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Space engineering

Compatibility testing for liquid propulsion components, subsystems and systems

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Foreword

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This Standard has been prepared by the ECSS-E-ST-35-10 Working Group, reviewed by the ECSS Executive Secretariat and approved by the ECSS Technical Authority.

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1 Scope

ECSS-E-ST-35-10 belongs to the propulsion field of the mechanical discipline, as defined in ECSS-S-ST-00, and concerns itself with compatibility testing of propulsion components, sub-systems and systems.

Compatibility encompasses the interaction of two or more materials, solids (e.g. structural materials), liquids (e.g. propellants, simulation and cleaning liquids) or gases (e.g. air, pressurants). In case the interaction has the effect that the properties of the materials change, there is the possibility of a compatibility issue.

The standard:

- identifies materials used in propulsion for which incompatibility can create problems,
- identifies the time scale at which problems can occur. It makes a difference whether a system is only stored or operational for a short period and is to function only during launch (time scale measured in months) and systems that have a long life in orbit (time scale measured in years),
- identifies the liquid propulsion components, subsystems and systems to be subject to compatibility testing,
- identifies, specifies and defines the tests, test conditions and compatibility test procedures to ensure that representative compatibility testing can take place, and
- establishes the test requirements.

The standard is applicable to the design and the qualification of liquid propulsion components, sub-systems and systems and can be applied to their development; it also applies to COTS items procured for the propulsion system.

From the tests described in this standard the effects of interactions of space propulsion materials and fluids on the components, subsystems and systems can be established. In this way it can be assured that the component, subsystem or system satisfies the requirements.

This standard is limited to tests on component-, subsystem- and system-level. Only for those cases where new materials, substances or conditions are involved for which there is no experience or data available, the performance of screening tests is specified.

This standard may be tailored for the specific characteristic 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 general requirements
ECSS-E-ST-32-10	Space engineering – Structural factors of safety for spaceflight hardware
ECSS-E-ST-35	Space engineering – Propulsion general requirements
ECSS-E-ST-35-06	Space engineering – Cleanliness requirements for spacecraft propulsion hardware
ECSS-Q-ST-70-36	Space product assurance – Material selection for controlling stress-corrosion cracking
ECSS-Q-ST-70-37	Space product assurance – Determination of the susceptibility of metals to stress-corrosion cracking
ECSS-Q-ST-70-45	Space product assurance – Mechanical testing of metallic materials
ASTM C 1291-00a	Standard Test Method for Elevated Temperature Tensile Creep Strain, Creep Strain Rate, and Creep Time-to-Failure for Advanced Monolithic Ceramics
ASTM C 1337-96	Standard Test Method for Creep and Creep Rupture of Continuous Fiber-Reinforced Ceramic Composites under Tensile Loading at Elevated Temperatures
ASTM C 1368-06	Standard Test Method for Determination of Slow Crack Growth Parameters of Advanced Ceramics by Constant Stress-Rate Flexural Testing at Ambient Temperature
ASTM C 1465-08	Standard Test Method for Determination of Slow Crack Growth Parameters of Advanced Ceramics by Constant Stress-Rate Flexural Testing at Elevated Temperatures
ASTM C 1576-05	Standard Test Method for Determination of Slow Crack Growth Parameters of Advanced Ceramics by Constant

	Stress Flexural Testing (Stress Rupture) at Ambient Temperature
ASTM D 395	Test Methods for Rubber Property—Compression Set
ASTM D 570-98	Standard Test Method for Water Absorption of Plastics
ASTM D 624-00	Standard Test Method for Tear Strength of Conventional Vulcanized Rubber and Thermoplastic Elastomers
ASTM D 638-03	Standard Test Method for Tensile Properties of Plastics
ASTM D 1434-82 (Reapproved 2003)	Standard Test Method for Determining Gas Permeability Characteristics of Plastic Film and Sheeting
ASTM D 2240-04	Standard Test Method for Rubber Property – Durometer Hardness
ASTM G 4-95	Standard Guide for Conducting Corrosion Coupon Tests in Field Applications
ASTM G 31-72 (Reapproved 1999)	Standard Practice for Laboratory Immersion Corrosion Testing of Materials
ASTM G 71-81 (reapproved 1998)	Standard Guide for Conducting and Evaluating Galvanic Corrosion Tests in Electrolytes.
ASTM G 72-01	Standard Test Method for Autogenous Ignition Temperature of Liquids and Solids in a High-Pressure Oxygen-Enriched Environment
ASTM G 86-98a	Standard test method for Determining Ignition Sensitivity of Materials to Mechanical Impact in Ambient Liquid Oxygen and Pressurized Liquid and Gaseous Oxygen Environments
ASTM G 111-97	Standard Guide for Corrosion Tests in High Temperature or High Pressure Environment, or Both
ASTM G 142-98	Standard Test Method for Determination of Susceptibility of Metals to Embrittlement in Hydrogen Containing Environments at High Pressure, High Temperature, or Both
ISO 175	Plastics; Methods of Tests for the Determination of the Effects of Immersion in Liquid Chemicals
ISO 1817, 3rd edition 1999-03-01	Rubber, vulcanized – Determination of the effect of liquids
ISO 10297	Transportable gas cylinders — Cylinder valves — Specification and type testing
ISO 15859-1	Space systems – Fluid characteristics sampling and test methods - Oxygen
ISO 15859-7	Space systems – Fluid characteristics sampling and test methods – Hydrazine
ISO 21010	Cryogenic vessels — Gas/materials compatibility
NACE TM0499-99 Item No. 21239	Standard Test Method Immersion Corrosion Testing of Ceramic Materials

3 Terms, definitions and abbreviated terms

3.1 Terms from other standards

For the purpose of this Standard, the terms and definitions from ECSS-ST-00-01 and ECSS-E-ST-35 apply.

For the purpose of this Standard, the following term from ECSS-E-ST-32 applies:

maximum expected operating pressure (MEOP)

For the purpose of this Standard, the following term from ECSS-Q-ST-70-36 applies:

stress corrosion

3.2 Terms specific to the present standard

3.2.1 ageing

entirety of all changes in chemical and physical characteristics occurring in a material in the course of time

3.2.2 auto ignition temperature

lowest temperature at which a substance produces hot-flame ignition in the environment and at the pressure without the aid of an external energy source

3.2.3 compatibility

absence of unacceptable performance or reliability loss due to chemical reactions and physical changes in materials or substances during the compatibility life

NOTE 1 Compatibility always involves two or more materials in contact with each other.

NOTE 2 Compatibility is always related to the application and the requirements.

3.2.4 compatibility life

life cycle from the first exposure of two or more materials to each other until disposal

3.2.5 contaminant gas

undesired gas present in the propulsion system at any time in its life

3.2.6 corrosion

reaction of the engineering material with its environment with a consequent deterioration in properties of the material

3.2.7 dissimilar metals

metals with different electrochemical potentials

3.2.8 galvanic corrosion

corrosion as a result of an electrochemical potential difference between electrical conductors in an electrolyte

3.2.9 hydrogen embrittlement

condition of low ductility or reduced mechanical properties resulting from the absorption of hydrogen

NOTE stress intensity factor, K

factor describing the stress state near the tip of a crack caused by a remote load, residual stress or both.

NOTE The magnitude of K depends on sample geometry, the size and location of the crack, and the magnitude and the modal distribution of loads on the material. $K = \sigma \cdot Y \cdot \sqrt{\pi \cdot a}$

where:

a	half the crack length
K	stress intensity factor
Y	dimensionless geometrical function
σ	applied stress

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**
CAAR	compatibility assessment and applicability report
COTS	commercial of-the-shelf
CPE	chlorinated poly ethylene
CTLP	compatibility testing for liquid propulsion
DSC	differential scanning calorimeter
EPDM	ethylene propylene diene monomer
EPR	ethylene propylene rubber

GOx	gaseous oxygen
LOx	liquid oxygen
MMH	mono methyl hydrazine
MON	mixed oxides of nitrogen (MON-X is X% NO and (100-X) % of N_2O_4
NVR	non-volatile residue
PVC	poly vinyl chloride
SEM	scanning electron microscope
SS	stainless steel
TGA	thermal gravimetric analysis

4 General requirements for compatibility tests

4.1 General

4.1.1 Compatibility test assessment

a. The supplier shall analyse and define the conditions for the compatibility tests with respect to the application and the requirements for the component, sub-system or system and define them in conformance with the DRD in Annex A.

4.1.2 Test conditions

a. Compatibility testing shall take place under conditions reproducing the actual use of the items.

NOTE For example: The test items treatments, processes and handling, to be the same as those for the actual flight hardware items.

b. The extent of compatibility testing shall comply with the reliability requirements for the component, subsystem or system.

4.1.3 Test duration

a. The duration of the compatibility test shall be established using the compatibility life and mission reliability requirements

NOTE 1 The type of information to be obtained for the component, subsystem or system is e.g. a quick first impression or an impression based on an exposure under well controlled conditions with detailed and precise measurements.

NOTE 2 For short compatibility lives (e.g. as for launchers), the duration of compatibility tests can be the same as the compatibility life or somewhat larger. For large compatibility lives (e.g. satellites in orbit) accelerated compatibility tests can be used.

4.1.4 Criticality

a. In Phase A and in Phase B the following shall be performed:

1. establish which compatibility problems are expected, or where there is a lack of information;
2. ranking of the severity of the compatibility problems;
3. assess and report the criticality and the effect on material selection and planning in conformance with Annex A.

NOTE The severity of the compatibility issue can lead to intensive investigations (new materials, development risks), which can endanger the development schedule.

4.1.5 Phasing of tests

a. The compatibility tests of clauses 4.2 and 5.1.2 shall be performed early during project Phase B.

NOTE This requirement is included in order that a proper material selection can be made, and that a proper data base can be established for the PDR. The priority and the planning of the tests is based on their duration or on those combinations of materials where the compatibility problems have been ranked severe.

4.2 Compatibility tests

4.2.1 Requirement for compatibility testing

a. Compatibility testing of material combinations in propulsion systems shall be done in case there is no experimental or historical evidence that the combination meets the compatibility requirements.

NOTE This includes simulation and cleaning fluids, purging gases and cleaning and drying processes.

b. The need for compatibility testing shall be assessed and included in Annex A.

