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Defect detection and cause analysis of HANARO research reactor fuel fabrication

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1. Introduction

The Korea Atomic Energy Research Institute (KAERI) has fabricated HANARO research reactor fuel since 2004. HANARO fuel is rod-type fuel with U_3Si dispersed in matrix of Al with aluminum cladding surrounding the outside of the fuel core. At both ends of the fuel rod, end-plugs are inserted and welded to the cladding. One important point when manufacturing the fuel is that it must be well sealed so that radioactive materials do not leak out.

There are various types of defects that may occur during the manufacturing of the fuel, such as cracks of the cladding or blowholes in the welds. Defects must be detected by appropriate non-destructive tests and evaluated against acceptance criteria.

This paper aims to detect defects that have recently occurred in HANARO fuel and their causes as analyzed through the non-destructive testing.

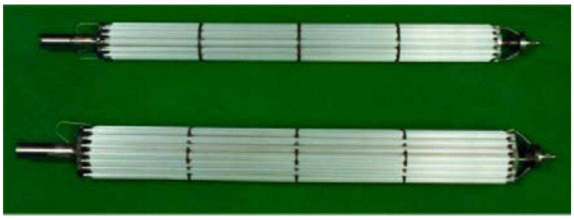

Fig. 1. Two types of HANARO research reactor fuel bundles

2. Methods and Results

2.1 Eddy Current Test of the fuel rod cladding

The fuel swells when irradiated in the nuclear reactor due to fission products or gas, which can cause Al cladding to tear. In order to prevent the cladding from bursting, defects in the cladding should be detected and appropriate measures should be taken beforehand.

Surface scratches, pinholes, blisters, dents and foreign particle inclusions can arise in the cladding during the cladding co-extrusion process. An eddy current test (ECT) can detect defects on the surface or below the surface of the 0.75 mm thick Al cladding [1]. Every fuel rod passes through a probe to record ECT signals of the cladding. The types and sizes of the defects are then interpreted through a comparison with the signals from a standard specimen with artificial defects. Fig. 2 presents an example of a fuel rod that failed to meet the acceptance criteria due to a surface scratch in the cladding, and Fig. 3 visually illustrates the defect in this case. Such fuel rods with defects are inspected again after removing defected cladding and re-clad.

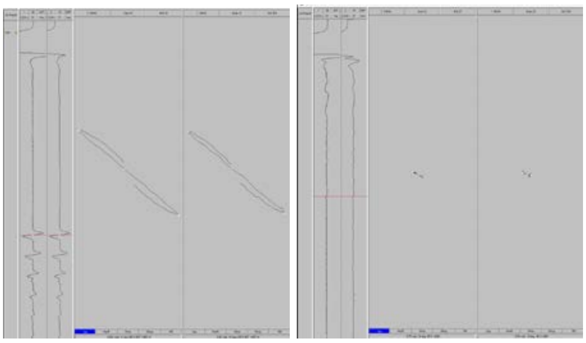

Fig. 2. Comparison 15 kHz and 30 kHz ECT signals of a standard specimen (left) and a fuel rod (right)

Fig. 3. Scratch on the surface of the cladding

Cladding defects of this type may be due to foreign substances in the mix or may stem from an air layer that was trapped in the cladding and burst during the co-extrusion process. Therefore, it should be considered to check the impurities in the cladding material and the cleanliness of the extrusion mold.

2.2 Real-Time X-ray Radiography of welds

End-plugs are inserted at both ends of the fuel rod and sealed by electron beam welding (EB welding) (Fig. 4). Both welds are examined by real time X-ray radiography (RTR) to check for defects.

