DEVELOPMENT OF AN EDDY CURRENT TESTING TECHNIQUE FOR INSPECTING INNER CORROSION OF CLADDING

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ABSTRACT

An eddy current testing (ECT) technique was developed to check the soundness of irradiated fuel pins non-destructively. Here, the technique was applied to detect the decrease in wall thickness of the fuel pin cladding due to corrosion occurrence which had been irradiated in the experimental fast reactor Joyo.

Dummy cladding provided with simulated inner corrosion was used to ascertain the technique applicability. This test confirmed that the decrease in wall thickness with simulated inner corrosion exceeding 30μm in depth could be detected. In the case of irradiated fuel pins, the decrease in wall thickness due to corrosion occurrence was not detected because the depth was too small; the maximum depth of the inner corrosion was 14μm.

In addition, it should be noted that the physical changes on the cladding due to irradiation might have an influence on the signal.

1. Introduction

In order to detect the decrease in cladding wall thickness of the fuel pin caused by fuel-cladding chemical interaction (FCCI) which was irradiated in Joyo, a probe coil eddy current testing (ECT) technique was developed in the Fuel Monitoring Facility (FMF).

Fig.1 shows an outline of the ECT apparatus installed in the hot cell of the FMF. In the inspection procedure, the sample is pulled up from the magazine at a constant speed (20mm/s) through the coil housing and is lifted until the bottom end passes the coil housing. Pin-guide rollers are kept closed throughout the detection to center and dampen vibration of

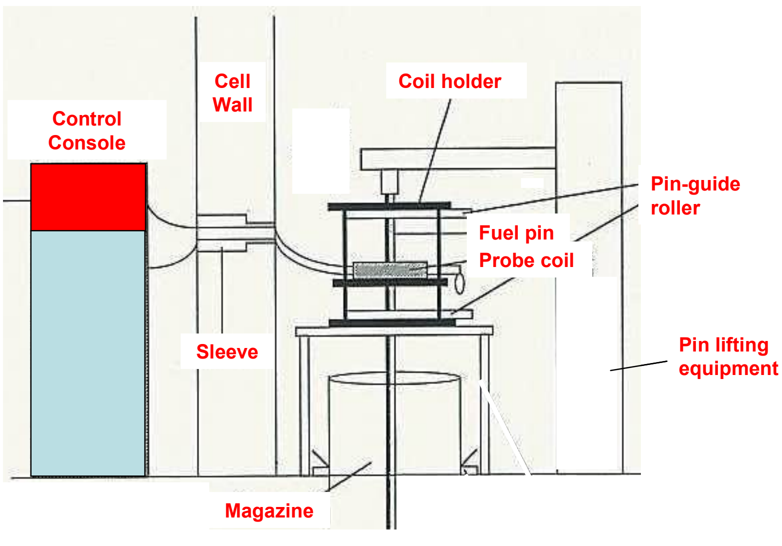

Fig.1 Outline of ECT apparatus

the cladding. Detection is done along the axial direction at every 90 deg, so 4 directions per sample are examined.

This paper describes the detection results by ECT of the wall thickness decrease in dummy cladding with simulated corrosion and in irradiated fuel pins with MOX fuel pellets.

2. ECT inspection method in France

Defects cased by FCCI in fuel pins irradiated in French nuclear reactors have been detected [1]. According to the report, it was possible to detect the cladding wall thickness decrease by ECT along the axial direction. In order to distinguish the signals by FCCI from other signals, Cs intensity from the pin gamma scanning test and pin diameter measurement results were used. Metallographic test results showed that the corroded depth was 180μm and 270μm remained uncorroded.

Cs is a fission product (FP) and it influences corrosion occurrence in the cladding, especially at points where it is accumulated. Pin diameter becomes bigger if Cs accumulates on the pins [2]. Based on the above information, Cs intensity and pin diameter could be used to help in distinguishing the signal of the wall thickness decrease caused by FCCI from other signals.

3. Preliminary test with dummy cladding

3.1 Procedure

A preliminary test was done using hollow dummy cladding with simulated inner corrosion to ascertain the applicability of the ECT technique and to choose the testing frequency and testing phase. After taking the defect signal to base noise signal (S/N) ratio into account, 32 kHz was chosen for the testing frequency, and as the lissajou shows 0 deg, the testing phase was set to 270 deg.

3.2 Results

Fig.2 shows the ECT signal obtained for the dummy cladding. The signal was around 0 V for locations with no decrease in the wall thickness by corrosion and a positive value for locations with decrease in it by corrosion. Metallographic test results showed the minimum corroded depth was 30 μm and 380 μm remained uncorroded in the cladding. The relationship between the ECT signal and the cladding wall thickness is shown in Fig.3. The ECT signal decreased as the cladding wall thickness became less.