4.2.2 Compatibility testing of surface treated samples

a. Samples of surface treated materials for propulsion systems, where there is no evidence that they meet the compatibility life, shall undergo compatibility testing.

b. 'Untreated' parts of the samples shall be insulated or protected in such a way that they do not disturb the measurements or cause false information.

NOTE Surface treatment of materials is done for various reasons, amongst which improving the material compatibility characteristics. Typical surface treatments encompass passivation / chemical etching, anodising, polishing, coating such as: painting, plating, vacuum spraying / vacuum deposition, electro-deposition, organic coating, or changing surface properties by chemical adsorption (e.g. nitration, carbonization).

4.2.3 Provision COTS components

4.2.3.1 General

a. It shall be demonstrated that COTS components meet the compatibility life requirement.

NOTE For cost or time reasons COTS components can be selected for propulsion systems. If there is no certainty that all components of the COTS components meet the compatibility requirements, solutions are sought (e.g. redesign, surface treatment, replacement, requalification).

4.2.3.2 Surface treatment of COTS components

a. If a component has undergone a surface treatment to meet the compatibility requirements, this component shall undergo compatibility testing in conformance with clauses 4.1.2 and 4.1.3.

b. Modified COTS components shall undergo re-qualification and full functional testing to ensure its functionality according to clause 6.10.

4.2.4 Compatibility testing logic

a. For completely unknown material combinations that involve energetic materials or materials for which the possibility exists of generating toxic or poisonous materials, safety tests shall be performed before starting compatibility testing, see clause 6.1.2.

b. Compatibility testing should take place following the logic of Figure 4-1

NOTE 1 This guarantees that they are performed with increasing complexity, generation of details, and for the specific applications.

NOTE 2 The requirements list needs to be tailored. It depends on the specific application which tests are going to be performed and which by-passed: e.g. if no hydrogen is involved, no hydrogen embrittlement tests are performed.

NOTE 3 An example of tailoring the requirements list is given in Annex C and Annex E.

4.2.5 Compatibility test plan and compatibility test procedure

a. For every propulsion compatibility test the following shall be performed:

1. establishing a compatibility test plan in conformance with the elements identified in Annex B,
2. establishing a compatibility test procedure in conformance with the elements identified in Annex B,
3. assessing the results.

b. In case no specific procedures have been identified in this standard, the compatibility test plan and compatibility test procedure shall be agreed with the customer.

4.2.6 Accept and reject criteria

a. For every propulsion compatibility test, accept and reject criteria shall be established.

NOTE 1 Accept and reject criteria judge the quality of the test itself as well as whether the material combinations meet the compatibility requirements.

NOTE 2 A 'grey zone' in the accept / reject criteria requires consultation with the customer.

4.2.7 Deviations from standards or standard guides

a. All deviations shall be identified, agreed with the customer and described in the compatibility test procedure 4.2.5a.2.

4.2.8 Execution of tests

4.2.8.1 Laboratories

a. The laboratories performing the compatibility tests shall provide documented evidence that

1. they are certified to perform these tests, or
2. they are well experienced in the foreseen tests.

4.2.8.2 Personnel

a. For the personnel executing the tests documented evidence shall be provided showing that

1. the personnel is certified to perform these tests or
2. the personnel is well experienced to perform these tests.

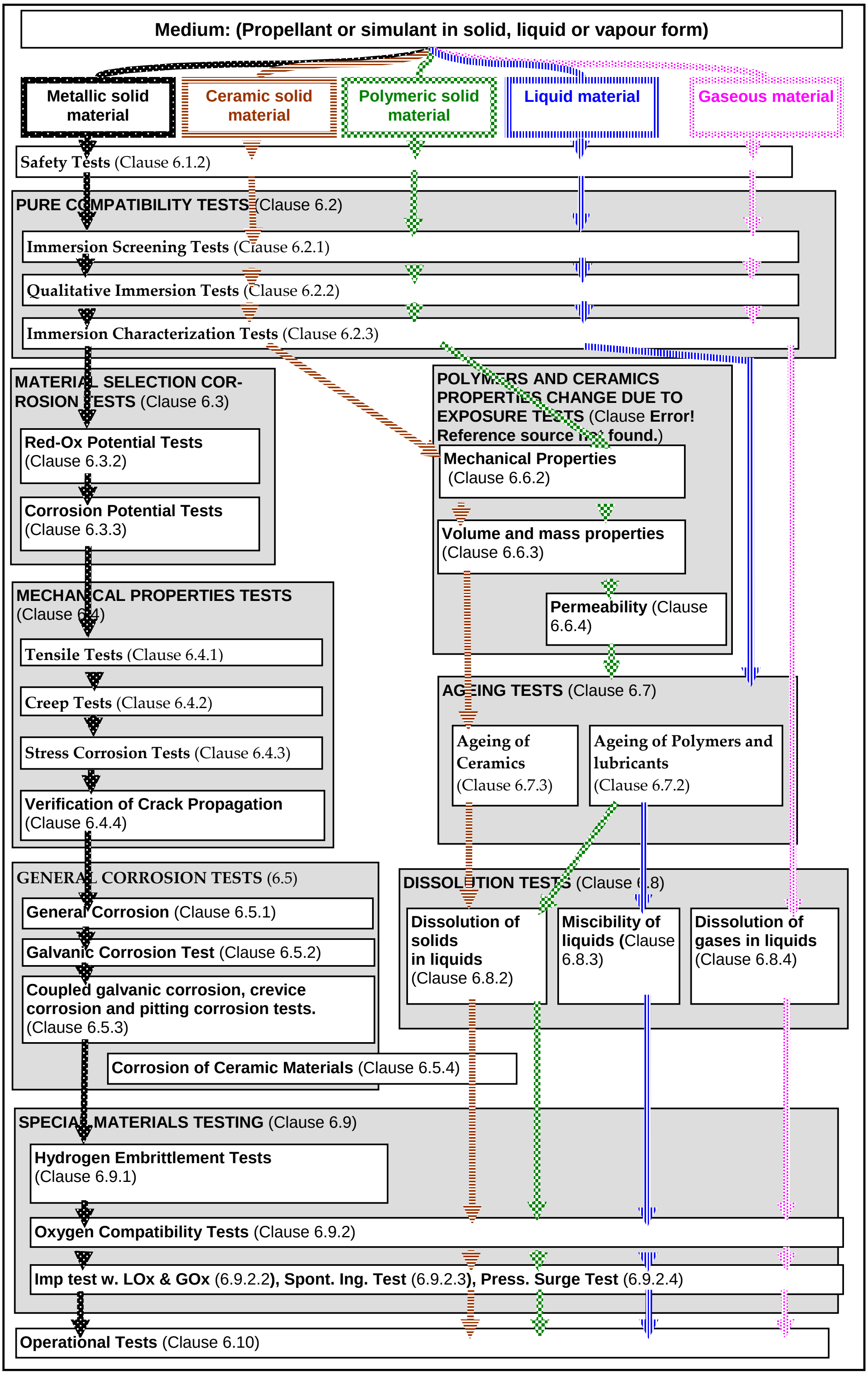

Figure 4-1: Compatibility testing flow chart

5 Identification of compatibility problems for liquid propulsion systems

5.1 General

5.1.1 Overview

The objective of Clause 5 is to highlight common propulsion system compatibility problems that have been experienced in the past. A list of examples and incompatibilities is given in Annex C and Annex D.

5.1.2 Compatibility aspects

a. The relevant propulsion configuration shall be analyzed for compatibility issues using cases and incompatibilities listed in Annex C and Annex D.

b. In order to assess the effects of incompatibility with contaminated fluids, e.g. as for external contamination, tests or analyses may be performed for these specific cases.

NOTE For example: 1 mg of copper and 1000 l of hydrazine.

c. Compatibility shall be assessed and verified, by similarity, analysis or test and reported in the CAAR.

d. It shall be demonstrated that the compatibility tests specified in the compatibility test plan cover the identified open incompatibilities and cases provided in Annex C and Annex D.

e. Test results shall be reported in conformance with Annex B.

5.2 Ground storage and transport

5.2.1 Ground storage

5.2.1.1 General

a. The supplier shall assess and report in conformance with Annex A compatibility problems due to the state of the propellant originating from:

1. saturation with pressurant gases during pressurized ground storage;
2. contamination during storage and transport.

5.2.1.2 Provision

a. The state of the propellant before loading the launcher or spacecraft, or before use shall be established to avoid compatibility problems.

NOTE Examples of states are composition, gas saturation level.

5.2.2 Transport

a. It shall be ensured that corrosion or contamination does not occur during transport.

b. Packaging shall be according to ECSS-E-ST-35-06 clause 8.1 'Approved coverings'.

c. The output of 5.2.2 a and 5.2.2 b shall be reported in conformance with Annex A.

5.3 Known incompatibilities

5.3.1 Table of known incompatibilities

In Annex D a table of known incompatibilities is given (Table D-1). The objective of this table is to highlight which combinations of materials used in liquid propulsion have shown incompatibilities. Whether or not material combinations are considered to be incompatible depends on the compatibility life. The table only identifies short-term incompatibility (order of months) and long-term incompatibility (order of several years). The table is neither exhaustive nor complete. References are given where available. If a material combination is not mentioned in Table D-1 this does not imply that the combination is compatible.

It is important to check the references to obtain more detailed information on the conditions under which the incompatibility has been established.

5.3.2 General

a. If material combinations are selected that appear in Table D-1 for the planned duration and conditions, the risks of using this combination shall be analysed.

6 Identification of tests to characterize the compatibility

6.1 Compatibility tests

6.1.1 Overview

Material tests encompass a number of tests performed to establish whether certain combinations of materials or substances are compatible under the conditions envisaged for the foreseen propulsion application.

The initial compatibility tests are qualitative tests, simple and fast that serve to establish if combinations are not compatible.

6.1.2 Safety test

a. The safety regulations of the laboratory where the tests are being performed shall be observed.

b. In case of unknown or new materials or substances, clause 4.2.4a and 6.1.2c shall apply.

c. A safety test may be performed by bringing small quantities of the substances into contact with each other under controlled conditions in a safety cabinet.

NOTE The safety test is not a compatibility test, but a test that ensures that personnel and equipment is not endangered and has to follow the local safety regulations. As it is not a compatibility test, it is not dealt with in detail in this standard.

6.1.3 Environmental pollution

a. The national regulations with regard to pollution and protection of the environment shall be observed when tests are executed.

