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Bolt Breakage Incident for Low-Level Radioactive Waste Container（2）

―Quantitative Assessments on Delayed Fracture Sensitivity of Lid Bolts for Low Level Radioactive Waste Container by Slow Strain Rate Test (SSRT)―

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Abstract

We found a total of five fractured lid bolts on low-level radioactive waste (“LLW”) containers in storage from February to June 2015. We identified the cause to be delayed fracture, which can occur in high-tensile strength bolts. Therefore, to prevent any such recurrences, we decided to use material with a lower tensile strength to improve the susceptibility to delayed fracture.

Lowering tensile strength is valid for preventing the recurrence of a delayed fracture, as indicated by reference publication[1)]. On the other hand, we conducted a slow strain rate test (SSRT) to quantitatively assess the effectiveness of the recurrence prevention measure.

As a result of SSRT, we confirmed that the delayed fracture susceptibility of 900MPa class tensile strength bolts, which have a reduced tensile strength, was a lower than that of 1200MPa class tensile strength bolts, which experienced delayed fracture. There was no significant difference in susceptibility to delayed fracture between 900MPa class tensile strength bolts and those having a tensile strength of 1000MPa for which we have never experienced a delayed fracture in over 20 years. Consequently, we confirmed that using 900MPa class tensile strength bolts is valid as a measure for preventing recurrence of delayed fracture.

Introduction

We replaced LLW containers (Fig.1) about three years ago (minor change in lid structure). After the replacement, we found a total of five fractured lid bolts on LLW containers in storage from February to June 2015. We had never experienced this phenomenon in the 20 years since we started LLW transport using the previous containers.

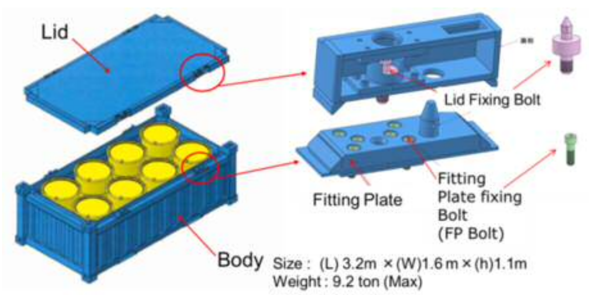

Fig. 1　Overview of LLW container

We conducted a survey of the conditions in which LLW containers were used and analyzed factors using a fault tree analysis to identify that the cause was delayed fracture, which is characteristic of 1200MPa class and higher high-tensile strength bolts (see PATRAM2016: "Bolt Breakage Incident for Low-Level Radioactive Waste Container(1)"). Because 1200MPa class tensile strength bolts were used on the new containers, on which five fractured lid bolts were found, we changed to a 900MPa class tensile strength bolt to prevent recurrence of delayed fracture.

Using 900MPa class tensile strength bolts is valid for preventing recurrence of delayed fracture as indicated by reference publication[1)]. On the other hand, we conducted a slow strain rate test (SSRT) to quantitatively assess the effectiveness of the recurrence prevention measure. Here, we present the results of the SSRT.

Mechanism of Delayed Fracture

Delayed fracture is caused by hydrogen embrittlement. There are various theories about the hydrogen embrittlement process. One theory is given below.[23)]

① Diffusible hydrogen enters into the steel due to corrosion of the steel surface.

② Diffusible hydrogen moves to concentrated stress regions of the threaded portion, and thickens.

③ Intercrystalline cracking occurs due to gasification of diffusible hydrogen in grain boundaries.

④ Intercrystalline cracking forms a new concentrated stress region, and diffusible hydrogen moves to this zone.

⑤ Cracking progresses due to intercrystalline cracking.

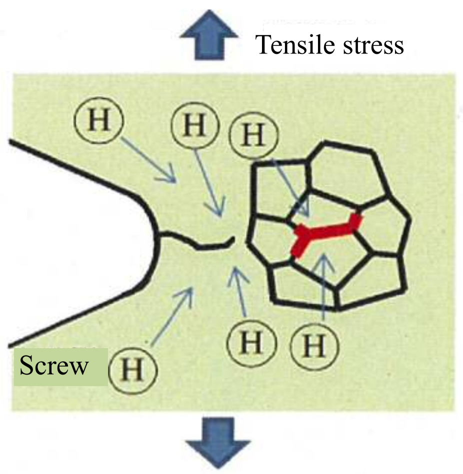

Fig. 2. Diffusible hydrogen moves to grain boundary of concentrated stress region

Delayed fracture is a phenomenon that occurs due to hydrogen embrittlement. Consequently, SSRT, which can compare the degree of embrittlement based on hydrogen charge, is effective when an assessment is desired of the susceptibility of a certain steel material to delayed fracture.

