C
Flammability	Pass (23,8 % O_2)	NASA-STD-6001

SPECIAL RECOMMENDATIONS

- This product is filled with micro-balloons which shall be thoroughly dispersed at the time of use.
- The resin shall be deaerated (by vacuum exposure) before casting and also briefly after casting.
- Recommended cure is 24 hours at room temperature. Post cure at 60 °C can be applied to reduce outgassing.
- Post cure at 60 °C for 24 hours is compulsory when material is used as insert potting.
- Temperature range and cure schedule are dependent on the catalyst used. Both 9 and 11 have space approval, and experience in space use.
- Different catalysts will also affect other properties.

C.14.12 Stycast 2850FT

PRODUCT

Type	2-part potting resin.	
Chemical Composition	Epoxy.	
Manufacturer	Emerson & Cumming Nijverheidsstraat 7, B-2260 Westerlo Belgium	Tel: +32 14 56 25 00 Fax: +32 14 56 25 01 Email: www.emersoncuming.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Low
Lot Reproducibility	Excellent
Space Experience	Extensive

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	2,3	Manufacturer's Data
Viscosity (before reaction)	70 000 cps	Manufacturer's Data
Pot Life	45 min	Manufacturer's Data
Hardness	94	Shore D
Tensile Strength	60 MPa	Manufacturer's Data
Compressive Modulus	80 MPa	Manufacturer's Data
Thermal Expansion Coefficient	29×10^{-6} °C $^{-1}$	Manufacturer's Data
Thermal Conductivity	1,44 W m^{-1} °C^{-1}	@ 25 °C
Electrical Resistivity (volume)	$5 \times 10^{12}\ \Omega$ m	@ 25 °C
Dielectric Constant	6,5	@ 60 Hz.
Loss Factor	0,02	@ 60 Hz.
Dielectric Strength	15 kV/mm	Manufacturer's Data

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	Up to 205 °C	Manufacturer's Data
Outgassing	TML = 0,38 %, RML =0,24 %, CVCM = 0,01 %	ECSS-Q-70-02
Oxygen Index	29,8	ECSS-Q-70-21
Toxicity/Offgassing	Pass	NASA-STD-6001
Water Absorption	< 0,15 %	Over 7 days
Flammability	Pass (23,8 % O_2)	NASA-STD-6001

SPECIAL RECOMMENDATIONS

- Recommended cure is 24 hours at room temperature, plus 4 hours at 60 °C with catalyst 9.
- Other catalysts are available for the same resin, but these affect the properties: Catalyst 11 for high-temperature cure; Catalyst 24 LV for low viscosity. Some experience in space is available for both.
- A derived resin (2 850 KT) can be used for extremely high thermal conductance (4,2 W m^{-1} °C^{-1}).

C.14.13 Upilex foam

PRODUCT

Type	High temperature polyimide foam.	
Chemical Composition	Polyimide.	
Manufacturer	UBE Europe GmbH Immermannstrasse 65B, 40210 Düsseldorf, Germany	Tel: +49-211-17 88 30 Fax: +49-211-3 61 32 97 Email: www.ube.com

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	High
Lot Reproducibility	Good
Space Experience	Limited so far in Europe, high in Japan

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	Depends on grade, varies between 6 and 270 kg m^{-3}	Manufacturer's Data
Thickness	available between 5 and 100 mm	Manufacturer's Data
Thermal Conductivity	0,03 W m^{-1} °C^{-1}	Manufacturer's Data (BF301)
Melting point	None	Manufacturer's Data/ESA data
Dielectric Constant	1,08 ε_r 1 to 1 MHz	Manufacturer's Data (BF301)

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Outgassing	Pass, TML = 0,94 %, CVCM = 0,01 % e.g. ε_n for 20 μm = 0,63	ASTM E959 (BP201)

SPECIAL RECOMMENDATIONS

- High thermal endurance.
- Good radiation stability.
- The following four grades of that foam are available, desity depends on grade:

Grade	Density
BF301	6 to 14 kg m^{-3}
BP101	23 to 34 kg m^{-3}
BP021	135 kg m^{-3}
BP011	270 kg m^{-3}

- Average commercial size 300 × 300 mm.

C.15 Reinforced plastics

C.15.1 Cycom C69

PRODUCT

Type	Prepreg for laminates.	
Chemical Composition	Modified epoxy/High modulus carbon fibres.	
Manufacturer	Cytec Fiberite Ltd. Abenbury Way, Wrexham Ind. Est. Wrexham LL13 9UZ, Clwyd UK	Tel: +44 (0)1978 665 200 Fax: +44 (0)1978 665 222 Email: www.cytec.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	High
Lot Reproducibility	Very Good
Space Experience	Fair

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	1,63	
0° Tensile Strength	930 MPa	Manufacturer's Data
0° Tensile Modulus	195 GPa	Manufacturer's Data
90° Tensile Strength	33 MPa	Manufacturer's Data
90° Tensile Modulus	8,2 GPa	Manufacturer's Data
0° Interlaminar	70 MPa	(Span:Depth = 5:1) @ 21 °C
Thermal Expansion Coefficient	Long. $-0,7 \times 10^{-6}$ °C^{-1}	Manufacturer's Data
	Trans. 30×10^{-6} °C^{-1}	Manufacturer's Data

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	-130 °C to 180 °C.	Manufacturer's Data
Outgassing	TML = 0,6 %, RML =0,3 %, CVCM = 0,01 %	ECSS-Q-70-02
Humid Heat	750 hours – no sizeable effect	70 °C – 95 %

SPECIAL RECOMMENDATIONS

- Recommended cure is one step at 140 °C, pressure application (0,7 MPa), then 1 hour at 170 °C. Post cure: 3 hours at 180 °C.
- The same resin can accommodate High Strength (HT-S) or type AS carbon fibres.
- When continuous use temperature does not exceed 120 °C, another prepreg with similar properties, Carboform 87, can be used.

C.15.2 Makrolon GV 30

PRODUCT

Type	Thermoplastic, reinforced.	
Chemical Composition	Polycarbonate / Glass.	
Manufacturer	Bayer AG Kaiser-Wilhelm-Allee D-51373 Leverkusen Germany	Tel: Fax: www.bayer.com www.bayer.de

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Very Low
Lot Reproducibility	Unknown
Space Experience	Fair

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	1,42	Manufacturer's Data
Tensile Strength	90 MPa	Manufacturer's Data
Tensile Modulus	6 GPa	Manufacturer's Data
Impact Strength	40 kp cm cm^{-2}	DIN 53453
Thermal Conductivity	0,16 W m^{-1} $°C^{-1}$	Manufacturer's Data
Specific Heat	1,1 J g^{-1} $°C^{-1}$	Manufacturer's Data
Thermal Expansion Coefficient	30×10^{-6} $°C^{-1}$	Manufacturer's Data
Volume Resistivity	$> 10^{17}$ Ω m	Manufacturer's Data
Dielectric Constant	3,3	50 Hz
Dissipation Factor	0,000 9	50 Hz

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	Up to +145 °C	Long term
Outgassing	TML = 0,15 %, CVCM = 0,0 %	ECSS-Q-70-02
Ionizing Radiation	10 Mrad	Mechanical properties
Water Absorption	0,1 %	Manufacturers Data
Flammability	Results depend on material thickness and whether or not edges are protect.	NASA-STD-6001

SPECIAL RECOMMENDATIONS

-

C.16 Rubbers and elastomers

C.16.1 Eccoshield SV-R

PRODUCT

Type	Electrically-conductive rubber, gasket.	
Chemical Composition	Metal-filled Silicone.	
Manufacturer	Emerson & Cumming Nijverheidsstraat 7, B-2260 Westerlo Belgium	Tel: +32 14 56 25 00 Fax: +32 14 56 25 01 Email: www.emersoncuming.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	High
Lot Reproducibility	Good
Space Experience	Limited

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	3,5	@ 20 °C
Tensile Strength	1,06 MPa	Manufacturer's Data
Hardness	40	@ 50 °C
Thermal Conductivity	4,3 W m^{-1} °C^{-1}	Manufacturer's Data
Electrical Resistivity (volume)	10^{-5} Ωm	Manufacturer's Data

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	Up to 200 °C	Long term
Outgassing	TML = 0,3 %, RML =0,3 %, CVCM = 0,08 %	ECSS-Q-70-02

SPECIAL RECOMMENDATIONS

- Standard dimensions of sheets: 30,5 cm × 15,25 cm × (0,5, 1 or 1,5) mm.
- The adhesive proposed by the manufacturer is 'Eccoshield RVS', which is not qualified for space use and is thus forbidden.