6.1.4 Test sequence

6.1.4.1 General

a. In case of unknown or new materials or substances, the sequence of compatibility test shall be as follows:

1. the immersion screening test.
2. if 6.1.4.1a.1 is successful, then the immersion screening test.

NOTE Qualitative immersion tests are of somewhat longer duration and generate some numerical and chemical data about the compatibility of the combination that has been investigated.

6.1.4.2 Test conditions

a. In case a mixture of two liquids is screened the mixture shall be submitted to a safety test according to clause 6.1.2a before undergoing the compatibility screening test according to clause 6.8.3.1.

b. The sample conditions shall represent the conditions in actual use in the propulsion system.

6.1.4.3 Tests

a. Exposure of the material to the fluid for two hours at ambient temperature and pressure shall not generate any visible effects or changes in either the material or the fluid.

b. The test results shall be reported according to Annex B.

6.2 Pure compatibility tests

6.2.1 Immersion screening tests

6.2.1.1 Overview

The immersion screening test is applicable for initially determining reactions between fluids and materials used in propulsion systems. The sample is immersed in the fluid.

6.2.1.2 Test condition

a. The sample conditions shall be the same as those foreseen in actual use in the propulsion system.

NOTE Examples so sample conditions are: surface conditions, cleanliness, manufacturing process, and passivation.

6.2.1.3 Tests

a. Exposure of the material to the fluid for two hours at ambient temperature and pressure shall not generate any visible effects or changes in either the material or the fluid.

6.2.2 Qualitative immersion tests

6.2.2.1 Overview

The objective of the immersion test is to quickly identify changes in the fluid and material qualitatively from exposure of a material to a fluid, both used in liquid propulsion systems.

NOTE The duration of an immersion test is in the order of days to a few weeks.

6.2.2.2 Test activities

a. The compatibility test procedure shall include:

1. preparation of the specimen;
2. the test temperature or test temperatures;
3. the test pressure or test pressures;
4. the inert gas to blanket or pressurize the container;
5. the duration of the test;
6. the selection of the test container:
   (a) including the size of the test specimen and the amount of fluid (ratio of the surface of the specimen to the volume of the fluid);
   (b) specifying the test temperatures and pressures;
   (c) specifying its material and surface preparation;
   (d) being inert with respect to the test specimen and fluid;
   (e) specifying the applicable safety procedures and measures.
7. the preparation of the container, including the:
   (a) internal surface;
   (b) cleanliness;
   (c) dryness;
   (d) leak tightness;
   (e) requirements for inert gas blanketing;
   (f) instrumentation.

b. In case of fluids that are known to auto decompose, a reference test shall be performed and included in the procedure specified in 6.2.2.2a, with the fluid only present for the envisaged immersion test duration.

NOTE 1 The duration of an immersion test is in the order of days to a few weeks.

NOTE 2 Fluids that show auto decompositions are e.g. hydrazines and hydrogen peroxide.

NOTE 3 It is observed in some cases that if a fluid is put into an inert closed container, the pressure or temperature can change with time. These changes with time are not related to the compatibility test. Therefore by executing a reference test run as described in a., a correction for this effect can be made. Carrying out a reference test in a second container is less useful since scatter from container to container is expected to be significant.

c. The container shall be prepared according to the compatibility test procedure specified in 6.2.2.2a, for the actual immersion test.

d. The test specimen and fluid shall be put into the container according to the compatibility test procedure specified in 6.2.2.2a.

e. The immersion test shall be executed according to the compatibility test procedure specified in 6.2.2.2a.

f. After completion of the immersion test, the measured data shall be evaluated.

6.2.2.3 Accept-reject criteria

a. The accept-reject criteria shall be defined including the following fluid and material changes:

1. visual

   NOTE For example: Colour, pitting and bubbles.

2. pressure;
3. temperature and heat generation;
4. volume and dimensions;
5. permeability;
6. mass;
7. mechanical properties;

   NOTE For example: Any mechanical property of interest, such as hardness, strength, compression behaviour.

8. composition;
9. NVR.

b. for polymers, mechanical properties before and after the immersion tests shall be determined according to clause 6.6.

6.2.3 Immersion characterization tests

6.2.3.1 Overview

The objective of immersion characterization tests is to obtain precise quantitative data on the potential change of material properties of two or more materials in contact with each other.

6.2.3.2 Material condition

a. The material to be tested in clause 6.2.3.3 shall meet the requirements of clause 4.1.2.

b. If the requirements specified in clause 4.1.2 cannot be met the following shall be performed:

    1. any deviation with respect to test conditions and sample material characteristics documented, or

    2. the state of the material used for testing described completely.

        NOTE For example the cast, forged, surface treatment and condition, heat treatment, processing, production batch.

c. If the requirements specified in clause 4.1.2 cannot be met the samples to be tested shall be approved by the customer.

6.2.3.3 Closed vessel immersion characterization tests

a. The compatibility test procedure shall specify:

    1. The following parameters:

        (a) the test temperature or test temperatures;

        (b) the test pressure or test pressures;

        (c) the type of gas to blanket the container;

        (d) the level of submersion of the solid;

        (e) the number of samples to be tested;

        (f) the duration of the test with a minimum of two weeks;

        (g) a reference test on the fluid alone;

        (h) a reference test on the solid alone.

    2. The selection of the test container, including:

        (a) the dimensions of the micro calorimeter, calorimeter or test vessel;

        (b) the amount of fluid in the container in view of contamination and accuracies;

        (c) the characteristics of the container together with the test specimen and the fluid (e.g. surface conditions, passivation, and compatibility);

(d) the applicable safety procedures;

(e) the possibility to hermetically seal the container (e.g. gas blanketing, pressure measurement);

3. The acquisition of the following data before and after the test:

(a) weight of the solid and the liquid;

(b) dimensions of the solid;

(c) the surface condition, by examination of a sample surface by SEM or other microscope at a minimum magnification in agreement with the test objectives;

NOTE 1 This is to see changes in the surface condition due to e.g. corrosion, dissolution.

NOTE 2 In case the observed changes in the surface conditions warrant this, more detailed investigations of the solid can be performed after the test.

(d) chemical analysis of the composition of the liquid;

NOTE The objective here is to identify changes in the composition of the liquid.

(e) chemical analysis of the NVR and particulates after the test.

4. The acquisition of the following data after the test

(a) weight of the particulates;

(b) level of contamination of the liquid by elements stemming from the solid after the test.

5. The preparation of the container, including:

(a) cleanliness;

(b) passivation;

NOTE The process depends on the fluid.

(c) dryness;

(d) leak tightness.

6. The instrumentation to be used, with the following characteristics:

(a) micro calorimeter or calorimeter, with a sensitivity of and an accuracy in agreement with the test objectives;

(b) pressure measurement device with a sensitivity, an inaccuracy and a stability in agreement with the test objectives;

(c) temperature measurement device with a sensitivity, an inaccuracy and a stability in agreement with the test objectives.

b. Requirements shall be defined for the test set-up if gas dissolution in the liquid is a parameter to be measured.

c. The containers shall be prepared according to the compatibility test procedure for the actual tests.

d. The test specimen and fluid shall be put into the container according to the compatibility test procedure specified in 6.2.3.3a.

e. The characterization test shall be executed according to the compatibility test procedure specified in 6.2.3.3a.

f. After completion of the characterization test, the measured data shall be evaluated.

6.3 Material selection corrosion tests

6.3.1 Overview

- Measurement of the oxidation-reduction potential of the liquid (e.g. propellant, simulant, cleaning fluid) gives the limit for the potential of the metals in contact with a solution. Normally, the corrosion potential is slightly negative or around 0 V versus a saturated calomel electrode for stainless steel in water. A high oxidation potential in the propellant solution indicates risks of crevice- and pitting corrosion.
- The surface potential (corrosion potential) of a metal immersed in a solution gives an indication if there is a risk of increased corrosion rate (all metals corrode but very slow also in their passive state). The corrosion potential also indicates the risks of crevice and pitting corrosion. Corrosion potential measurements can be used to rank different materials with respect of risks of galvanic corrosion.

6.3.2 Red-Ox potential test

a. Clause 4.2.5b shall apply for the red-ox potential test execution.

6.3.3 Corrosion potential test

a. Clause 4.2.5b shall apply for the corrosion potential test execution.

6.4 Mechanical properties testing

6.4.1 Tensile tests

a. Tensile tests to measure tensile properties of materials before and after exposure shall be carried out:

1. for metallic materials, in conformance with ECSS-Q-ST-70-45, clause 4.2 ‘tensile test’,
2. for elastomers and ceramics clause 6.6.1 applies.

6.4.2 Creep tests

a. Creep tests to assess the load-carrying ability of a material before and after exposure shall be carried out in conformance with ECSS-Q-ST-70-45 clause 4.8 'creep test'.

6.4.3 Stress corrosion tests

a. Materials, which do not meet the selection requirements in ECSS-Q-ST-70-36, shall be tested and classified in conformance with ECSS-Q-ST-70-37.

b. Materials exposed to environments other than humid air or sea coastal environment shall be tested for stress-corrosion susceptibility in the specific conditions of temperature, chemical environment, stress level or stress intensity factor as envisaged for the application.

NOTE Depending on the compatibility test plan, tests are performed in a specified environment, after exposure to that environment and a subsequent cleaning process, or both.

c. If the selected material has shown susceptibility to stress corrosion cracking under different conditions than for the envisaged application, the following shall be performed:

1. test the material for stress-corrosion susceptibility in the specific conditions of temperature, chemical environment, stress level or stress intensity factor as envisaged for the application, in conformance with ECSS-Q-ST-70-45 clause 4.7 'stress corrosion cracking test';

2. analyse chemically the exposure medium shall immediately before and after testing to confirm that no external contamination occurred.

3. verify that the test duration is longer than the characteristic time for the material in the medium considered to show evidence of stress corrosion cracking.

4. estimate a characteristic time for a material to show evidence of stress-corrosion cracking by applying previous test results or in service experience.

NOTE Stress-corrosion cracking is a time dependent phenomenon. A certain time elapses between the exposure of a susceptible material to an environment promoting stress-corrosion and the instant at which evidence of stress-corrosion can be observed. This time interval, generally expressed in terms of hours or days, is typical of a material in a specific environment.

d. If the characteristic time is not known or no previous test data can be found, an analysis of the susceptibility of the material to stress corrosion in the considered medium shall be performed or exposure tests with different durations shall be carried out in order to establish the test duration.

