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PLT test equipment set-up for delayed hydride cracking of PWR cladding

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1. Introduction

Zr alloys are used as fuel cladding material in PWR due to the low capture cross-section for thermal neutrons. Although Zr alloy has the resistance to water corrosion, hydrogen pick-up is derived as a result of the surface oxidation. The hydrogen pick-up leads to the formation of hydrides and these hydrides cause the embrittlement in the alloys. Delayed Hydride Cracking (DHC) is one of the phenomena which cause the embrittlement. When the temperature decreases from high to low, some solved hydrogen atoms maintain the metastable state. These hydrogen atoms can easily form the hydride in the high stress region such as a flaw or crack tip and cause time-dependent crack growth especially in dry storage conditions. Therefore, it is important to find the condition which does not cause DHC. In the present study, DHC Pin Loading Tension (PLT) test equipment was constructed for PWR cladding. The equipment was installed in the radiation area for the irradiated cladding test.

2. Methods and Results

In the present study, the test procedure followed the report published by Studsvik [1].

2.1 Specimen preparation

The PLT-specimens with the nominal length of 13 mm have been manufactured from hydrogen charged Zircaloy-4 cladding. Hydrogen was charged in the conditions of 300 torr H_2 and 400˚C. The notches were machined in the specimen at the front edge (loading position) and back edge [2].

2.2 Test equipment set-up

DHC PLT test is divided by two steps. The first step is fatigue pre-cracking and the second step is DHC cracking. The purpose of first step is to shorten the incubation time in DHC cracking. Accordingly, the equipment, which has the function of dynamic force control, was required for the test. In here, MTS Acumen3 was chosen and the picture of the equipment is shown in Fig. 1.

The purpose of DHC test is to determine the K_{IH} and the DHC velocity, V_{DHC}. During DHC cracking, the crack growth should be monitored in real time to determine the crack propagation. If DHC crack growth is observed at the certain tensile load, the load gradually lower by 5N until the crack stops. The K_{IH} is calculated at this load,. Two measuring instruments were installed to monitor the crack growth; one is COD gage and another one is DCPD. The pictures of the instruments are shown in Fig. 2-3. DCPD can reflect only crack growth effect, but it is difficult to spot weld the DCPD wire to irradiated Zr alloys. On the other hand, COD gage is easier to install. The tests have been performed with two instruments to find the optimum solution.

Fig. 1. DHC testing equipment

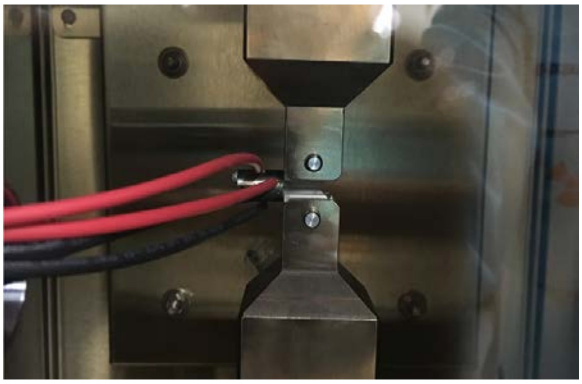

Fig. 2. Spot welded DCPD wires on PLT specimen

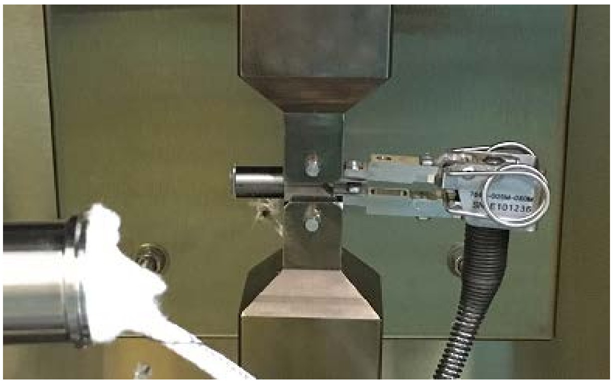

Fig. 3. COD gage mounted on PLT fixtures

2.3 Test results

The fatigue test was performed to produce fatigue pre-crack. The target length of crack was 2 mm and the load control condition is shown in Table 1. To check the pre-crack length, the crack opening was performed after the fatigue. The fracture surface is shown in Fig.5. The length is about 2 mm and the notch, pre-crack and the fracture regions were possible to be distinguished in optical image.

The pre-crack growth is affected by the machining status of the notches. Thus, the pre-crack length can be changed in the same fatigue condition. Because crack growth length is reflected indirectly on the variation of load line displacement (LLD), the LLD variation was considered to be a better measure for the crack length reproducibility. The load and measured LLD as a function of the fatigue cycle is shown in Fig. 5.

