ECSS-E-ST-32-08C Rev.1
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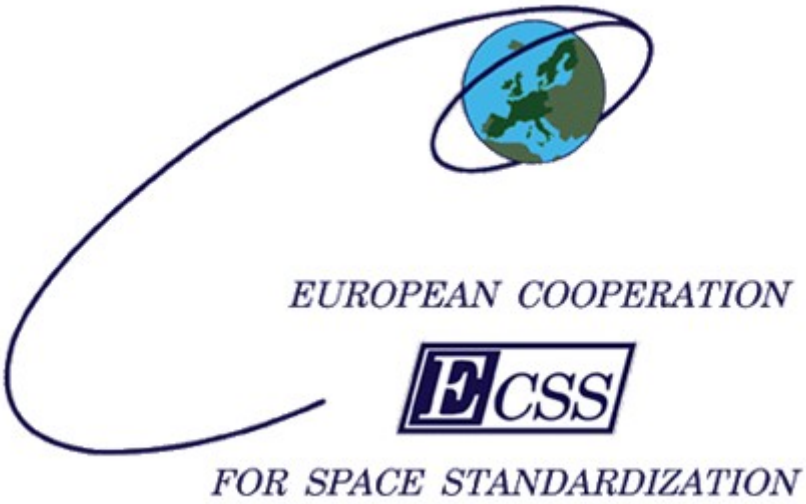

Space engineering

Materials

ECSS Secretariat
ESA-ESTEC
Requirements & Standards Division
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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.

This Standard has been prepared by the ECSS Executive Secretariat Working Group, reviewed by the ECSS Executive Secretariat and approved by the ECSS Technical Authority.

Disclaimer

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Change log

ECSS-E-30 Part 8A 25 April 2000	First issue
ECSS-E-30 Part 8B	Never issued
ECSS-E-ST-32-08C 31 July 2008	Second issue
ECSS-E-ST-32-08C Rev.1 15 October 2014	Second issue, Revision 1 Changes with respect to ECSS-E-ST-32-08C (31 July 2008) are the following and identified in the document with revision tracking: Main changes are: Alignment of the three Standards ECSS-E-ST-32-08C Rev.1, ECSS-Q-ST-70C Rev.1 and ECSS-Q-ST-70-71C. Implementation of TA approved Change requests. Added requirements: 4.1a; 4.2.11a; 4.6.3b and c. Modified requirements: 4.2.4a; 4.2.5b; 4.2.7b and f; 4.2.9a; 4.2.10a; 4.3.1a; 4.3.2a; 4.3.3a; 4.3.4a; 4.3.5b; 4.3.8a and b; 4.3.9a; 4.4.1b NOTE 2 and 3 added; 4.5.2b, c, e and f; 4.6.1a; 4.6.2c and f; 4.6.4b, e, f and h; 4.6.5d and e; 4.7b. Deleted requirements: 4.4.2a; 4.4.3a. Editorial corrections: Interleaved Notes in 4.5.1a, 4,5.2a moved after last require list item

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1
Scope

ECSS-E-ST-32-08 specifies the mechanical engineering requirements for materials. This Standard also encompasses the mechanical effects of the natural and induced environments to which materials used for space applications can be subjected.

This Standard specifies requirements for the establishment of the mechanical and physical properties of the materials to be used for space applications, and the verification of these requirements.

Verification includes destructive and non-destructive test methods. Quality assurance requirements for materials (e.g. procurement and control) are covered by ECSS-Q-ST-70.
This standard may be tailored for the specific characteristics and constrains of a space project in conformance with ECSS-S-ST-00.

2
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 revision 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 more recent editions of the normative documents indicated below. For undated references, the latest edition of the publication referred to applies.