6.4.4 Verification of crack propagation

a. Fatigue and crack propagation testing in special environments shall be carried out in conformance with ECSS-Q-ST-70-45 clause 5.5 'Fatigue crack propagation test'.

6.5 General corrosion tests

6.5.1 General corrosion

a. Corrosion behaviour of a material in a specific medium shall be assessed by immersion corrosion testing in conformance with ASTM G 31-72 Clauses 5 through 9.

b. For elevated pressures (i.e. > 0,17 MPa) and temperatures (i.e. > 50 °C), the corrosion behaviour of a material in a specific medium shall be assessed by immersion corrosion testing according to ASTM G 111-97 Clauses 6 through 10.

c. The immersion corrosion tests shall be carried out under conditions representative of the service environment.

NOTE This is particularly important in terms of electrolyte chemical composition and temperature.

6.5.2 Galvanic corrosion test

a. Galvanic corrosion of two dissimilar metals in electrical contact in an electrolyte under low-flow conditions shall be tested in conformance with the method in ASTM G 71-81 Clauses 4, through 7.

b. The test shall be carried out under conditions representative of the service environment.

NOTE This is particularly important in terms of electrolyte chemical composition and temperature.

6.5.3 Coupled galvanic corrosion, crevice corrosion and pitting corrosion tests.

a. For unknown 'solid material - liquid' combinations the following types of corrosion tests shall be performed:

1. coupled galvanic corrosion tests,
2. crevice corrosion tests, and
3. pitting corrosion tests.

b. The tests specified in 6.5.3a shall be executed in conformance with the test methods described in ASTM G4-95 Clauses 5, through 18.

c. The tests shall be carried out under conditions that are representative of the propulsion system service environment.

6.5.4 Corrosion of ceramic materials

a. The corrosion behaviour of a ceramic material in a medium shall be assessed according to NACE Standard TM0499-99 item No. 21239 Clauses 2.3.4 and Clause 5.

b. The corrosion behaviour of a ceramic material in a medium shall be evaluated according to NACE Standard TM0499-99 item No. 21239 Clause 6.

c. Ceramic materials susceptible to stress corrosion shall be tested according to ASTM C 1368 or ASTM C 1465 or ASTM C 1576 or ASTM C 1337.

6.6 Polymers and ceramics properties change due to liquid exposure tests

6.6.1 General

a. The applicable testing standards in clauses 6.6.2 and 6.6.3 shall be adapted to the testing of ceramic materials.

6.6.2 Mechanical properties

a. Tensile strength and elongation at rupture before and after exposure to the liquid of interest, shall be determined according to either:

— ISO 1817 Clauses 3 through 6 and 7.7, or

— ASTM- D-638-03 Clauses 5 through 11.

b. Hardness before and after exposure to the liquid of interest shall be determined according to either:

— ISO 1817 Clauses 3, through 6 and 7.6. or,

— ASTM D 2240-04 Clauses 5 through 9.

c. Compression set before and after exposure to the liquid of interest shall be determined according to ASTM 395 Clauses 5, 6 and either

— Clauses 8, through 10, or

— Clauses 12 through 14

d. Tear strength before and after exposure to the liquid of interest shall be determined according to ASTM D 624-00 Clauses 6 through 10.

e. Ceramic materials susceptible to creep crack growth during exposure shall be tested according to ASTM C 1291 or ASTM C 1337.

6.6.3 Volume and mass properties

a. The change in volume and mass properties due to the absorption of liquids shall be determined according to either:

1. ASTM D 570-98 Clauses 5 through 8 or
2. ISO 1817 Clauses 3 through 6, 7.1 through 7.5, and 7.8 or
3. ISO 175 clauses 4 through 6.

NOTE ASTM D 570-98 specifically applies water as absorption liquid; the same procedure can be followed for other liquids of interest.

b. The change in volume, mass and surface properties due to the absorption of liquids shall be determined according to 6.6.3a.2.

6.6.4 Permeability

a. The permeability of polymer sheet materials shall be determined in accordance to either:

— an established procedure to be agreed with the customer, or

— ASTM D 1434-82 (Reapproved 2003) Clauses 4 to 8 and

o 9 through 12, 14, 16 and 17, or

o 19 through 22, and 24.

NOTE Permeability is important for propellant tank diaphragms and bladders and for gaskets. In tanks the total pressure on both sides of the bladder or diaphragm are the same.

The permeation is in two directions:

- pressurant gas permeates to the propellant side,
- propellant vapours permeate to the pressurant gas side.

6.7 Ageing tests

6.7.1 Overview

Polymers are susceptible of ageing. Ageing typically occurs for water absorption and the effect of chemical substances.

NOTE Ageing is considered here with regard to compatibility issues that can occur because of the changed characteristics of aged materials.

6.7.2 Ageing of polymers and lubricants

6.7.2.1 General

a. An analysis shall be performed in conformance with Annex A to determine if polymers and lubricants exposed to fluids (e.g. propellants), vacuum, thermal and mechanical loads can change their characteristics over time and change their compatibility with the fluids to which they are exposed.

NOTE Lubricants are sometimes used in propulsion systems during the mounting of O-rings.

b. If in conformance with the analysis specified in 6.7.2.1a a polymer or a polymer with a lubricant, in the specific environment foreseen for the application, can change its compatibility characteristics, specific application oriented tests shall be specified, agreed with the customer and executed to establish the long term compatibility characteristics of the polymer or polymer and lubricant and the fluid.

c. If the transition temperatures of the polymer are not known, TGA or DSC tests shall be performed.

d. It shall be ensured and documented in Annex B that the characteristics (i.e. mechanical, physical, and chemical) of the polymer are known.

e. If the properties of 6.7.2.1c are not known, they shall be obtained from data sheets and tests as described in clauses 6.2.2 and 6.2.3.

6.7.2.2 Loads and analysis

a. The typical loads with their history, the conditions with their history, and the environment that the polymer and the fluid see during the application shall be analysed.

b. The analysis shall identify the conditions that are reproduced in the application oriented test as indicated in Annex B.

6.7.2.3 Test conditions

a. The test temperature shall at least be the upper temperature of the qualification temperature range.

b. Ageing behaviour may be accelerated by testing at temperatures higher than the upper temperature of the qualification temperature range.

c. The test temperature shall be below the first transition point 6.7.2.1c, above the upper temperature of the qualification temperature range.

d. Tests may be carried out at different temperatures to establish the acceleration effect of increased temperatures.

e. The test duration shall be established,

f. By using accelerated aging the test duration may be reduced.

g. An application oriented test set-up shall be designed and built reproducing the conditions and simulating the configuration for the test sample and fluid as identified in 6.7.2.2a.

h. The compatibility test plan shall include the:

1. test objectives,
2. compatibility test procedures,
3. duration of the test runs, including accelerated aging,
4. loads, conditions and environment in conformance with 6.7.2.2a,
5. instants to take the samples.

i. After completion of the application oriented test(s) the sample(s) and fluid shall be analysed in conformance with the test objectives.

NOTE For example: A sample of diaphragm material under stress in hydrazine.

6.7.3 Ageing of ceramics

6.7.3.1 Provisions

a. An analysis shall be performed according to Annex A to determine if ceramics exposed to fluids (e.g. propellants), vacuum, thermal and mechanical cyclic loads can change their characteristics over time and change their compatibility with the fluids to which they are exposed.

NOTE This test applies to ceramics used in propulsion systems such as: C/C, C/SiC, SiC/SiC, BN.

b. If in conformance with the analysis performed in 6.7.3.1a a ceramic material in the specific environment foreseen for the application, can change its compatibility characteristics, a specific application oriented test or set of tests shall be established (covering the load and conditions history), agreed with the customer and executed to establish the long term compatibility characteristics of the ceramic material and the fluid.

c. The applicable characteristics (e.g. mechanical, physical, chemical) of the ceramic shall be known and be reported as required in Annex B.

NOTE If the properties of the ceramics are not known they can be obtained from data sheets and tests as described in clauses 6.2.2 and 6.2.3.

d. The typical loads with their history, the conditions with their history, and the environment that the ceramic material and the fluid see during the application shall be analysed in order to identify the conditions to be reproduced in the application oriented test.

e. The test temperature shall at least be the upper temperature of the qualification temperature range.

f. A test set-up shall be designed and built reproducing the conditions and simulating the configuration for the test sample and fluid as identified in 6.7.3.1d.

g. The compatibility test plan shall include the:

1. test objectives;
2. compatibility test procedures;

3. duration of the test runs, including accelerated aging;
4. loads, conditions and environment in conformance with 6.7.3.1d;
5. instants to take the samples.

h. After completion of the application oriented test(s) the sample(s) and fluid shall be analysed in conformance with the test objectives.

6.8 Dissolution test

6.8.1 Overview

The objective of this test is to obtain the dissolution level or miscibility for the considered material combination.

The dissolution test can be based on clause 6.2.3.3, the closed vessel immersion characterization test set-up.

The difference between the dissolution test and the closed vessel immersion characterization test is that samples are investigated at specified time intervals to establish how the dissolution of solid material evolves over time. Examples of liquids mixed with other liquids are oil and grease that is used for lubrication and comes into contact with propellants, cleansing or simulation fluids and in case procedures for removing cleansing and simulation fluids have not been followed properly, the mixing of these fluids with the propellant. Mixed fluids can cause a compatibility problem in a propulsion component, subsystem or system. Also they can undergo a slow reaction and the reaction products can cause a performance loss of the propulsion system.

6.8.2 Dissolution of solids in liquids

a. The maximum amount of solid material that can be dissolved in the liquid (solubility) shall be known or established.

b. The test duration shall be established in relation to the envisaged application.

c. The ratio of exposed surface area to the liquid mass may be increased with respect to the planned application to accelerate the dissolution of solid material.

d. The consequences of the dissolution of solid material in the liquid shall be analysed and determined at propulsion component, subsystem or system level.

NOTE 1 Silica filler from rubber diaphragms or bladders in hydrazine tanks can leaching out. This dissolved silica can precipitate out in injector orifices or deposit itself on the catalyst bed, thereby causing a performance loss of the hydrazine propulsion system.

NOTE 2 Polymers or their additives can dissolve in liquids, be transported by the liquid into the propulsion sub-system and be deposited elsewhere, where they can cause e.g. flow blockage, valve sticking or filter blockage.

