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Thermo-mechanical testing of Li–ceramic for the helium cooled pebble bed (HCPB) breeding blanket

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Abstract

The helium cooled pebble bed (HCPB) Test blanket module (TBM) for the DEMO Reactor foresees the utilization of lithiate ceramics as breeder in form of pebble beds. The pebbles are organized in several layers alternatively stacked among couples of cooling plates (CP). ENEA has launched an experimental programme for the out-of-pile thermo-mechanical testing of mock-ups simulating a portion of the HCPB-TBM. The programme foresees the fabrication and testing of different mock-ups, to be tested in the HE-FUS3 facility at ENEA Brasimone. The paper describes the HELICHETTA III campaign carried-out in 2003. In particular, the test section layout, the pebble filling procedure, the experimental set-up and the results of the relevant thermo-mechanical test are herewith presented.

1. Introduction

Since 2001, ENEA has launched experimental activities on a family of mock-ups called HELICHETTA simulating a small portion of the ITER TBM HCPB breeding blanket.

The main aim of the test is the thermomechanical characterisation of the reference Lithiate ceramics, Li_4SiO_4 and Li_2TiO_3 pebble beds, both candidates as Tritium breeder for the ITER HCPB TBM breeding blanket module [1].

The mock-up reproduces a small prismatic breeder cell whose structural material is AISI 316 whilst the experimental boundary conditions are simplified respect to the reactor reference.

In 2001 and 2002, ENEA has carried out the first two HELICHETTA I and II test campaigns with the lateral containment of the breeder cells operated by flexible cooling plates (CP) [2–4].

In 2003 the HELICHETTA III test campaign was started on a rigid lateral breeder cell assembly. The experimental tests were carried-out on the HE-FUS3 facility at ENEA Brasimone.

2. Test objective

The HELICHETTA I test campaign has been carried-out in 2001 with Li_4SiO_4 and Li_2TiO_3 pebble beds without helium purge flow [2]. The tests have found negligible dependencies of the bed thermal behaviour neither the cell orientations nor the pressure on the superior filling plug. Relatively low CP deformations were also measured (±0.1 mm for Li_4SiO_4 and ±0.2 for Li_2TiO_3) because the spring plug adsorbs the thermal expansion of the bed up to 800 °C.

The HELICHETTA II test campaign, carried-out in 2002 only on Li_4 SiO_4 pebbles, have simulated both a very elastic and a very rigid superior plug closure of the cells. These two boundary conditions simulated the different possibilities of the pebbles to relocate in the cells, to expand towards the CP and plug and to experience modifications in the packing. The HELICHETTA II test campaign [4] has shown that Li_4SiO_4 pebble beds, when filled and packed by high frequency vibrations, contained by elastic cup spring at low pressure and swept by helium purge flow, exhibit thermal behaviour

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almost stable versus the repetitive heat flux ramps and the pebble thermal expansion procured negligible CP elastic deformations. On the contrary, the tests on highly pressed beds (several MPa) have evidenced large elasto-plastic deformations on the pebbles and also on the CPs. Bed height reduction, due to bed compaction, has shown to be considerable.

Aim of the HELICHETTA III test campaign is to verify the pebble thermo-mechanical behaviour in terms of bed height reduction, temperatures and lateral loads at the reference mechanical constrains, temperatures and purge flow conditions.

3. Helichetta III test section

The HELICHETTA III test section, Fig. 1, represents two breeder cells separated by a flat electrical resistor and contained by two cooling plates loaded by three load cells per side. These two cells were formerly closed by a top plug provided with an opening for the pebble pouring. This opening also contains an alumina bar with a steel plate end pushed by a spring against the pebble bed top surface for the monitoring of its superior height measured by an LVDT. The helium tightness of this system was guarantee by a metallic bellow whilst the spring stiffness was regulated at 316 [N/m] with a pressure over the bed of only 0.014 [MPa]. The test section CPs are cooled via the HE-FUS 3 helium facility at a nominal flow rate of 35–40 g/s, inlet pressure of 1.3–1.5 MPa and temperature of 200 °C. The purge flow was regulated at 0.01 g/s with velocity inside the bed lower 0.05 m/s, at inlet pressure of 0.1 MPa and temperature of 200 °C. The load cells are water cooled up a temperature below 50 °C. The tests were performed on Li_2TiO_3 pebbles produced by CEREM CEA, Fig. 2, and Li_4SiO_4 produced by SCHOTT, Fig. 3. The packing factors obtained, after the pebble filling and pneumatic hammering at 5 kHz, were 57% for Li_2TiO_3 and 62% for Li_4SiO_4. Before starting the heat flux tests, at steady state temperature condition in the bed, each load cell has been preloaded at about 1 kN.