C.16.2 VHDS

PRODUCT

Type	Elastomer, rubber, antivibration.	
Chemical Composition	Silicone.	
Manufacturer	Vibrachoc Parc d'activités de l'Eglantier CE 2804 Lisses, F- 91028 Evry France	Tel: +33 (0)1 69 91 50 00 Fax: +33 (0)1 64 97 50 28 Email: www.hutchinson.fr

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	-
Lot Reproducibility	Fair
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	1,1 to 1,4	Manufacturer's Data
Hardness	33 to 77	DIDC
Tensile Strength	6,5 MPa to 10,5 MPa	Manufacturer's Data
Strain at Failure	400 % to 800 %	Manufacturer's Data
Tear Strength	250 N cm^{-1} to 300 N cm^{-1}	Manufacturer's Data
Rebound	26 % to 30 %	Zwick @ Room temperature

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	-80 °C to 200 °C	Long term
Outgassing	TML = 0,2 %, RML =0,2 %, CVCM = 0,02 %	ECSS-Q-70-02

SPECIAL RECOMMENDATIONS

- Elastomer pieces to be used in space receive a special thermal treatment by the manufacturer to reduce their outgassing to the above value. This shall be specified at the time of procurement.

C.16.3 Viton B910

PRODUCT

Type	Elastomer, rubber.	
Chemical Composition	Vinylidene Fluoride, Hexafluoropropylene Copolymer.	
Manufacturer	DuPont Dow Elastomers GmbH DuPont Strasse 1 D-61352 Bad Homburg v.d.H. Germany	Tel: +49 (0) 61 72 87 13 55 Fax: +49 (0) 61 72 87 13 51 Email: www.dupont-dow.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Medium
Lot Reproducibility	Excellent
Space Experience	Extensive

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	1,85	Manufacturer's Data
Tensile Strength	15 MPa	Manufacturer's Data
Hardness	78	Manufacturer's Data
Modulus (100 %)	6,5 MPa	Manufacturer's Data
Electrical Resistivity	2×10^{11} Ω m	Manufacturer's Data

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	Cryogenic to 230 °C	Long term
	-25 °C to +230 °C	Long term dynamic
Outgassing	TML = 0,5 %, RML =0,3 %, CVCM = 0,02 %	ECSS-Q-70-02
Ionizing Radiation	10 Mrad	Dynamic application
Oxygen Index	50	ECSS-Q-70-21
Offgassing/Toxicity	Pass	NASA-STD-6001
Flammability	Pass (24,5 % O_2)	NASA-STD-6001

SPECIAL RECOMMENDATIONS

- There are many other grades of Viton with modified properties; e.g. GLT for extra-low temperature (-40 °C), VTR-4590 for high fluid resistance. Also, gasket manufacturers have their own designations.
- All Viton formulations tested so far pass ECSS-Q-70-02 and have an Oxygen Index similar to that cited above.

C.17 Thermoplastics (non-adhesive tapes and foils [MLI])

C.17.1 Sheldahl 146368

PRODUCT

Type	Thermal-control polymer film.
Chemical Composition	Fluorocarbon (FEP), Silver and Inconel coated.

Manufacturer Sheldahl
1150 Sheldahl Rd.
Northfield, MN 55057
USA
Tel: +1 507 663 8000
Fax: +1 507 663 8545
Email: sheldahl.info@sheldahl.com
www.sheldahl.com

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	High
Lot Reproducibility	Good
Space Experience	Limited

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	2,15	DuPont's Data
Thickness	50 μm	Manufacturer's Data
Standard Width	1 220 mm	Manufacturer's Data
Ultimate Tensile Strength	21 MPa	DuPont's Data, 298 K
Thermal Expansion Coefficient	83×10^{-6} °C^{-1}	DuPont's Data, 223 - 343 K
Thermal Conductivity	0,194 W m^{-1} °C^{-1}	DuPont's Data, 223 - 343 K
Specific Heat	1,17 J g^{-1} °C^{-1}	DuPont's Data, 223 - 343 K
Dielectric Strength (of FEP film)	160 kV/mm	DuPont's Data, 296 K
Surface Resistance	$> 10^{15}$ Ω	DuPont's Data, 296 K
Volume Resistivity	$> 10^{15}$ Ω m	DuPont's Data, 296 K, 38 % RH
Solar Absorbtance	0,10	Typical value only
Thermal Emittance	0,61	Typical value only

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	88 K to 423 K	DuPont's Data
Moisture Absorption	0,01 %	DuPont's Data

SPECIAL RECOMMENDATIONS

- The material is available in thicknesses of 12 μm, 25 μm, 50 μm and 125 μm.
- The material is available in widths up to 1 220 mm.
- The material is available with Y966 adhesive on the metallized side.
- The material is available with perforations.
- An ITO transparent, conductively-coated film is available. Consult the manufacturer for further details.

C.17.2 Sheldahl 146372

PRODUCT

Type	Thermal-control polymer film.
Chemical Composition	Fluorocarbon (FEP), aluminized.
Manufacturer	Sheldahl 1150 Sheldahl Rd. Northfield, MN 55057 USA
	Tel: +1 507 663 8000 Fax: +1 507 663 8545 Email: sheldahl.info@sheldahl.com www.sheldahl.com

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	High
Lot Reproducibility	Good
Space Experience	Limited

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	2,15	DuPont's Data
Thickness	50 μm	Manufacturer's Data
Standard Width	1 220 mm	Manufacturer's Data
Ultimate Tensile Strength	21 MPa	DuPont's Data, 298 K
Thermal Expansion Coefficient	83×10^{-6} °C^{-1}	DuPont's Data, 223 - 343 K
Thermal Conductivity	0,194 W m^{-1} °C^{-1}	DuPont's Data, 223 - 343 K
Specific Heat	1,17 J g^{-1} °C^{-1}	DuPont's Data, 223 - 343 K
Dielectric Strength (of FEP film)	160 kV/mm	DuPont's Data, 296 K
Surface Resistance	$> 10^{15}$ Ω	DuPont's Data, 296 K, 38 % RH
Volume Resistivity	$> 10^{15}$ Ω m	DuPont's Data, 296 K, 38 % RH
Solar Absorbtance	0,16	Typical value only
Thermal Emittance	0,47	Typical value only

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	88 K to 423 K	DuPont's Data
Moisture Absorption	0,01 %	DuPont's Data

SPECIAL RECOMMENDATIONS

- The material is available in thicknesses of 12 μm, 25 μm, 50 μm and 125 μm.
- The material is available in widths up to 1 220 mm.
- The material is available with Y966 adhesive on the metallized side.
- The material is available with perforations.
- An ITO transparent, conductively-coated film is available. Consult the manufacturer for further details.