NOTE 3 Due to corrosion, corrosion products from e.g. tank material can dissolve in the propellant and can precipitate out at places where it can adversely affect the propulsion subsystem performance, e.g. valve seats, injector orifices, filters, catalyst beds.

6.8.3 Miscibility of liquids

6.8.3.1 Safety test

a. Before performing a miscibility test of two or more liquids, it shall be established that the combination does not create dangerous situations (e.g. ignition, or generation of poisonous or toxic materials).

b. The safety of the mixing of the liquids shall be established by:

1. experience, or
2. analysis, or
3. test

NOTE See clause 6.1.2.

6.8.3.2 Compatibility screening test

a. For the compatibility screening test equal masses of liquids shall be put in a test container (order of magnitude 10 ml to 100 ml in total) and a test shall be performed according to 6.2.2 (Qualitative immersion tests) where the test specimen is one of the two liquids.

6.8.3.3 Compatibility test

a. In case the liquids meet the acceptance criteria of the compatibility screening tests, equal amounts of the liquids shall be put in a test container to undergo a compatibility test.

b. The amount of fluid to be used shall be established based on the objectives and methods of the test and the measurements to be performed after the completion of the compatibility tests.

NOTE Examples of methods or the tests are micro calorimeter, and pressure measurement.

c. The compatibility test shall be performed according to 6.2.3.3, where the solid material has been replaced by one of the two liquids.

6.8.3.4 Miscibility test

a. To establish the miscibility of two liquids, the following procedure shall be used:

1. Mix one part of the first liquid with 100 parts of the second liquid in a transparent test vessel and stir thoroughly.

2. Observe whether

   (a) the liquid changes appearance,

   NOTE For example colour, gas bubbles, cloudy change appearance.

   (b) the added liquid floats on the other liquid (e.g. like an oil film),

   (c) the added liquid lies on the bottom of the container,

   (d) one or more liquid bubbles float in the other liquid, or

   (e) the added liquid has completely mixed with the other liquid in the container.

3. If the liquids have completely mixed, mix again one part of the first liquid with the mixture.

4. Observe whether the added liquid has completely mixed with the mixture.

5. Repeat steps 6.8.3.4a.3 and 6.8.3.4a.4:

   (a) the liquids do not mix anymore, or

   (b) 100 parts of the first liquid have been added to the second liquid and have completely mixed.

6. In case clause 6.8.3.4a.5(b) still shows complete miscibility, repeat the steps 6.8.3.4a.1 through 6.8.3.4a.5 with the first and second liquid interchanged.

b. The criteria shall be that in case step 6.8.3.4a.6 still shows complete miscibility, the liquids are miscible in all ratio's.

6.8.4 Dissolution of gases in liquids

6.8.4.1 Pressurant gas

a. The pressurant gas (e.g. He, N_2) dissolution level in the propellant should be determined.

b. For the propulsion system the range of dissolved pressurant gas under which the propulsion system can operate shall be defined.

NOTE 1 Gas dissolved in the propellant can change the propellant's physical properties and cause problems such as: gas lock, combustion instability, cavitation, loss of cooling capacity due to reduced heat transfer and pressure decay.

NOTE 2 There is uncertainty on the solubility limits of pressurant gases in propellants. Also, the dissolution of the same pressurant gas into e.g. the oxidizer and fuel of a bipropellant propulsion system can be very different.

NOTE 3 Most diaphragms in diaphragm tanks are to some extent permeable to pressurant gases. Over time the gas dissolves into the propellant.

6.8.4.2 Contaminant gas

a. The amount of CO_2 and NH_3 in N_2H_4 shall be determined according to ISO 15859-7 Clauses 7.5 and 7.11.

b. The amount of N_2 in LOx shall be determined by gas chromatography according to ISO 15859-1 Clause 7.16.

NOTE 1 CO_2 can react with N_2H_4 to form carbazic acid (NH_2-NH-COOH). The carbazic acid, together with hydrazine can form hydrazinium carbazate salt that can jam valves or block injector orifices.

NOTE 2 NH_3 in N_2H_4 can degrade the catalyst performance of hydrazine thrusters, especially for cold starts.

NOTE 3 N_2 in LOx can lower the performance of the propulsion system as compared to non-contaminated LOx.

6.9 Special materials testing

6.9.1 Hydrogen embrittlement tests

a. Materials that during their compatibility life are exposed to hydrogen, and for which it is not known whether they are susceptible to hydrogen embrittlement shall undergo a fracture toughness test after being exposed to hydrogen.

b. Exposure to the test environment of samples shall be representative of the specific application in terms of hydrogen concentration, pressure and temperature.

c. For applications involving the presence of tensile residual or other sustained stress, the susceptibility to hydrogen embrittlement shall be assessed under the effect of a representative sustained stress test during exposure.

d. Test exposure time shall be longer than the characteristic time for the material under the specific test conditions to show evidence of hydrogen embrittlement.

e. If the characteristic time is not known, an analysis of the susceptibility of the material to hydrogen embrittlement shall be performed in order to establish the test duration.

f. Susceptibility to hydrogen embrittlement shall be evaluated by comparing mechanical properties (in hydrogen rich environment with those obtained in air or inert gas.

NOTE Examples or mechanical properties are fracture toughness and tensile strength.

g. Fracture toughness tests shall be carried out in conformance with ECSS-Q-ST-70-45 clause 5.3 ‘Fracture toughness test’.

h. Tensile tests in hydrogen rich environment to assess the residual strength after exposure shall be carried out in conformance with ASTM G 142-98 Clauses 6 and 8 through 12.

6.9.2 Oxygen compatibility tests

6.9.2.1 General

a. Materials (especially non-metallic materials) that during their compatibility life are exposed to oxygen, and for which it is not known whether they are compatible to oxygen shall undergo specific tests in a representative oxygen environment (state of aggregation, temperature, pressure).

b. Any combustible non-metallic material, like plastics, elastomers, lubricants, used in steady or incidental contact with oxygen where the presence of a potential source of ignition is a risk shall be tested under representative conditions (state of aggregation, temperature, pressure).

c. Three kinds of tests can be performed to evaluate the oxygen compatibility of materials in an oxygen environment:

1. Mechanical impact test in liquid oxygen (LOx) or gaseous oxygen (GOx).
2. Spontaneous ignition test in gaseous oxygen (bomb test).
3. Pressure surge test in gaseous oxygen (adiabatic compression test).

6.9.2.2 Mechanical impact test with LOx and gaseous oxygen

a. The ignition sensitivity of materials to mechanical impact in an oxygen environment (LOx, GOx or high oxygen concentration) shall be established according to

1. ISO 21010 Clauses 4.1 through 4.3 and Clause 4.4.2.4, or
2. ASTM G 86-98a Clauses 4 and7 through 14.

6.9.2.3 Spontaneous ignition test (bomb test)

a. The spontaneous ignition temperature of non-metallic materials in pressurised gaseous oxygen shall be determined according to

1. ISO 21010 Clauses 4.1 through 4.3 and Clause 4.4.2.2, or
2. ASTM G 72-01 Clauses 1, 5 through 8 and 10.

6.9.2.4 Pressure surge test (adiabatic compression test)

a. The reactivity of non-metallic materials under maximum working pressure shall be determined during a pressure surge test, using oxygen, air or of a gas mixture containing oxygen according to:

1. a ISO 21010 Clauses 4.1 through 4.3 and Clause 4.4.2.3, or
2. b ISO 10297 Clause 6.14.

NOTE Non-metallic materials are solids, pastes or liquids.

6.10 Operational tests

6.10.1 Overview

Operational tests can be performed on propulsion component, subsystem and system level.

Operational tests are primarily intended to demonstrate the proper functioning of the propulsion component, subsystem and system and to demonstrate that the performance and qualification requirements are being met.

Operational tests are normally done at qualification or operational conditions.

These operational tests, at the same time allow to make particular compatibility investigations.

6.10.2 Provisions

a. The possibility to perform compatibility verification during or after an operational test of a propulsion component, subsystem or system shall be assessed.

NOTE For example: Contamination check of propellant, simulation fluid, disassembling the component, subsystem or system and verifying absence of corrosion, inspecting surface conditions.

b. For every identified compatibility verification, the objectives shall be defined and documented according to Annex A.

c. For every identified compatibility verification, where the objectives have been defined, plans shall be established according to Annex B, identifying:

1. compatibility verification activities before, during and after the operational tests including:
   (a) data measurements,
   (b) sample rate and sample size,
   (c) inspections
   (d) of surface conditions and identifying the positions for these inspections,
   (e) specific instrumentation needed for the compatibility verification,
   (f) dismantling or dissection of the equipment.
   (g) the possibility of galvanic corrosion in subsystems and systems,
   (h) the interaction of the various components in a subsystem (e.g. upstream particle generation and downstream clogging),
   (i) the possibility of reactions (combustion) between parts and the oxidizer,
   (j) the solution of pressurant gas,
   (k) time effects.

7 Deliverables

a. The following documents shall be prepared and delivered:

1. The "Compatibility Assessment and Applicability Report for Liquid Propulsion Components, Subsystems and Systems" in conformance with Annex A

2. The "Compatibility Testing for Liquid Propulsion Report" in conformance with Annex B.

Annex A (normative) Compatibility assessment and applicability report for liquid propulsion components, subsystems and systems (CAAR) - DRD

A.1 DRD Identification

A.1.1 Requirement identification and source document

This DRD is called from ECSS-E-ST-35-10 requirements 4.1.1a, 4.1.4a.3, 4.2.1b, 5.2.1.1a, 5.2.2c, 6.7.2.1a, 6.7.3.1a, 6.10.2b, and 7a.1.

A.1.2 Purpose and objective

The objective of the compatibility assessment and applicability report is to:

- identify from the system configuration for which material combinations (solids, liquids and gases with two or more different materials present) compatibility problems can arise;
- justify and verify for which combinations potential compatibility problems have been solved already or have been identified not to be a problem for the envisaged applications;
- identify the material combinations in need of further investigations;
- identify the scope and nature of the required further investigations.

A.2 Expected response

A.2.1 Scope and content

<1> Introduction

a. The CAAR shall contain a description of the purpose, objective, content and the reason prompting its preparation.

<2> Applicable and Reference Documents

a. The CAAR shall list the applicable and reference documents in support to the generation of the document.