ECSS-S-ST-00-01	ECSS system - Glossary of terms
ECSS-E-ST-32	Space engineering - Structural
ECSS-Q-ST-70	Space product assurance - Materials, mechanical parts and processes
ECSS-Q-ST-70-37	Space product assurance - Determination of the susceptibility of metals to stress-corrosion cracking
ECSS-Q-ST-70-71	Space product assurance - Material, processes and their data selection
EN 4179:2005	Aerospace series - Qualification and approval of personnel for non-destructive testing

3
Terms, definitions and abbreviated terms

3.1 Terms and definitions from other standards

a. For the purpose of this Standard, the terms and definitions from ECSS-S-ST-00-01 and ECSS-E-ST-32 apply, in particular for the followings:

1. A-basis design allowable (A-value)
2. B-basis design allowable (B-value)
3. corrosion

3.2 Terms specific to the present standard

3.2.1 composite sandwich construction

panels composed of a lightweight core material, such as honeycomb, foamed plastic, and so forth, to which two relatively thin, dense, high-strength or high stiffness faces or skins are adhered

3.2.2 material design allowable

material property that has been determined from test data on a probability basis and has been chosen to assure a high degree of confidence in the integrity of the completed structure

3.2.3 micro-yield

applied force to produce a residual strain of 1×10^{-6} mm/m along the tensile or compression loading direction

3.2.4 polymer

high molecular weight organic compound, natural or synthetic, with a structure that can be represented by a repeated small unit, the mer

NOTE E.g. polyethylene, rubber, and cellulose.

3.3 Abbreviated terms

For the purpose of this Standard, the abbreviated terms from ECSS-S-ST-00-01 and the following apply:

Abbreviation	Meaning
ASTM	American Society for Testing Materials
CFRP	carbon fibre reinforced plastic
CMC	ceramic matrix composites
CME	coefficient of moisture expansion
CTE	coefficient of thermal expansion
DRD	document requirements definition
EB	electron beam
EN	European Standard
K_{ic}	plane strain critical stress intensity factor
K_{iscc}	plane strain critical stress intensity factor for a specific environment
LEO	low Earth orbit
MIG	metal inert gas
MMC	metal matrix composite
NDE	non-destructive evaluation
NDI	non-destructive inspection
NDT	non-destructive test
PTFE	polytetrafluoroethylene
SCC	stress-corrosion cracking
STS	space transportation system
TIG	tungsten inert gas
UD	uni-directional
UV	ultra violet

3.4 Nomenclature

The following nomenclature applies throughout this document:

a. The word “shall” is used in this Standard to express requirements. All the requirements are expressed with the word “shall”.

b. The word “should” is used in this Standard to express recommendations. All the recommendations are expressed with the word “should”.

NOTE It is expected that, during tailoring, recommendations in this document are either converted into requirements or tailored out.

c. The words “may” and “need not” are used in this Standard to express positive and negative permissions, respectively. All the positive permissions are expressed with the word “may”. All the negative permissions are expressed with the words “need not”.

d. The word “can” is used in this Standard to express capabilities or possibilities, and therefore, if not accompanied by one of the previous words, it implies descriptive text.

NOTE In ECSS “may” and “can” have completely different meanings: “may” is normative (permission), and “can” is descriptive.

e. The present and past tenses are used in this Standard to express statements of fact, and therefore they imply descriptive text.

4
Requirements

4.1 General

a. The supplier shall perform the review of materials for structures to be used in space at Materials, Mechanical Parts and Processes Control Board (MPCB) in conformance with requirements from clause 4.2.3 of ECSS-Q-ST-70.

NOTE This clause covers only structural subjects affecting materials for use in space projects.

4.2 Functionality

4.2.1 Strength

a. The material strength shall be established for the worst combination of mechanical and thermal effects expected during its lifetime.

NOTE The strength of a material is highly dependent on the direction as well as on the sign of the applied load, e.g. axial tensile, transverse compressive, and others. Structural subjects are covered in ECSS-E-ST-32.

4.2.2 Elastic modulus

a. For composites, the specified elastic modulus shall be verified by test on representative samples, in tension and in compression directions.

NOTE 1 For metallic and alloy, it can be based on values certified by the manufacturer.

NOTE 2 The elastic modulus defined as the ratio between the uniaxial stress and the strain (e.g. Young's modulus, compressive modulus, shear modulus) is for metals and alloys weakly dependant on heat-treatment and orientation. However, for fibre reinforced materials, the elastic modulus depends on the fibre orientation.

4.2.3 Fatigue

a. For all components subject to alternating stresses, it shall be demonstrated that the degradation of material properties over the complete mission remains within the specified limits.

NOTE Fatigue fracture can form in components which are subjected to alternating stresses. These stresses can exist far below the allowed static strength of the material. For fracture control, see ECSS-E-ST-32-01.