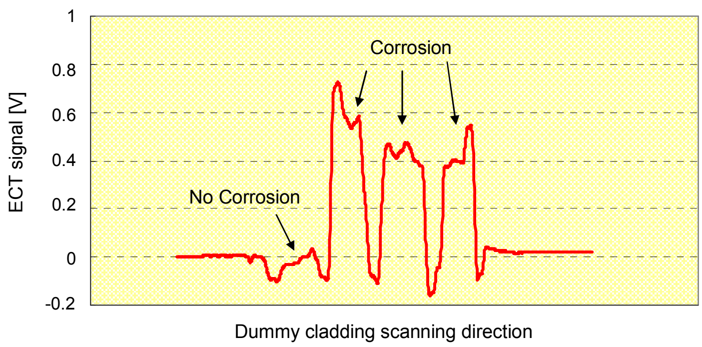

Fig.2 ECT signal of dummy cladding

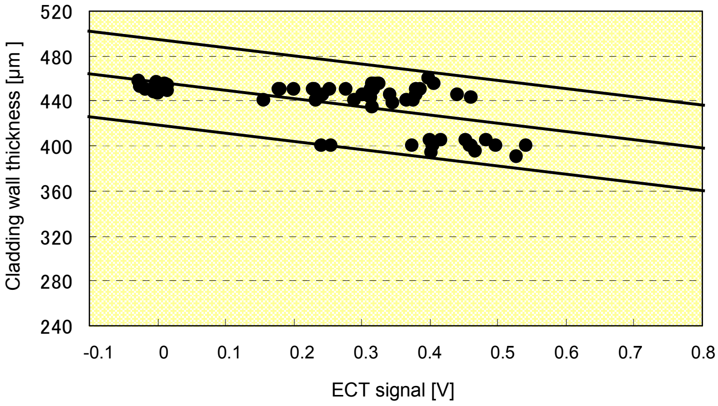

Fig.3 Relationship between ECT signal and cladding wall thickness

4. Application of ECT for irradiated fuel pins

4.1 Irradiation conditions and test procedure

A total of 14 fuel pins which had been irradiated in the experimental fast reactor Joyo were applied to the ECT test; each pin contained MOX fuel pellets. Maximum burn-up and temperature in the cladding were 84.2 GWd/t and 652 deg, respectively. The oxygen to metal (O/M) ratio of the MOX fuel pellets was controlled to 1.97. These pins achieved the maximum burn-up allowed in Joyo.

The testing frequency and phase were the same as in the dummy cladding test, 32 kHz and 270 deg. A metallographic test was conducted to locate where the decrease of the cladding wall thickness caused by FCCI had occurred after the ECT was completed.

4.2 Results

Fig.4 shows the ECT signal along the axial direction of the irradiated fuel pin and its relationship to Cs intensity and pin diameter measurement result. The ECT signal which indicated a decrease in the cladding wall thickness caused by FCCI was not able to be obtained. The metallographic test results showed that there was only corrosion to a depth of 14 μm and 457 μm remained uncorroded in the cladding.

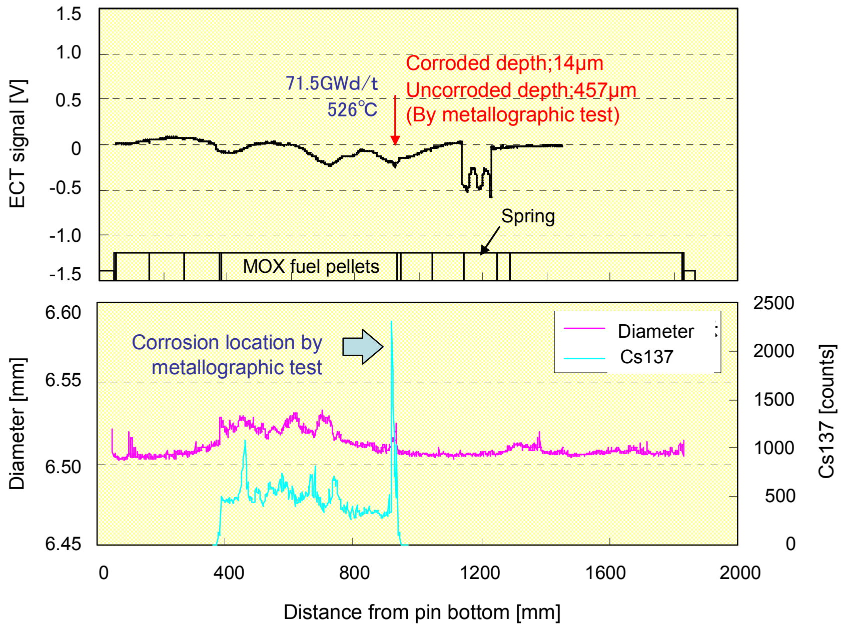

Fig.4 ECT signal of irradiated fuel pin and its relationship to Cs intensity and pin diameter