C.17.3 Sheldahl 146633

PRODUCT

Type	Electrically-conductive thermal-control polymer film.
Chemical Composition	Polyimide Kapton HN, Aluminium and ITO coated.

Manufacturer Sheldahl
1150 Sheldahl Rd.
Northfield, MN 55057
USA
Tel: +1 507 663 8000
Fax: +1 507 663 8545
Email: sheldahl.info@sheldahl.com
www.sheldahl.com

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	High
Lot Reproducibility	Good
Space Experience	Limited

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	1,42	DuPont's Data
Thickness	50 µm	Manufacturer's Data
Standard Width	1 220 mm	Manufacturer's Data
Ultimate Tensile Strength	170 MPa	DuPont's Data, 298 K
Thermal Expansion Coefficient	20×10^{-6} °C^{-1}	DuPont's Data, 259 – 311 K
Thermal Conductivity	0,155 W m^{-1} °C^{-1}	DuPont's Data, 296 K
Specific Heat	1,09 J g^{-1} °C^{-1}	DuPont's Data, 296 K
Surface Resistance	< 1 000 Ω	Manufacturer's Data, 296 K, 2 VDC
Solar Absorbtance	0,50	Typical value only
Thermal Emittance	0,72	Typical value only

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	78 K to 473 K	DuPont's Data
Moisture Absorption	1,3 % @ 50 % RH, 296 K	DuPont's Data

SPECIAL RECOMMENDATIONS

- Normal use is for the external sheet of multilayer insulation (MLI). Suitable venting shall be provided.
- The material is available in thicknesses of 12 µm, 25 µm, 50 µm and 125 µm.
- The material is available in widths up to 1 220 mm.
- The front surface of ITO coating can withstand light handling and abrasion, but it should be protected against excessive handling. Consult the manufacturer for further details.

C.17.4 Sheldahl G423020

PRODUCT

Type	Thermal-control, electrically-conductive, polymer film.
Chemical Composition	Fluorocarbon (FEP), aluminized and ITO coated.

Manufacturer: Sheldahl
1150 Sheldahl Rd.
Northfield, MN 55057
USA
Tel: +1 507 663 8000
Fax: +1 507 663 8545
Email: sheldahl.info@sheldahl.com
www.sheldahl.com

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	High
Lot Reproducibility	Good
Space Experience	Limited

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	2,15	DuPont's Data
Thickness	50 μm	Manufacturer's Data
Standard Width	1 220 mm	Manufacturer's Data
Ultimate Tensile Strength	21 MPa	DuPont's Data, 298 K
Thermal Expansion Coefficient	83×10^{-6} °C^{-1}	DuPont's Data, 223 - 343 K
Thermal Conductivity	0,194 W m^{-1} °C^{-1}	DuPont's Data
Specific Heat	1,17 J g^{-1} °C^{-1}	DuPont's Data
Dielectric Strength (of FEP film)	160 kV/mm	DuPont's Data, 296 K
Surface Resistance	< 1 000 Ω	Manufacturer's Data, 2 VDC
Volume Resistivity	> 10^{15} Ω m	DuPont's Data, 296 K, 38 % RH
Solar Absorbtance	0,16	Typical value only
Thermal Emittance	0,47	Typical value only

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	88 K to 423 K	DuPont's Data
Moisture Absorption	0,01 %	DuPont's Data

SPECIAL RECOMMENDATIONS

- The material is available in thicknesses of 12 μm, 25 μm, 50 μm and 125 μm.
- The material is available in widths up to 1 220 mm.
- The material is available with Y966 adhesive on the metallized side.
- The material is available with perforations.
- The front surface of ITO coating can withstand light handling and abrasion, but it should be protected against excessive handling. Consult the manufacturer for further details.

C.17.5 Dunmore DE291

PRODUCT

Type	Thermal control polymer film.
Chemical Composition	Polyimide (Kapton HN), aluminized with protective coating on both sides.

Manufacturer	Dunmore Corporation	Tel: +1 215 781 8895
	Keystone Industrial Park, 2900 Wharton Rd.	Fax: +1 215 781 9293
	Bristol, PA 19007	Email:
	USA	www.dunmore.com

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	High
Lot Reproducibility	Good
Space Experience	Limited

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	1,42	Dupont Data
Thickness	7,6 μm	Manufacturer's Data
Tensile Strength	170 MPa	Dupont Data
Thermal Expansion Coefficient	20×10^{-6} °C $^{-1}$	Dupont Data
Thermal Conductivity	0,028 W m $^{-1}$ °C $^{-1}$	Dupont Data (@ 23 °C)
Specific Heat	1,09 J g^{-1} °C $^{-1}$	Dupont Data (@ 23 °C)
Volume Resistivity	10^{10} Ω m	Dupont Data (@ 23 °C)
Solar Absorptance	0,14	Manufacturer's Data
Normal Emittance	0,030	Manufacturer's Data
Standard Width	122 cm	Manufacturer's Data

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	-190 °C to +204 °C	Manufacturer's Data
Outgassing	TML = 0,64 %, CVCM = 0,03 %	ASTM E-595
Moisture Absorption	1,8 % @ 50 % RH	Dupont Data

SPECIAL RECOMMENDATIONS

- Complies with MIL-STD-810 Method 509 after 24 hours exposure to 5 % salt fog, and ASTM B-117.
- Intended primarily for use as inner layers on MLI thermal-control blankets for space vehicles where condensation can be a problem.
- This product is also available in 12,5 μm, 25 μm, 51 μm and 76 μm thicknesses.
- The full Dunmore part number shall be designated for precise material description.
- Perforated or embossed versions of the above-mentioned films are available, although film thickness can control selection. Patterns are to be specified at the time of ordering.
- These films can be aluminized and corrosion-resistant coated on one or both sides.
- Protective coating is a proprietary, fully-cured clear overcoat which protects the aluminized surface from moisture that causes corrosion.

C.17.6 Dunmore DM100

PRODUCT

Type	Aluminized Kapton HN, acrylic (Y966) pressure-sensitive release liner.	
Chemical Composition	Polyimide (Kapton HN), aluminized/Acrylic adhesive.	
Manufacturer	Dunmore Corporation Keystone Industrial Park, 2900 Wharton Rd. Bristol, PA 19007 USA	Tel: +1 215 781 8895 Fax: +1 215 781 9293 Email: www.dunmore.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Medium
Lot Reproducibility	Excellent
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	1,42	Dupont Data
Thickness	25 μm	Dupont Data
Tensile Strength	170 MPa	Dupont Data
Thermal Expansion Coefficient	20×10^{-6} °C $^{-1}$	Dupont Data(-14 °C to 38 °C)
Thermal Conductivity	0,015 5 W m $^{-1}$ °C $^{-1}$	Dupont Data (@ 23 °C)
Specific Heat	1,09 J g^{-1} °C $^{-1}$	Dupont Data (@ 23 °C)
Volume Resistivity	$1,5 \times 10^{15}$ Ω m	Dupont Data (@ 38 % RH)
Solar Absorptance	0,15 (aluminized side)	Manufacturer's Data
Normal Emittance	0,60	Typical value only
Shelf Life	12 Months (from manufacture date)	@ Room Temperature
Standard Width	2,54 cm	Manufacturer's Data

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	-40 °C to +160 °C	Manufacturer's Data
Outgassing	TML = 0,70 % CVCM = 0,04 %	3M data / NASA 1061 and ASTM E-595
Moisture Absorption	1,8 % @ 50 % RH	Dupont Data (@ 23 °C)
Adhesion	55,8 g mm width	Manufacturer's Data / ASTM D3330
Toxicity/Offgassing	Pass	NASA NHB 8060.1A

SPECIAL RECOMMENDATIONS

- All tapes are a standard length of 105 ft ± 5 %. (Maximum length available is ca. 160ft.).
- All tapes are wound on a (3±0,5) inch diameter core.
- Recommended shelf life is a period of one year after date of manufacture, when tape has been stored properly at normal room temperature.
- Kapton HN / Y966 acrylic pressure-sensitive tapes can be perforated.
- This product is also available with Dunmore's "corrosion-resistant coating".
- "Y966" acrylic P/S release liner can also be applied to the metallized surface to provide second-surface mirror capabilities, if desired.
- "Y966" acrylic P/S release liner can also be applied to 51 μm, 76 μm and 125 μm thick films.
- The full Dunmore part number shall be designated for precise material description.
- "Y966" high-temperature acrylic tapes are primarily used when high-temperature performance and excellent bond strength are required.
- Solar absorptance value is measured on the aluminized side only.