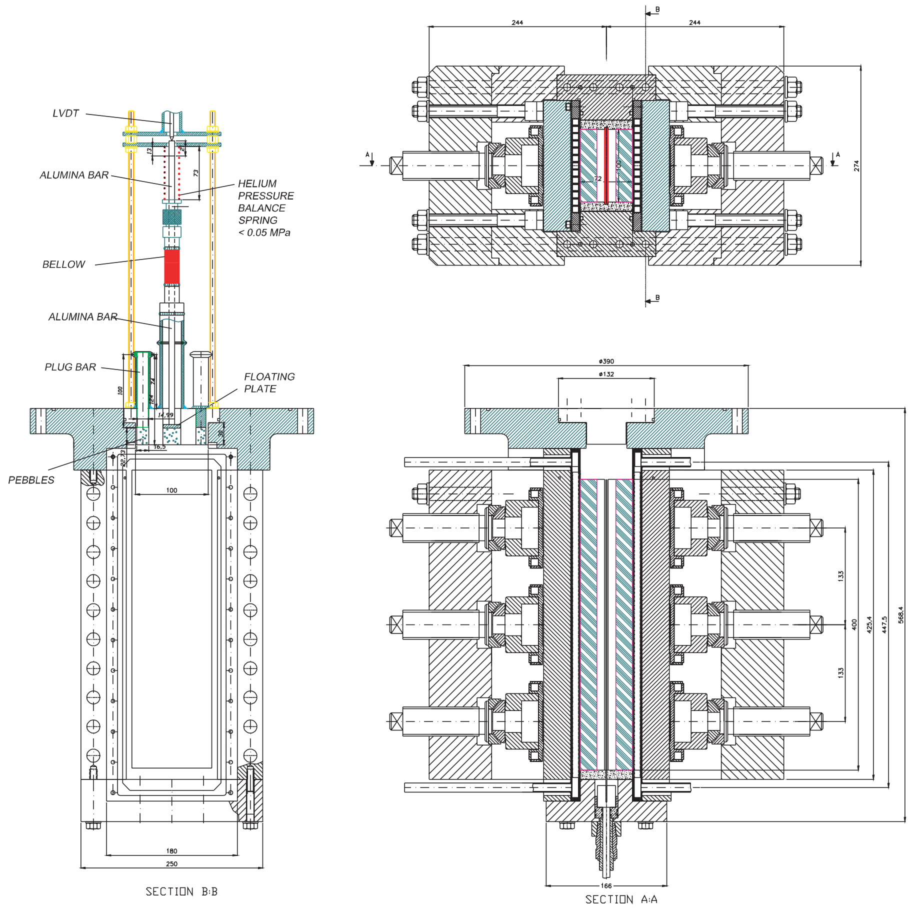

Fig. 1. HELICHETTA III Test Section Scheme.

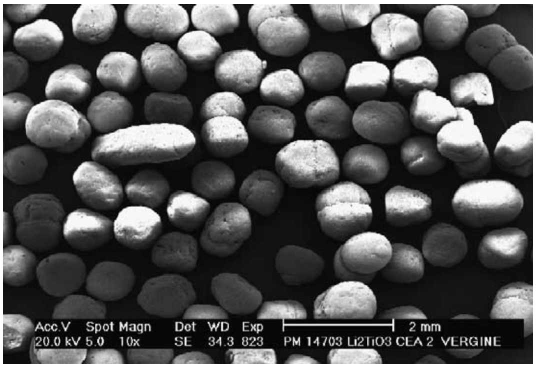

Fig. 2. Li_2TiO_3 pebbles before test.

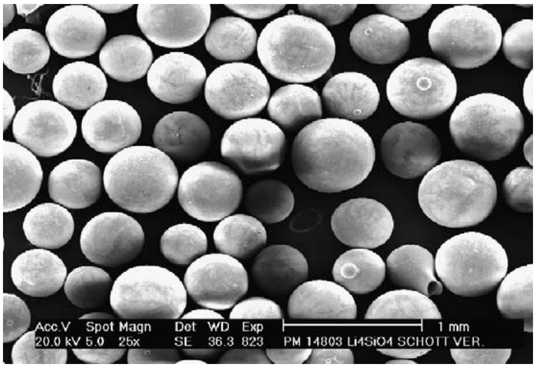

Fig. 3. Li_4SiO_4 pebbles before test.

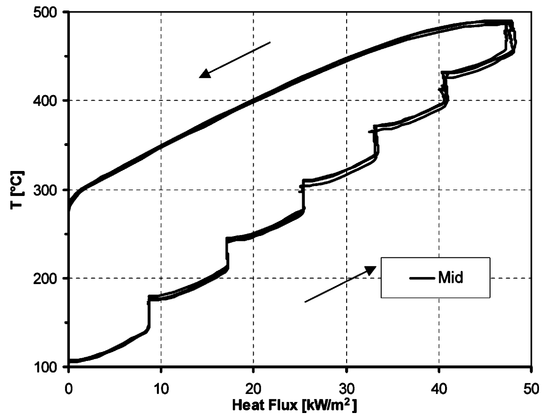

Fig. 4. Li_2TiO_3 pebble temperature during the tests at mid cell location.