Overview of SSRT

SSRT is a method for measuring the tensile strength of hydrogen charged specimens by slow strain rate. The tensile strength of specimens having high susceptibility to delayed fracture decreases sharply with an increase in the hydrogen charge quantity. It is possible to quantitatively assess delayed fracture susceptibility of bolts by conducting SSRT where multiple hydrogen charge levels are applied multiple test specimens having various tensile strength classes.

For example, the stress-elongation chart shown in Fig. 3 can be obtained by conducting SSRT using three hydrogen charge conditions applied to one steel material. Because hydrogen charge quantity is actually uneven, it is easier to assess the susceptibility to delayed fracture by rearranging tensile strength and elongation to hydrogen charge quantities as shown in Fig. 4 if comparing multiple steel materials.

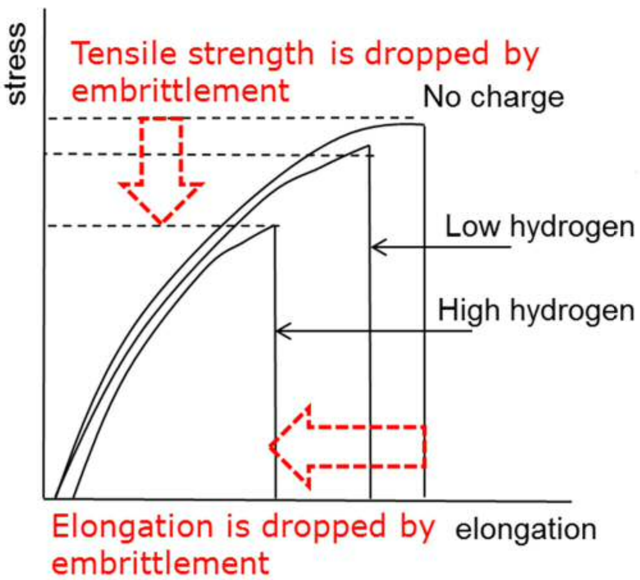

Fig. 3. Stress-elongation chart obtained using SSRT

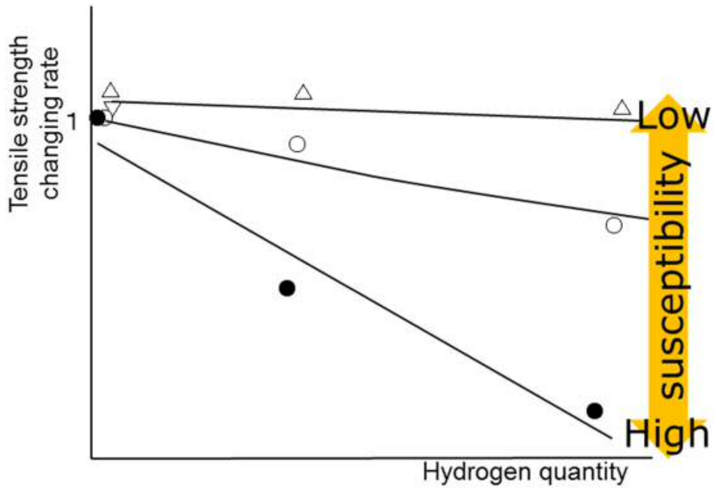

Fig. 4. Stress-elongation chart arranged according to hydrogen charge quantity

Test conditions

1. Tension test rate: 5µm/min

2. Material, tensile strength class and configuration of specimens
   ① SNCM447 1000MPa (used for bolts on the former LLW container)
   ② SCM435H 1200MPa (used for broken bolts)
   ③ SCM435H 900MPa (to be used for bolts to prevent recurrence of fractures)

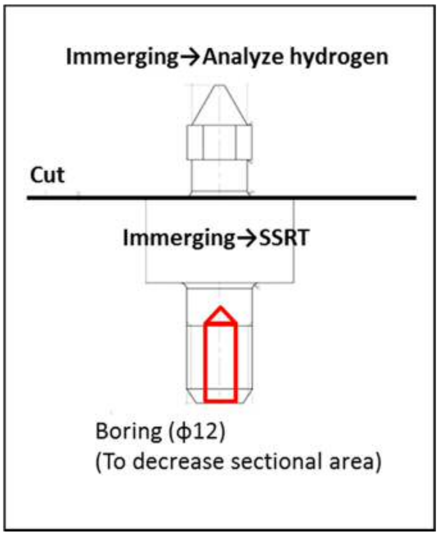

Fig.5 Configuration of specimen

3. Hydrogen charge conditions

① No charge (baking treatment (hydrogen elimination treatment))

② HCL (to simulate hydrogen quantity in an actual environment)

③ 20%NH4SCN (to simulate hydrogen quantity in a strict corrosive environment)

Results of SSRT

The stress-elongation charts for each materials produced using SSRT are shown in Fig. 6 to Fig. 8. The chart showing an arrangement according to hydrogen charge quantity is shown in Fig. 9.

