Mechanical Integrity of Spent Nuclear Fuel Rods

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INTRODUCTION

The properties of spent nuclear fuel (SNF) rods change significantly during their operation life in the reactor core. Further changes occur after their discharge mainly due to the heating-cooling processes and possible ageing associated with the cumulative effects of radioactive decay induce damage in the fuel. Such changes may affect the response of the SNF rods to mechanical solicitations corresponding to normal and accidental conditions.

Research activities at JRC-KARLSRUHE aim at assessing the integrity of SNF rods and processes which might affect their mechanical properties during their interim storage, transport or other handling operations. JRC Hot Cell facilities have been fully adapted to fulfil the experimental goals. The number of experiments that can be performed, however, is limited and there is an acute need to model them, using this process to validate codes, to deeper understand and to extend the results gained at the JRC beyond the conditions that have been tested. For the experimental campaigns two devices for gravitational impact and 3-point bending tests were developed and installed in a hot cell. Segments of real SNF rods pressurized at their original pressures after discharge have been investigated. The setup is fully operational and new results are reported continuously.

EXPERIMENT AND RESULTS

Experimental

Gravitational impact and 3-point bending tests are performed on segments of irradiated SNF rods with the devices shown in Fig. 1 and Fig. 2, respectively. The pressurized segments undergo rupturing under dynamic (impact) and quasi static (bending) loading to study thus the rod's response under boundary accidental loading scenarios. Detailed description of equipment and methodology together with results from "cold" tests conducted on SNF rod simulants during the developing and optimization phase, as well as from the first hot tests have been recently presented [1, 2].

This paper summarizes the latest results obtained on both equipment on a 67 GWd/tHM spent fuel rod pressurized at 70 bar and compares them with data from previous experiments on other SNF rods. The irradiation history and post irradiation data of the rod studied can be found elsewhere [2, 3].

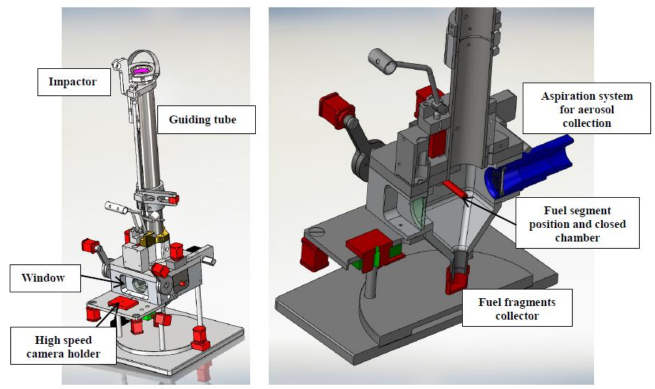

Fig. 1. Overview of the impact test device (left) and sectioned view of the closed chamber (right) where the impacting takes place.

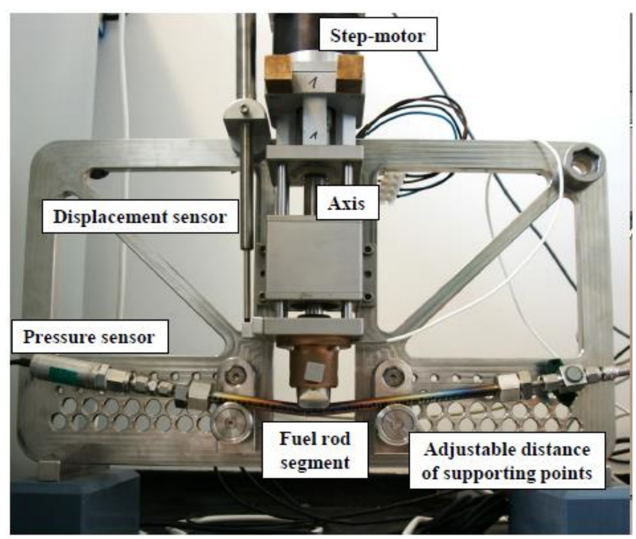

Fig. 2. Overview of the 3-point bending test device with equipped sensor system for load and displacement online measurements.

It must be noted that this is the second impact test conducted on the same SNF rod. The test has been repeated, since the device has been slightly modified to ensure similar configuration and thus comparable results between impact and bending tests. Only one sample breakage occurs in the modified system, as the sample supports have been rounded and are now analogous to the supporting system of the bending device (roles, see Fig. 2). In the previous configuration the SNF ample was breaking at 3 positions [2, 4], due to its fixation at the walls of the chamber.

Results

Impact test

The impacting has been recorded with a high speed camera and some of the obtained photographs are presented in Fig. 3. The recorded video is analyzed to determine the absorbed energy by the sample and its deflection at the fracture point. The sample's rupture energy is calculated from the reduction of the hammer speed just before the hammer contact and at cracking completion, as shown in Fig. 4. The method gave already reasonable results, but the analysis is still under evaluation.