C.17.7 Dunmore DE 028

PRODUCT

Type	Thermoplastic film.	
Chemical Composition	Polyethylene Terephthalate / PETP, aluminized.	
Manufacturer	Dunmore Corporation Keystone Industrial Park, 2900 Wharton Rd. Bristol, PA 19007 USA	Tel: +1 215 781 8895 Fax: +1 215 781 9293 Email: www.dunmore.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Low to Medium
Lot Reproducibility	Good
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	1,4	Dupont Data
Thickness	6,3 μm	Manufacturer's Data
Tensile Strength	210 MPa	Dupont Data (@ 25 °C)
Thermal Expansion Coefficient	30×10^{-6} °C^{-1}	Dupont Data
Thermal Conductivity	0,61 W m^{-1} °C^{-1}	Dupont Data
Specific Heat	1,3 J g^{-1} °C^{-1}	Dupont Data
Surface Resistance	10^{16} Ω	Dupont Data (@ 25 °C, 38 % RH)
Volume Resistivity	10^{14} Ω m	Dupont Data (@ 25 °C)
Solar Absorptance	0,07	ASTM E-424 Method A
Normal Emittance	0,020	Manufacturer's Data
Standard Width	142 cm	Manufacturer's Data

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	-180 °C to +150 °C	Dupont Data
Outgassing	TML = 0,29 %, CVCM = 0,00 %	ASTM E-595
Moisture Absorption	Less than 0,8 % @ 23 °C	ASTM D-570-63
Toxicity/Offgassing	Pass	NASA NHB 8060.1A

SPECIAL RECOMMENDATIONS

- Normal use is for internal sheets of multilayer insulation (MLI). Use depends on blanket type and requirement. Suitable venting should be considered for blanket use. Can also be used in crinkled form for cryogenic insulation.
- This product is available with vacuum-deposited aluminium on one or both sides.
- Widths up to 1 574 mm available on special request.
- The full Dunmore part number shall be designated for precise material description.
- This product can be perforated, embossed or crinkled if desired. Patterns are to be specified at the time of ordering.
- Also available in 12,5 μm, 25 μm, 51 μm and 76 μm thicknesses.
- Normal emittance value is measured on the aluminized surface.

C.17.8 Dunmore DE 320

PRODUCT

Type	Thermal Control Polymer Film.
Chemical Composition	Polyimide (Kapton HN), aluminized.

Manufacturer Dunmore Corporation
Keystone Industrial Park, 2900 Wharton Rd.
Bristol, PA 19007
USA
Tel: +1 215 781 8895
Fax: +1 215 781 9293
Email:
www.dunmore.com

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	High
Lot Reproducibility	Good
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	1,42	Dupont Data
Thickness	25 μm	Dupont / Manufacturer's Data
Tensile Strength	170 MPa	Dupont Data (@ 25 °C)
Thermal Expansion Coefficient	20×10^{-6} °C $^{-1}$	Dupont Data (-14 °C to 38 °C)
Thermal Conductivity	0,155 W m $^{-1}$ °C $^{-1}$	Dupont Data (@ 23 °C)
Specific Heat	1,09 J g^{-1} °C $^{-1}$	Dupont Data (@ 23 °C)
Volume Resistivity	$1{,}5 \times 10^{15}$ Ω m	Dupont Data
Solar Absorptance	0,14 (aluminized surface)	Manufacturer's Data
Normal Emittance:		
Aluminized Surface	0,02	Manufacturer's Data
Film Side	0,70	Manufacturer's Data
Standard Width	112 cm	Manufacturer's Data

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	-190 °C to +204 °C	Average exposure range
Outgassing	TML = 0,21 %, CVCM = 0,00 %	ASTM E-595
Moisture Absorption	1,8 % @ 23 °C and 50 % RH	Dupont Data

SPECIAL RECOMMENDATIONS

- Normal use is for external sheet on multilayer insulation (MLI). Suitable venting shall be provided, where applicable.
- This product is also available in 7,6 μm, 12,6 μm, 51,76 μm and 125 μm thicknesses.
- The 7,6 μm and 12,6 μm grades are available in widths up to 1 270 mm; 25 μm to 125 μm grades in widths up to 1 524 mm.
- The full Dunmore part number shall be designated for precise material description.
- Perforated or embossed versions of the above-mentioned films are available. Patterns are to be specified at the time of ordering (film thickness can determine selection).
- These products can also be aluminized on both sides, if desired.
- Solar absorptance value is measured on the aluminized surface.

C.17.9 Dunmore TM05564

PRODUCT

Type	Thermal Control Plastic Film
Chemical Composition	Fluorocarbon (FEP-Type C), aluminized

Manufacturer Dunmore Corporation
Keystone Industrial Park, 2900 Wharton Rd.
Bristol, PA 19007
USA
Tel: +1 215 781 8895
Fax: +1 215 781 9293
Email:
www.dunmore.com

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	High
Lot Reproducibility	Good
Space Experience	Limited

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	2,15	Dupont Data
Thickness	50 μm	Manufacturer's Data
Tensile Strength	21 MPa	Manufacturer's Data
Thermal Expansion Coefficient	$89{,}3 \times 10^{-6}$ °C $^{-1}$	Dupont Data (-50 °C to +70 °C)
Thermal Conductivity	0,194 W m $^{-1}$ °C $^{-1}$	Dupont Data
Specific Heat	1,17 J g^{-1} °C $^{-1}$	Dupont Data (-50 °C to +70 °C)
Dielectric Strength	160 kV mm $^{-1}$ (of FEP Film)	Dupont Data (@ 23 °C)
Surface Resistance	$>10^{15}$ Ω	Dupont Data / ASTM D257-61
Volume Resistivity	$>10^{15}$ Ω m	Dupont Data (@ 23 °C and 38 % RH)
Solar Absorptance:		
Aluminized Surface	0,07	ASTM E424 Method A
Film Side	0,10	ASTM E424 Method A
Normal Emittance:		
Aluminized Surface	0,02	ASTM E408 Method A
Film Side	0,67	ASTM E408 Method A
Standard Width	122 cm	Manufacturer's Data

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	-175 °C to +150 °C. Max. Operating Temp. 205 °C	Dupont Data
Outgassing	TML = 0,21 %, CVCM = 0,00 %	ASTM E-595
Moisture Absorption	1,3 % @ 50 % RH	Dupont Data (@ 23 °C)

SPECIAL RECOMMENDATIONS

- Normal use is for external sheet on multilayer insulation (MLI). Suitable venting is recommended.
- This product is also available in 8 μm, 12 μm, 75 μm and 125 μm thicknesses.
- Available in a range of widths, depending on film thickness.
- Also available in two(2)-side-treated form for VDAL bonding, designated as Type C-20; to be specified at time of purchase.
- The full Dunmore part number shall be designated for precise material description.
- Perforated versions of the above-mentioned films are available. Patterns are to be specified at the time of ordering.

