

Necessity of HG-SCC test method for aluminum alloys

Transmitted by Japan

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1. Background

- Japan has been proposing Humid Gas Stress Corrosion Cracking (HG-SCC) test method at the previous GTR No.13 IWG. However the necessity of this test method does not seem to be understood by each country's representative.
- The common consensus of the necessity for HG-SCC test method is desirable, by sharing the target corrosion phenomena and the position of this test method.

2. Understanding on corrosion phenomena of aluminum alloys

2 types of corrosion phenomena in aluminum alloys

SLC : Sustained Load Cracking
 SCC : Stress Corrosion Cracking

Type	Anodic dissolution	SCC in humid gas environment
Principle	<p>Electrochemical corrosion by salt water</p> <p>(b) Cathode reaction : $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$</p> <p>Chloride solution</p> <p>Migration</p> <p>Passive film</p> <p>Precipitate</p> <p>Al</p> <p>Anodic reaction : $Al \rightarrow Al^{3+} + 3e^-$</p> <p>Hydrolysis reaction : $Al^{3+} + 3H_2O \rightarrow Al(OH)_3 + 3H^+$</p>	<p>SCC by the reaction of metallic Al and H_2O</p> <p>Hydrogen atom generated by reaction of water on fresh metallic surface</p> <p>Intergranular cracking by continuous hydrogen atom penetration</p>
Reaction	<p>Anodic reaction : $Al \rightarrow Al^{3+} + 3e^-$</p> <p>Cathode reaction : $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$</p>	<p>$2Al + 3H_2O \rightarrow Al_2O_3 + 6H$</p>
Characteristics	<ul style="list-style-type: none"> • Need oxygen and solution • Need Cl^- (break passive film) • Not occur in high pressure H_2 (no oxygen and no solution) <p>⇒ Occur only outside of containers</p>	<ul style="list-style-type: none"> • Occur under the presence of H_2O • Crack growth by accumulation of hydrogen atoms at the crack tip (on fresh metallic surface), not by dissolution of metal into ion <p>⇒ Occur both outside and inside of containers</p>
Evaluation	<p>Current test method applied by each car OEM</p>	<p>✳ HG-SCC test method (Improved SLC test) proposed by Japan for GTR13</p>

✳ HG-SCC test method is different from H_2 compatibility test method in high pressure hydrogen gas environment.

3. Past accident cases

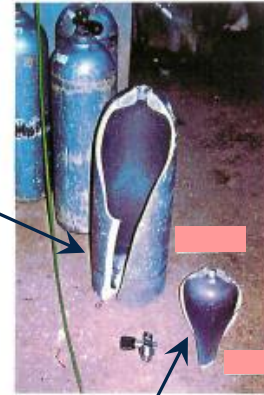
- Some accidents that seem to be caused by HG-SCC occurred in scuba containers of 6351 alloys.

Accident cases of cylinder made of aluminum alloy for SCUBA

From accident Investigation Committee in KHK (11.2001)

No.	Date (M/D/Y)	Place of occurrence	Human damage	Material	Manufacturing date	Duration of use	Damage condition	Handling condition
1	6.4.1994	Miami, Florida, USA	Severe:1	A6351	11.1982	11.5 years	Rupture	During refilling
2	7.1996	Alabama, USA	Unknown	A6351	Unknown	Unknown	Rupture	During refilling
3	5.30.1997	Vestfold, Norway	None	A5283	1973	24 years	Rupture	During storage
4	1.1998	New South Wales, Australia	Unknown	A6351	10.1982	15.3 years	Rupture	During storage
5	2.1.1998	Riviera Beach, Florida, USA	Severe:1 Slight :2	A6351	Unknown	Over 10 years	Rupture	During refilling
6	8.1998	Tairua, New Zealand	Injury	A6351	10.1980	18 years	Rupture	During refilling
7	12.1998	Tampa, Florida, USA	None	A6351	Unknown	Unknown	Rupture	During refilling
8	3.2000	Key Largo, Florida, USA	Severe:1	A6351	1987	13 years	Rupture	During refilling