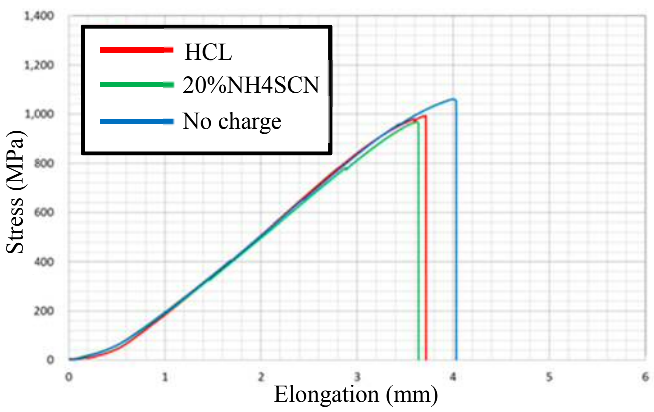

Fig. 6. SSRT results for SNCM447 1000MPa

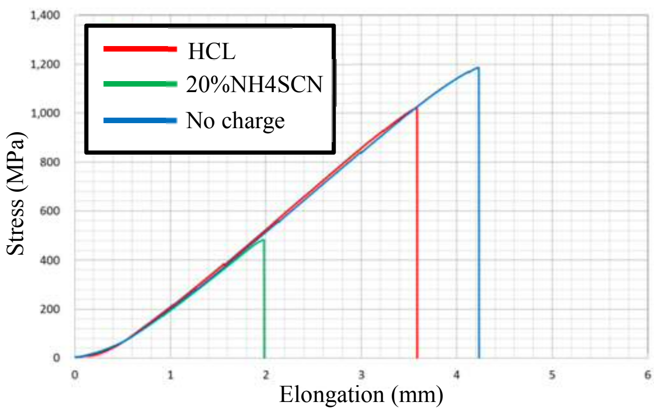

Fig. 7. SSRT results for SCM435H 1200MPa

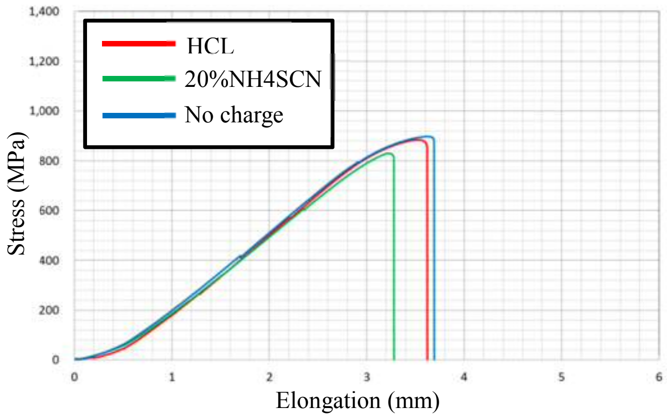

Fig. 8. SSRT results for SCM435H 900MPa

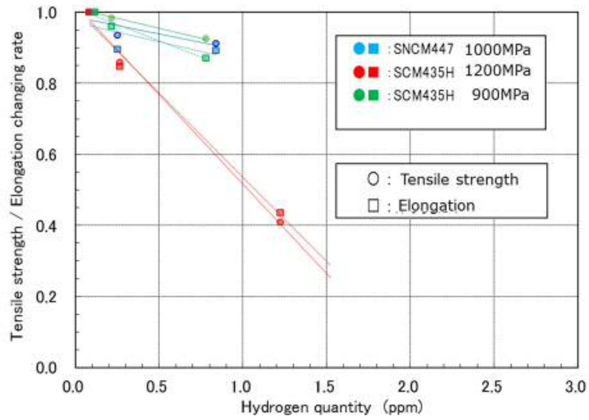

Fig. 9. Comparison of delayed fracture sensitivity

We founded that only the tensile strength and elongation of specimens having a 1200MPa class tensile strength decreased sharply as the hydrogen charge quantity increased. Thus, we confirmed that the delayed fracture susceptibility of specimens having a 900MPa class tensile strength, which were the replacement bolts adopted as a measure to prevent recurrence of delayed fracture, was significantly better than specimen bolts having a 1200MPa class tensile strength which had experienced delayed fractures. And, delayed fracture susceptibility of the 900MPa class tensile strength bolt specimens was comparable to that of 1000MPa class tensile strength bolt specimens, with which we had never experienced a delayed fracture in over 20 years. Consequently, the use of 900MPa class tensile strength bolts is effective for preventing recurrence of delayed fracture.

Also, we observed fracture surfaces on all specimens. From our results, we could not confirm brittle fracture surface in either the 900MPa or 1000MPa class tensile strength specimens. However, we were able to confirm brittle fracture surface in 1200MPa class tensile strength specimens. Results of the observations of fracture surface in NH4SCN hydrogen charge condition are shown in Fig. 10 and Fig. 11.

