Eddy Current Detection of Cladding Defects Due to Fuel Pellet Imperfections

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Abstract. An eddy current device has been used to localise cladding defects on irradiated fuel rods. The system has been initially tested with cold specimens, providing very good results and is now in regular operation in a hot cell at the Institute for Transuranium Elements (ITU). In this paper we demonstrate the system's performance and present recent results on a series of irradiated fuel rods with PCI-failures and partly long splits (secondary failures). The rods were delivered in tight capsules and only gamma scans could be done in the β-, γ-reception cell. Big defects were well visible through distortions in the gamma profile, whereas the smaller ones were very hardly detectable. They could be precisely localised later on, as soon as we cut the fuel rod and examined the individual segments with the eddy current device in an α-cell. Careful sampling around the defect location, specimen preparation and detailed microscopic analysis confirmed cladding cracks driven by fuel pellet imperfections or, more specifically, by missing chips from the pellet surface (MPS). MPS in fuel rods increases the probability of cladding failures caused during power changes. In addition to uniform stresses engendered by pellet expansion, local strains are applied onto the cladding at regions where a piece of pellet is missing. In the examined rods the MPS meniscus sizes varied between 26° and 44°.

1. INTRODUCTION

One of the primary non-destructive tests (NDT) of the post irradiation examinations (PIE) per-formed on irradiated fuel rods is to control the cladding integrity and search for cladding cracks, deformations or other anomalies that could permit escape of volatile fission products or even spent fuel particles and therefore cause risks of contamination. In nuclear research eddy current techniques are routinely used in examinations related to defect or failure in the cladding material. The corresponding eddy current equipments are in the most cases utilised to study the complete rod length in a reasonable time with properly adapted sensitivity. However, very small clad defects can be sometimes either not detectable, or must be precisely localised in order to proceed with further examinations. At ITU, fuel rod testing equipment is available and installed in a non-alpha contaminated hot cell, where the spent fuel rods are received and studied as a whole. After completion of the NDT the fuel rod is segmented; another small eddy current device has been installed in a hot cell in order to perform in-depth analysis at a level allowing a precise localisation of cladding defects.

2. EDDY CURRENT DEVICE AND COLD TEST

The photos and the drawing of Fig. 2.1 show the small eddy current device and the sensor, respectively. The sensor, connected with the controlling hardware, is positioned inside a bronze holder

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and its nose tip is softly touching the fuel segment, which can be rotated. The sensor can be axially moved along the segment and the data acquisition can be performed on the complete specimen outer surface. The distortions of the sensor's magnetic field are then presented through proper software in holographic format, as shown in Fig. 2.2.
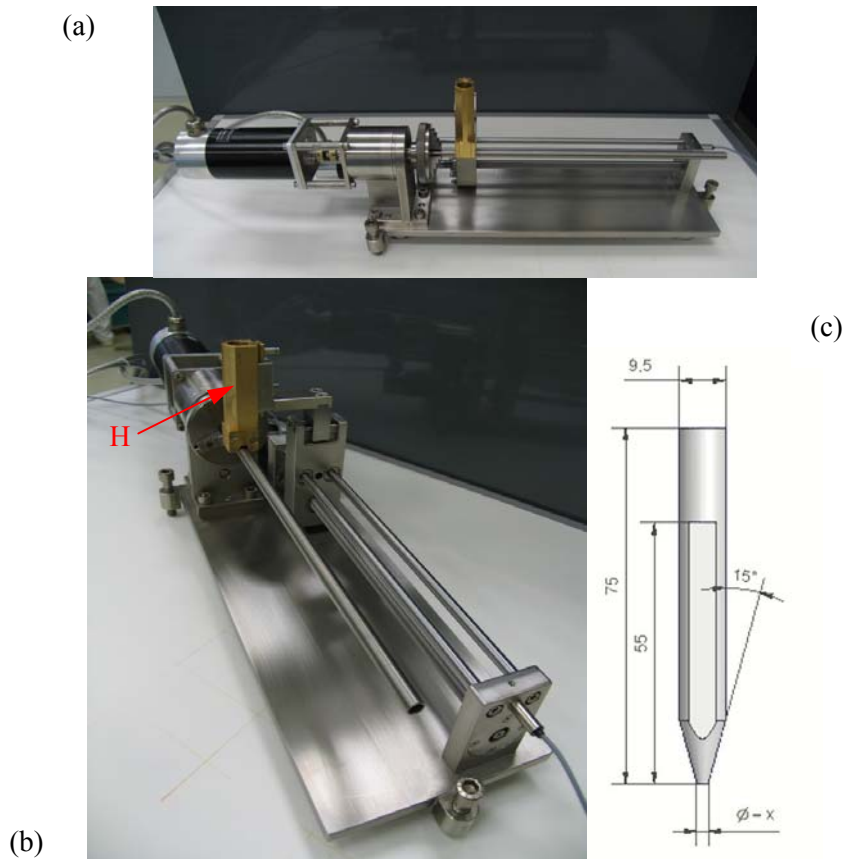

