Metallographic study of end plates of a damaged pakistani fuel bundle irradiated at Karachi nuclear power plant (Kanupp)

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Abstract

The various post irradiation examinations were carried out at Pakistan Institute of Nuclear Science and Technology (PINSTECH) for the first time in 1991-93 on a fuel bundle which was fabricated in Pakistan and was irradiated at Karachi Nuclear Power Plant (KANUPP) up to a maximum burn-up of 6947 MWD/TeU. This bundle had its end plates in damaged condition. Attempts were made to determine the cause of their damage during microstructural study of the material. Therefore metallographic examinations were carried out in great detail. The measurements of oxide layer thickness and hydride concentrations were main areas of study. The study revealed the hydridation and severe oxidation effect on the end plate material. There was found to be an increase in the concentration of radial hydrides which might have resulted in the embrittlement of material and thus caused the failure of end plates.

Riassunto

All'Istituto Pachistano di Scienza e Tecnologia Nucleari sono stati eseguiti per la prima volta negli anni 1991-93 i diversi esami post-irradiazione su un fascio di elementi combustibili fabbricato in Pakistan ed irradiato fino ad un consumo massimo di combustibile di 6947 MWD/TeU. Le placche terminali del fascio sono apparse danneggiate, per cui è stato condotto uno studio microstrutturale metallografico altamente particolareggiato del materiale di cui erano composte per determinarne la causa, misurando principalmente lo spessore dello strato ossidato e le concentrazioni degli idruri. I risultati dello studio hanno dimostrato l'effetto pesante dell'idrurazione e dell'ossidazione sul materiale delle placche. L'aumento rilevato della concentrazione degli idruri radiali era tale d'aver potuto portare all'infragilimento del materiale e quindi al cedimento delle placche.

INTRODUCTION

KANUPP, a Candu type reactor has been operating successfully on Pakistani fabricated fuel bundles for more than a decade. In 1990 it was planned that Post Irradiation Examination of few such bundles be carried out at PIE facility of PINSTECH. Therefore a fuel bundle which had an irradiation history of about five years in reactor and had total burn-up of about 6947 MWD/TeU was studied at PINSTECH in detail. It had its end plates in damaged and severely deformed condition. Some of its fuel pins were in loose condition. Therefore, attempts were made to find out the cause of damage of end plate material by their metallographic study in the hot cells of Post Irradiation Examination (PIE) facility. The results of oxidation layer thickness and hydridation effect have been discussed in detail in this paper.

FABRICATION DATA AND IRRADIATION HISTORY OF FUEL BUNDLE

This fuel bundle was fabricated at fuel fabrication plant Kundian Nuclear Complex-I (KNC-I) of PAEC. It was typical Candu type fuel bundle and consisted of 19 fuel pins arranged in a geometrical pattern of 1,6 and 12 in numbers. Each pin was fabricated of sintered uranium dioxide fuel pellets with Zircaloy-4 Cladding. Both of its end plates were of Zircaloy-4 material.

The bundle had identification No. 851474 and its irradiation data has been described in Table 1.

TABLE 1 - Irradiation data of fuel bundle

Fuel bundle's Identification	Uranium content	Date of loading in reactor core	Date of discharge from reactor core	Neutron Fluence (in n/Kb)	Burn-up
No. 851474	13.381 Kg	22.7.1985	6.04.1990	1.7374	6947 MWD/TeU

VISUAL INSPECTION

The end plates of fuel bundle were designated as end plate No. I and end plate No. II respectively.

Both the end plates were found in severely damaged state (fig. 1 and 2). Some fuel pins of outer most layer of bundle were in loose condition as well. Some macrocracks were apparent at the welded joints of various fuel pins with end plate material (fig. 3). Some fretting mechanical scratches were present at various portions of end plate material.