4.2.4 Fracture toughness

a. For homogeneous materials the K_{ic} or K_{iscc} shall be measured according to procedures approved by the customer at MPCB.

b. Metallic materials intended for use in corrosive surface environments shall be tested for fracture.

NOTE The fracture toughness is a measure of the damage tolerance of a material containing initial flaws or cracks. The fracture toughness in metallic materials is described by the plain strain value of the critical stress intensity factor. The fracture toughness depends on the environment. For fracture control, see ECSS-E-ST-32-01.

4.2.5 Creep

a. A risk analysis shall be performed to assess the risk of creeping.

b. If analysis specified in 4.2.5a confirms that creep can occur, the creep testing campaign to be performed shall be agreed with the customer at MPCB.

NOTE Creep is a time-dependant deformation of a material under an applied load. It usually occurs at elevated temperature, although some materials creep at room temperature. If permitted to continue indefinitely, creep terminates in rupture. Extrapolations from simple to complex stress-temperature time conditions are difficult.

4.2.6 Micro-yielding

a. A risk analysis shall be performed to assess the risk of micro-yielding.

NOTE Micro-yielding can have an impact in the dimensional stability.

b. When the analysis specified in 4.2.6a predicts that micro-yielding can occur in an element, the dimensional stability of the element shall be verified by testing.

NOTE 1 Some materials can exhibit residual strain after mechanical loading.

NOTE 2 In general the most severe mechanical loading occurs during launch.

4.2.7 Coefficient of thermal expansion and coefficient of moisture expansion

a. Thermal mismatch between structural members shall not generate stresses in the specified operational temperature range for the item higher that the specified allowable limit.

b. Each project shall define the values of the coefficients of thermal expansion (CTE) and of moisture expansion (CME) for high stability structural application.

c. The CTE of composite materials used in high stability structural applications shall be determined by means of dry test coupons under dry test conditions after release of all potential moisture.

d. For hygroscopic materials used in high stability structural applications, the CME shall be determined by test.

e. A sensitivity analysis shall be performed for all composite materials used in high stability structural applications.

f. The sensitivity analysis specified in 4.2.7e shall include the inaccuracies inherent to the manufacturing process agreed with the customer at MPCB.

NOTE The difference in thermal or moisture expansion between, members of a construction or between the constituents of a composite or a coated material can induce large stresses or strains and can eventually lead to failures.

4.2.8 Corrosion fatigue

a. For all materials in contact with chemicals and experiencing an alternating loading it shall be demonstrated that the degradation of properties over the complete mission is below the specified limits.

NOTE Corrosion fatigue indicates crack formation and propagation caused by the effect of alternating loading in the presence of a corrosion process. Because of the time dependence of corrosion, the number of cycles before failure depends on the frequency of the loading. Since chemical attack takes time to take effect, its influence is greater as the frequency is reduced. No metals or alloys demonstrate complete resistance to corrosion fatigue.

4.2.9 Hydrogen embrittlement

a. For hydrogen embrittlement the requirements of clause 5.1.19 of ECSS-Q-ST-70 and requirements 4.2.6b, 4.2.7b and 4.3.10c from ECSS-Q-ST-70-71 shall apply.

NOTE Metals can be embrittled by absorbed hydrogen to such a degree that the application of the smallest tensile stress can cause the formation of cracking. The following are possible sources of hydrogen:

- thermal dissociation of water in metallurgical processes (e.g. casting and welding);
- decomposition of gases;
- pickling;
- corrosion;
- galvanic processes (e.g. plating);
- ion bombardment.

4.2.10 Mechanical contact surface effects

a. For mechanical contact surface effects the requirements of clause 5.1.16 of ECSS-Q-ST-70 shall apply.

NOTE For very clean surfaces strong adhesion occurs at the regions of real contact, a part of which can result from to cold-welding.

4.2.11 Hydrogen, Oxygen and Nitrogen uptake

a. For Hydrogen, Oxygen and Nitrogen uptake of Titanium and Titanium alloys requirement 4.2.5a of the ECSS-Q-ST-70-71 shall apply.

4.3 Interfaces

4.3.1 General

a. For interfaces, requirements from clause 4.3.9.1 of ECSS-Q-ST-70-71 shall apply.