FIG. 2.1. (a), (b) The eddy current device for segment analysis. The sensor shown in the drawing (c) is placed inside the bronze holder, H.
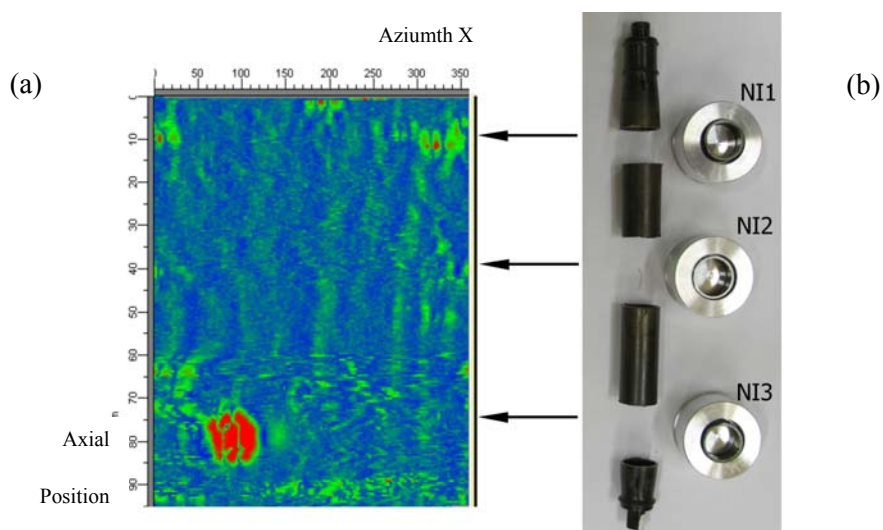

FIG. 2.2. (a). Eddy current hologram of a non-irradiated creep test cladding specimen (b). The green colour on the hologram represents small, and the red colour bigger defects.

The hologram in Fig. 2.2 has been recorded on the surface of a cladding tube after creep test. In this graph the X-abscissa-axis gives the azimuth and the Y-ordinate-axis the axial position of the sensor. The colour variation from the blue background (corresponding to surface level) denotes presence of small (green colour) or bigger (red colour) cladding defects. In order to confirm this, three small pieces of the tube specimen were cut at the positions of interest, embedded in proper holders, polished and observed with an optical microscope (Fig. 2.2(b)). In all cases the observed defects are in very good agreement with the hologram result.
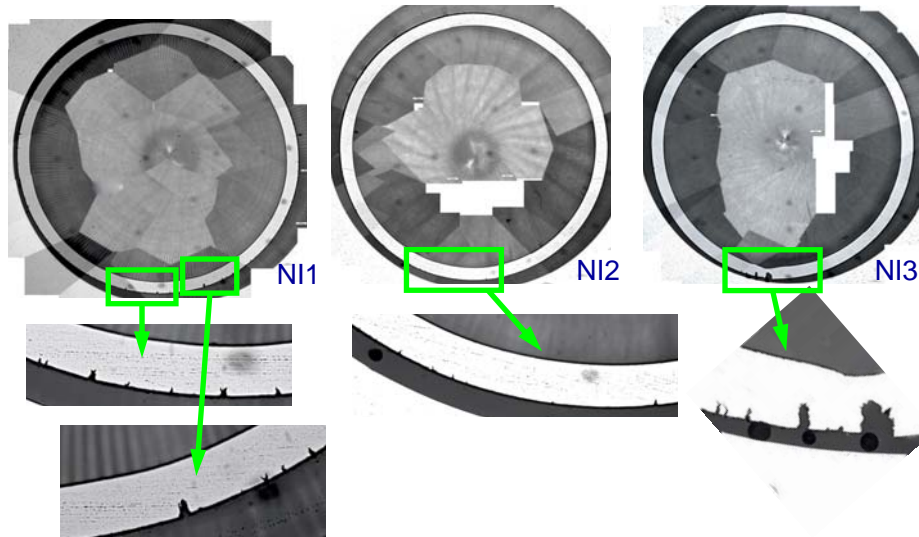

FIG. 2.3. Macrographs and detailed cladding photographs of the cross sections of the three specimens cut as shown in Fig. 2.2.