C.17.10 Gude space D96

PRODUCT

Type	Lacing tape, flat braid.
Chemical Composition	Dacron fibres (impregnated).

Manufacturer	Gudebrod Inc.	Tel: +1 610 327 4050
	274 Shoemaker Rd.	Fax: +1 610 327 4588
	Pottstown PA 19464	Email: sales@gudebrod.com
	USA	www.gudebrod.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Low
Lot Reproducibility	Good
Space Experience	Extensive

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Strength	18 N to 600 N	Manufacturer's Data
Thickness	0,12 mm to 0,4 mm	Manufacturer's Data
Width	0,9 mm to 5 mm	Manufacturer's Data

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	-73 °C to +177 °C	Manufacturer's Data
Outgassing	TML 0,5 %, RML = 0,4 %, CVCM = 0,04 %	ECSS-Q-70-02 (after cleaning – see below)
Flammability	Burns (21 % O_2)	NASA-STD-6001

SPECIAL RECOMMENDATIONS

- Cleaning according to ESA PSS-01-732 is compulsory.
- Non-impregnated version exists under the name Super Gude Space PT and this does not require cleaning.
- If used as individual ties on non-inflammable insulation, this material can be acceptable from the point of view of flammability. Configuration shall be discussed beforehand.

C.17.11 Kapton H, HN

PRODUCT

Type	Plastic film.	
Chemical Composition	Polyimide.	
Manufacturer	DuPont Corporate Information Center Barley Mill Plaza, P10 Wilmington, DE 19880-0010 USA	Tel: +1 302 774 1000 Fax: Email: info@dupont.com www.dupont.com
(Europe)	DuPont de Nemours (Luxembourg) S.A. Contern Luxembourg Grand Duché de Luxembourg	Tel: +352 3666 5674 Fax: +352 3666 5015 Email: www.dupont.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Medium
Lot Reproducibility	Excellent
Space Experience	Extensive

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value (25 µm film @ 25 °C)	Remarks
Specific Gravity	1,42	ASTM D1505-90
Tensile Strength	170 MPa	ASTM D882-64T
Tensile Modulus	3 GPa	ASTM D882-64T
Initial Tear Strength	20 kg/mm	ASTM D1004-61
Thermal Expansion Coefficient	20×10^{-6} °C $^{-1}$	ASTM D696-44
Thermal Conductivity	0,155 W m $^{-1}$ °C $^{-1}$	Manufacturer's Data
Specific Heat	1,09 J g^{-1} °C $^{-1}$	Manufacturer's Data
Dielectric Constant	3,5	ASTM D150-64T (1 kHz)
Loss Factor	0,003	ASTM D150-64T
Volume Resistivity	10^{16} Ω m	ASTM D257-61
Dielectric Strength	276 kV/mm	ASTM D149-64
Solar Absorptance	0,35	ECSS-Q-70-09 (Al. back)
Hemispherical Emittance	0,61	ECSS-Q-70-09

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	-269 °C to +300 °C	Long term
Outgassing	TML = 1,3 %, RML = 0,2 %, CVCM = 0,02 %	ECSS-Q-70-02
Ionizing Radiation	5 000 Mrad	Manufacturer's Data
UV/Particle Effects	$\Delta\alpha_s = 0{,}12$	7 years/OTS spec. 75µm film
Moisture Absorption	1,3 %	50 % RH, 23,5 °C
Oxygen Index	32,7	ECSS-Q-70-21
Toxicity/Offgassing	Pass	NASA-STD-6001
Flammability	Self-extinguishing (23,8 % O_2)	NASA-STD-6001

SPECIAL RECOMMENDATIONS

- Water desorption corresponds to a geometrical shrinkage and a change in hemispherical emittance.
- Available thickness range from 7,6 µm to 127 µm; max. width: 1 320 mm. Thinner film can be available soon.
- Flammability depends on film thickness.
- Etched by oxygen atoms in low Earth orbit at a rate of approx. 3×10^{-24} cm^3/atom.

C.17.12 Makrofol N

PRODUCT

Type	Plastic film.	
Chemical Composition	Polycarbonate.	
Manufacturer	Bayer AG	Tel:
	Kaiser Wilhelm Allee	Fax:
	D-51373 Leverkusen	www.bayer.com
	Germany	www.bayer.de

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Low
Lot Reproducibility	Fair
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	1,2	Manufacturer's Data
Tensile Strength	850 MPa	Manufacturer's Data
Surface Resistivity	10^{13} Ω □	4 days @ 80 % RH
Dielectric Constant	3,1	50 Hz
Dissipation Factor	0,002 5	50 Hz
Dielectric Strength	170 kV/mm	4 days @ 80 % RH

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	Up to +140 °C	Manufacturer's Data
Outgassing	TML= 1,4 %, RML= 0,35 %, CVCM= 0,01 %	ECSS-Q-70-02
Ionizing Radiation	10 Mrad	Mechanical properties
Water Absorption	0,5 %	24 hours immersion
Flammability	Fail (21 % O_2)	NASA-STD-6001

SPECIAL RECOMMENDATIONS

- Post cure 24 hour at 80 °C recommended.
- Other grades of Makrofol exist, of which the space qualification is incomplete.

C.17.13 Hostaform C9021

PRODUCT

Type	Thermoplastic.	
Chemical Composition	Acetal copolymer.	
Manufacturer	Ticona GmbH	Tel: +49 (0)69 30 58 47 32
	Industriepark Höchst	Fax: +49 (0)69 30 58 47 35
	D-65926 Frankfurt	Email:
	Germany	www.ticona-eu.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Low
Lot Reproducibility	Good
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	1,41	Manufacturer's Data, ISO 1183
Tensile Strength	64 MPa	Manufacturer's Data, ISO 527
Tensile Modulus	2,85 GPa	Manufacturer's Data, ISO 527
Hardness	85	Shore D
Impact Strength	6,5 kPa	Notched, Manufacturer's Data, ISO 179 1eU
Thermal Conductivity	0,31 W m^{-1} $^{o}C^{-1}$	Manufacturer's Data
Specific Heat	1,47 J g^{-1} $^{o}C^{-1}$	Manufacturer's Data
Thermal Expansion Coefficient	110×10^{-6} $^{o}C^{-1}$	Manufacturer's Data
Volume Resistivity	10^{13} Ω m	Manufacturer's Data
Dielectric Constant	4	50 Hz, 20 ^{o}C
Dissipation Factor	0,002	Manufacturer's Data @ 100Hz
Dielectric Strength	> 70 kV/mm	Manufacturer's Data

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	-40 ^{o}C to +100 ^{o}C	Long term
Outgassing	TML = 0,4 %, RML = 0,2 %, CVCM = 0,02 %	ECSS-Q-70-02
Ionizing Radiation	3 Mrad	Mechanical properties
Water Absorption	0,65 %	Immersion
Oxygen Index	> 15	Manufacturer's Data
Flammability	Burnt	NASA-STD-6001

SPECIAL RECOMMENDATIONS

- This material can be reinforced with glass fibres (e.g. Hostaform C9021 GV1/30) or carbon fibres.

C.17.14 PETP (Mylar, Melinex, Terphane, ...)

PRODUCT

Type	Thermoplastic film.
Chemical Composition	Polyethylene Terephthalate.
Manufacturer	Several (DuPont USA, ICI UK, La Cellophane France, ...)