4.3.2 Anodizing

a. For anodizing, requirements from clause 4.3.9.2 of ECSS-Q-ST-70-71 shall apply.

4.3.3 Chemical conversion

a. For chemical conversion, requirements from clause 4.3.9.3 of ECSS-Q-ST-70-71 shall apply.

4.3.4 Metallic coatings (overlay and diffusion)

a. For metallic coatings, requirements from the clause 4.3.10 of ECSS-Q-ST-70-71 shall apply.

4.3.5 Hard coatings

a. The combination of a hard coating and a soft substrate should be avoided.

NOTE The reason is that the coating can break under pressure. Hard coatings are used to improve the abrasive properties of the surface.

b. For hydrogen embrittlement the requirements of clause 5.1.19 of ECSS-Q-ST-70 and requirements 4.2.6b, 4.2.7b and 4.3.10c from ECSS-Q-ST-70-71 shall apply.

NOTE Hard coatings reduce the ability to cold weld.

4.3.6 Thermal barriers

a. The thermal barrier coating shall not spall.

NOTE Thermal barrier coatings are used to retard component heating due to high heat fluxes. Thermal barrier coatings are ceramic overlay coatings, where the thickness is approximately 0,4 mm.

b. Spalling of the thermal barrier coating shall be verified by inspection.

NOTE Thermal coatings are applied to selected regions only.

c. Effectiveness of the thermal barrier shall be demonstrated by test.

d. The mechanical properties of the substrate shall not be irreversibly changed due to the application of the thermal barrier.

NOTE The coating process can modify the condition of the substrate.

4.3.7 Moisture barriers

a. Moisture barrier coatings shall be impermeable to moisture and organic species.

b. Effectiveness of the moisture barrier shall be demonstrated by test.

NOTE Coatings can be used to prevent moisture absorption or desorption of dimensionally stable

structures or to prevent the release of organic volatiles which can affect the performances of some equipment.

4.3.8 Coatings on CFRP

a. Coating material shall be selected in accordance with procedures and tables approved by the customer at MPCB.

NOTE For the selection of materials, see ECSS-Q-ST-70-71.

b. In case 4.3.8a is not met, the coating shall be:

1. bonded to the CFRP substrate using a non-conductive adhesive, or

2. applied to a resin-rich CFRP surface.

NOTE Coatings on CFRP are used as moisture stoppers, as protection against atomic oxygen or for adjusting optical properties. In most cases these coatings are metallic. See Table 5-1 of ECSS-Q-ST-70 for dissimilar material contacts using CFPR.

4.3.9 Organic coatings as paint

a. For organic coatings as paintings, requirements from the clause 4.2.13 of ECSS-Q-ST-70-71 shall apply.

4.4 Joining (mechanical fastening)

4.4.1 General

a. Galvanic corrosion due to contact between dissimilar materials shall be precluded.

b. To avoid damage, tapped screws shall not be used with composite materials.

NOTE 1 The function of the joint elements is to connect two or more parts together in order to transfer loads between them. The selection of fasteners is governed by panel thickness, loading, environmental exposure, disassembly and accessibility requirements.

NOTE 2 For bolted joints, see guidelines in clause 4.3.15.1 of ECSS-Q-ST-70-71.

NOTE 3 For riveted joints, see guidelines in clause 4.3.15.1 of ECSS-Q-ST-70-71.

4.4.2 Bolted joints

a. << deleted, see Note 2 in 4.4.1b. >>

4.4.3 Riveted joints

a. << deleted, see Note 3 in 4.4.1b. >>

4.4.4 Inserts

a. All inserts shall have their surfaces protected against corrosion.

NOTE An insert system consists of a removable threaded fastener and a fixture embedded into the honeycomb structure using a potting mass.

4.5 Design

4.5.1 Metallic design allowables

a. The determination of A-basis and B-basis design allowables shall include all factors relating to the processing and environmental effects, including:

1. Form.
2. Size, thickness range.
3. Manufacturing process.
4. Grain direction.
5. Temper condition
6. Test direction.

NOTE 1 Example for requirement 4.5.1a.1: bar, sheet and plate.

NOTE 2 Example for requirement 4.5.1a.3: extrusion, rolling and forging.

NOTE 3 Example for requirement 4.5.1a.4: longitudinal, longitudinal transverse and short transverse.

