Hydride effect on low-cycle fatigue property of HANA-6 cladding tube

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1. Introduction

Nuclear fuel cladding tubes in pressurized water reactors could undergo cyclic stresses due to power fluctuation. Power fluctuation occurs when starting / shutting down the power plants and driving control rod at NPPs in base load operation, in the case of NPPs in load following operation experience it more frequently. It causes internal fission gas release, thermal expansion of the pellets, and pellet-clad interaction, so that cyclic diameter changes occur in the cladding tubes, which causes radial direction low-cycle fatigue[1-3]. Thus fatigue property is very important to predict lifespan of the cladding tubes. Moreover, fatigue property is one of the major factors for fuel design, therefore, it is important to understand the hydride effect on fatigue life on the cladding tubes. Soniak et al. proposed a special fatigue tester which pressurize the inside of cladding tubes in the radial direction, and obtained the fatigue curve on irradiated/unirradiated Zircaloy-4 cladding tubes with this tester[4]. Other commercial alloys including M5, ZIRLO, Optimized ZIRLO cladding tubes were also tested low-cycle fatigue properties[5].

It is well known that the presence of hydrides on cladding could causes changes of mechanical properties, such as diminution of ductility, decrease of fracture toughness, and shortening of fatigue life[6-7]. Jang et al. showed a low-cycle fatigue results that significant load drops on hydrided ZIRLO cladding tube with maximum hydrogen content of 600 wppm compare to non-hydrided cladding tube[5].

In this study, low-cycle fatigue properties of the HANA-6 cladding tube developed by KNF were evaluated under cyclic pressurization. As well, pre-hydrided HANA-6 cladding tubes were also tested to understand the effect of hydride on the fatigue life.

2. Methods and Results

2.1 Test Specimen

The cladding tube used in this study is HANA-6 (Zr-1.1Nb-0.06Cu) which has an outer diameter and thickness of 9.5 mm and 0.57 mm, respectively. The length of the specimen is 200 mm. The specimens were charged with hydrogen up to 1500 wppm at an elevated temperature to form zirconium hydride.

2.2 Fatigue Test

Fig. 1 shows a picture of the internal pressurization fatigue tester for a cladding tube. It consists of four major components which are hydraulic power unit, boosters, high temperature furnace, and data acquisition system. The hydraulic power unit and the boosters can apply the cyclic pressure to the specimen up to 100 MPa, which means about 750 MPa in hoop stress. The tester is stress-based fatigue machine so that hoop stress is applied based on the initial cladding geometry. The pressure variations obey a periodic triangular signal with the frequency in the range of 0.5 to 5 Hz.

In this study, maximum hoop stress varied from 260 MPa to 320 MPa were applied to the specimen while minimum hoop stress was held constant at 38 MPa. The temperature and frequency were maintained constant at 350 ℃ and 1 Hz during the test. After the fatigue test, samples taken from rupture part were analyzed for hydrogen content.

Fig. 1. Photograph of the fatigue tester under internal pressurization on the cladding tube.

2.3 Test Results

Fig. 2. shows the fatigue test results of pre-hydrided / non-hydrided HANA-6 cladding tubes. At first, fatigue limit of non-hydrided cladding tubes were measured, which is 275 MPa in hoop stress. In case of the pre-hydrided cladding tubes, fatigue life may be not affected by amount of hydrogen at higher stress (320 MPa), on the other hand, at lower stress, the cladding tubes with lower hydrogen contents have higher number of cycles. Furthermore, it was found that low-cycle fatigue property of the non-hydrided cladding tubes satisfies the

O'Donnell & Langer reference curve, however, only few pre-hydrided cladding tubes with hydrogen contents lower than 800 wppm satisfies that curve. According to recent results of the HANA-6 cladding tube with a burn-up of 54 GWd/MtU, less than 100 wppm hydrogen contents were measured. Thus, it would be considered that fatigue property of the pre-hydrided HANA-6 cladding tube is also enough to satisfy the reference curve.

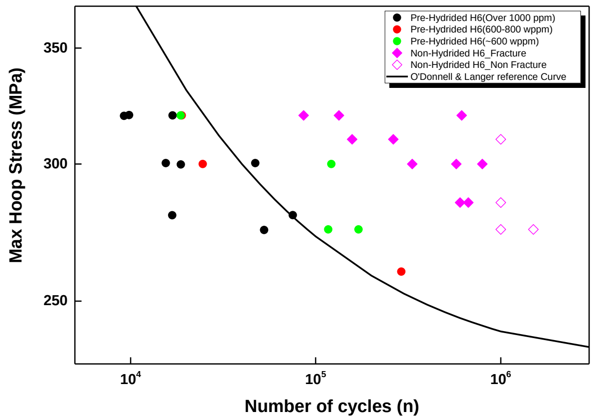

Fig. 2. Fatigue curve (Stress-Number of cycle curve) of the pre-hydrided/non-hydided HANA-6 cladding tube.

3. Conclusions

Low-cycle fatigue tests were performed at 350 ℃ at 1 Hz for the pre-hydirded / non-hydrided HANA-6 cladding tubes using tube fatigue tester by repeated internal pressurization.

It appears that HANA-6 cladding tubes with hydrogen contents less than 800 wppm satisfy the O'Donnell & Langer reference curve. Moreover, at higher stress, fatigue life of pre-hydrided HANA-6 cladding tubes is not affected by amount of hydrogen contents in the cladding tubes.

4. Acknowledgements

This research was financially supported by Korea Hydro & Nuclear Power Co. Ltd. (No. L17S083000).

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