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# Technique Comparison of the Fracture Toughness Tests for Irradiated Fuel Claddings in a Hot Cell

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## 1. Introduction

The degradation of a fracture toughness in a fuel cladding is a important factor to restrict the operation safety in nuclear power plants. The fracture properties of claddings were traditionally measured through a rubber bung test, a burst test, etc. Those results were the qualitative fracture characteristics, and could not be used as design or operation safety evaluation data. We need to evaluate the quantitative characteristics of claddings under normal operation and in accidents. The application of a fracture mechanics concept in testing a fuel cladding is restricted by the cladding geometry and creating the correct stress-state conditions. The geometry of claddings does not meet the requirement of the ASTM Standards for a specimen configuration and an applied load. The specimen may be produced from previously flattened claddings [1], but the flattening causes some uncertainties in the results due to changes in the microstructure of the material and a new distribution of the internal stresses. Therefore many efforts have been devoted to developing new test techniques, to quantify the fracture characteristics of claddings. Researchers from JAEA and NFI in Japan, Studsvik Company Ltd in Sweden, IAEA in Australia, and KAERI in Korea have independently developed fracture test techniques. This study is designed to review the independently developed techniques and to compare of their merits. Finally we shall apply the other techniques to upgrade our developing techniques.

## 2. Basic description of the fracture test

The quantified fracture parameters like as a stress intensity factor ($K_{IC}$), a J-Integral ($J$), and a crack growth resistance ($dJ/da$) can be calculated from the test data proposed by ASTM Standards. Unfortunately, the specimen dimensions from the claddings can not meet the size requirements in the Standards. Sharply notch thin-walled tubular specimens like as the claddings subjected to a uniaxial circumferential tension can not provide the proper stress-biaxiality due to the transverse-axial contraction of a specimen during a tension. A narrow, through net cross section, area where processes of a plastic deformation and fracture take place arises in a specimen. In such a case, elastic deformation stored in the loading system strongly influences the low-ductility material behavior leading to a spontaneous failure of a specimen at extremely small displacements immediately after the maximum load [1].

To solve the above-mentioned difficulties many researchers have been inventing various specimen shapes and loading fixtures.

## 3. Status and comparison of the techniques

In this section, the developed techniques by various researchers are reviewed and compared for their merits. Each technique has its own shape in a specimen and a loading fixture, and furthermore the method to measure a crack length.

### *3.1 JAEA and NFI Ltd*

Researchers in JAEA and NFI Ltd have developed the technique where the loading fixture has the shape of a compact tension type, so called a NCT method [2]. Fig. 1 shows a sample and a compact tension (CT) shaped loading fixture. The detailed test procedures are as follows. A test part with 15 mm in length in a cladding is cut off from the selected position of a cladding. A sample, actual test part is machined by using an electric discharge machine (EDM) from the test part cladding. The sample is assembled into the CT shaped test fixture as shown in Fig. 1. Assembled CT shaped specimen is set up in a fatigue tester and applied cyclic load for a pre-cracking. The pre-cracked specimen is loaded in the tensile testing machine and tested. After the test, pre-cracked length is measured by the optical microscope. A J value-like, fracture toughness is evaluated of the basis of the ASTM E-1820 Standard. The developed technique was applied to evaluate the J-value for the fracture toughness of BWR spent fuel claddings.

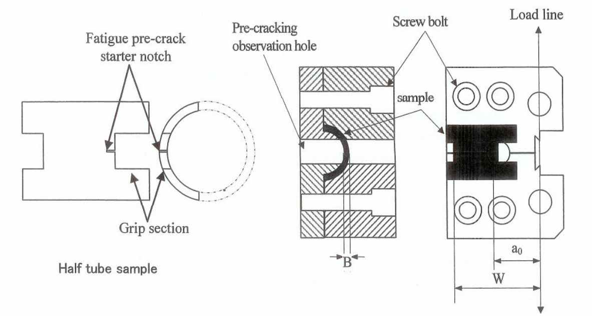
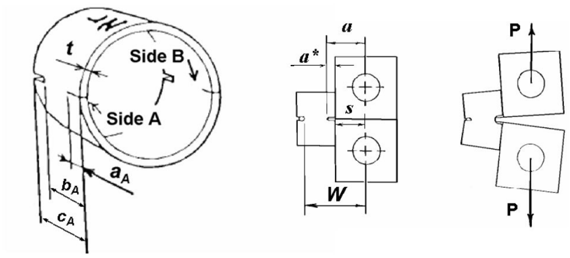



