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Thermo-mechanical characterization of ceramic pebbles for breeding blanket

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HIGHLIGHTS

- Experimental activities to characterize the Li_4SiO_4.
- Compression tests of pebbles.
- Experimental evaluation of thermal conductivity of pebbles bed at different temperatures.
- Experimental test with/without compression load.

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ABSTRACT

An open issue for fusion power reactor is to design a suitable breeding blanket capable to produce the necessary quantity of the tritium and to transfer the energy of the nuclear fusion reaction to the coolant. The envisaged solution called Helium-Cooled Pebble Bed (HCPB) breeding blanket foresees the use of lithium orthosilicate (Li_4SiO_4) or lithium metatitanate (Li_2TiO_3) pebble beds.

The thermal mechanical properties of the candidate pebble bed materials are presently extensively investigated because they are critical for the feasibility and performances of the numerous conceptual designs which use a solid breeder.

This study is aimed at the investigation of mechanical properties of the lithium orthosilicate and at the characterization of the main chemical, physical and thermo-mechanical properties taking into account the production technology. In doing that at the Department of Civil and Industrial Engineering (DICI) of the University of Pisa adequate experiments were carried out. The obtained results may contribute to characterize the material of the pebbles and to optimize the design of the envisaged fusion breeding blankets.

1. Introduction

The international thermonuclear experimental reactor (ITER) will test some breeding blanket designs. One of these is based on the use of ceramic breeder material in form of pebble beds (Helium Cooled Pebble Bed (HCPB)) [1].

A candidate material for the tritium breeding blanket, must: (a) release tritium, (b) exhibit thermophysical, chemical, and mechanical stability at high temperature, (c) be compatible with the other materials, and (d) have desired irradiation behaviour.

The thermal mechanical properties of pebble beds are of meaningful importance for the thermo-mechanical design (and feasibility) of ceramic breeder blanket [2–6].

In this study lithium orthosilicate —Li_4SiO_4— (pebbles with diameter in the range 0.25–0.63 mm) has been investigated in the aim of analyzing the heat transfer processes in packed pebble beds as a continuous and homogeneous medium. Therefore it is important to know the effective thermal conductivity of pebble beds.

Piazza in Ref. [2] presents the measurements of the effective thermal conductivity of ceramic breeder material carried out with the hot wire test method.

Several drawbacks arise also when (impulsive) hot wire technique is used; in particular this method requires an axial symmetric geometry of experimental device: moreover the temperatures have to be measured inside the bed. In consideration of that, in this study, the “hot plate with guardian ring method” was used to determine the effective thermal conductivity (λ) of the Li_4SiO_4; strain effects have been also considered [5].

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Moreover the main chemical and physical properties of Li_4SiO_4 were determined; the stability of Li_4SiO_4 pebbles was therefore investigated.

The procedure and the method adopted in performing experimental tests have been described in Refs. [3] and [6]. The effective thermal conductivity was determined in steady state heat flux conditions and in relation to a reference material (Alumina) of known conductivity. This latter was (properly) experimentally evaluated with the hot wire method for temperature ranging from 20° to 900 °C [7].

2. Experimental activities

The experimental activities to characterize the Li_4SiO_4, performed at the Department DICI of the Pisa University, are:

1) Physical and chemical characterization of Li_4SiO_4;
2) Compression tests of pebbles;
3) Pebble beds thermal tests.

The first ones aimed at the evaluation of stability [8–10] of lithium-orthosilicate pebbles. In doing that XRD analyses have been carried out. The importance of this characterization relies on the evaluation of the mechanical performance of the pebbles that has to be guaranteed since the fabrication process [11–13].

The compression test of single pebbles allowed to determine their mechanical characteristics which have been correlated with the results obtained by the pebble bed compression. The latter tests allowed to determine the effective thermal conductivity of Li_4SiO_4 pebble beds.

2.1. Li_4SiO_4 characterization

Li_4SiO_4 pebbles (mean diameter <0.5 mm), produced by KIT [13] are produced using as raw materials lithium hydroxide and silica to obtain pebbles via a melt-based process with 2.5 wt% excess of silica. Due to the excess of silica and rapid quenching, the resulting products have two phases: lithium orthosilicate as main phase and lithium orthodisilicate as minor phase. After the annealing process in air, the phase decomposes and pebbles may consists of 90 mol% lithium orthosilicate and 10 mol% lithium metasilicate.