3. EXAMINATION OF ACTIVE SAMPLES

After some additional cold tests confirming the system's good performance, the device has been installed in hot cell and used to examine 4 irradiated fuel rods. Due to strong suspicion of clad defects, at the reactor site the rods were already packed in welded outer capsules and delivered to ITU for post irradiation examinations. The rods, just referred as No.1, 2, 3 and 4, were burnt up to 51.7 $GW \cdot d \cdot t^{-1}$ U, 58.4 $GW \cdot d \cdot t^{-1}$ U, 56.3 $GW \cdot d \cdot t^{-1}$ U and 55.7 $GW \cdot d \cdot t^{-1}$ U, respectively. The only non-destructive control that could be performed outside the tight capsules was γ-spectrometry.

The obtained spectra, shown in Fig. 3.1, did not provide unequivocal information about the suspected positions of cladding failures. The fuel rods were then cut in 480 mm long segments and the segment eddy current device was used to identify and precisely localise the defects. The obtained EC-hologram around the interesting rod axial region helped successfully to identify and localise the cladding defect, as can be seen in Fig. 3.2.

The assumption of the power plant experts was that the defects could be due to pellet imperfections, such as missing chips from the pellet edge, usually called MPS [1,2]. In such a case, stress-corrosion cracking caused by iodine (Zrl_4 is brittle) can take place in the cladding.

It was expected therefore that the tips of the initiating cladding defects in the delivered fuel rods would be close to a pellet-pellet interface. For this purpose, cuts were implemented just before the corresponding pellet of interest, whose position had been located by finding a dishing position at the beginning of the segment and counting the pellets up to the desired position. Such a cut from fuel rod No. 4, as well as the prepared specimen and photographs of the identified cladding defects are presented in Fig. 3.3, whereas Fig. 3.4 shows photographs of the MPS areas with the cracked cladding from all examined fuel rods.
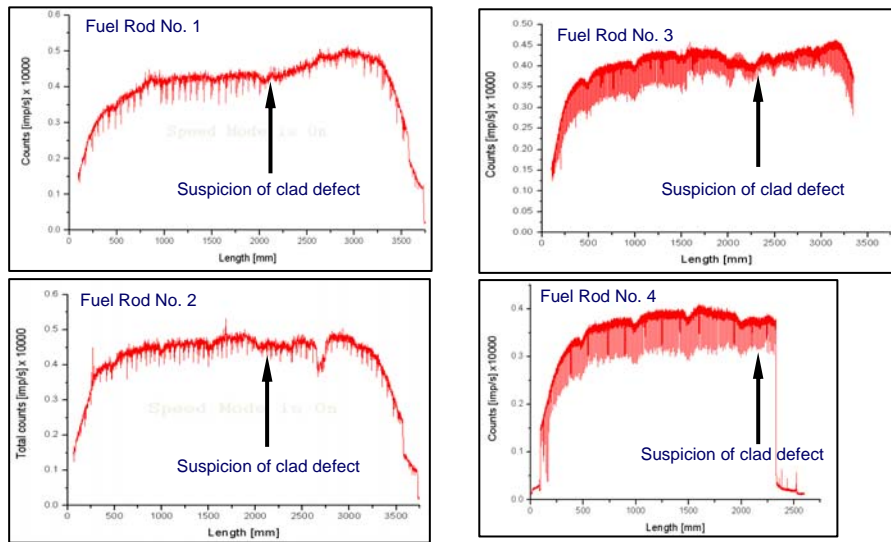
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FIG. 3..1 The γ-spectra of the 4 irradiated fuel rods; the suspected position of cladding defects are indicated.
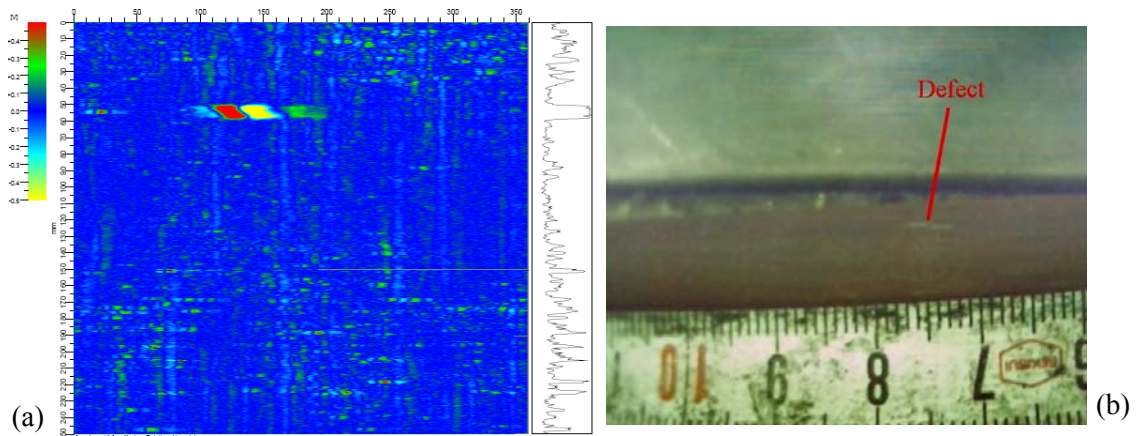

