Temperature Effect on the Dimensional Change of Zirconium Alloy Grid

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1. Introduction

Through the previous studies on irradiation growth in annealed Zirconium alloy spacer grid, it is well understood that the magnitude of growth is dependent on the main variables: crystallographic texture, fast neutron fluence and temperature [1-3]. The effect of crystallographic texture on irradiation growth is well explained and the fast neutron effect is also analyzed with the combined crystallographic texture effect [4]. Although the above two main variables are well explained, there have been controversial mechanism analysis and ambiguous experimental results on the temperature effect [5-8]. Recently, there were some new researches that the corrosion and hydrogen pickup result in the considerable dimensional changes [9], while prior study have dealt with the temperature effect on the irradiation growth. In this view, one of the main factor causing the corrosion and hydrogen pickup is the temperature effect [10-11]. In this study, we measured the total growth of Zirconium Alloy grid quantitatively in 16ACE7 & PLUS7 fuel assembly and analyzed the temperature effect on the grid growth based on the recent study that dimensional changes result from the corrosion and hydrogen pickup.

2. Measurement

The raw data for analyzing dimensional change of Zirconium Alloy grid are acquired by measuring both as-built width of grid and width of grid after burnup. The as-built width is acquired by measuring equipment named Test Rig in manufacturing process and the width of irradiated grid is acquired by software program for the acquisition, processing and management of data for fuel assembly grid width measurement in PSE (Pool Side Examination), the hardware of software program is equipped with LVDT (Linear Variable Differential transformers) sensors for taking an accurate measurement. The measurement of both data is taken on the four faces of each Zirconium alloy grid and the mean value of four faces width measurement is used for analyzing total grid growth of grid. And then the total grid growth data are obtained from the differences of each width of grid between before and after burnup.

3. Evaluation

3.1 Temperature effect on the total Grid Growth

The reactor inlet and outlet temperature were measured in the plant at 100% thermal output state and it was assumed that the gird temperature is reasonably proportional to the each grid height. The temperature is transformed to Arrhenius corrosion term in accordance with mechanism. The total grid growth with temperature is shown in Fig. 1 and 2. The total grid growth seems higher as the temperature increases and burnup progresses.

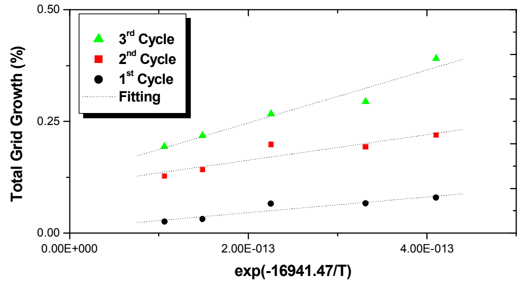

Fig.1. The measured total grid (16ACE7) growth results after each cycle of burnup in the temperature range of 560 ~ 600 °K. Total grid growth from low to high value at the same burnup represents respectively that of grid located from low to high in fuel assembly. And the linear fitting lines are shown for the further analysis of C_1 constant

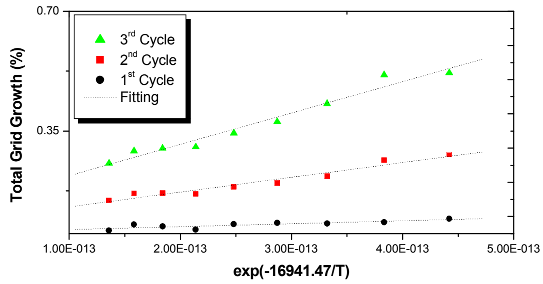

Fig.2. The measured total grid (PLUS7) growth results after each cycle of burnup in the temperature range of 570 ~ 600 °K.

The results shown in Fig. 1 and 2 explain that higher temperature increases the dimensional changes because the irradiation growth among grids differences is negligible at the same fuel assembly. And the increased growth by the high temperature is considerable at total grid growth in comparison with low temperature total growth. The cause of dimensional changes can be explained well by the kinetics view of corrosion with temperature. However, more study is required to explain clearly and quantitatively the relation between corrosion behaviors and hydrogen solution content that forms the zirconium hydrides.

3.2 Mechanism

The hydrogen generated from corrosion easily diffuses into the Zirconium Alloy base by the driving force of concentration gradient differences. And then the hydrogen pickup content in the Zirconium Alloy base beyond solution limit forms zirconium hydrides (ZrH_2) that causes the dimensional change [11]. Therefore, based on the corrosion and hydrogen pickup mechanism, the total grid growth mechanism can be written below.

$$\frac{\Delta l_l}{l_l}(\%) = C_1 \exp(-\frac{Q_1}{RT})t + C_m(F)^n$$

Where,
Δ *l*/*l* : total grid growth percentage
Q_1 : activation energy (28200 cal/mole)
R : universe constant (1.987 cal/mol-K)
t : time in days
F : fast neutron fluence (n/cm^2, E>1 MeV)
C_1 : temperature effect factor
C_m : material irradiation constant

The different mechanism between irradiation growth and dimensional changes due to the corrosion enables the total grid growth to be simply summed up by two main terms. One is corrosion term combined of hydrogen pickup, time and temperature effect. It is applicable that the generally known corrosion equation with C_1 constant that considers temperature effect factor on the dimensional change. The other is well known irradiation growth term, which already originates from the empirical expression [1].

3.3 C_1 constant Analysis

Table 1: The C_1 constant results with each type of Fuel and Burnup Cycle

Fuel Type	Burnup (GWD/MTU)	C_1 constant (10^8 /days)
16ACE7	19.7	4.565
	36.1	3.739
	51.1	5.239
PLUS7	19.6	1.596
	38.6	4.006
	53.2	5.658

For our analysis, two types of grid were identified. The grids of 16ACE7 and PLUS7 have individually transverse texture strip and longitudinal texture strip. Each C_1 constant was acquired by fitting and the correlation coefficient value was at least over 0.93 except for 0.84 of the first cycle of PLUS7. And each result of C_1 constant in the analysis mechanism is shown in Table 1 with each burnup cycle. The C_1 constant in the grid of 16ACE7 generally are equal at every cycle. However, C_1 constant in the grid of PLUS7 shows accelerated value as the burnup cycle progresses. Because the C_1 constant means the increment rate with the temperature, the grid growth of PLUS7 seems more sensitive to the temperature at high burnup. And the other variables (burnup history and fluence between 16ACE7 and PLUS7 fuel assemblies) are similar, the result seems to be due to the texture effect in this study. However, the corrosion acceleration with time can have a chance to affect the C_1 constant.

4. Conclusions

In this study, the total grid growth summed up with irradiation term and corrosion/hydrogen pickup term increases with the temperature. Especially, based on the previous study, the total grid growth dependency on the temperature was explained by corrosion/hydrogen pickup mechanism, which has considerable portion at the total grid growth as the temperature increases. However, more study is required to explain clearly and quantitatively relation between corrosion behaviors and hydrogen pickup content that forms the zirconium hydrides.

The grid of PLUS7 is more sensitive to the temperature than that of 16ACE7 at the high burnup. However, grid of 16ACE7 is more sensitive to the temperature than that of PLUS7 at the low burnup. The result seems to be due to the texture effect in this study.

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