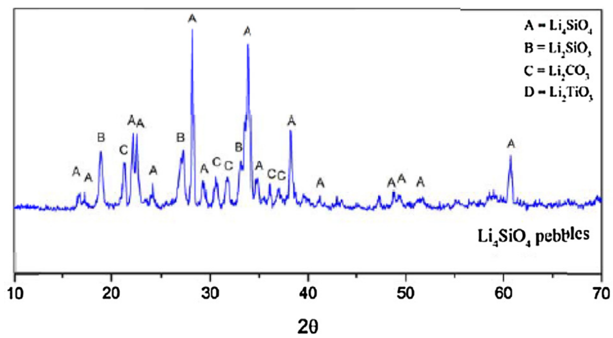

Fig. 1. XRD diagram of Li_4SiO_4 pebbles.

Several pebbles were exposed to air at controlled humidity (saturated air) for 72 h. The analysis of the pebble surface at XRD (patterns were obtained by using a Philips PW 1050/25 X-ray diffractometer with Cu-Kα radiation, and recorded over a 2θ range between 15° and 70°) before and after the exposure to the air were done. Single pebbles were exposed to air, in a not controlled environment, for long period of time (greater than 200 days).

The diffraction diagram (Fig. 1) showed the presence of lithium carbonate Li_2CO_3 whose peaks, are likely due to the reaction of pebbles surface with water and CO_2 during the storage stage.

In addition the thermogravimetric analysis (by TA Instruments Q500 thermobalance with runs conducted under nitrogen flow (100 mL/min) in the temperature range from 30 °C to 800 °C, at a heating rate of 10 °C/min) of sintered pebbles showed about 15% reduction of weight around 710 °C caused by chemisorption. The same weight loss has been observed on surface of Li_4SiO_4 pebbles for a simulated wet environment.

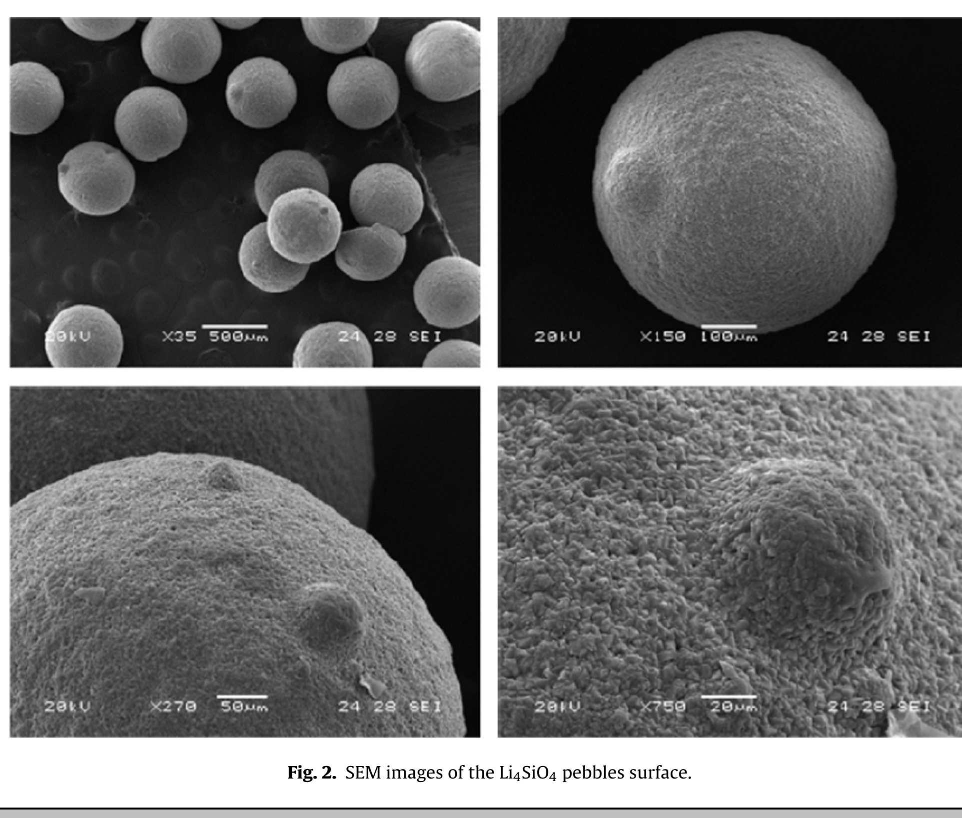

Fig. 2. SEM images of the Li_4SiO_4 pebbles surface.

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