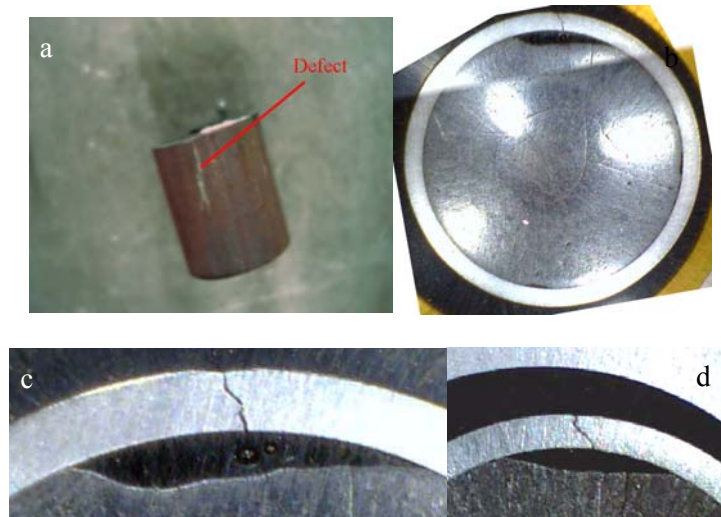*FIG. 3.2. The EC-hologram (a) and the cladding defect visually identified (b).*

FIG. 3.3. a) Sections from which the metallographic sample was prepared;b) Overview of the metallographic sample with the MPS defect;c) Close up of the defect area at the beginning of the fuel pellet;d) Defect area at an axial location ca. 0.8 deeper (after grinding) than in c.
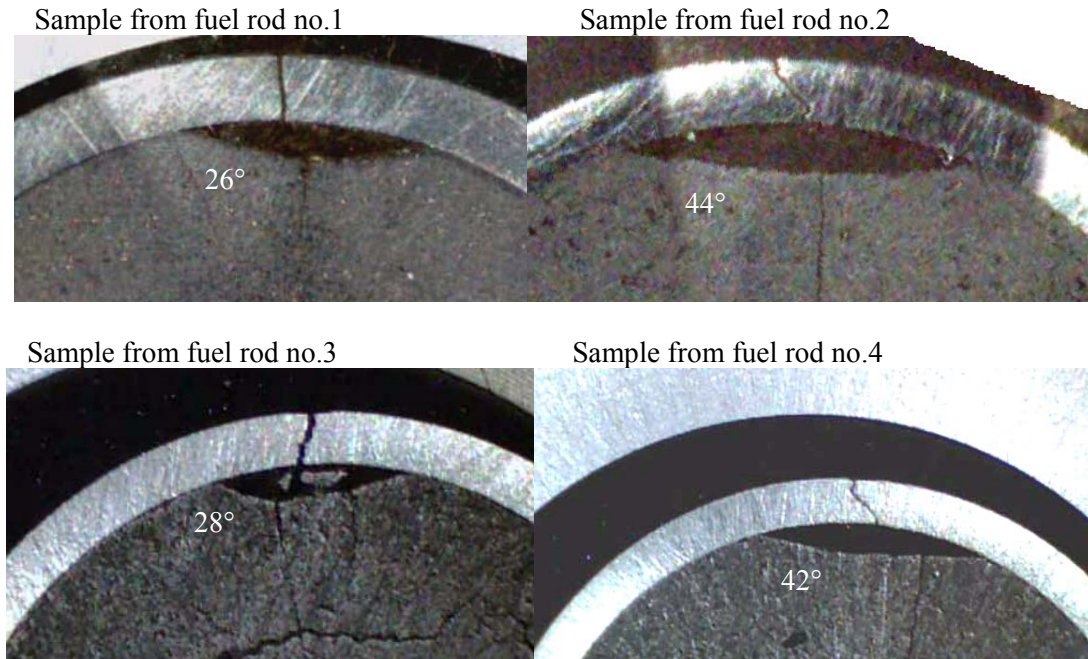
Sample from fuel rod no.1   Sample from fuel rod no.2

Sample from fuel rod no.3   Sample from fuel rod no.4

FIG. 3.4. Photographs of all confirmed MPS and corresponding cladding defects in the four rods analysed.

4. CONCLUSION

Using a small EC device assembled and installed at ITU, cladding material defects due to pellet imperfections (MPS) could be successfully identified and precisely localised. MPS areas are endangering the cladding integrity because of the local strains that can be generated in these areas. The holograms of the data obtained on a series of spent fuel rods confirmed the expectations of clad failures and permitted the preparation of exact and proper specimens to study cladding crack growth and MPS meniscus sizes.

5. ACKNOWLEDGMENTS

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