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Very Low
Lot Reproducibility	Excellent
Space Experience	Extensive

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	1,4	
Tensile Strength	210 MPa	
Tear Strength	0,787 kg/mm	
Folding Endurance	> 100 000	ASTM D2176
Thermal Expansion Coefficient	30×10^{-6} °C $^{-1}$	
Thermal Conductivity	0,61 W m $^{-1}$ °C $^{-1}$	
Specific Heat	1,3 J g^{-1} °C $^{-1}$	
Volume Resistivity	10^{16} Ω m	
Dielectric Constant	3,2	50 Hz, 25 °C
Dissipation Factor	0,002	50 Hz, 25 °C
Dielectric Strength	280 kV/mm	
Refractive Index	1,64	

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	-180 °C to +150 °C	Long term
Outgassing	TML = 0,3 %, RML = 0,1 %, CVCM = 0,03 %	ECSS-Q-70-02
Oxygen Index	31	ECSS-Q-70-21
Ionizing Radiation	10 Mrad	Mechanical properties
UV Radiation	Unstable	
Water Absorption	0,6 %	Immersion
Toxicity/Offgassing	Pass	NASA-STD-6001
Flammability	Burnt	NASA-STD-6001

SPECIAL RECOMMENDATIONS

- Aluminized films (1 or 2 faces) exist in the trade and are extensively used in space programmes since Al protects the plastic against destruction by unfiltered UV light.
- Sizes available are down to 3μm thick and up to 300 cm wide, depending on the vendor.
- Flammability depends on thickness and configuration.
- PETP is etched by atomic oxygen in low Earth orbit at a rate of approx. $3{,}4 \times 10^{-24}$ cm^3/atom.

C.17.15 PTFE (Teflon, Halon, Fluon, Hostaflon)

PRODUCT

Type	Thermoplastic.
Chemical Composition	Polytetrafluoroethylene.
Manufacturer	Several (e.g. DuPont USA, Hoechst D, Montecatini I)

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Medium
Lot Reproducibility	Excellent
Space Experience	Excellent

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	2,15	
Hardness	55	Shore D
Tensile Strength	25 MPa	
Tensile Modulus	420 MPa	
Thermal Conductivity	0,25 W m $^{-1}$ °C $^{-1}$	
Specific Heat	1 J g^{-1} °C $^{-1}$	40 °C approx.
Thermal Expansion Coefficient	100×10^{-6} °C $^{-1}$	
Volume Resistivity	$> 10^{16}$ Ω m	
Dielectric Constant	2,1	60 Hz
Dissipation Factor	0,000 2	60 Hz
Dielectric Strength	18,9 kV/mm	ASTM D149

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	Cryogenic to +260 °C	Long term
Outgassing	TML = 0,05 %, RML = 0,02 %, CVCM= 0,0 %	ECSS-Q-70-02
Oxygen Index	95	ECSS-Q-70-21
Ionizing Radiation	0,1 Mrad	Threshold damage under vacuum.
Toxicity/Offgassing	Pass	NASA-STD-6001
Flammability	Pass (30 % O_2)	NASA-STD-6001

SPECIAL RECOMMENDATIONS

- PTFE has a strong tendency to creep and is unable to sustain constant high load. Creep can occur during thermal cycling.
- All PTFE-insulated wires and cables tested up to now have been found acceptable for space use.
- PTFE is rather sensitive to radiation and its use outside a spacecraft, particularly in high-radiation zones (Van Allen belts, geostationary orbit) requires special testing.
- Volume change associated with a change of crystallinity occurs between approx. 22 °C to 27 °C.

C.17.16 Sheldahl 146401 (previously G401500)

PRODUCT

Type	Thermal-control plastic film.
Chemical Composition	Fluorocarbon (FEP), Silver and Inconel Coated.

Manufacturer Sheldahl
1150 Sheldahl Rd.
Northfield, MN 55057
USA
Tel: +1 507 663 8000
Fax: +1 507 663 8545
Email: sheldahl.info@sheldahl.com
www.sheldahl.com

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	High
Lot Reproducibility	Good
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	2,15	DuPont's Data
Thickness	127 μm	Manufacturer's Data
Tensile Strength	21 MPa	DuPont's Data
Thermal Expansion Coefficient	83×10^{-6} °C^{-1}	DuPont's Data, -70 °C to +70 °C
Thermal Conductivity	0,194 W m^{-1} °C^{-1}	DuPont's Data, -70 °C to +70 °C
Specific Heat	1,17 J g^{-1} °C^{-1}	DuPont's Data, -70 °C to +70 °C
Dielectric Strength (of FEP film)	138 kV/mm (25 °C, 60Hz)	DuPont's Data, -70 °C to +70 °C
Surface Resistance	10^{16} Ω	ASTM D257-61
Volume Resistivity	10^{16} Ω m	ASTM D257-61
Solar Absorbtance	0,08	ECSS-Q-70-09
Thermal Emittance	0,78	ECSS-Q-70-09
Standard Width	122 cm	Manufacturer's Data

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	-185 °C to +150 °C	Long term
Outgassing	RML = 0,05 %, CVCM = 0,01 %	ECSS-Q-70-02
UV/Particle Radiation	$\Delta\alpha_s = 0{,}18$	OTS Spec. 7 years.
Moisture Absorption	< 0,01 %	DuPont's Data
Oxygen Index	95	ECSS-Q-70-21
Toxicity/Offgassing	Pass	NASA-STD-6001

SPECIAL RECOMMENDATIONS

- Thinner films of the same material exist: 50μm 146374, 25μm 146400, 251μm 146435 (G404000) and also thicker. Other widths than standard can be obtained.
- Similar films with incorporated adhesive exist, either acrylic pressure sensitive, suitable for space, or silicones of which the suitability is doubtful. It is anyway preferable to fasten the film on a separately applied double-sided adhesive tape in order to avoid crazing in the metal layer due to the peeling off of the liner.
- The nomenclature of the Sheldahl company can be confusing so it is essential that each type of film used is identified exactly.
- Depending on the adhesive used, Sheldahl silvered FEP can be damaged by thermal cycling according to ECSS-Q-70-04.
- Perforated versions of the film are available.
- Protective coverlay is available.
- Electrically conductive versions are also made by Sheldahl (front layer ITO deposit). However, conductivity is not maintained during wide temperature band of thermal cycling and ITO layer is degraded by long-term exposure to RH > 60 %.

C.17.17 Sheldahl 146383 (previously G400900)

PRODUCT

Type	Thermal-control plastic film.	
Chemical Composition	Fluorocarbon (FEP), aluminized.	
Manufacturer	Sheldahl 1150 Sheldahl Rd. Northfield, MN 55057 USA	Tel: +1 507 663 8000 Fax: +1 507 663 8545 Email: sheldahl.info@sheldahl.com www.sheldahl.com

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	High
Lot Reproducibility	Good
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	2,15	DuPont's Data
Thickness	127 μm	Manufacturer's Data
Tensile Strength	21 MPa	DuPont's Data
Thermal Expansion Coefficient	83×10^{-6} °C^{-1}	-70 °C to +70 °C
Thermal Conductivity	0,194 W m^{-1} °C^{-1}	DuPont's Data
Specific Heat	1,17 J g^{-1} °C^{-1}	DuPont's Data
Dielectric Strength (of FEP film)	138 kV/mm	25 °C, 60Hz
Surface Resistance	10^{16} Ω	ASTM D257-61
Volume Resistivity	10^{16} Ω m	ASTM D257-61
Solar Absorbtance	0,13	ECSS-Q-70-09
Thermal Emittance	0,77	ECSS-Q-70-09
Standard Width	122 cm	Manufacturer's Data

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	-185 °C to +150 °C	Long term
Outgassing	RML = 0,05 % CVCM = 0,01 %	ECSS-Q-70-02
UV/Particle Radiation	$\Delta\alpha_s = 0{,}18$	OTS Spec. 7 years.
Moisture Absorption	< 0,01 %	DuPont's Data
Oxygen Index	95	ECSS-Q-70-21
Toxicity/Offgassing	Pass	NASA-STD-6001

SPECIAL RECOMMENDATIONS

- Thinner films of the same material exist: 50μm 146377 (G.400500), 25μm 146416 (G402000) and also thicker; 254μm 146434 (G403800). Other widths than standard can be obtained.
- Similar films with incorporated adhesive exist, either acrylic pressure sensitive, suitable for space, or silicones of which the suitability is doubtful. It is anyway preferable to fasten the film on a separately applied double-sided adhesive tape in order to avoid crazing in the metal layer due to the peeling off of the liner.
- The nomenclature of the Sheldahl company can be confusing so it is essential that each type of film used is identified exactly.
- Depending on the adhesive used, Sheldahl aluminized FEP can be damaged by thermal cycling according to ECSS-Q-70-04.
- Perforated versions of the film are available. Perforation is recommended for space use.
- Electrically conductive versions are also made by Sheldahl (front layer ITO deposit). However, conductivity is not maintained during wide temperature band of thermal cycling and ITO layer is degraded by long-term exposure to RH > 60 %.
- Protective overlay is available.