Fig. 1 Sample and CT shaped loading fixture in a NCT method

### *3.2 Studsvik Co. Ltd and IAEA*

Researchers in Studsvik Co. had invented a pin loading tension (PLT) method to measure the fracture toughness as shown in Fig. 2 [3]. The specimen is approximately 13mm long and contains notches. The proportions of the specimen dimensions are selected to prevent an axial contraction in the deformed area, and to have the dimension $c_A$ unchanged during a testing. A special fixture has been designed to consist of two half cylinders. The design of the fixture for a PLT testing can be seen in Fig. 2(b). The fixture halves, being loaded with a tension through the pins, have the capability of a mutual rotation around an axis determined by a small pin placed between the fixture halves at the outside end of the cylindrical holders. The rotation of the fixture halves is similar to the rotation of the CT specimen halves under a loading. During a PLT test, the load applied to the specimen is recorded versus the load-line displacement. They applied the PLT method for the irradiated claddings successfully. PLT method is now under an upgrading through a coordinate research program in the IAEA since 2005. It aims to measure a delayed hydride cracking velocity in a cladding.




(a) (b) (c)

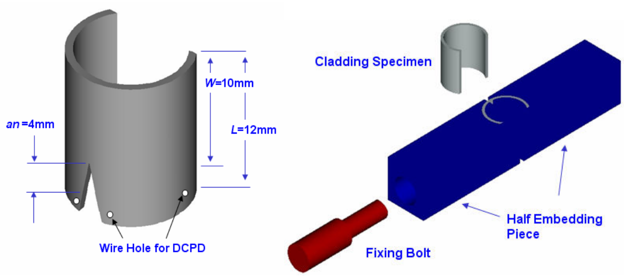
Fig. 2 Sample and loading fixture shapes in the PLT method

*3.3 KAERI*

Researchers in KAERI developed a KAERI Embedded Charpy (KEC) method as shown in Fig. 3 [4]. The specimen is approximately 12mm long, and contains a notch and the holes to connect wires to measure the dropped voltage. The shape of the notch and the holes are different from that in the PLT and the NCT specimens. The specimen is machined to have the ratio 0.4 of an initial crack length to a width by the EDM. A special fixture has been designed to consist of two pieces of a rectangular bar containing a slot to fix the cladding by bolts. The fixture to load the compression during a testing has the dimensions of 10 mm width, 40 mm span, 55 mm total length according to the single edge bend (SEB) specification in ASTM E 1820-99 Standard. The upper and lower fixture supports, with the rollers, are fabricated to endure the compression load to the cladding through the fixture during a testing. During a KEC testing, the compression load is recorded versus the load-line displacement. The amount of crack growth is measured by the direct current potential drop (DCPD) method. The KEC method was applied to test the irradiated claddings in a hot cell successfully.

*3.4 Discussion on the developed techniques*

Each techniques has it's own features in the specimen shape, the fixture, the loading method and the crack length measurement. These are thought to be caused from the independent development programs, and the aims to measure different characteristic values during a test.




(a) (b)

Fig. 3 Sample and loading fixture shapes in the KEC method.

The PLT technique has priorities in a simple test procedure to the others, but has difficulties to position the specimen in the fixture during a testing. The NCT method has the most complicated procedures to fit the specimen into the fixture, but it is expected to give better results than the others. The KEC method has simpler procedures to fit the specimen than the NCT method. It has the priorities to measure the crack length using the DCPD method, which is different from the others, measured by the COD method. It provides a good chance to apply the KEC method to severe test conditions, like under an extremely high and low temperature atmosphere. To upgrade the KEC method the fixing technique of the cladding should be improved, and the COD method should be introduce to measure a crack length for more precise test results.

## 4. Conclusion

Various techniques to measure the fracture toughness of nuclear fuel claddings in a hot cell are reviewed and compared. Through a comparison of each technique, the KEC method developed by KAERI needs to be improved introducing the new specimen fixing technique and the COD method to measure the crack length.

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