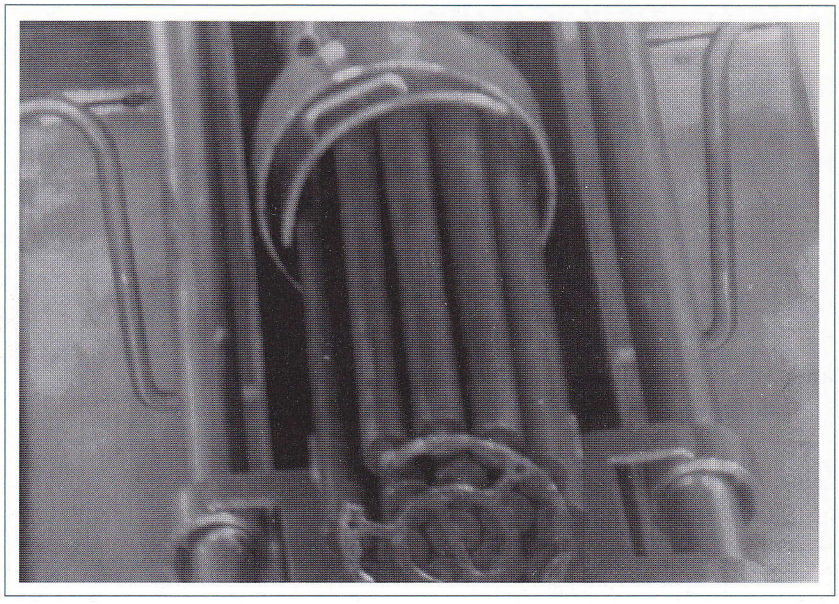

Figure 1: Photograph showing damaged end plate of fuel bundle

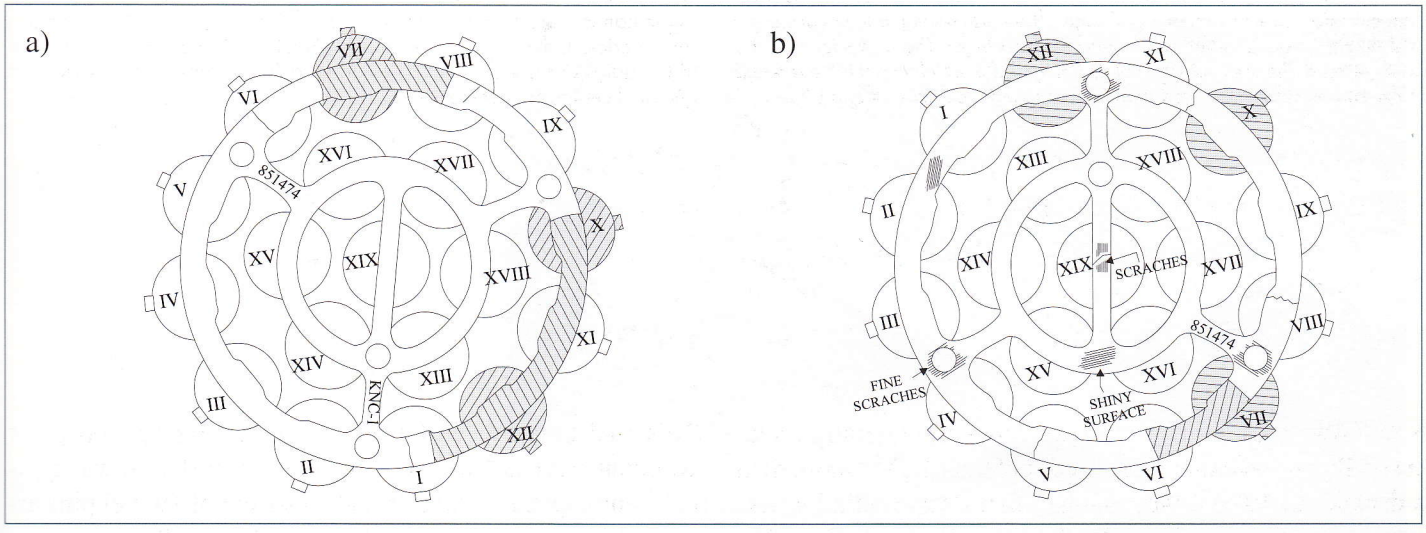

Figure 2: The end plates of fuel bundle
a) End plate No. I (Having KNC-I engraved on it)
b) End plate No. II