Larger piece



Smaller piece

Appearance of the broken container

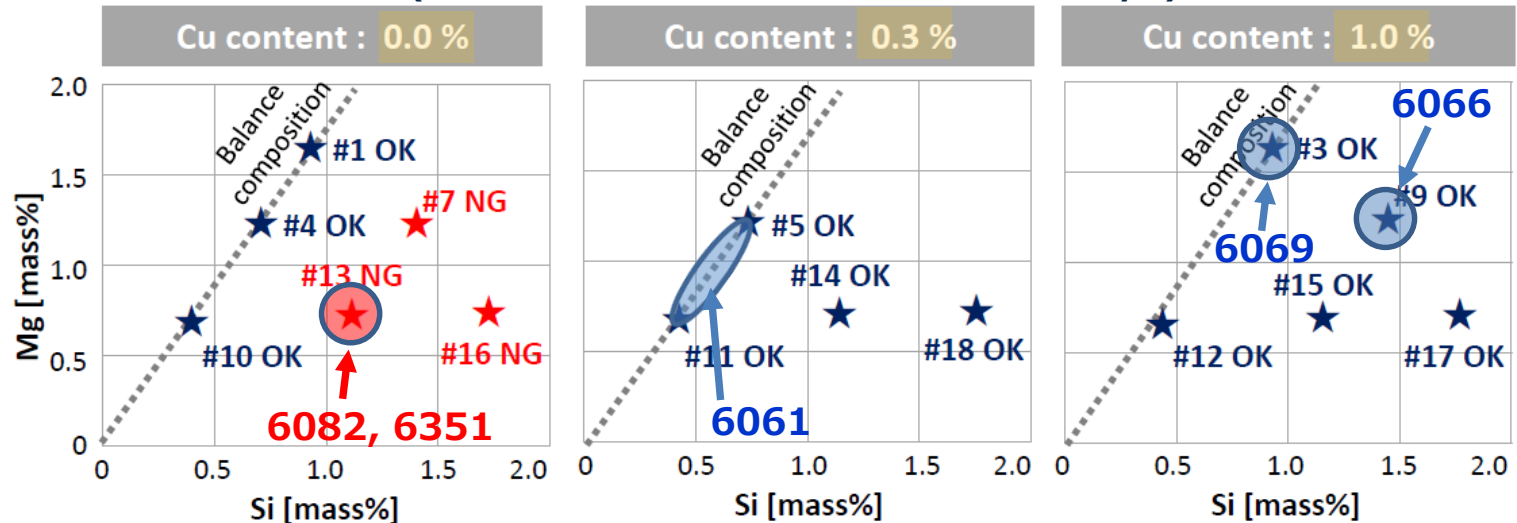
4. Position of HG-SCC test method

- Only for aluminum alloys
 - Application to other metals such as stainless steel is unnecessary.
- Effective for evaluating safety when expanding the types of aluminum alloys
 - In addition to existing 6061-T6 alloys, HG-SCC test has been done for other various alloys (see below) in humid air in Japan.
 - It does not greatly inhibit future expansion of material types.

Result of HG-SCC test classified by alloy composition (Mg, Si and Cu)

- Test condition : 25°C , RH85 % , 90 days
- Qualification : The crack extension exceeds 0.16 mm or not.

(In the case of 6000 series aluminum alloys)



6. Plan of verification test (in humid hydrogen gas environment)

- **objective : Confirm whether the same results as the evaluation under humid air environment can be obtained also under humid hydrogen environment.**

- ◎ Samples

 - A6061-T6 / A6082-T6 / A7075-T6

- ◎ Specimen shape

 - ½ inch compact tension (CT) specimen based on ISO 7539-6

- ◎ Test type

 - Stepwise-load test or rising-load test.

- ◎ Gas condition

 - High purity hydrogen gas (Pure H₂)

 - 10MPa, G1 grade (99.99999%; 7N), Frost point: -80°C* (~0.004ppm H₂O)

 - Humid hydrogen gas (Wet H₂)

 - 10MPa at 20°C, Frost point: -15°C (24.7~27.3ppm H₂O*)

 - (* GAS specification)

- ◎ Temperature

 - Room temperature (ambient temperature)

 - Low temperature : -15°C±1°C

- ◎ Test schedule

 - Modification of sample setup jig

 - ~2019.05

 - Preparation of test pieces

 - ~2019.06

 - Modification of cooling system

 - ~2019.06

 - Pretest

 - 2019.07~2019.08

 - Test

 - 2019.09~

(Reference) Verification tests of the other test labs

- Validation test plan at Sandia National Laboratories (US)
 - ✓ Constant displacement SCC test in high pressure humid hydrogen environment : end of August
 - ✓ Fatigue crack growth test in high pressure humid hydrogen environment : end of summer

- Validation test plan at MPA Stuttgart (Germany)
 - ✓ HG-SCC test in humid air environment based on Japanese proposal (HPIS E 103:2018) : end of March, 2020
(1st data : end of December)

7. Summary

- 2 types of corrosion phenomena exist in aluminum alloys.
 - The anodic dissolution corrosion by salt water occur outside of the containers. It is possible to evaluate this phenomenon using the current test method applied by each car OEM.
 - The stress corrosion cracking in humid gas environment (HG-SCC) may occur both outside and **inside of the containers**. Since it is difficult to detect HG-SCC especially **inside of the containers**, new test method at material level is necessary.
- This HG-SCC test method is for evaluating safety of aluminum alloys in humid gas environment. It does not greatly inhibit future expansion of material types.
- In addition to evaluation in humid air environment, other verification tests in humid hydrogen gas environment have been planned for validation of HG-SCC test method.
 - Japan will show some of the test results at the 7th GTR No.13 IWG on November 2019.

**Thank you for
your kind attention**