C.17.18 Sheldahl 146631 (previously G425120)

PRODUCT

Type	Thermal-control, electrically-conductive plastic film.
Chemical Composition	Polyimide (Kapton H), ITO/aluminized.

Manufacturer	Sheldahl 1150 Sheldahl Rd. Northfield, MN 55057 USA	Tel: +1 507 663 8000 Fax: +1 507 663 8545 Email: sheldahl.info@sheldahl.com www.sheldahl.com

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	High
Lot Reproducibility	Unknown
Space Experience	Limited

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	1,42	DuPont’s Data
Thickness	25 μm	Manufacturer’s Data
Tensile Strength	170 MPa	DuPont’s Data
Thermal Expansion Coefficient	20×10^{-6} °C^{-1}	DuPont’s Data
Thermal Conductivity	0,155 W m^{-1} °C^{-1}	DuPont’s Data
Specific Heat	1,09 J g^{-1} °C^{-1}	DuPont’s Data
Surface Resistivity	200 kΩ □	@ 1V
Solar Absorbtance	0,35	ECSS-Q-70-09
Thermal Emittance	0,61	ECSS-Q-70-09
Standard Width	122 cm	Manufacturer’s Data

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	-250 °C to +285 °C	Manufacturer’s Data (continuous exposure)

SPECIAL RECOMMENDATIONS

- Other thicknesses of the same material exist: 12,5μm to 127μm.
- Normal use is as external sheet of multilayer insulation. Suitable venting shall be provided.
- The nomenclature of the Sheldahl company can be confusing so it is essential that each type of film used is identified exactly.
- Front-face ITO layer is degraded by long-term exposure to RH > 60 %.
- The ITO layer protects the film from atomic oxygen etching if not damaged.
- The ITO layer is stabilized against handling damage by a thermal treatment in air at 250 °C.

C.17.19 Super Gude space PT

PRODUCT

Type	Lacing tape, flat braid.	
Chemical Composition	Dacron (Polyethylene Terephthalate).	
Manufacturer	Gudebrod Inc. 274 Shoemaker Rd. Pottstown PA 19464 USA	Tel: +1 610 327 4050 Fax: +1 610 327 4588 Email: sales@gudebrod.com www.gudebrod.com

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	Low
Lot Reproducibility	Good
Space Experience	Fair

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Strength	54 N to 360 N	Manufacturer's Data
Thickness	0,17 mm to 0,37 mm	Manufacturer's Data
Width	1,2 mm to 2,7 mm	Manufacturer's Data

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	-75 °C to +180 °C	Manufacturer's Data
Outgassing	TML 0,35 %, RML = 0,19 %, CVCM = 0,02 %	ECSS-Q-70-02
Ionizing Radiation	> 10 Mrad	
Flammability	Fail (23,8 % O_2)	NASA-STD-6001

SPECIAL RECOMMENDATIONS

-

C.17.20 Upilex RN

PRODUCT

Type	Thermal control film	
Chemical Composition	Polyimide	
Manufacturer	UBE Europe GmbH Immermannstrasse 65 B D-40210 Düsseldorf Germany	Tel: +49 (0)211 178830 Fax: +49 (0)211 3613297 Email: www.ube.com

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	High
Lot Reproducibility	Good
Space Experience	Limited so far in Europe, high in Japan

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	1,4 g cm^{-3}	Manufacturer's Data
Thickness	various, with and without coatings (e.g. Al and ITO) 12,5 μm , 20 μm, 25 μm, 50 μm, 75 μm , 125 μm	
Tensile Strength	330 MPa	Manufacturer's Data (25 μm)
Elongation	160 %	Manufacturer's Data (25 μm)
Tensile Modulus	4 000 MPa	Manufacturer's Data (25 μm)
Melting Point	None	Manufacturer's Data/ESA data

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Remarks
Outgassing	Pass, TML = 0,76 %, RML = 0,10 %, CVCM = 0,00 %	ECSS-Q-70-02
Solar Absortance	Depends on the thickness and coatings e.g. α_s for 25 μm = 0,32	Manufacturer's Data (25 μm)
Thermal Emmittance	Depends on the thickness and coatings e.g. ε_n for 25 μm = 0,65	Manufacturer's Data (25 μm)

SPECIAL RECOMMENDATIONS

- High thermal endurance.
- Good radiation stability.
- Material tends to absorb less humidity than Kapton HN.
- Several film thicknesses are available that comprise metallisations and anti-static coatings.
- Rolls are available in the following widths:

UPILEX Vacuum Deposited Aluminum Films and UPILEX Bare Films

7,5 micron	R	480mm
12,5 micron	R	1016mm
25 micron	R	1016mm
50 micron	R	1016mm

UPILEX ITO Coated Films

25 micron	R	508mm
50 micron	R	508mm

C.17.21 UPILEX S

PRODUCT

Type	Thermal control film	
Chemical Composition	Polyimide	
Manufacturer	UBE Europe GmbH Immermannstrasse 65 B D-40210 Düsseldorf Germany	Tel: +49 (0)211 178830 Fax: +49 (0)211 3613297 Email: www.ube.com

EXPERIENCE and AVAILABILITY

Development Status	Special Commercial Product
Cost Range	High
Lot Reproducibility	Good
Space Experience	Limited so far in Europe, high in Japan

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	1,47 g cm^{-3}	Manufacturer's Data
Thickness	Various, with and without coatings (e.g. Al and ITO) 7,5 μm, 12,5 μm, 20 μm, 25 μm, 50 μm, 75 μm, 125 μm	Manufacturer's Data
Tensile Strength	520 MPa	Manufacturer's Data (25 μm)
Elongation	42 %	Manufacturer's Data (25 μm)
Tensile Modulus	9120 MPa	Manufacturer's Data (25 μm)
Thermal Expansion	12 ppm/K for 20 °C/200 °C	Manufacturer's Data (25 μm)
Thermal Conductivity	0,29 W m^{-1} $°C^{-1}$	Manufacturer's Data (25 μm)
Melting Point	None	Manufacturer's Data (25 μm)
Special Heat	1,13 kJ/kg K	Manufacturer's Data (25 μm)
Volume Resistivity	10^{15} Ω m	Manufacturer's Data (25 μm)

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Remarks
Outgassing	Pass, TML = 0,76 %, RML = 0,07 %, CVCM = 0,00 %	ECSS-Q-70-02
Solar Absorbtance	Depends on the thickness and coatings e.g. α_s for 20 μm = 0,39	ECSS-Q-70-09
Thermal Emittance	Depends on the thickness and coatings e.g. α_s for 20 μm = 0,63	ECSS-Q-70-09

SPECIAL RECOMMENDATIONS

- Very high thermal endurance, outperforms other commercial polyimide films in several aspects.
- Good radiation stability at higher temperature.
- Material tends to absorb less humidity than Kapton HN.
- Several film thicknesses are available that comprise metallisations and anti-static coatings.
- Rolls are available in the following widths:

  UPILEX Vacuum Deposited Aluminum Films and UPILEX Bare Films

7,5 micron	S	480mm
12,5 micron	S	1016mm
25 micron	S	1016mm
50 micron	S	1016mm

  UPILEX ITO Coated Films

25 micron	S	508mm
50 micron	S	508mm

- There are also other grades of Polyimides available like Upilex VT that is used for heat bondings of FPC (Flexible Printed Circuits) or ceramic laminates.
  Very high thermal endurance, outperforms other commercial polyimide films in several aspects.