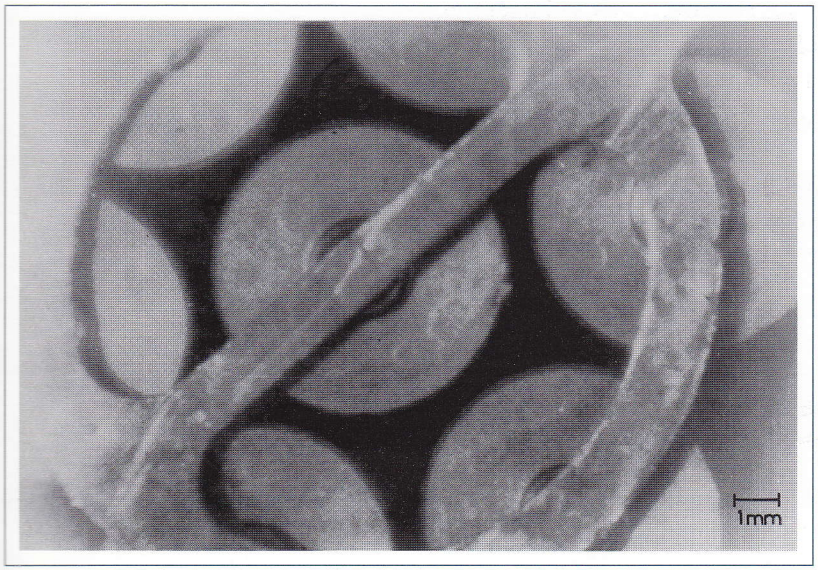

Figure 3: An example of presence of a macrocrack at the welded joint of central fuel pin with end plate No. 2

METALLOGRAPHIC STUDY

Specimen Preparation

Four specimens of approximate size 15 x 10 mm each were sectioned from end plate material. The specimens were placed in perspex glass mounts and mounted in araldite resin. They were prepared by conventional preparation method. After final cloth polishing using diamond paste of 1/4 micron size the specimens were ultrasonically cleaned in distilled water and etched using etchant of following composition.

Conc. Nitric acid	=	3 ml
Conc. Hydrofluoric acid (40%)	=	4 ml
Ethylene Glycol	=	2 ml
Distilled water	=	18 ml
Etching time	=	35 seconds to one minute

Observations

Oxide Layer Thickness

The oxide layer thickness on end plate material was measured in each of the transversely sectioned specimens. The layer of oxidation was found to be in the range from 17 to 45 microns in thickness (Table 2 and fig. 4).

Figure 4: Photomicrograph showing the presence of oxidation layer on end plate material

TABLE 2 - Measurement of oxide layer thickness (olt) of end plate material

Sr. No. Specimen No.	Oxide layer thickness at various points (in mm at mag. 200X) a	b	c	d	Average OLT in mm at mag 200X	Actual OLT in Microns
1. 851474/EP1	3	5	6	4	4.5	22.5
2. 851474/EP2	2	4	2	6	3.5	17.50
3. 851474/EP3	7	5	5	4	5.25	26.25
4. 851474/EP4	10	7	9	10	0.0	45.00

DISCUSSIONS

The performance of fuel bundle during irradiation in reactor depends mainly on the integrity of its end plates. The end plate material has in turn great influence on its behaviour during irradiation. Zircaloys are susceptible to hydrogen pick up from the moderator/coolant and therefore study of hydridation effect helps to give a lot of information about hydrogen absorption. Similarly the measurement of oxide layer thickness of end plate provides information about the extent of oxidation taken place during irradiation history.

The thick oxide layer in the various transverse sections of end plates and the higher radial hydride orientation factor up to more than 0.3 clearly depicted that the end plate had the chances of failure during irradiation. From the literature study it has been known that factor greater than 0.3 is susceptible to cause failure [2]. Similarly the oxidation layer of 45 micron thickness might have added influence on embrittlement of end plate and which might have resulted in its failure.