<3> Terms, Definitions, Abbreviated terms and Symbols

a. The CAAR shall use the terms, definitions, abbreviated terms and symbols used in ECSS-E-ST-35 and ECSS-E-ST-35-10.

b. The CAAR shall include any additional term, definition, abbreviated term and symbol used.

<4> General Description

a. The CAAR shall present the compatibility assessment and tailoring and introduce its terminology.

b. Reference shall be made to the applicable design definition file, inclusive of its revision status.

<5> Summary and Understanding of Compatibility

a. The CAAR shall list the materials, liquids and gases for which potential compatibility problems have been identified with the applicable operational, handling and storage conditions for the components, subsystem or propulsion system.

b. The CAAR shall present a justification of which compatibility problems have been solved already or have been identified not to be a problem for the envisaged application.

c. The CAAR shall include an evaluation of the compatibility problems for the material combinations that need further evaluation and identify the most appropriate means to solve the problems.

d. Following point A.2.1<5>c, the CAAR shall identify the required compatibility testing.

<6> Assessment Description

a. The CAAR shall contain a list of all applicable customer or project requirements, including those to cover Clauses 4 and 5.

b. The material combinations that have been analysed to identify possible compatibility issues shall be presented in the CAAR

c. For each build level, lower build level analyses shall be included for reference.

d. The result of A.2.1<6>a to A.2.1<6>c shall be presented in tabular form (see examples in Figure A-1 and Figure A-2.

e. The material combinations that have been analysed to identify possible compatibility issues shall be presented in the CAAR.

<7> Evaluation of Results

a. The CAAR shall give evidence how has been verified that a material combination

1. does not pose a compatibility problem, or
2. does pose a potential compatibility problem

b. In the case of A.2.1<7>a, the CAAR shall justify the reasons for selecting one of the following methods of verification:

1. a solution by analysis or similarity, or
2. a solution by testing.

c. In case the incompatibility issue for the propulsion system has been addressed by test, the CAAR shall state the type and number of tests to be performed.

d. The criticality of the incompatibility shall be included.

e. A compatibility test plan shall be included.

<8> Recommendations

Not applicable.

<9> Summary of Conclusions

a. The CAAR shall summarize the tests to be performed.

A.2.2 Special remarks

None.

Component / Subsystem / System Identification: Tank (Propellant, Part No. xxxyyyzzz)												
No.	Material Combinations	Project Requirements [1]	Annex C [2] and compatibility issues from other sources	Compatibility Issues [3] according to the Compatibility testing flow chart (Figure 4-1)								Status [4]
				Pure Compatibility tests [5] (6.2)	Material Selection Corrosion tests [6] (6.3)	Mechanical Properties tests [7] (6.4)	General Corrosion Tests [8] (6.5)	Change of Mechanical Properties of Polymers [9] (6.6)	Ageing Tests [10] (6.7)	Dissolution tests [11] (6.8)	Special Materials Testing [12] (6.9)	
1	Ti6Al4V / MON3 / He	15 yrs life Temp 0°C - 50°C 150 Pressure Cycles to MEOP	C.2.1 a C.2.1 c C.2.1 f	S1	6.3.2: S2, 6.3.3: S3	TBD	6.5.1:S1, S2 6.5.2, 6.5.3, 6.5.4:n/a1	n/a2	n/a3	6.3.3:n/a4 6.8.3:n/a5 6.8.4:S4	n/a7	O
2	Ti 6Al4V/ MON3 / CRES316	15 yrs life Temp 0°C - 50°C 150 Pressure Cycles to MEOP	C.2.1 a C.2.1 c C.2.1 f	S4	6.3.2: S2, 6.3.3: S3	TBD	TBD	n/a2	n/a3	6.3.3:S5 6.8.3:n/a6 6.8.4:S4	n/a7	O

[1] Project Requirements (e.g. Temperature, time, pressure cycles)
[2] Annex C – Identify the relevant item from Annex C or other item, to assess potential problems
[3] Codes – Not applicable n/a, Solved by Similarity S, To Be Determined TBD.
[4] Status – Open O, Compliant C. In 'status' only a C appears if none of the issues has a TBD
[5] Direct Reaction between Solid and Liquid (screening, Immersion, and Compatibility Immersion characterisation tests)
[6] Red-Ox Potential and Corrosion Potential tests.
[7] Tensile, Creep, Stress Corrosion, Verification of Crack Propagation,
[8] General Corrosion, Galvanic Corrosion and Coupled Galvanic, Crevice and Pitting Corrosion, and Ceramic corrosion tests.
[9] Mechanical Properties, Volume and Mass properties, Permeability.
[10] Aging of Polymers and lubricants, Aging of Ceramics.
[11] Dissolution of Solids in Liquids, Miscibility of Liquids, Dissolution of Gases in Liquids.
[12] Hydrogen Embrittlement, Impact with Lox and Gox, Autoignition Tests.

Figure A-1: Example of compatibility assessment

Component / Subsystem / System Identification: Tank (Propellant, Part No. xxxyyyzzz)			
Code	**Document Reference**	**Explanation / Title**	**Issue**
n/a1	--	No Polymers present	
n/a2	--	No galvanic coupling.	
n/a3	--	No ceramics or polymers	
n/a4	--	No dissolution of Ti6Al4V in MON3	
n/a5	--	No miscibility of liquids	
n/a6	--	No miscibility of liquids	
n/a7	--	No hydrogen or oxygen present	
S1	PROJ-RP-xxxx-ESA	Titanium Compatibility Test Report	Issue 1
S2	SSC Redox Test Rpt X ZZ	Redox potential tests of Ti alloys in MON	Issue 4
S3	SSC CrPt Test Rpt C/5	Corrosion potential tests of Ti alloys in MON	Issue 3
S4	Proj-RP-375C ESA	Cress Compatibility Test Report	Issue 1
S5	Rept XX / YY 2003 ESA	Dissolution of He in MON3	Issue 2

Figure A-2: Example of compatibility assessment, references

Annex B(normative) Compatibility Testing for Liquid Propulsion Report (CTLP) - DRD

B.1 DRD Identification

B.1.1 Requirement Identification

This DRD is called from ECSS-E-ST-35-10 requirements 5.1.2e, 6.1.4.3b, 6.7.2.1d, 6.7.3.1c, 6.10.2c, and 7a.2.

B.1.2 Purpose and objective

The objective of the CTLP is to:

- to give the reasons for performing the compatibility tests,
- to specify the compatibility tests ,
- to issue a compatibility test plan, and
- to present the results of the compatibility tests.

B.2 Expected Response

B.2.1 Scope and content

b. If deemed advantageous, the report can be delivered in separate volumes, where each volume can deal with an individual test or groups of similar tests.

c. The CTLP Report or each volume shall provide information presented in the following sections.

Introduction

a. The CTLP report shall contain a description of the purpose, objective contents and reasoning prompting its preparation.

<1> Applicable and reference documents

a. The CLTP report shall list the applicable and reference documents in support to the generation of the document.

<2> Terms, Definitions, Abbreviated terms and Symbols

a. The CLTP shall use the terms, definitions, abbreviated terms and symbols used in ECSS-E-ST-35 and ECSS-E-ST-32-10.

b. The CLTP shall include any additional term, definition, abbreviated term and symbol used.

<3> General Description

a. The CTLP Report shall contain:

1. a description and the objective of each test,
2. the compatibility test plan for each test or a reference to the compatibility test plan,
3. a list of accept / reject criteria,
4. the test specification for each test and a reference to the compatibility test procedure,
5. a test report inclusive any deviation or anomaly that occurred or was observed during execution of the test,
6. an evaluation of the results.

<4> Test description

a. The CLTP report shall give a detailed description of the test set-up and execution, including test equipment, instrumentation, data acquisition and accuracy of data.

b. Upon customer request photos and video recordings of tests and descriptive reports by specialists shall be provided.

<5> Review of results and comparison with requirements

a. The CLTP report shall include an analysis of the test results in view of

1. the accuracy of the data,
2. the validation of the test methods used,
3. deviations in test conditions and samples used to obtain the test results,
4. the results in comparison with the requirements,
5. ambiguous results or results that require approval by the customer.

b. In case previous test results are available a comparison with the previous results shall be made and the differences evaluated.

<6> Recommendations

a. Based on the information provided in B.2.1<5> the following recommendations shall be made:

1. improvements of the test methods,
2. improvements in the test equipment.

<7> Summary and conclusions

b. In the CLTP Report a summary of the test results shall be given, specifically addressing:

1. whether the compatibility requirements have been met,
2. limitations of the test method,
3. anomalies that have been observed during testing.

Annex C (normative) Propulsion components and subsystems compatibility aspects

C.1 General

C.2 to C.6 list the compatibility aspects for propulsion components and subsystems to be analysed when fulfilling requirement 5.1.2a and 5.1.2d.

C.2 Pressurization and propellant feed systems

C.2.1 Tanks

a. effect on tank material and instrumentation (chemical, physical)

b. dissolution of chemical compounds in the propellant

c. dissolution of pressurant gas into the propellant

d. leaching of SiO_2 from diaphragm / bladder

e. hydrogen embrittlement

f. stress corrosion

g. catalytic decomposition of the propellant

h. decomposition of the propellant due to autonomous chemical reactions

i. Liquid and gaseous oxygen compatibility (metals and non-metals)

C.2.2 Piping and orifices

a. transition joints: dissimilar metals in combination with electrolytes

b. effect on piping material (chemical, physical)

c. dissolution of chemical compounds in the propellant

d. hydrogen embrittlement

e. stress corrosion

f. catalytic decomposition of the propellant

g. decomposition of the propellant due to autonomous chemical reactions

h. Liquid and gaseous oxygen compatibility (metals and non-metals)

C.2.3 Valves and regulators

a. compatibility between propellant and structure materials

b. compatibility between propellant and seat materials

c. compatibility between propellant and seal material

d. compatibility between propellant and actuation gas

e. hydrogen embrittlement

f. stress corrosion

g. catalytic decomposition of the propellant

h. liquid and gaseous oxygen compatibility (metals and non-metals)

i. galvanic corrosion (dissimilar metals in contact with electrolytes)

C.2.4 Filters

a. compatibility with propellants and gases

b. catalytic decomposition of the propellant

c. corrosion (galvanic and general)

d. dissolution of chemical compounds into the propellant

C.2.5 Heat exchangers

a. compatibility with propellants and hot gases

b. stress corrosion

c. hydrogen embrittlement

d. liquid and gaseous oxygen compatibility

e. sulphur contamination with hydrocarbon fuels

C.2.6 Instrumentation

a. compatibility with propellants and gases

C.3 Engine

C.3.1 Valves

a. compatibility between propellant and structure materials

b. compatibility between propellant and seat materials

c. compatibility between propellant and seal material

d. compatibility between propellant and actuation gas

e. hydrogen embrittlement

f. stress corrosion

g. catalytic decomposition of the propellant

h. liquid and gaseous oxygen compatibility (metals and non-metals)

i. galvanic corrosion (dissimilar metals in contact with electrolytes)

C.3.2 Turbine

a. effects of oxidizer rich gases

b. effects of hydrogen embrittlement

c. stress corrosion in bearings

d. compatibility with lubricants (bearings and seals)

e. compatibility with turbine starter gases.

