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Experimental facility to study transient thermo-mechanical behavior of the clad tube under high temperature conditions

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1. Introduction

In the design of nuclear power plant, the hypothetical accidents like Loss of coolant accident (LOCA) are investigated so that suitable mitigating systems can be deployed to maintain the integrity of fuel cladding. Keeping in view above facts, the effect of the internal pressure, heating rate and temperature on the ballooning deformation of Zircalloy-4 cladding has been widely investigated [1,2]. The large azimuthal temperature gradient around periphery of clad tube causes uneven wall thickness in ballooned region resulting into small burst strain [3,4]. It has been observed that phase transformation from α to β phase plays an important role in the deformation of Zircaloy-4 [5]. The transient ballooning deformation in azimuthal direction is a vital information which has been not reported in open literature. Keeping in view above facts, an experimental facility has been designed for measurement of transient temperature and deformation over the clad tube by indirect heating using fuel simulator.

2. Details of Experimental setup

2.1 General layout

The Fig. 1 shows schematic layout of the experimental setup. The clad tube (outer diameter of 9.5 mm) is placed concentrically inside a cylindrical enclosure (inner diameter of 50 mm). The clad tube will be pressurized using helium gas up-to the desired pressure through a SS pipeline connected to a cylinder in which gas is stored at 120 bar pressure. The pressure is controlled by using a solenoid valve in combination with a pressure switch. The pressure in the clad tube will be measured by a pressure transducer, which is mounted in the SS pipeline near to the clad tube pressurization port. To create non-oxidizing atmosphere around the clad tube, helium gas will be supplied to the enclosure too through the bottom end flange from a separate cylinder. The clad tube will be internally heated using a tungsten heater of 100 mm length. The power will be supplied to the tungsten heater through flexible copper cables (600 Amp capacity) connected to a programmable DC power supply (capacity 1000 Amp and 10 Volts). All the signals from thermocouples, LVDTs, pressure transducer and DC power supply will be acquired using a Data acquisition system (Dewesoft make).

2.2 Details of clad tube mounting arrangement

As shown in Fig. 2, the bottom end of clad tube was connected to flexible cooper clamp and kept concentric with the enclosure using annular support fixture. The purpose of this arrangement is to accommodate axial expansion/contraction [2]. The molybdenum rod connected to the tungsten heater is taken out concentrically through the T-joint for connection with DC power supply cable. The Fig. 3 shows the details of the test section. The clad tube of length 330 mm is mounted concentrically inside the cylindrical enclosure of length 450 mm. The clad tube will be internally heated using a tungsten heater of 100 mm length. The tungsten heater is placed concentrically inside clad tube at central position (i.e. 225 mm apart from top end flange) by using annular alumina pallets. The both ends of tungsten heater are connected to Molybdenum rod. To capture transient temperature over the clad tube, eight K-type thermocouples (outer diameter 0.8 mm) are used and their location is shown in Fig. 3. At the central location (i.e. 225 mm apart from top end flange), four thermocouples are spot welded using zirconium foil of 0.1 mm thickness at angular position of 90 degree to measure azimuthal temperature difference.

2.3 *Details of the test section*

The design specifications are shown in Table1. One thermocouple is spot welded on either sides at 40 mm above and below of the central position to measure axial temperature difference.

