The effects of irradiation and temperature on the growth of Zircaloy-4 tubes

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ABSTRACT

The growth strain was measured after irradiation for 16 Zircaloy-4 tubes of the recrystallised and stress relieved types. The operating temperature during irradiation ranged between 317 and 344 °C. The average fast neutron fluence was 9.6×10^{20} n/cm² . Experimental results indicated the dependence of the growth on the irradiation temperature. The stress relieved result was compared with data of the literature.

1 INTRODUCTION

The performance of fuel elements in the severe conditions of temperature pressure and irradiation dictates the efficiency and availability of light water nuclear power reactors. One phenomenon that is most relevant to the service life of the fuel element is the growth strain induced in the Zircaly-4 cladding of the UO_2 fuel. The growth strain which occurs in certain anisotropic metals and alloys under the influence of irradia - tion, causes changes in dimensions in the absence of the applied stress. There exist theories and mechanistic models regarding the causes of the growth strain.

(Kelly 1975),(Ibrahim & Winegar 1972/73) and (Daniel 1972) showed that irradiation growth occur in all zirconium alloys. (Adamson 1977) proposed microstructural factors that considered to be contributing to the growth such as : depleted zones , vacancy loops , interstitial loops dislocation climb and glide , grain boundary absorption , hydrides , reidual stresses and voids.

The effect of temperature during irradiation on the growth strain was studied by few investigators (Harbottle 1970) , (Fedleris 1973) due to the difficulty of achieving different operating temperatures at comparable neutron fluences.

This paper describes experiments conducted in Osiris Research Reactor (France) to study the evolution of the growth of tubular test specimens made of recrystallised and stress relieved Zircaloy-4 under different irradiation and temperature conditions.

2 EXPERIMENT DESCRIPTION

Sixteen Zircaloy-4 tubes were included in a standard irradiation device called COLIBRI (CEA 1969) which was installed in the core of Osiris

Table 1. Geometrical characteristics of the Zircaloy-4 tubes

Outer diameter	9.56 mm
Thickness	0.60 mm
Length	110 mm

Reactor. Eight Zircaly-4 tubes were of the recrystallised type (2 hours at 575 °C) and the other eight tubes were of the stress relieved type (2 hours at 490 °C) . The geometrical characteristics of the tubes are indicated in Table 1. All the sixteen tubes were immersed in an NaK bath and instrumented to monitor the operating temperature by using 15 Chromel - Alumel thermocouples .

A typical temperature distribution along the Zircaloy-4 tubes is shown in Figure 1. The gamma heating in the chosen irradiation position of the reactor core was 9 W/g. The fast neutron flux was determined by 10 copper wires (0.8 mm diameter) through the utilisation of the $Cu^{63}(n,\alpha)Co^{60}$ nuclear reaction.

Figure 1 also shows a typical axial variation of the fast neutron flux (neutron energy E > 1 MeV) , which was obtained by correlating the 6.9 MeV threshold copper reaction with the 1 MeV value (Alberman 1978) . The duration of irradiation was 3 reactor cycles (i.e. 70.54 days of full reactor power) .

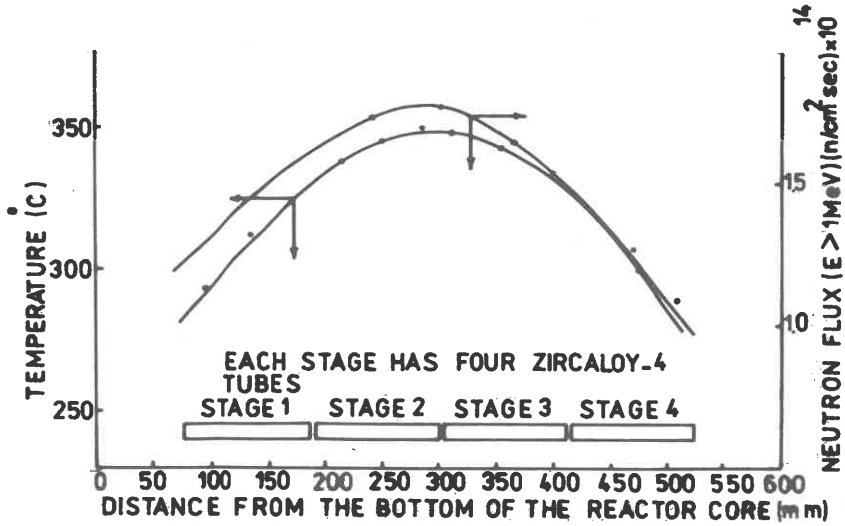

Figure 1. Typical neutron flux and temperature distributions along tubes.

3 RESULTS AND DISCUSSION

Growth strain was measured in the (LHA) Post-Irradiation Examination Laboratories of Saclay . The metrology results were obtained by comparing the lengths of the irradiated and non irradiated Zircaly-4 tubes.