C.3.3 Pump

a. liquid oxygen compatibility

b. hydrogen embrittlement

c. stress corrosion in bearings

d. compatibility with lubricants (bearings and seals)

e. compatibility of lubricants and propellants

C.3.4 Gas generator and pre-burner

a. hydrogen embrittlement

b. effects of oxygen rich gases

c. effects of igniter gases

C.3.5 Injector

a. propellant compatibility

b. compatibility with combustion gases (face plate)

c. deposition of NVR

C.3.6 Igniter

a. includes compatibility problems that are encountered in combustion chambers

b. compatibility with combustion products

c. compatibility with plasma for spark plug igniters

C.3.7 Combustion chamber

a. oxygen radical contamination (blanching)

b. hydrogen embrittlement

c. compatibility with igniter gases

d. compatibility with coolant film

e. compatibility with combustion gases.

C.3.8 Catalyst bed

a. poisoning of the catalyst due to contaminants in the propellant (typically carbonaceous materials, silica and chlorides) and intermediate and final decomposition products.

C.3.9 Nozzle

a. Compatibility with combustion products

b. hydrogen embrittlement

c. ambient atmosphere compatibility (e.g. salt air, hot nozzle and atmosphere)

d. compatibility with coolant film

e. stress corrosion

C.3.10 Instrumentation

a. compatibility with combustion gases

b. compatibility with the propellants

C.4 Gimbal joint and actuation system

C.4.1 Gimbal joint

a. dissimilar metals (galvanic corrosion)

b. stress corrosion

c. compatibility with lubricants

C.4.2 Actuators

a. compatibility with actuator fluids

b. dissimilar metals (galvanic corrosion)

c. compatibility with lubricants

C.5 GSE

C.5.1 Test and measuring equipment

a. compatibility with propellants, cleaning fluids, pressurant gases and purge gases

NOTE 1 Plasticizers in polymer tubing can be extracted by propulsion fluids, deposited in the propulsion system and cause problems.

NOTE 2 During servicing activities due to permeable flexible connections or due to connect/disconnect activities small mounts of propellant can be spilled. Materials that can come into contact with propellant (e.g. floor of work area, spacecraft thermal protection) can be protected using materials that meet the compatibility requirements.

b. compatibility with the ambient (e.g. wet or salt atmosphere)

c. hydrogen embrittlement

d. liquid and gaseous oxygen compatibility

C.5.2 Loading and unloading equipment

a. compatibility with propellants, cleansing fluids, pressurant gases and purge gases

NOTE Plasticizers in polymer tubing can be extracted by propulsion fluids, deposited in the propulsion system and cause problems.

b. compatibility with the ambient (e.g. wet or salt atmosphere)

c. hydrogen embrittlement

d. liquid and gaseous oxygen compatibility

C.6 Miscellaneous

C.6.1 Interface joints

a. Galvanic corrosion (dissimilar metals)

b. compatibility of seals with joint materials and fluids

c. hydrogen embrittlement

d. liquid and gaseous oxygen compatibility

e. compatibility with fluids used in the propulsion system

f. compatibility with the environment

g. corrosion, stress corrosion

Annex D (normative) Known incompatibilities

This table is required to support the compatibility assessment (CAAR) as required in clauses 5.1.2a, 5.1.2d.

Table D-1: Known incompatibilities

'X' indicates that there is evidence of incompatibility. The absence of a 'X' implies that there is no evidence found of incompatibility but also not that compatibility has been demonstrated.

Fluid	Solid	Incompatibility		Remarks	References
		Short term [a]	Long term [b]		
Hydrazine (N_2H_4) (See Note 1)	Mild steels	X	X		c,d
	Stainless steel with Molybdenum		X		c
	Stainless steel 316	X	X	SS 304 is preferred	c
	Aluminium alloys 2020, 7075	X	X		c
	Magnesium	X	X		c,d
	Nickel (pure)	X	X		
	Materials alloyed with Nickel	X	X		
	Copper	X	X		c,d
	Copper alloys	X	X		c,d
	Zinc	X	X		c,d
	Cadmium	X	X		d
	Cobalt	X	X		d
	Lead	X	X		d
	Iron	X	X		d
	Molybdenum	X	X		d
	Metal oxides (general)	X	X		
	Epoxy		X		g
	Epoxy Epon VI		X	Probably short term incompatible	g

Fluid	Solid	Incompatibility		Remarks	References
		Short term [a]	Long term [b]		
	Polycarbonate (e.g. Lexan)	X	X	Dissolves in hydrazine	g
	Viton	X	X		c
	Vespel SP	X	X		e
	Kel-F	X	X		c
	PVC		X		c
	Mylar-A (polyethyleneterephthalate)	X	X		c
	Neoprene	X	X		c
	Silicone rubber	X	X		c
	Graphite	X	X		c
	Polyethylene		X		c
	Nylon	X	X		c
	Natural Rubber	X	X		
MMH ($N_2H_3CH_3$) (see Note 1)	SS 316		X		c,d
	Nickel-Maraging		X		d
	Nickel		X		c,d
	Molybdenum	X	X		d
	Monel		X		d
	Copper		X		d
	Chromium		X		d
	Iron (pure)	X	X		c,d
	Metal oxides (general)	X	X		
	Chloroprene			Probably long term incompatible	g
	Epoxy		X		g
	Epoxy Epon VI		X	Probably short term incompatible	g
	Kalrez			Avoid use in dynamic sealing applications, e.g. with periodic wetting and drying and temperature variations.	f
	Kel-F	X	X		d
	Natural Rubber	X	X		c

Fluid	Solid	Incompatibility		Remarks	References
		Short term [a]	Long term [b]		
	Phenol resins		X		g
	Silicone Rubber	X	X		c
	Viton, Viton A, Viton B		X		g
UDMH ($N_2H_2(CH_3)_2$) (See Note 1)	Cadmium	X	X		c
	Copper	X	X		c
	Copper-Alloys	X	X		c
	Metal oxides	X	X		c
	Tin (Sn)	X	X		c
	Zinc (Zn)	X	X		c
	Butyl rubber		X		c
	Viton	X	X		c
	Kel-F	X	X		c
	Silicone rubber	X	X		c
	Hycar	X	X		c
	Nylon		X		c
	PVC	X	X		c
	Mylar	X	X		c
	Viton, Viton A, Viton B		X		g
H_2 (Hydrogen)	See Note 2				
Kerosene	SS 316		X	corrosion rate 0,5 mm/year @ 120 °C	i
	Hastelloy C-276		X	corrosion rate 0,5 mm/year @ 100 °C	h
	Tantalum		X	corrosion rate 0,5 mm/year @ 20 °C	h
	Titanium		X	corrosion rate 0,05 mm/year @ 20 °C	h
	Styrene Butadiene	X	X		i
	Natural rubber	X	X		i
	Butyl	X	X		i
	Ethylene-propylene (EPDM, EPR)	X	X		i,j,o

Fluid	Solid	Incompatibility		Remarks	References
		Short term [a]	Long term [b]		
	Neoprene		X	According to Refs. h and n Neoprene is compatible with kerosene temperatures < 80 °C but not compatible with JP4 and JP5	c,i,h,n
	Polysulfide		X		i
	Silicone rubber	X	X		i,o
	Vamac		X		i
	Polyethylene, Low Density Polyethylene	X	X		k,l,m
	PVC	X	X		l,m,n
	Buna-N	X	X		o
	Viton A	X	X	According to Ref. j Viton is compatible with kerosene and jet fuel	o
	Polyurethane	X	X		p
	Linatex rubber	X	X		
Low molecular hydrocarbons (e.g. CH4, C2H6, C3H8)					
CH_4	Tantalum		X	corrosion rate 0,5 mm/year @ 120 °C	h
	Linatex rubber	X	X		h
	Natural rubber	X	X		k
	Butyl	X	X		i
	Ethelene-Propylene, (EPDM, EPR)	X	X		i,k
C_2H_6	EPDM, EPR	X	X		j
C_3H_8	SS 316		X	corrosion rate 0,5 mm/year @ 120 °C	h
	Hasteloy C-276		X	corrosion rate 0,5 mm/year @ 20 °C	h
	Tantalum		X	corrosion rate 0,5 mm/year @ 20 °C	h
	Titanium		X	corrosion rate 0,5 mm/year @ 20 °C	h
	Linatex rubber	X	X		h
	Ethylene-propylene (EPDM,EPR)	X	X		i,j
	Styrene Butadiene	X	X		i
	Natural rubber	X	X		i
	Butyl	X	X		i

Fluid	Solid	Incompatibility		Remarks	References
		Short term [a]	Long term [b]		
	Neoprene		X		i
	Silicone rubber	X	X		i
Alcohols					
CH_3OH	SS 316		X	corrosion rate 0,5 mm/year @ 120 °C	h
	Tantalum		X	corrosion rate 0,5 mm/year @ 120 °C	h
	Titanium		X	corrosion rate 0,5 mm/year @ 80 °C	h
	Aluminium	X	X		j,k
	Butyl	X	X		i
	EPR, EPDM	X	X		j
	PVC	X	X		o
	Chlorinated Polyethylene (CPE)	X	X		k
C_2H_5OH	Aluminium		X		q
	Brass, 360		X		q
	Carbon steel		X		l
	SS 316		X	corrosion rate 0,5 mm/year @ 120 °C	m
	Polycarbonate		X		q
	PVC		X		l,o
	Buna N		X		l
	Chlorinated Polyethylene (CPE)		X		o
	Viton	X	X		j
	Polyacrylate	X	X		i
	Polyurethane	X	X		i
$CH_3CHOHCH_3$ (Iso propyl alcohol)	Aluminium	X	X		j,k
	Hasteloy C 276		X	corrosion rate 0,05 mm/year @ 20 °C	h
	Tantalum		X	corrosion rate 0,5 mm/year @ 20 °	h
	Titanium		X	corrosion rate 0,05 mm/year @ 20 °C corrosion rate 0,5 mm/year @ 80 °C	h
	Polyurethane	X	X		i,n
	Polyacrylate	X	X		i
	EPDM	X	X		k
	Buna-N	X	X		k