5. Discussion

A past study reported that the minimum detectable decrease of the internal wall thickness was 10 % of the cladding wall thickness [3]. As the decrease in the dummy cladding was about 8 %, it was able to be detected. In the case of the irradiated pins, the decrease was only about 3 % of the cladding wall thickness; it was too small to detect. The fuel pins for Joyo are designed to maintain their soundness if the inner corrosion depth is less than 100 μm. That is equivalent to about 20 % of the entire cladding wall thickness. A 14 μm decrease cannot influence the soundness of the fuel pin. If the inner corrosion is deep enough to influence the soundness, it must be more than 10 % of the cladding wall thickness, and it can be detected. Hence the ECT technique is applicable to checking the soundness of irradiated fuel pins.

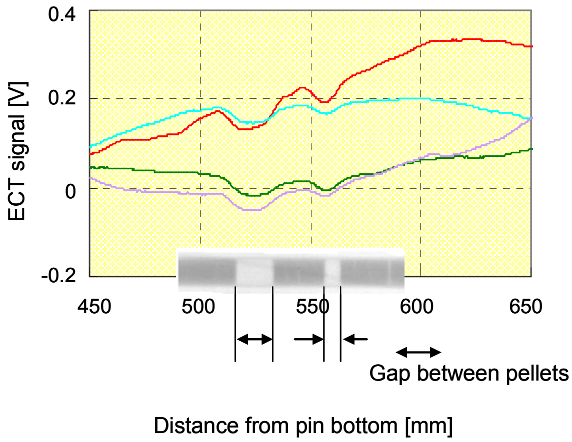

Fig.5 Comparison of ECT signal with X-RG test results

In order to check the influence of physical change on the signals, an X-ray radiography test results were used [2]. The comparison of the ECT signals with X-ray radiography test results is shown in Fig.5. Four ECT signals obtained at 90 deg intervals are plotted. All ECT signals became smaller near the location of the gap between pellets. This indicated the signal was influenced by whether there were pellets or not.

The inner corrosion caused by FCCI is correlated with O/M ratio, burn-up and temperature in the cladding [4]. The relationship between the corrosion depth and inner cladding temperature is shown in Fig.6. The corrosion depth increased as the inner cladding temperature rose above about 500 deg. In spite of achieving the maximum burn-up in this test, the corrosion depth was only 14 μm.

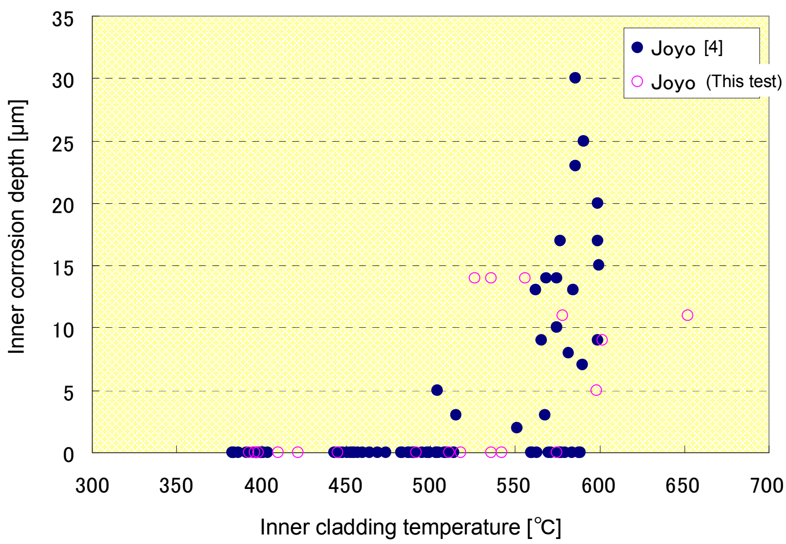

Fig.6 Relationship between inner cladding temperature and inner corrosion depth

6. Conclusion

The ECT technique was confirmed to be able to detect the decrease in the cladding wall thickness in a test using dummy cladding with simulated corrosion. In the case of fuel pins irradiated in Joyo, no decrease could be detected because the corrosion depth was too small. However in the case the soundness of the fuel pin is influenced by the decrease in the cladding, the corrosion would be deep enough to detect. Hence it was concluded that the ECT technique can be applied to check the soundness of irradiated fuel pins cladding.