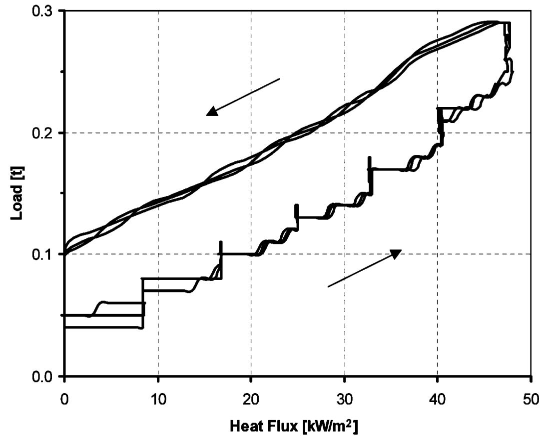

Fig. 5. Li_4SiO_4 pebble bed lateral loads during the tests at top location.

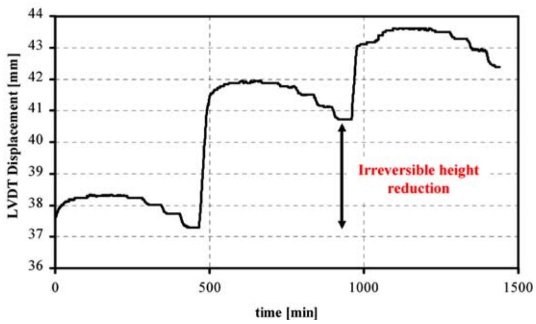

Fig. 6. Li_4SiO_4 pebble bed height reduction after three cycles.

4. Tests results

For both the Lithiate breeder materials 30 slow thermal cycles were performed from 0 up to 48 kW/m^2 with six stepping increasing of 8.5 kW/m^2 and duration of an hour per each step. The maximum temperature reached in the pebble bed was about 750 °C close to the resistor. During these tests, both the pebble temperatures and the lateral loads have exhibited reproducible cyclical behaviours as shown in Figs. 4 and 5.

Both pebble beds have shown an irreversible overall height reduction as measured on the top location by LVDT. This phenomenon is particularly evident at beginning of the cycling tests and in particular for Li_4SiO_4 pebbles, although tends to be reduced after some tens ramps, Fig. 6. The total overall measured bed reduction has been of 16.5 mm (3.63%) and 40.4 mm (8.88%) respectively for Li_2TiO_3 and Li_4SiO_4.

The pebble bed thermal conductivities have been derived from the heat flux and the temperature difference between thermocouples located in the bed. The dependence from the temperature and cycle was evident, Fig. 7, even if the relative measurements were affected by errors mainly due to the uncertainties of the thermocouple locations. The conductivity was higher on the top of the test section where the load cells have also measured higher values. Therefore these differences were

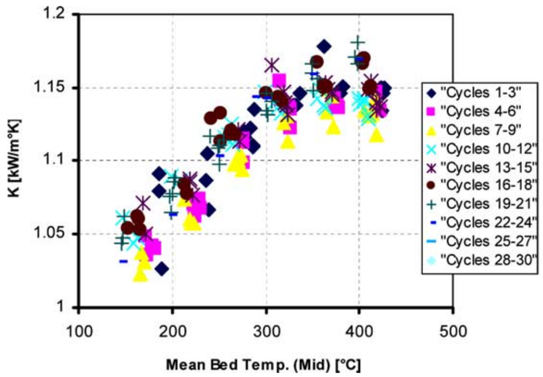

Fig. 7. Li_2TiO_3 pebble bed thermal conductivity during the cycles.

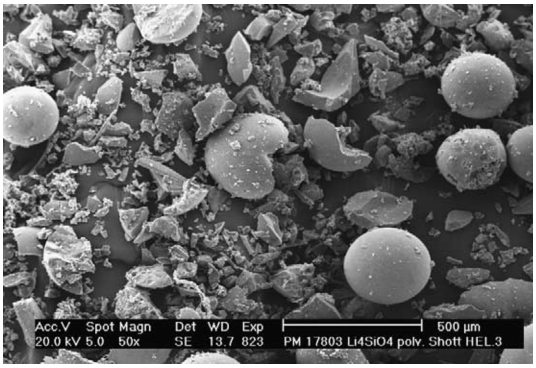

Fig. 8. Li_4SiO_4 Pebbles after test.

probably due to different pebble bed packing in vertical direction.

After each bed discharging, performed by an air ejector, sub-micrometric powders were released, especially in the case of Li_4 SiO_4. Proper SEM investigations have shown the size of these powders and the pebble fragmentations, Fig. 8.

5. Conclusions

The HELICHETTA III test campaign has given a further confirmation, already verified in the two previous campaigns, that both Li_2TiO_3 and Li_4SiO_4 pebble beds, when correctly filled in as rigid breeder cell containment and swept by helium purge flow, exhibited thermal behaviour cyclically repetitive versus the heat flux stepping ramps. The thermal conductivity was mainly affected by the temperature with some differences probably due to different packing of poly-dispersed pebbles along the mock-up height. Although the fillings were executed with high frequency vibrations, the overall bed height reductions, was very evident for both pebbles at the beginning of the thermal cycling reaching saturation after 25–30 cycles. During the bed discharges, sub-micrometric powders were released, especially for Li_4SiO_4. These powders and the pebble fragmentations were also revealed by proper SEM investigations. Both phenomena could affect the temperature control in the reactor and the release of particulate in the purge flow circuits.

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