C.18 Thermoset plastics

C.18.1 Rexolite 1422

PRODUCT

Type	Thermosetting resin laminate.
Chemical Composition	Polystyrene, cross-linked.

Manufacturer	C-LEC Plastic Inc. 6800 New State Road Philadelphia, PA 19104 USA	Tel: +1 215 708 7731 Fax: +1 215 708 7728 Email: rexolite@AOL.COM www.rexolite.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	–
Lot Reproducibility	Excellent
Space Experience	Good

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	1,05	ASTM D792
Tensile Strength	62 MPa	Manufacturer's Data
Flexural Strength	80 MPa	Manufacturer's Data
Thermal Expansion Coefficient	70×10^{-6} °C^{-1}	Manufacturer's Data
Thermal Conductivity	0,146 W m^{-1} °C^{-1}	Manufacturer's Data
Volume Resistivity	> 10^{14} Ω m	Manufacturer's Data
Dielectric Constant	2,53	Manufacturer's Data
Dissipation Factor	0,000 12	@ 1 MHz
Dielectric Strength	19,7 kV/mm	3,18 mm sample.

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Temperature Range	-60 °C to 100 °C	Manufacturer's Data
Temperature Range	TML = 0,2 %, RML = 0,2 %, CVCM = 0,01 %	ECSS-Q-70-02
Water Absorption	<0,05 %	Manufacturer's Data
Ionizing Radiation	1 000 Mrad	Manufacturer's Data

SPECIAL RECOMMENDATIONS

- The material is sold as rods, sheets and copper-clad laminates.
- A glass mat reinforced version of the same product is Rexolite 2200, this should be used for cases where high mechanical stresses are present.

C.19 Miscellaneous non-metallic materials

C.19.1 Sigraflex foil

PRODUCT

Type	Heat-transfer foil.
Chemical Composition	Expanded natural graphite.

Manufacturer SGL Carbon Group
SGL Technik GmbH, Industrial Sealing
Werner-von-Siemens-Strasse 18
D-86405 Meitingen
Germany

Tel: +49 08271 83 2276
Fax: +49 08271 83 2419
Email: norbert.berg@sglcarbon.de
www.sglcarbon.com

EXPERIENCE and AVAILABILITY

Development Status	Commercial Product
Cost Range	Low
Lot Reproducibility	Unknown
Space Experience	Fair

GENERAL PROPERTIES (Physical, Mechanical, Thermal, Electrical, Optical)

Nature	Typical Value	Remarks
Specific Gravity	0,7 to 1,3	Manufacturer's Data, @ 20 °C
Thermal Expansion Coefficient:		
In-plane	~ 1×10^{-6} °C^{-1} (specific gravity 1,2)	Manufacturer's Data, @ 20 °C
Perpendicular	~ 30×10^{-6} °C^{-1} (specific gravity 1,2)	Manufacturer's Data, @ 20 °C
Emissivity	0,47	Manufacturer's Data, @ 20 °C
Volume Resistivity		
In-plane	~ 8×10^{-6} Ω m	Manufacturer's Data, @ 20 °C
Perpendicular	~ 650×10^{-6} Ω m	Manufacturer's Data, @ 20 °C

PROPERTIES RELEVANT TO SPACE USE

Nature	Typical Value	Type of Test
Outgassing	TML = 0,92 %, RML = 0,88 %, CVCM = 0,01 %	ECSS-Q-70-02

SPECIAL RECOMMENDATIONS

This material can be a source of stains and particle contamination.

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Annex D (informative)

Index to data sheets

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Annex E (informative)

Considerations for general corrosion protection and electrical bonding

3xxx, 4xxx, 5xxx and 6xxx Aluminium Alloys

- General corrosion protection
  Chemical conversion coatings (CCC) can be always used with or without paint.
- Electrical bonds
  - Permanent
    - Class H and S bonds*:
      CCC may be used, providing that the resistance requirements are met.
    - Class R bonds*:
      CCC may be used, providing that the resistance requirement is met and the bond is hermetically sealed.
  - Removable
    - Class H and S bonds:
      CCC may be used, providing that the resistance requirements are met.
    - Class R bonds:
      Metallic (i.e. Nickel) plating shall be used.

2xxx and 7xxx Aluminium Alloys

- General corrosion protection
  - CCC shall be used with paint, or
  - Anodizing, or
  - Metallic (i.e. Nickel) plating.
- Electrical bonds
  - Permanent
    - Class H and S bonds:
      CCC shall be used, providing that the resistance requirements are met.
    - Class R bonds:
      CCC shall be used, providing that the resistance requirement is met and the bond is hermetically sealed.
  - Removable
    - Class H and S bonds:
      CCC shall be used, providing that the resistance requirements are met.
    - Class R bonds:
      Metallic (i.e. Nickel) plating shall be used.

* Class S bond: resistance less then 1,0 Ω
Class H bond: resistance less then 0,1 Ω
Class R bond: resistance less then 0,0025 Ω

Bibliography

Informative references to the extent specified in the text are cited at appropriate places and listed hereafter.

ECSS-E-30	Space engineering — Mechanical
ECSS-E-30-04 [3)]	Space engineering — Structural material handbook
ECSS-E-30-05 [3)]	Space engineering — Adhesive bonding handbook
ECSS-E-30-06 [3)]	Space engineering — Insert design handbook
ECSS-E-30-07 [3)]	Space engineering — Guidelines for threaded fasteners
ESA-RD-01	Outgassing and thermo-optical data for spacecraft materials
ESA-RD-02	Flammability and offgassing data for spacecraft materials
ESA SP-1173 (1994)	Evaluation of conformal coatings for future spacecraft applications
NASA RP-1124	Outgassing data for selecting spacecraft materials
NASA MSFC-STD-3029	Guidelines for the selection of metallic materials for stress corrosion cracking resistance in sodium chloride environments
NASA-STD-6001	Flammability, odor, offgassing and compatibility requirements and test procedures for materials in environments that support combustion NOTE Previously published as NASA NHB 8060.1.
NASA MAPTIS	Materials and processes technical information system

3) To be published.

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ECSS Document Improvement Proposal

1. Document I.D.	**2. Document date**	**3. Document title**
ECSS-Q-70-71A rev. 1	18 June 2004	Data for selection of space materials and processes
4. Recommended improvement (identify clauses, subclauses and include modified text or graphic, attach pages as necessary)		
5. Reason for recommendation		
6. Originator of recommendation		
Name:	Organization:	
Address:	Phone: Fax: e-mail:	**7. Date of submission:**
8. Send to ECSS Secretariat		
Name: W. Kriedte ESA-TOS/QR	Address: ESTEC, P.O. Box 299 2200 AG Noordwijk The Netherlands	Phone: +31-71-565-3952 Fax: +31-71-565-6839 e-mail: Werner.Kriedte@esa.int

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