In addition, it was found that the signal was influenced by whether there were pellet in a location or not. It is necessary to accumulate more ECT results to determine the influence on the signal due to various factors.

References

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[2] S. Sasaki, et al. “Post Irradiation Examination of Subassembly PFC040 Based on the Agreement between CEA and PNC in the area of fuel and material development in FBR –Non-Destructive Examination Results of the Fuel Pins–,“ JNC ZN9410 2004-004

[3] K. Tsukui, et al. “Eddy-Current Testing of Reactor Fuel Cladding Using Encircling and Probe-Coil Systems,” Proceeding of 26th Conference on Remote Systems Technology, 1978

[4] T. Donomae, et al. “Evaluation of Irradiation Performance in Monju-type Fuel Subassembly (MFA-1),” JNC TN9400 2000-075

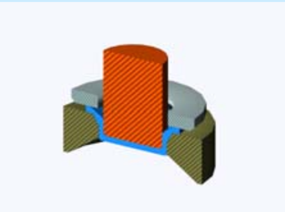
Materials and Component Safety

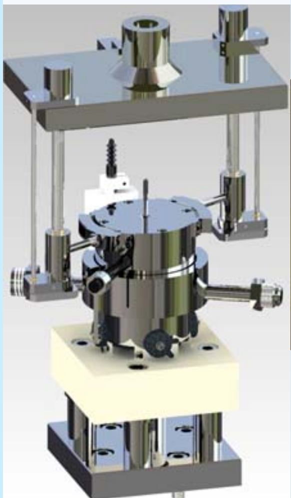
Nuclear Safety Research

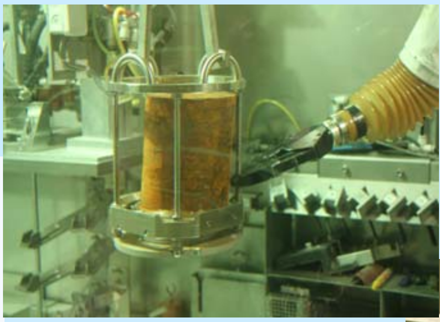
Equipment in Hot Cell Testing Facilities of FZD

metallographical laboratory

- tools for the sample preparation
- microscopes for imaging and analysing
- Vickers thoughness test tool







logistic, stock and other equipment

- pallet lifting system with crane
- security container for stocking
- clamping and handling system
- stud welding apparatus for specimen reconstitution
- specimen labelling tool
- measuring microscop

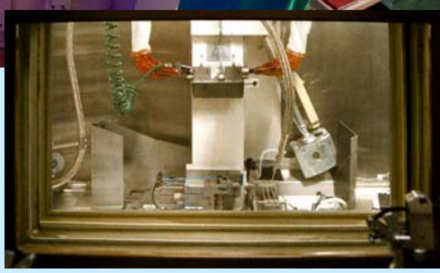
wire EDM machine (AGIECUT CLASSIC)

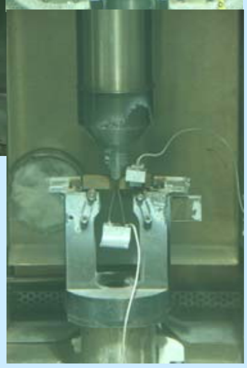
- cutting of trepans and manufacturing of different specimen types

screw-driven testing machine (TestInspekt)

- computer-controlled small punch testing
- 10 kN load frame
- temperature chambers for -150...T…+300° C

- ✓ **wallthickness for shielding 150 mm in machining area and 100mm in testing area**
- ✓ **maximum activity of the specimen 5 · 10^{12} Bq Co-60**





instrumented pendulum impact tester PSd300

- Charpy V-notch specimen testing
- dynamic fracture toughness
- max. impact energy 300 J
- max. velocity 5.5 m/s
- temperature chamber for -115°C...T...+300°C

servo-hydraulic universal testing system (MTS)

- uniaxial tensile testing
- static fracture testing
- load capacity max. ± 50 kN
- temperature chambers for -150...T…+300° C
- various mechanical extensometers

actual main topic:

investigation of trepan from WWER-440 reactor pressure vessels of the Greifswald nuclear power plant

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