Burst Test of Zirconium Alloy at High Temperature under Internal Pressure

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1. Introduction

It is important to maintain the integrity of zirconium alloy fuel cladding because that is a barrier against radioactive fission products. Many researchers investigated the behavior of cladding under loss-of-coolant accident (LOCA). When LOCA occurs, cladding temperature rise rapidly and primary system pressure drop to atmospheric range. However, the internal pressure of cladding is preserved ~MPa because of the generation of fission products and the swelling of fuel pellets. Therefore, the difference of pressure can induce the local ballooning and burst.

Some investigators conducted ballooning-burst tests. F. J. Erbacher and S. Leistikow researched the oxidation and embrittlement behavior of zircaloy cladding by simulating a LOCA[1]. F. Erbacher et al. studied single rod and bundle tests in the fuel rod simulator[2]. P. Hofmann investigated the influence of iodine on the burst test[3], and Jun Hwan Kim et al. studied the deformation of Zircaloy-4(Zry-4) under isothermal and transient-heating tests[4]. Only Zry-4 was used in their study, except for an Nb-added alloy. Also most of the investigations were tested under transient temperatures to simulate a LOCA. Therefore, fundamental data of the ballooning-burst on the uniform temperature is insufficient.

In this study, the ballooning-burst behavior of Zry-4 and an Nb-added alloy was studied and fundamental data was produced.

2. Experimental

2.1 Specimen

Table 1 shows the chemical composition of Zry-4 and Zirlo used in this study. The length of the used as-received specimen was 195mm and it was cleaned using acetone and methyl alcohol.

Table 1. Chemical composition of specimen

	Zr (wt%)	Nb (wt%)	Sn (wt%)	Fe (wt%)	Cr (wt%)
Zry-4	bal.	-	1.35	0.2	0.1
Zirlo	bal.	1.0	1.0	0.1	-

2.2 Apparatus and method

Fig. 1 shows the apparatus for burst at high temperature (isothermal) under constant internal pressure. The electronic heater can move up and down because of the reduction of the effective oxidation time. Helium was used as an internal inert gas and steam was generated using the steam generator. The regulator controlled the internal gas pressure. The line from the steam generator to the reactor was wrapped inside a heating bend in case the steam is condensed. An alumina tube in the reactor was used to protect the heater from steam.

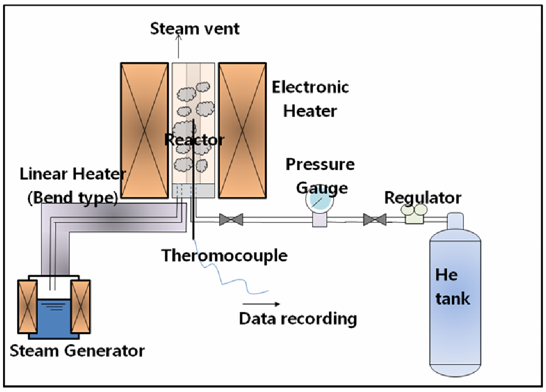

Fig. 1. Apparatus for burst test at high temperature and constant internal pressure

The specimen was fixed in the reactor using fittings and another end was also sealed with a fitting. After the specimen was located in the test position, the electronic heater was run to set up the temperature. As the set-up internal pressure was reached, the electronic heater was fallen to heat up the specimen. The burst time was measured from the beginning of the heating to the burst of the specimen. The set-up temperature was 900-1100℃ and the internal pressure was 2-10MPa.

3. Results and Discussion

Hoop stress was generated by the internal gas pressure. The hoop stress was derived as follows:

$$\sigma = \frac{PD}{2t} \qquad (1)$$

Where σ denotes the hoop stress, P is the internal gas pressure, D is the mid-wall diameter, and t is the thickness of the cladding wall, respectively.

Fig. 2 shows the burst time along with the internal pressure and hoop stress. As the internal pressure and specimen temperature were increased, burst time was shorter. Especially, in high internal pressure and specimen temperature relatively, the burst time of Zirlo was shorter than Zry-4.

Some researchers studied the behavior of cladding, Zry-4 and an Nb-added alloy, under normal operation and in accident conditions. In their studies, an Nb-added alloy has many advantages over Zry-4, such as corrosion resistance and mechanical properties. In this study, Zirlo may have a weak point in accident conditions, so there is a need to conduct more studies.

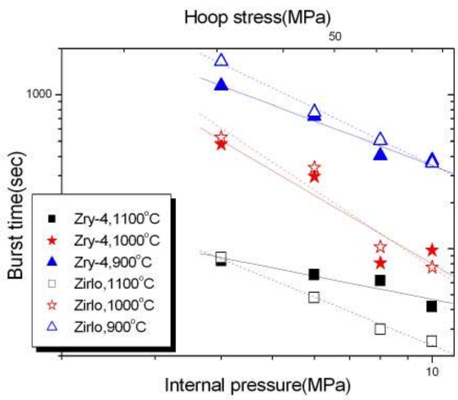

Fig. 2. Comparison of burst time

Fig. 3 and Fig. 4 show the burst shape of Zry-4 and Zirlo when the internal pressures were 8 and 10MPa. As the internal pressure was increased, the burst strain was large. However, the change by some internal pressures was not clear. The difference in the two kinds of cladding was clearly observed. When the internal pressure was 10MPa, the burst part of Zirlo was bigger than Zry-4.

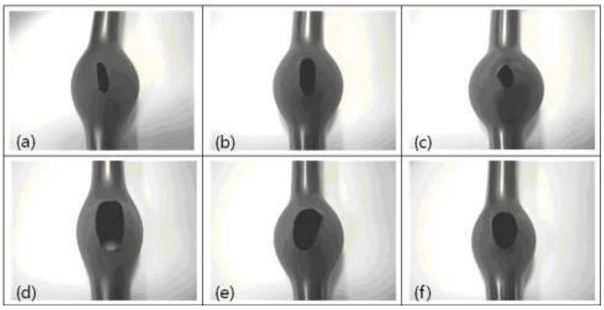

Fig. 3. Burst shape of Zry-4
(a)900℃, 8MPa (b)1000℃, 8MPa (c)1100℃, 8MPa
(d)900℃,10MPa(e)1000℃,10MPa(f)1100℃,10MPa

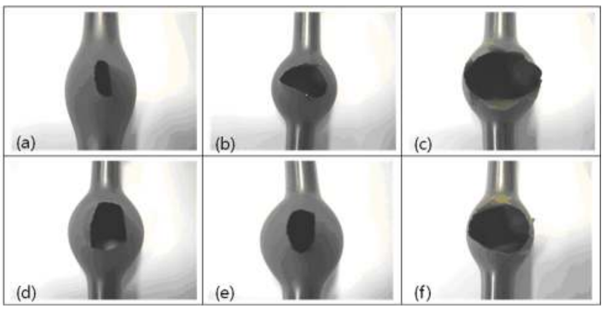

Fig. 4. Burst shape of Zirlo
(a)900℃, 8MPa (b)1000℃, 8MPa (c)1100℃, 8MPa
(d)900℃,10MPa(e)1000℃,10MPa(f)1100℃,10MPa

4. Conclusion

The isothermal burst test under constant internal pressure was conducted. Two kinds of specimen presented a shorter burst time as the temperature and internal pressure grew. The burst time of Zirlo was shorter than Zry-4 in a specific temperature and internal pressure range. Recently, cladding materials were changed to the Nb-added alloy because of high burn-up and the extended operation of nuclear power plants. As a result of this study, the coolant flow channel, deformation and burst phenomena of Zirlo may need a detail examination.

Acknowledgment

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