ACKNOWLEDGEMENTS

We are grateful to Chairman PAEC for allowing us to undertake this assignment. The contribution made by technical staff of our Post Irradiation Examination Group in this works is recorded with satisfaction.

CONCLUSION

The visual inspection and metallographic study of end plate material revealed that the material had undergone severe embrittlement due to hydridation effect and it caused failure of end plates during irradiation.

REFERENCES

1. ASTM Hand Book, Volume 12.02, (1983). Ref. ASTM-Method No. B-253.
2. Millhollen, M. R. G. R. Horn and J.L. Bates. "Hydriding in purposely defect Zircaloy-clad fuel rods". HW-65465.

Hydridation Effect

The radial hydrides of end plate material were studied in various specimens and Fn, the hydride orientation factor was determined for each of the studied surfaces as per ASTM Method No. B-353 [1]. The observations have been recorded in Table 3 (fig. 5). The Fn factor was calculated to be in the range from 0.28 to 0.361.

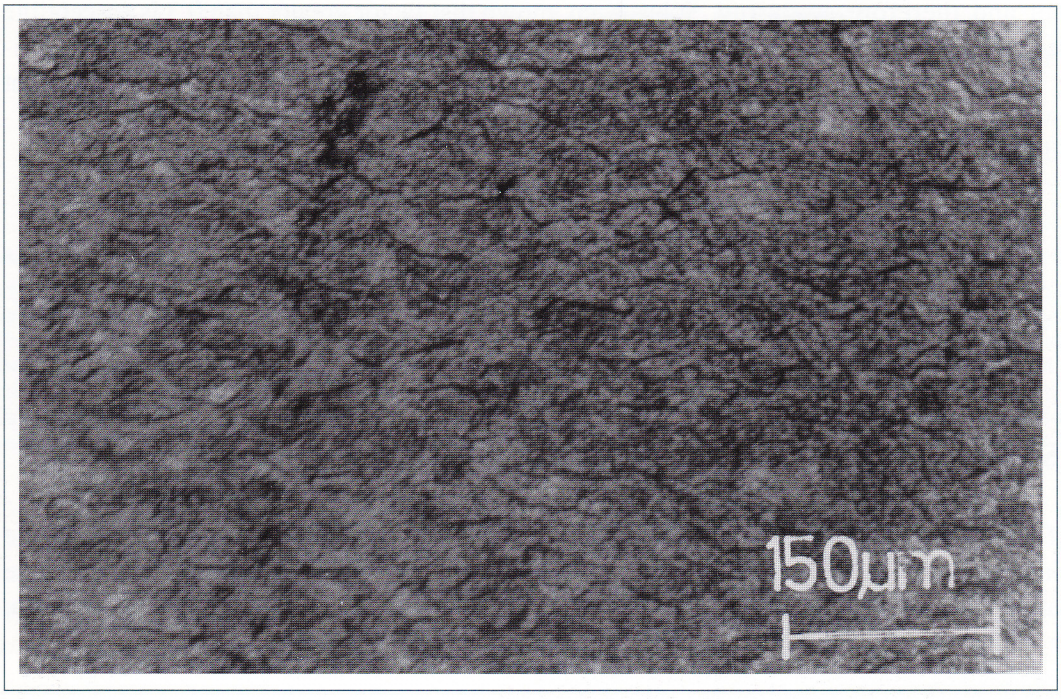

Figure 5: Photomicrograph showing hydrides in the end plate material

TABLE 3 - Determination of Fn factor for hydrides in end plate material

Sr. No.	Specimen No.	Measurements No. of Hydrides in measured area of 1" square at mag 200X			$Fn = \frac{H_r}{H^T}$
1.	851474/EP1	11.00	28	39.00	0.28
2.	851474/EP2	17.00	30	47.00	0.361
3.	851474/EP3	17.00	32	49.00	0.346
4.	851474/EP4	15.00	28	43.00	0.348

* Radial Hydrides
** Circumferential Hydrides
*** Total Hydrides (Plate lets)

P.N.: Min. size of Hydride for measurement was taken as 1.5 mm