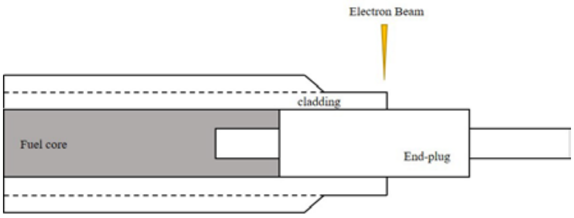

Fig. 4. Schematic design of the EB welding of a fuel rod

The most common type of defect is a blowhole. The material of end-plug and cladding is both pure aluminum and when a high-energy electron beam is concentrated in a very thin area, blowholes can be generated in the weld [2]. According to the specifications in the HANARO fuel manufacturing instructions, the number of pores should be less than 5 and the sound bead depth should be at least 0.33 mm [3]. Fig. 5 shows an example of a blowhole in the weld. The thickness of the weld of this fuel rod is 0.28 mm, and it did not meet the acceptance criteria.

The main causes of such blowholes being generated in the weld are an inappropriate EB welding setting (e.g., voltage, current, welding speed) or an improper thermal diffusion effect. The EB welding machine currently used for HANARO fuel manufacturing is a newly introduced equipment, and through the further studies that analyze the heat sink designs of this device, it is expected that the generation of blowholes could be suppressed by controlling the thermal diffusion effect.

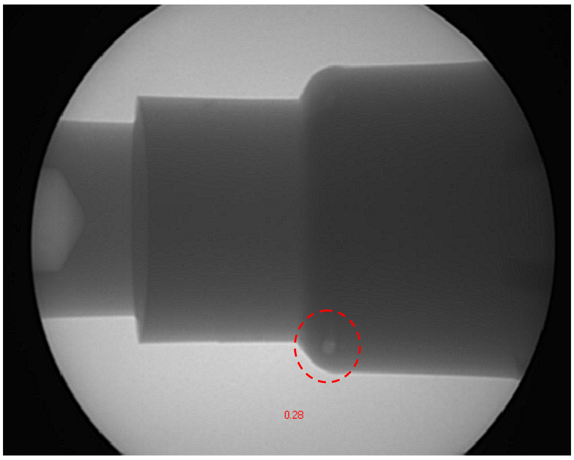

Fig. 5. RTR of a blowhole in the weld

Another form of defect is a gap defect. A gap defect refers to a defect in which the cladding is not in close contact with the end-plug, being instead slightly separated. These are indicated by a bright line on the RTR inspection screen. Fig. 6 shows a gap defect in a fuel rod.

The end-plug hole machining process could cause gap defects. If there is an air layer between the end-plug and the machined insertion hole in the fuel core, the gas can expand during EB welding and diffuse to the end-plug cladding boundary layer. Another possible cause of such a defect is deviated straightness of the fuel rod, a problem that arises after the co-extrusion process. If fuel core is bent, the cladding may float slightly over the fuel core after co-extrusion. Therefore, it is necessary to consider whether the straightness calibration of the fuel core is properly performed.

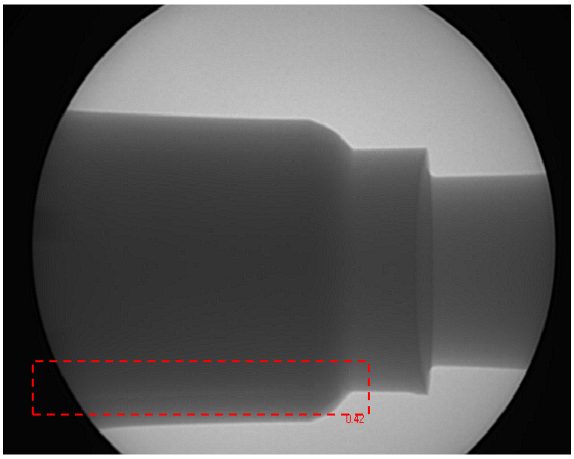

Fig. 6. Gap defect between an end-plug and the cladding

3. Conclusions

The current defect status and causes of defects detected through non-destructive testing of HANARO fuel were analyzed here. In future studies, it will be necessary to conduct in-depth experiments focusing on issues that can cause defects in an effort to improve HANARO fuel manufacturing productivity outcomes.

REFERENCES

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[3] HANARO fuel manufacturing instruction: RTR (II) inspection for fuel rod end-plug welding, HFMI 370-3, Rev.4, 2020.

ACKNOWLEDGMENT

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