Table 1. Fatigue conditions for pre-cracking

Step	P_{max} / P_{min} (N)	Cycles
1	200 / 50	3000
2	150 / 50	3500
3	120 / 50	7000
4	100/50	7000

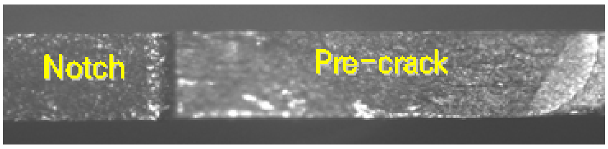

Fig. 4. Fracture surface after pre-cracking

To evaluate the availability of DCPD and COD gage on DHC testing, each instrument was installed on DHC equipment during crack growth. Fig. 6 shows the results of DCPD reading during tensile test. When the load increased, the potential drop ratio was constant. After the inflection point of the load, the potential drop ratio increased due to the crack propagation. Although the data is not for DHC, it was clear to measure the crack growth in real time during DHC cracking. DCPD will be used for the DHC PLT test after finding the optimum condition of the spot welding on Zr alloy

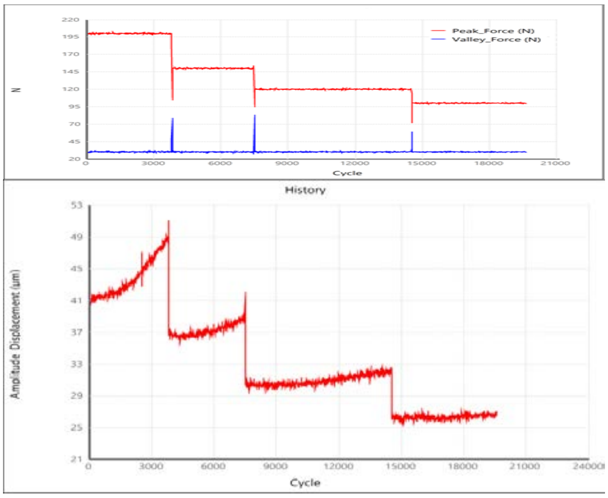

Fig. 5. Load and load line displacement as a function of fatigue cycle

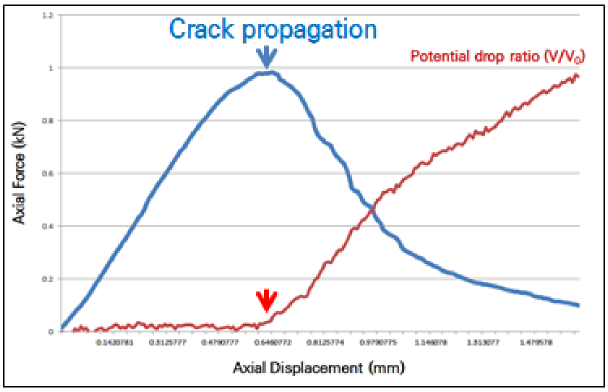

Fig. 6. DCPD reading value during tensile test

Fig. 7 shows the result of DHC test with COD gage. The COD increased with the test time on the constant load. Because the increment reflects DHC cracking growth, COD gage could be used effectively for the DHC test.

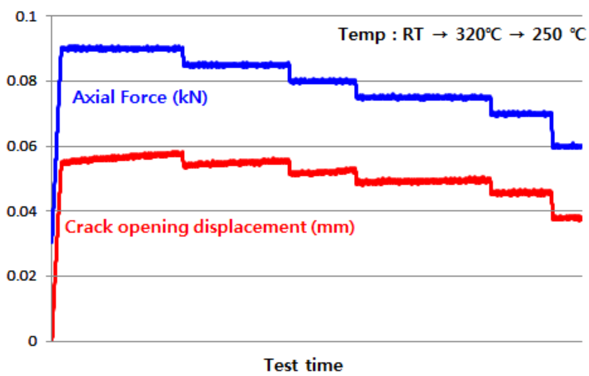

Fig. 7. DHC test result

3. Conclusions

The DHC testing equipment was installed in the radiation area. Fatigue conditions for pre-cracking were derived and the produced pre-crack was observed by optical microscopy. In addition, it was confirmed that DCPD and COD gage could be utilized in the DHC PLT test. In the future, the DHC tests for un-irradiated and irradiated cladding will be performed.

REFERENCE

[1] V. Grigoriev, R. Jakobsson, STUDSVIK/N-05/281 (2005)
[2] V. Grigoriev, R. Jakobsson, SKI Report 00:57 (2000)