1. Materials definition

1.1. The material under consideration shall be defined by a materials specification – the specification can be a nationally-recognized standard or a company-defined specification. The materials specification shall include requirements for the following:

1.1.1. allowable compositional ranges;

1.1.2. specified minimum tensile yield strength, Sy;

1.1.3. specified minimum tensile strength, Su;

1.1.4. specified minimum tensile elongation, El.

1.2. The material should be tested in the final product form whenever possible. When the component geometry precludes extraction of test specimens, the material may be tested in the semi-finshed product form with mechanical properties that are nominally equivalent to the mechanical properties of the component.

1.3. Either the materials manufacturer's certification or equivalent testing performed in air at room temperature may be used to verify that the material meets the specification. The measured tensile strength is denoted S* (average value from at least two tests at room temperature in air or from the mill certification) and is used to define the maximum stress for fatigue testing.

1.4. Welds and metallurgically-bonded materials

1.4.1. When materials are welded (or metallurgically-bonded) and the joint is exposed to hydrogen gas, weld specimens shall be tested in conjunction with the base materials for hydrogen compatibility.

1.4.2. Welds and metallurgically-bonded materials shall be defined by a welding procedure specification (WPS) that defines the joining procedure as well as the composition and specified minimum tensile requirements (Sy, Su and El) of the joined structure (e.g., weld metal).

1.4.3. Test specimens should be extracted from the joined structure whenever possible. Representative joints can be prepared, if test specimens cannot be extracted from the joined structure.

1.4.4. Weld test specimens shall be measured in gaseous hydrogen and shall satisfy the requirements of the WPS as well as the fatigue life requirements in section 3.2.

2. Environmental test conditions

2.1. Gas purity: the purity of the gaseous hydrogen from the testing chamber (referred to as the sampled gas) shall be verified to satisfy the requirements from Table 2.1. The hydrogen source gas shall meet the requirements of applicable fueling standards or the values in Table 2.1.

2.1.1. If three consecutive tests of the sampled gas meet the oxygen and water vapor requirements in Table 2.1, the gas may be sampled periodically at an interval not exceeding 12 months. If the sampled gas does not meet the requirements, the test system is modified, the purging procedures are changed, or the gas sampling interval exceeds 12 months, three consecutive gas samples shall be evaluated to demonstrate that the test system and procedures meet the requirements of Table 2.1.

Table 2.1. Gaseous hydrogen purity requirements in parts per million by volume (except where noted).

Species	Source gas requirements	Sampled gas requirements
H2	99.999% min	–

O2	≤ 1	< 2
H2O	≤ 3.5	< 10
CO + CO2	≤ 2	–

2.2. Pressure

2.2.1. Testing in gaseous hydrogen shall be performed at a minimum hydrogen pressure of 1.25xNWP.

2.3. Temperature

2.3.1. The specimen temperature for fatigue life testing in hydrogen shall be 293 ± 5K.

2.3.2. The specimen temperature for slow strain rate tensile (SSRT) test in hydrogen shall be 228 ± 5K.

3. Testing requirements

3.1. The requirements for either the notched specimen methodology (option 1) or the smooth specimen methodology (option 2) shall be satisfied. It is not necessary to satisfy both the notched and smooth methods.

3.2. Notched specimen methodology (option 1).

3.2.1. Notched bar specimens shall be used with an elastic concentration factor (Kt) of greater than or equal to 3. A minimum of three specimens shall be tested in the environmental conditions decribed in section 2.

3.2.1.1. Force-controlled fatigue life tests shall be performed with a constant load cycle in accordance with internationally-recognized standards. The stress at maximum load during fatigue cycling shall be greater than or equal to 1/3 of S* (the average tensile strength measured at room temperature in air). The stress is defined as the load divided by the net-section stress (i.e., minimum initial cross sectional area of the specimen). The load ratio (R) shall be 0.1, where $R = S_{min}/S_{max}$ (S_{min} is the minimum net-section stress and S_{max} is the maximum net-section stress).

3.2.1.2. The frequency shall be 1 Hz or lower.

3.2.2. Requirements

3.2.2.1. For notched-specimen fatigue testing, the number of applied cycles (N) shall be greater than 10^5 cycles for each tested specimen.

3.3. Smooth specimen methodology (option 2).

3.3.1. Smooth fatigue specimens shall be used in accordance with internationally-recognized standards. A minimum of three specimens shall be tested in the environmental conditions decribed in section 2.

3.3.1.1. Force-controlled fatigue life tests shall be performed with a constant load cycle in accordance with internationally-recognized standards. The stress at maximum load during fatigue cycling shall be greater than or equal to 1/3 of S* (the average tensile strength measured at room temperature in air). The stress is defined as the load divided by the net-section stress (i.e., minimum initial cross sectional area of the specimen). The load ratio (R) shall be -1 (fully reversed tension-compression load cycle), where $R = S_{min}/S_{max}$ (S_{min} is the minimum net-section stress and S_{max} is the maximum net-section stress.

3.3.1.2. The frequency shall be 1 Hz or lower.

3.3.2. Slow strain rate tensile (SSRT) test specimens shall be used in accordance with internationally-recognized standards. A minimum of three specimens shall be tested in the environmental conditions described in section 2.

3.3.2.1. Displacement during the test shall be measured on the specimen over a conventional gauge length (≥ 12 mm and 3-5 times the diameter of the specimen). Normally, this is an extensometer attached directly to the specimen, but other equivalent methods are acceptable. The measured strain rate (between the yield force and the maximum force) shall be ≤5 x 10^{-5} s^{-1}.

3.3.3. Requirements

3.3.3.1. For smooth-specimen fatigue testing, the number of applied cycles (N) shall be greater than $2x10^5$ cycles for each tested specimen.

3.3.3.2. For SSRT testing, the measured yield strength shall be greater than 80% of the yield strength measured in air at the temperature defined in section 2.3.2.

4. Summary of tests and requirements

4.1. Table 4 summarizes the test requirements for the two testing method options: notched and smooth respectively.

Table 4. Summary of tests and requirements for hydrogen compatibility of materials.

		Notched method (option 1)	Smooth method (option 2)
Fatigue life	Test conditions	• H2 pressure = 1.25 NWP • Temperature = 293 ± 5K • Net section stress ≥ 1/3 S* • Frequency = 1 Hz	• H2 pressure = 1.25 NWP • Temperature = 293 ± 5K • Net section stress ≥ 1/3 S* • Frequency = 1 Hz
	Number of tests	3	3
	Requirements for each test	$N > 10^5$	$N > 2x10^5$
SSRT	Test conditions	Not required	• H2 pressure = 1.25 NWP • Temperature = 233 ± 5K • Displacement rate ≤ $5x10^{-5}$ s^{-1}
	Number of tests		3
	Requirements for each test		Yield strength > 0.80 yield strength in air at same temperature