Measurements were performed through direct mechanical contact with the tube ends. The end faces of the tubes were prepaed in a careful manner in order to improve the precision of the length measurements. The influence of the irradiation temperature on the growth for an average value of fast

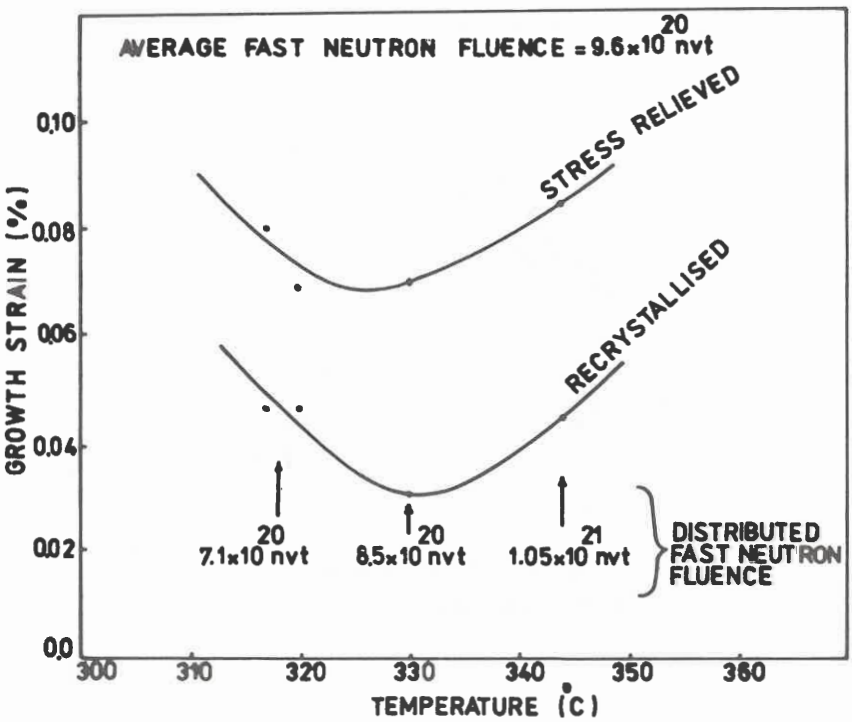

Figure 2. The variation of the growth strain of Zircaly-4 tubes.

neutron fluence is demonstrated in Figure 2. The measurement of the irradiated Zircaloy-4 tubes indicated that the diametral growth was almost non existent.

Figure 2 shows that the growth is larger for the stress relieved than the recrystallised tubes. The growth strain of the tubes for both the recrystallised and the stress relieved types is shown to approach a minimum value at temperatures between 310 to 330 °C.

The results of (Harbottle 1970) on Zircaloy-2 showed little effect of temperature on the growth , but (Adamson 1977) found that the growth of recrystallised Zircaly reached a maximum value at around 300 °C . The temperature range of Adamson was from 0 to 400 °C and the fast neutron fluence was fixed near 1.5×10^{21} n/cm² .

(Pedraza and Fainstein - Pedraza 1982) showed in an analytical microstructructural studies a similar trend in the growth to the experimental results of Figure 2. They explained the dependence of the growh strain on irradiation temperature (for the same cell size) as due to the rate of removal of vacancies to form vacancy loops per Frenkel pair produced per atom and the variation of the density of the interstitial vacabcy loops.

The depression in the growth - temperature curve of Figure 2 was also predicted by (Dollins 1975) who assigned it to the strains caused by straight climb , loop growth and subgrain boundaries.

The tabulted data of (Adamson 1977) (Material I : Zircaloy-4 tubes) was plotted in Figure 3 and compared with the present result of the stress relieved tubes which were irradiated at 317 °C. The irradiation temperature of Adamson was ranged between 244 and 295 °C for these tubes. Apart from the differences in the microstructure and texture , it is

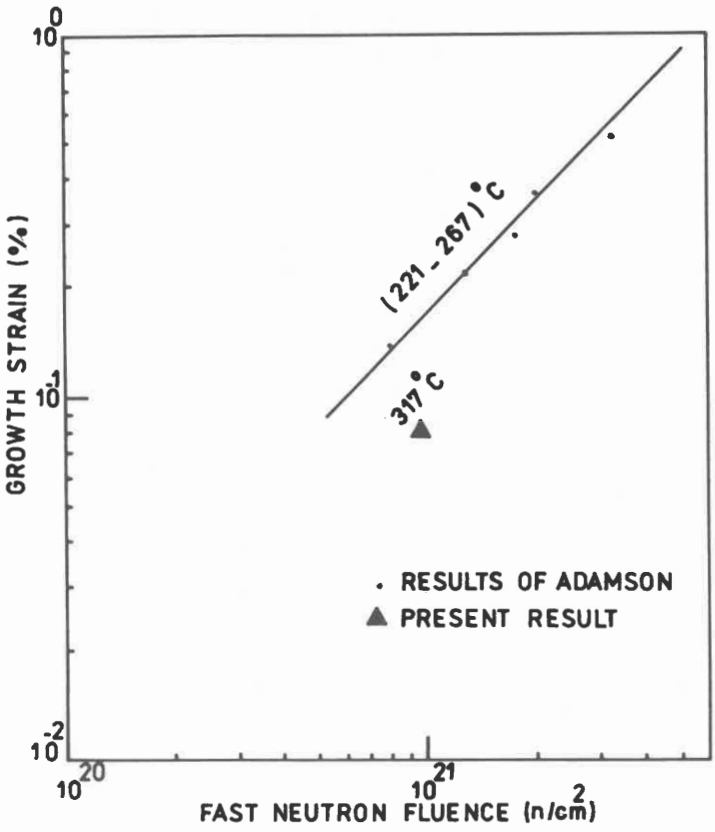

Figure 3. Comparison of growth in stress relieved Zircaloy-4 at 317 °C and 221 - 267 °C.

believed that the difference between the irradiation temperature of the present result and those of Adamson was one of the reasons of producing different values of growth strain.

ACKNOWLEDGEMENT

This paper is published by permission of the Iraqi Atomic Energy Commission. The author is pleased to acknowledge the assistance and co-operation in France of J.P. Genthon, H. Vidal, M. Bauge, A. Alberman P. Morize , J. Baicry and the staff of the LHA and Osiris Reactor.

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