NOTE 4 Example for requirement 4.5.1a.5: heat treatment and cold working.

4.5.2 Composite design allowables

a. The determination of the allowables for composite materials shall include the following factors:

1. The level of control of the manufacturing process.
2. Deviation of lamina properties from the nominal values.
3. Failure modes in either the fibre, the matrix or the fibre to matrix interface.
4. The size of residual strains due to the curing process.
5. Effects of combined loading.

6. Scatter in compression strength properties.

7. Susceptibility to environmental effects.

8. Dependence of the non-linearity on the specimen, load conditions and test environment.

NOTE 1 For requirement 4.5.2a.1: composite materials are created at the same time as the finished component, and therefore the control of the manufacturing process has a very strong influence on the final material properties.

NOTE 2 For requirement 4.5.2a.2: lamina properties exhibit large differences in directional properties, as well as small strain to failure with limited yielding or plastic behaviour.

NOTE 3 Example for Requirement 4.5.2a.7: humidity, temperature, radiation and cycling loading.

b. The supplier shall justify his choice of composite material for approval by the customer at MPCB, including the provision of the technical information on which the selection was based.

c. The supplier shall justify the allowables to use, in any pre-dimensioning phase, for approval by the customer at MPCB.

d. The composite material shall be specified, including both qualification and lot control and indicates the test methods and the accept or reject criteria including the minimum acceptable mechanical and physical properties.

e. The autoclave and other manufacturing process critical parameters as specified in the requirement 7.6.3c from the ECSS-Q-ST-70 shall be validated by test before manufacturing the final items.

f. The autoclave and other manufacturing process critical parameters as specified in the requirement 7.6.3c from the ECSS-Q-ST-70 used to manufacture the samples used for allowable determination shall be the same as the ones used to manufacture the final items.

g. The test plan shall include:

1. The statistical basis for deriving the allowables.

2. Explanation on how any interpolation to allow for different lay up configurations is established.

h. The test methods used to establish the material engineering data shall be identified.

i. The requirement for any configuration related component testing, in support of the generation of design allowables, shall be established by the supplier.

4.6 Verification

4.6.1 Metallic materials

a. Properties of metallic material shall be obtained using test methods approved by the customer at MPCB.

NOTE 1 Metallic material properties are determined by the composition, including levels of impurities, by the forming technique (e.g. forging, plate, bar, cast), heat-treatment, level of mechanical working and surface finish. Material properties can be obtained from material suppliers.

NOTE 2 Material properties can change with the environment (e.g. temperature).

b. Metallic material properties shall be determined on samples or coupons having the same composition, including level of impurities, forming technique, heat-treatment, level of mechanical working and surface finish, as the parts used for the construction of the flight hardware.

4.6.2 Composite materials - laminates

a. The overall performance characteristics of the laminate shall be predicted using laminated plate theory.

b. Test coupons made with the proposed raw materials shall be evaluated to establish and verify the actual properties for a given lay-up or joint design before it can be used to manufacture a part.

c. The analysis specified in 4.6.2a shall be verified by comparing multi-directional test data obtained with the behaviour predicted by theoretical models.

NOTE Material properties for unidirectional composite materials under room temperature and standard conditions can be obtained from material suppliers.

d. The designer shall analyse the change of the properties of the laminate throughout its life cycle at each critical point.

NOTE Environmental effects can degrade mechanical properties to varying degrees, depending on the fibre-resin system.

e. Composite materials shall be characterized by elementary tests on samples.

f. Except for near net shape manufacturing techniques, the production laminate shall be fabricated to a greater size than the final one, then cut down to the final dimensions, and the excess pieces be used for quality control testing.

NOTE Example of near net shape manufacturing techniques is RTM “Resin Transfer Moulding”.

4.6.3 Test methods on metals

a. The following test shall be performed to characterized the metallic material:

1. tension tests,
2. compression tests,
3. hardness tests,
4. creep tests,
5. fracture toughness tests,
6. fatigue tests,
7. fatigue crack growth tests, and
8. stress corrosion tests.

b. Mechanical tests shall be performed in conformance with requirements from clause 5 of ECSS-Q-ST-70-45.

c. Stress-corrosion tests shall be performed in conformance with requirements from clause 5 of ECSS-Q-ST-70-37.

