Proposal for GTR no13 phase II

Humid Gas Stress Corrosion Cracking of Aluminum Alloys

1. Materials definition

1.1. The materials are wrought aluminum alloy products.

1.2. 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:

1.2.1. allowable compositional ranges;

1.2.2. specified minimum yield strength, Sy

1.2.3. specified minimum tensile strength, Su

1.2.4. specified minimum tensile elongation, El

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 0.2% proof stress is denoted $\sigma_{0.2}$ (average value from two specimens measured at room temperature in accordance with the procedures given in ISO 6892-1) and is used for fatigue pre-crack introducing.

2. Environmental test conditions and period

2.1. Temperature: 298 K $\pm$ 5 K for the entire duration of test

2.2. Atmosphere and humidity: no generation of dew in air measuring 85% of higher in relative humidity for the entire duration of the test

2.3. Test period: 90 days (in accordance with B6.6 of ISO 7866:2012)

3. Testing requirements

3.1. Test specimen: One of the specimen geometries, or a combination of them, shall be used for test.

1) Compact specimen of ISO 7539-6:2011

2) Single edge bend specimen (SE specimen or cantilever bend specimen of ISO 7539-6:2011)

3) Double-cantilever-beam specimen (DCB specimen) of ISO 7539-6:2011

4) Modified wedge-opening-load-specimen (modified WOL specimen) of ISO 7539-6:2011

5) C-shaped specimen of ISO 7539-6:2011

3.2. Specimen orientation: the orientation of specimen sampling shall be Y-X orientation. Other orientation may be added when necessary.

3.3. Fatigue pre-crack shall be introduced in accordance with class 6 of ISO 7539-6

3.4. A load is applied under constant load or constant displacement conditions.

1) For constant load condition, it is necessary to employ a testing machine capable of load accuracy control within ±1% of the load applied, as defined in 7.6.3 of ISO 7539-6:2011.

2) For constant displacement condition, the sensitivity of the displacement gage shall be not less than 20mV/mm so as to minimize the excess amplification of small signals. The linearity of the gage is such that the deviation from the true displacements shall not exceed 3 μm (0.003 mm) for smaller displacements up to 0.5 mm and not exceed 1 % of recorded values for larger displacements. These conditions are in accordance with 7.5.3 of ISO 7539-6:2011.

3) The value of K_{IAPP} obtained by the following equation given in B.6.2 of ISO 7866:2012 is loaded.

$$K_{\mathrm{IAPP}} = 0.056\sigma_{0.2} \quad (1)$$

3.5. Measurement of load: For constant displacement condition, the load shall be measured by the following method after the 90-day test period.

3.5.1 When the load is not monitored:

1) At the end of the test, the crack mouth opening displacement is measured before removal of the load.

2) The load is removed.

3) The load is reapplied until the crack mouth opening displacement attains the value in 1) with a load measuring instrument.

3.5.2 When the load is monitored, the load at the end of the test is measured. It is also acceptable to calculate the load value from the values of elastic strain measured between the start and the end of the test.

3.6. Fatigue post-cracking and breaking shall be introduced as follow

1) For constant load condition, a fatigue post-crack is introduced until the post-crack length is extended to 1 mm or more by applying a fatigue load equivalent to a stress intensity factor not exceeding 0.6 times the value of K_I obtained by loading.

2) For constant displacement condition, after the load measurement as 3.5 the load is removed and a fatigue post-crack is introduced until the post-crack length is extended to 1 mm or more by applying a fatigue load equivalent to a stress intensity factor not exceeding 0.6 times the value of K_I obtained in 3.5

After the introduction of a fatigue post-crack the specimen shall be broken open. If it is possible to identify the HG-SCC fracture surface, the specimen may be broken by a method other than the introduction of a fatigue post-crack.

3.7. Measurement of crack length: After breaking of the specimen, the following aspects of crack length shall be measured using a scanning electron microscope (SEM) or other measuring instruments with an accuracy within ±0.01 mm.

1) effective crack length including the fatigue pre-crack a_{pre}

2) effective crack length up to the tip of the HG-SCC crack a_{scc}

The measurement shall be conducted from the direction perpendicular to the broken surface at the positions 25 %, 50 % and 75 % of the specimen thickness, and the average value of the measurements at these 3 points is selected as the effective crack length.

3.8. Validity of test

3.8.1 Fatigue pre-crack: Of the a_{pre} values for the position of 25%, 50% and 75% of the specimen thickness, it shall be verified that the difference between the largest and smallest values does not exceed 5% of net specimen width W.

3.8.2 Small scale yielding and plane strain condition: It shall be verified that a, (W-a) and B satisfy the following equation as specified in B6.7 of ISO 7866:2012

$$a,\ (W\text{-}a),\ B \geqq 1270(K_I/\sigma_{0.2})^2$$

Where, a, (W-a) and K_I are as follows.

For constant load condition: $a = a_{scc}$

$$(W\text{-}a) = (W\text{-}a_{scc})$$

$$K_I = K_{IAPP}$$

For constant displacement condition: $a = a_{pre}$

$(W\text{-}a) = (W\text{-}\ a_{pre}\ )$

$K_I = K_{IAPP}$If test condition do not satisfy these requirements, the test is invalid.

3.9. Requirement

The applicability of materials shall be judged as follows.

1) The crack extension (a_{scc} - a_{pre}) by HG-SCC [see 3.8] is examined to exceed 0.16 mm or not.

2) The actual applied value of K_{IAPP}, which is defined as K_{IA}, is calculated by using a_{pre} and the load applied according to 3.4 1**)** for constant-load condition and 3.4 2**)** for constant-displacement condition.

3) The validity of materials is judged as shown in Table 1.

Table 1 Qualification of materials

Case	Crack extension	K_{IA} versus K_{IAPP}	Judgment*
I	($a_{scc} - a_{pre}$) $\leqq$ 0.16mm	$K_{IA} < K_{IAPP}$	invalid
II		$K_{IA} \geqq K_{IAPP}$	pass
III	($a_{scc} - a_{pre}$) > 0.16mm	$K_{IA} \leqq K_{IAPP}$	fail
IV		$K_{IA} > K_{IAPP}$	invalid

* Material shall be judged as follows

Pass : Materials that satisfy this requirement are judged to have applicable resistance to HG-SCC for compressed hydrogen containers as specified in B.7.3 of ISO 7866:2012

Fail : Materials are judged to be failed for application for compressed hydrogen containers.

Invalid : Materials cannot be judged in these conditions.

In case I, another testing is recommended in the condition K_{IA} equals to K_{IAPP} or is in some degree greater than K_{IAPP} .

In case IV, where K_{IA} is considerably greater than K_{IAPP}, another testing is recommended because materials may pass in the condition K_{IA} is a little greater than K_{IAPP}.

4) A minimum of three valid specimens shall be passed in this test.

4. Summary of tests and requirements

Table 2 Summary of test conditions and Requirement

Load	Constant load or Constant displacement
Temperature	298 K $\pm$ 5 K
Atmosphere and humidity:	Air (85% or higher in relative humidity)
Number of specimens	3 (valid)
Test period	90 days
Criteria	$(a_{scc} - a_{pre}) \leqq 0.16$ mm $K_{IA} \geqq K_{IAPP}$