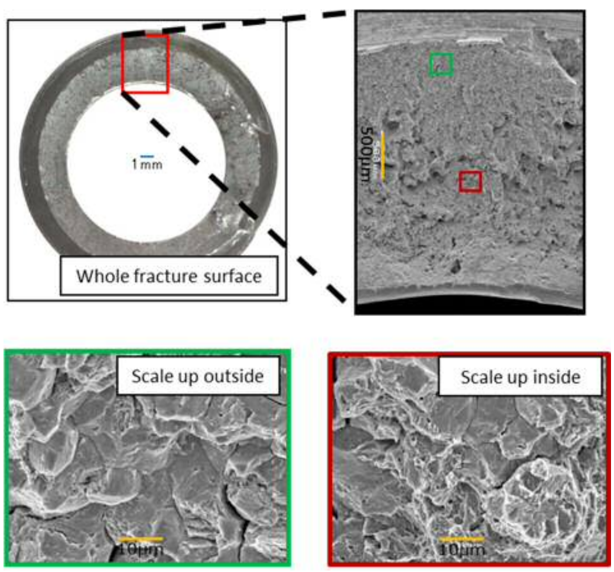

Fig.10 Results of observation of fracture surface SCM435H 1200MPa class 20%NH4SCN

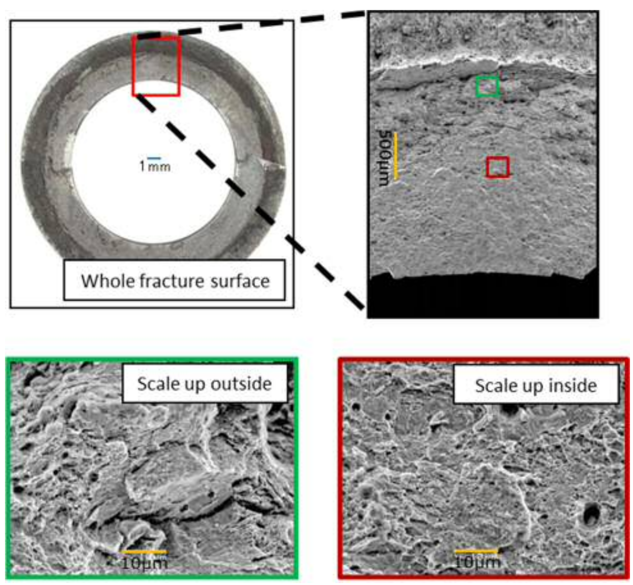

Fig.11 Results of observation of fracture surface SCM435H 900MPa class 20%NH4SCN

Conclusions

We changed to a 900MPa class tensile strength bolt to prevent recurrence of delayed fracture, and we conducted SSRT to quantitatively assess the effectiveness of this recurrence prevention measure.

As a result of SSRT, we confirmed that the delayed fracture susceptibility of bolts having a 900MPa class tensile strength, which were the replacement bolts adopted as a measure to prevent recurrence of delayed fracture, was significantly better than bolts having a 1200MPa class tensile strength which had experienced delayed fractures. And, delayed fracture susceptibility of the 900MPa class tensile strength bolts was comparable to that of 1000MPa class tensile strength bolt specimens, which had been used on the previous containers. Consequently, 900MPa class tensile strength bolts are effective for preventing recurrence of delayed fracture.

References

(1) Matsuyama, Shinsaku. *Delayed fracture*, Nikkan Kogyo Shinbun (1989).

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