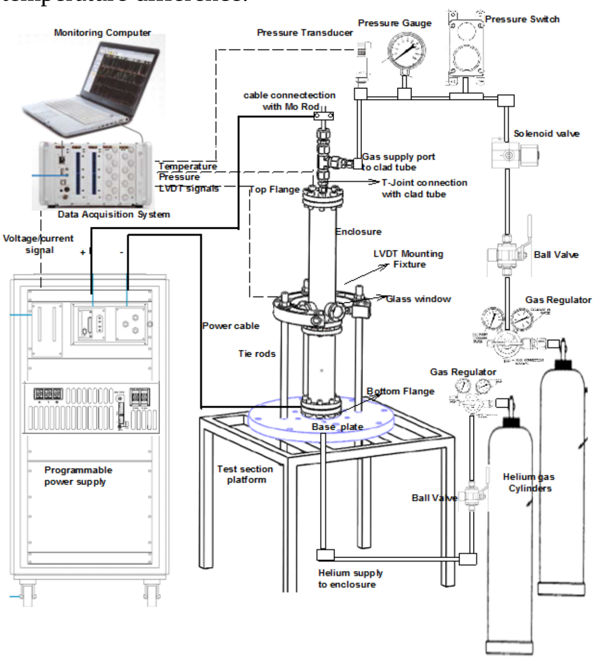

Fig.1. Schematic layout of experimental setup

Table 1: Design Specifications

Component	Material	Dimensions
Clad tube	Zircaloy-4	Outer Diameter (O.D): 9.5 mm Inner Diameter (I.D): 8.36 mm Length : 330 mm
Heating element	Tungsten	O.D, Tungsten: 3 mm Length : 100 mm Outer Diameter, Molyb.: 6 mm
Pallets	Alumina (Al_2O_3)	Pallet of tungsten: O.D = 8.3 mm, I.D = 3.1 mm, Length = 10 mm Pallet, Molyb. O.D = 8.3 mm, I.D = 6.1 mm, Length = 50 mm
Enclosure	SS-316	O.D : 54 mm, I.D: 50 mm, Length : 450 mm
Clad tube annular support	SS-316	O.D: 49 mm, I.D:16 mm Thickness : 2 mm

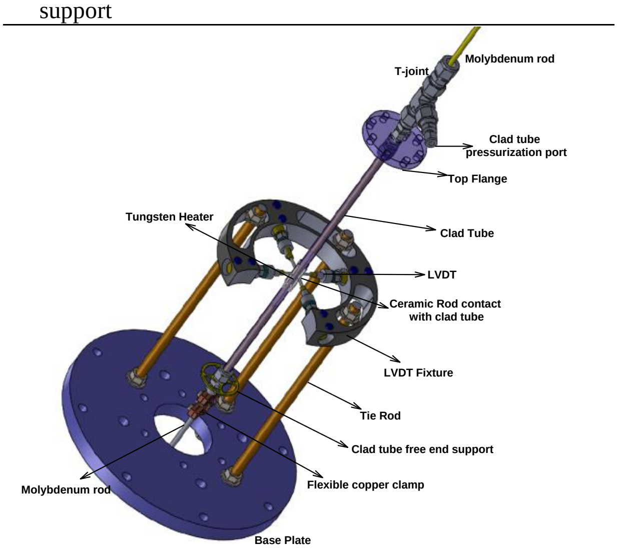

Fig. 2. Details of Clad tube mounting arrangement

To measure bulk temperature of inert gas, one thermocouple is placed in the annular space between clad tube and enclosure. Apart from that one thermocouple is spot welded to the inner surface of enclosure to measure the portion of heat transfer due to radiation. To measure the transient deformation, four LVDTs are mounted to the wall of enclosure at central position using a LVDT Fixture. As the temperature at the surface of clad tube is expected to rise in the range of 1000 °C, the deformation will be measured by using a ceramic rod (diameter 2.5 mm).

3. Conclusions

The data from out of pile single rod experiment can provide vital information about transient temperature variation and deformation rate of the cladding, which can be extensively used for validation of fuel behavior code. With this motivation, an experimental setup has been designed and the present paper discuss about the design characteristics of the facility. Future tests are planned with various heat-up rates and internal pressure under steam/inert gas atmosphere to understand thermo-mechanical behavior of Zircaloy-4 cladding.

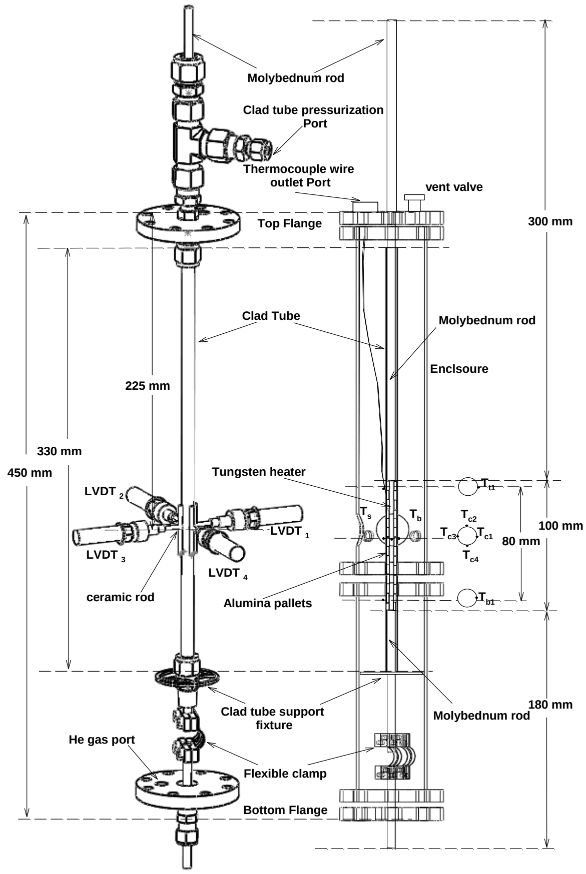

Fig. 3. Details of test section

Acknowledgement

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