



Space engineering

Materials

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-E-ST-32-08C Working Group, reviewed by the ECSS Executive Secretariat and approved by the ECSS Technical Authority.

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Change log

<p>ECSS-E-30 Part 8A 25 April 2000</p>	<p>First issue</p>
<p>ECSS-E-30 Part 8B</p>	<p>Never issued</p>
<p>ECSS-E-ST-32-08C 31 July 2008</p>	<p>Second issue</p> <p>The following is a summary of changes between issues A and C:</p> <ul style="list-style-type: none"> • Former clause 4.2 mission has been removed because it did not contained normative material. • The following requirements have been deleted because they are already covered by more specific ECSS standards: <ul style="list-style-type: none"> ○ In former clause 4.3 (now 4.2, Functionality), Requirements on Stress corrosion have been deleted because they are now covered by Q-70 standards. ○ Former clause 4.4 (Mission constrains) has been deleted because is now covered by Q-70 standards. ○ In former clause 4.5 (now 4.3, Interfaces), former requirements passivation layers, high temperature oxidation protective coatings, diffusion barriers have been deleted because they are now covered by Q-70 standards. ○ In former clause 4.6 (now 4.4, Joining), requirements relative to adhesive bonding and fusion have been deleted because they are now covered by Q-70 standards. ○ In former clause 4.7 (now 4.5, Design), requirement on composite sandwich constructions, Aluminium, Steel, Titanium, Magnesium alloys, Beryllium and Beryllium alloys, Mercury, Refractory alloys, Superalloys, Other metals, Castings, Forgings, Glass and ceramics, CMC, Polymers, Rubbers, Lubricants, Thermal control insulants, and Optical materials, have been deleted because they are now covered by Q-70 standards. ○ In former clause 4.8 (now 4.6, Verification), former requirements General, Mechanical and physical test methods, and Proof testing, have been deleted because they are now covered by ECSS-E-ST-10-02, ECSS-E-ST-10-03, and Q-70 standards. ○ Former clauses 4.9 (Production and manufacture) and 4.10 (In service) have been deleted because they are now covered in Q-70 standards. ○ Former clause 4.12 (Product assurance), has been deleted because is now covered by Q-20 standards.

	<ul style="list-style-type: none">• The remaining requirements have been reworded for clarity, and to comply with the ECSS drafting rules.• The following requirements have been added:<ul style="list-style-type: none">○ In 4.2.5, a requirement to perform a creep analysis○ In 4.2.6, a requirement to perform a micro-yielding analysis○ In 4.3.9, a requirement a requirement on organic coatings as paint
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1 Scope

ECSS-E-ST-32-08 defines 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 defines 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 constraints of a space project in conformance with ECSS-S-ST-00.

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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 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-10-02	Space engineering – Verification
ECSS-E-ST-10-03	Space engineering – Testing
ECSS-E-ST-32	Space engineering – Structural
ECSS-Q-ST-70	Space product assurance – Materials, mechanical parts and processes
ECSS-Q-ST-70-71	Space product assurance – Data for selection of space materials and processes
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

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:

A-basis design allowable (A-value)

B-basis design allowable (B-value)

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
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 Symbols

Symbol	Meaning
K_{Ic}	plane strain critical stress intensity factor
K_{Isc}	plane strain critical stress intensity factor for a specific environment

4 Requirements

4.1 Overview

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 dependant 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_{Isc} shall be measured according to procedures approved by the customer.
- 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.

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 than the specified allowable limit.
- b. Each project shall define the values of the coefficients of thermal expansion (CTE) and of moisture expansion (CME) required 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.

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. The possibility of hydrogen embrittlement occurring during component manufacture or use shall be analysed, including the evaluation and the assessment of their protection and control.

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

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

4.3 Interfaces

4.3.1 General

- a. For interfaces, ECSS-Q-ST-70-71 clause "General requirements for surface treatment" shall apply.

4.3.2 Anodizing

- a. For anodizing, ECSS-Q-ST-70-71 clause "Anodizing" shall apply.

4.3.3 Chemical conversion

- a. For chemical conversion, ECSS-Q-ST-70-71 clause "Chemical conversion" shall apply.

4.3.4 Metallic coatings (overlay and diffusion)

- a. For metallic coatings, ECSS-Q-ST-70 clause "Plating" 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. Components subject to fatigue or sustained loading stresses, which are made of material susceptible to hydrogen embrittlement, shall be heat treated after coating.

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 equipments.

4.3.8 Coatings on CFRP

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

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

- b. If provision 4.3.8a is not met, the coating shall be bonded to the CFRP substrate using a non-conductive adhesive or alternatively the coating shall be 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. In dissimilar material contact, the CFRP usually behaves as the cathode and as such can corrode the coating material.

4.3.9 Organic coatings as paint

- a. For on organic coatings as paintings, ECSS-Q-ST-70-71 clause "Paint and coating" 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 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.

4.4.2 Bolted joints

- a. For bolted joints, ECSS-Q-ST-70-71 clause "Bolted joints" shall apply.

4.4.3 Riveted joints

- a. For riveted joints, ECSS-Q-ST-70-71 clause "Riveted joints" shall apply.

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.
NOTE E.g. bar, sheet and plate.
 2. Size, thickness range.
 3. Manufacturing process.
NOTE E.g. extrusion, rolling and forging.
 4. Grain direction.
NOTE E.g. longitudinal, longitudinal transverse and short transverse.
 5. Temper condition
NOTE E.g. heat treatment and cold working.
 6. Test direction.

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.
NOTE 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.
 2. Deviation of lamina properties from the nominal values.
NOTE Lamina properties exhibit large differences in directional properties, as well as small strain to failure with limited yielding or plastic behaviour.
 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.
NOTE E.g. humidity, temperature, radiation and cycling loading.

8. Dependence of the non-linearity on the specimen, load conditions and test environment.
 - b. The supplier shall justify his choice of composite material for approval by the customer, 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.
 - 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 shall be validated by test before manufacturing the final items.
 - f. The autoclave and other manufacturing process critical parameters 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.

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 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 proper size, 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.

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 (called the 0° direction) as well as in the direction transverse to the fibres (the 90° direction).

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

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

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 shall be provided or presented to the customer for approval.
- 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.
- 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 (NDI)

- 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 EN 4179:2005.
- 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.

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.

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.

Bibliography

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