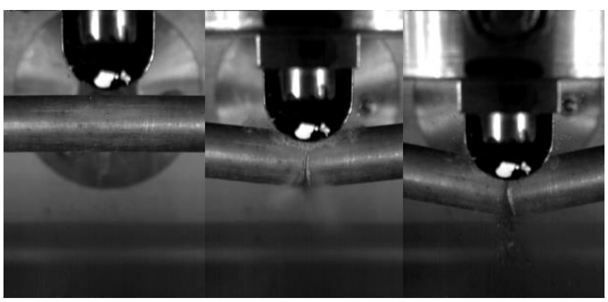

Fig. 3. Sequence of photographs at several stages obtained with a high speed camera.

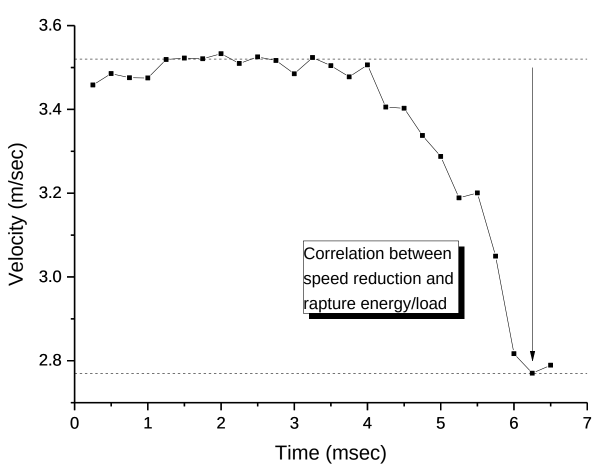

Fig. 4. The hammer speed is measured via video digital analysis and used to calculate the impacting energy.

Released fuel particles can be collected and their size distribution is investigated by SEM EDX, which is ongoing. In this test the mass of fuel released (determined by gravimetric analysis of the rods before and after the test) was in the 0.81 to 2.33 grams range, i.e. far less than the mass of a single fuel pellet.

3-point bending test

As it can be seen in the plot of Fig.5, the sample ruptured at 3 kN load after a 0.9 cm displacement from the initial horizontal position. The simultaneous rapid drop of the pressure confirms the sample rupture. Almost 1 g fuel released after rupture, which is less compared to the corresponding impact test release. This is due to the fact that the sample broke at a location very close to a pellet-pellet interface, as the photographs in Fig. 6 signify.

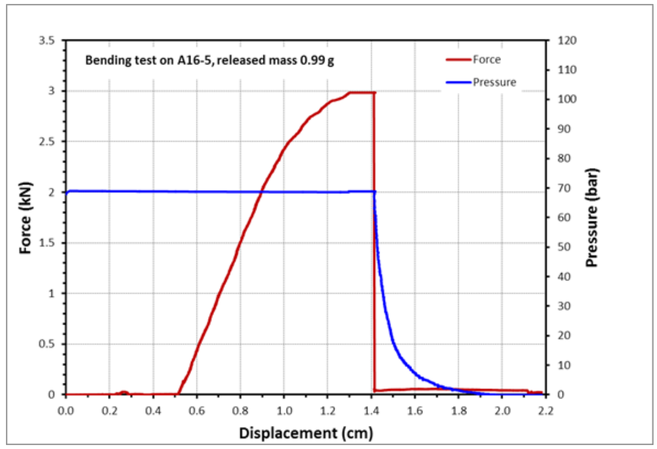

Fig. 5. Bending test on a 67 GWd/tHM SNF rod segment; 0.99 g fuel has been released.

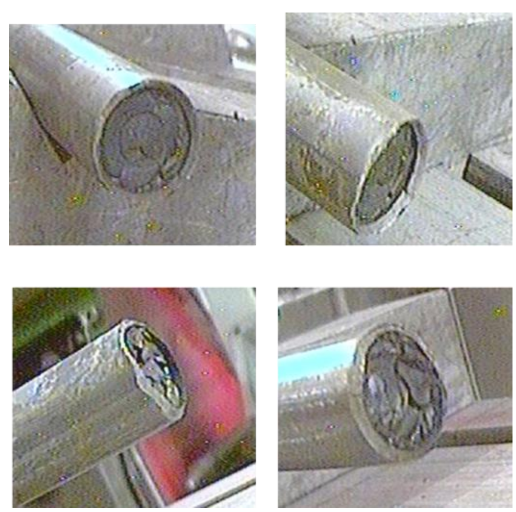

Fig. 6. Several views of the SNF rod at the breakage after bending test.

CONCLUSION

The fuel mass released during the bending test was 0.99 g, i.e. comparable to the impact tests. No enhanced fuel release due to depressurization was detected. The majority of the fuel is released as big fragments.

Effects of different types of cladding and individual clad-ding properties per se do not clearly affect the amounts of fuel released. In all bending and impacts tests on SNF rods the collected released fuel per breakage did not exceed 5 g, i.e. less than the mass of a single fuel pellet and is comparable regardless of the static or dynamic conditions. The next stages of these campaigns foresee exposure of rodlets to heating cycles to evoke hydride reorientation prior to impact and bending tests and the extension of these tests to more simplified conditions, i.e. ring compression tests on the cladding alone.

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