4.6.4 Test methods on composites

a. Properties for each kind of ply shall be measured.

NOTE Supplier data sheets can be used for pre-design purposes.

b. For unidirectional ply, the properties shall be measured in the direction parallel to the fibres as well as in the direction transverse to the fibres.

NOTE 1 Direction parallel to the fibres is called the 0º direction. Direction transverse to the fibres is called the 90º direction.

NOTE 2 For fibre reinforced polymer composed of unidirectional layers, the most common properties for design purposes are:

- tensile strength of the UD plies, in the 0º and 90º directions;
- elastic modulus of the UD plies, in the 0º and 90º directions;
- interlaminar shear strength;
- CTE (Coefficient of Thermal Expansion) of the UD plies, 0º direction and 90º direction;
- CME (Coefficient of Moisture Absorption) of thud plies, 0º direction and 90º direction;
- moisture content;
- poisson's ratio;
- compression strength of the UD plies, 0º direction and 90º direction;
- in plane shear strength.

c. The validation of the composite material shall be performed by measuring properties on test pieces having the hardware lay-up configuration at ambient under nominal conditions and under worst case conditions expected during the life.

d. Measurements shall be performed in the main direction of reinforcement and in the transverse direction.

NOTE 1 The most common properties to be assessed to validate a new generated composite material are:

- tensile strength;
- elastic modulus;
- compression strength;
- CTE (Coefficient of Thermal Expansion);
- CME (Coefficient of Moisture Absorption);
- through thickness thermal conductivity;
- in plane shear strength.

NOTE 2 Where the material is quasi-isotropic, measurements in the second direction can be useful to check the isotropicity of the material.

e. For compression and shear strength, the test methods shall be agreed with the customer at MPCB.

NOTE Well established but different test methods can be used, to obtain compression and shear strength. As a result, values can differ and therefore it is important to take care when establishing or comparing engineering values obtained from different test methods.

f. The procurement specification used for all supplied material used for the manufacture the test pieces shall be provided or presented to the customer for approval at MPCB.

g. The test pieces shall be prepared using the processes intended for the flight application.

h. The supplier shall apply a traceability system for the test pieces in conformance with requirements from clause 5.2.5 of ECSS-Q-ST-20.

i. The following tests shall be performed as a minimum:

1. volume fibre, porosity and ply thickness measurements;
2. in the case of thermoset resin matrix: degree of cure and glass transition temperature measurements;
3. non-destructive inspection (NDI).

NOTE The test methods used are determined in relation to the kind of material to be tested and the property to be measured and can be taken from the standards listed below:

- ECSS Standards where available;

- EN (European Standards), ASTM, other space agencies or national standards of the member states;
- supplier's procedures or other national standard.

4.6.5 Non-destructive inspection

a. The supplier shall develop an NDI programme, defining the frequency, extent and methods of inspection for interpretation in requisite design development and maintenance plans.

NOTE No single NDI technique is capable of detecting all types of defects in a given material. Consequently, techniques are complementary. Equipment configuration, operator competence and conditions of use, significantly affect the sensitivity of a particular technique.

b. Personnel conducting NDI shall be certified in accordance with EN4179:2005.

c. Inspection standards shall be established.

NOTE 1 The aim of this standard is that decisions to accept, rework or scrap parts are based on the probable effect that a given flaw has on the service life or product safety.

NOTE 2 NDI techniques for defect detection and measurement and types of defects can be found in ECSS-E-HB-32-20.

d. The customer and supplier shall agree in advance the design of the reference standard and to the procedure for using it at MPCB.

NOTE Most non-destructive inspections rely on a reference standard to define acceptance limits or to estimate flaw sizes.

e. The NDI plan shall be available for review by the customer upon request at MPCB.

4.7 Data exchange

a. The supplier shall establish that all known factors influencing the deterioration of the candidate materials have been evaluated in the design.

b. Materials data shall be made available to the customer according to a format approved by the customer at MPCB.

Bibliography

ECSS-S-ST-00	ECSS system - Description, implementation and general requirements
ECSS-E-ST-32	Space engineering - Structural general requirements
ECSS-E-ST-32-01	Space engineering - Fracture control
ECSS-E-HB-32-20	Space engineering - Structural materials handbook