Fluid	Solid	Incompatibility		Remarks	References
		Short term [a]	Long term [b]		
	Butyl	X	X		i
	EPR, EPDM	X	X		j
	PVC	X	X		o
	Chlorinated Polyethylene (CPE)	X	X		k
N_2O_4 (and MON) (See Note 3)	Cadmium	X	X		c
	Copper	X	X		c
	Copper alloys	X	X		c
	Silver (Ag)	X	X		c
	Nickel	X	X		c
	Magnesium Alloys	X	X		c
	Pure iron	X	X		c
	Chromium		X		c
	Zinc	X	X		c
	Zirconium	X	X		c
	Butyl rubber		X	Used on Ariane 4	c
	Chloroprene	X	X		g
	Epoxy resin	X	X	Compatibility depends strongly on type of epoxy resin. It can vary from 'completely degraded' and 'dissolved in 7 days' to 'discoloration'	g
	Epoxy Epon VI		X		g
	EPR		X		g
	Fluorinated rubbers (Viton, Fluorel)		X	Viton B seems to be compatible with N_2O_4 ; and Fluorel KX-2141may be short term compatible if a large swell is acceptable	g
	Kalrez			Avoid use in dynamic sealing applications, e.g. with periodic wetting and drying and temperature variations.	f
	Kel-F	X	X		c,d
	PMMA (Plexiglas, Perspex, Lucite, etc.)	X	X		c
	Polyamide (Nylon, Capran)	X	X		c,g

Fluid	Solid	Incompatibility		Remarks	References
		Short term [a]	Long term [b]		
	Polycarbonate (Lexan)	X	X		g
	Polyesters (Mylar)	X	X		c,g
	Polyether	X	X		c
	Polyethylene	X	X		g
	Polyoxymethylene (POM, Polyacetal, Derlin)	X	X		g
	Polypropylene	X	X		c
	Polyurethane	X	X		g
	Silicone polymers	X	X		g
	Silicone rubbers	X	X		g
	Vinyl benzene (Styrene)	X	X		g
Hydrogen peroxide (H_2O_2)	Copper containing alloys		X		c
	Silver (Ag)	X	X	Decomposition catalyst!	c
	High strength Aluminium alloys		X		c
	SS series 400	X	X		c
	Cobalt alloys	X	X		c
	Nickel-alloys	X	X	Except Inconel X	c
	Zinc	X	X		c
	Tungsten	X	X		c
	Titanium	X	X		c
	Magnesium	X	X		c
	Beryllium	X	X		c
	Cadmium	X	X		c
	Chromium	X	X		c
	Lead	X	X		c
	Manganese	X	X	MnO_2 is a decomposition catalyst	c
	Platinum	X	X		c
	Buna N	X	X		c
	Butyl rubber	X	X		c
	Adiprene C	X	X		c
	Neoprene	X	X		c
	Nylon	X	X		c

Fluid	**Solid**	**Incompatibility**		**Remarks**	**References**
		Short term [a]	**Long term** [b]		
	PMMA (Perspex, plexiglas, Lucite)	X	X		c
LOx, Gaseous O_2	*Material and equipment are always be thoroughly degreased before use.* See further Note 4				
Distilled, demineralized or softened water is extremely corrosive unless it is completely de-aerated r					
Acetone	Aflas	X	X		s
	Buna-N	X	X		s
	Fluorocarbon	X	X		s
	Natural Rubber		X		s
	Polysulfide	X	X		s
Methyl Ethyl Ketone	Aflas	X	X		t
	Buna-N	X	X		t
	Epichlorohidirn	X	X		t
	Fluorocarbon	X	X		t
	Fluorosilicone	X	X		t
	Hypalon	X	X		t
	Natural Rubber	X	X		t
	Neoprene	X	X		t
	Hydogenated Nitrile	X	X		t
	Polyacrylate	X	X		t
	Polyurethane	X	X		t
	Silicone Rubber	X	X		t
	Styrene Butadiene	X	X		t
	Vamac	X	X		t

Fluid	Solid	Incompatibility		Remarks	References
		Short term [a]	Long term [b]		

NOTE 1 Compatibility of hydrazines: the incompatibility effects are in general severest for pure hydrazine (N2H4) and decrease with increasing methane branches, i.e. MMH (N2H3CH3) shows less severe incompatibility than N2H4, but slightly more severe than UDMH (N2H2(CH3)2). An exception is compatibility w.r.t. catalyst poisoning, that very strongly increases with carbon content; here the order of incompatibility sensitivity is reversed.

NOTE 2 Liquid hydrogen and gaseous hydrogen at low temperatures are both considered being non-corrosive. Embrittlement of metals by gaseous hydrogen is a more important factor. A number of metals can be rated compatible with hydrogen; among these are the 300 series stainless steels, Type 410 stainless steel, aluminium and most of its alloys, some nickel alloys, cobalt alloys and molybdenum. The use of organic materials for liquid hydrogen is limited because of the effect of low temperature on their physical properties c.

NOTE 3 In general most organic hydrocarbon compounds are considered incompatible with N2O4 and MON's . Compatibility of metals with N2O4 strongly depends on the amount of water in the N2O4 and the amount of NO. The higher the NO-content, in general, the better the compatibility with metals, and the lower the water content the better the compatibility.

NOTE 4 Liquid and gaseous oxygen can ignite combustible materials (e.g. metals, polymers). The safe and reliable use of materials in combination with oxygen very much depends on operational conditions. Specific tests can be necessary to establish whether the material is compatible with oxygen under the envisaged conditions.

a Order of months

b Order of years.

c Compatibility of materials with rocket propellants and oxidizers, Battelle Memorial Institute, Columbus Ohio, 29 January 1965.

d P.E. Uney & D.A. Fester, Material Compatibility with Space Storable Propellants – Design Handbook, MCR-72-26 / NASA – CR 127057, NASA / JPL California Institute of Technology, (Prepared by Martin Marietta), March 1972

e Vespel S-Line Design Handbook, E.I. Dupont de Nemours (not dated)

f Experience with Cluster satellites, Information EADS ASTRIUM UK, 10th July 2008

g N. E. Beach "Compatibility of Plastics with Liquid Propellants, Fuels and Oxidizers", Plastec Report 25, Plastics Technical Evaluation Center, Picatinny Arsenal, Dover, New Jersey, January 1966

h Rosemount Technical data sheet 00816-0100-3033, Rev. CA July 2002

i Engineering Fundamentals eFunda 2005 O-ring Chemical Compatibility Guide

j Smith meter Inc. Compatibility manual, Bulletin AB0A002

k Naval Facilities Engineering Service Center, User Guide UG-2033-ENV "Spill Prevention Guidance Document", October 1998, Appendix E,"Chemical / Material Compatibility Matrix"

l Chemical resistance: A Guide to common materials (Internet)

m Ben Meadows Company TechInfo Corrosion & Chemical Resistance, A Guide to Common Materials, Document # 164

n Eaton Weatherhead Hose Assembly Master catalogue W-HYOV-MC002-E November 2002

o Chemical compatibility guide www.millipore.com

p Rosemount Technical data sheet 00816-0100-3033, Rev. CA July 2002

q Chemical compatibility, valve communication and control, StoneL support

r Water (http://httd.njuct.edu.cn/matweb/water/e_h2o.htm)

s www.efunda.com/designstandards/oring/oring_chemical.cfm?SM=none&SC=Acetone

t www.efunda.com/designstandards/oring/oring_chemical.cfm?SM=none&SC=Methyl%20Ethyl%20Ketone%20%28MEK%29#mat

Annex E (informative) Example of tailoring the requirements list for propulsion systems

7.2 Use of the compatibility testing flow chart for Liquid Propulsion System compatibility testing

The compatibility testing flow chart is given in Figure 4-1. A case is considered where a completely new storable liquid propellant is used in an existing propulsion system. The liquid propellant is an electrolyte.

Therefore all structural materials are known and compatibility tests are mandatory but at this stage no material selection tests.

The first test to be performed is a safety test, 6.1.2 on the propellant and propellant material combinations. Safety tests are not part of compatibility testing but are performed in case safety risks have been identified or the safety characteristics of the propellant or the propellant-material combinations are unknown to ensure the safety of personnel and equipment.

The first compatibility test is the immersion screening test, 6.2.1, or the immersion characterization test, 6.2.3, depending on how detailed information one wants.

Accept / reject criteria have been established beforehand.

In this case it is assumed that the metal properties can only be affected for what concerns stress corrosion and crack propagation. Those materials that passed the immersion screening test, 6.2.1, or the immersion characterization test, 6.2.3 , are subjected to the stress corrosion tests, 6.4.3, and those materials that pass are submitted to the verification of crack propagation tests, 6.4.4.

Subsequently, the general corrosion tests, 6.5.1, the galvanic corrosion tests, 6.5.2, and the Coupled galvanic corrosion, crevice corrosion and pitting corrosion tests, 6.5.3, are performed.

Polymers and lubricants are subjected to aging of polymers and lubricants test, 6.7.2, to establish whether their ageing characteristics have changed due to the contact with the propellant. For comparative reasons the properties of the untested material are known in advance.

Those polymers that pass this test are then again subjected to mechanical properties test, 6.6.2, and the volume and mass properties test, 6.6.3.

Sheet material (e.g. bladder, diaphragm, gasket) is subjected to the permeability test 6.6.4. In this test the appropriate gas that is used as pressurant gas is used, e.g. N_2 or He.

Finally the polymers are subjected to the dissolution of solids in liquids test, 6.8.2, and the propellant is submitted to the dissolution of gases in liquids test, 6.8.4, for the appropriate gases, e.g. N_2 or He that are being used as pressurant gas.

Only those tests are executed where there is no information on the compatibility of the existing materials with the new propellants. If certain information is available from other sources, certain tests can be deleted.

In the operational tests, 6.10, specific compatibility aspects can be identified that allow operational verification of the compatibility of materials and propellant.

Bibliography

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