§16. Large-scale In-silico Experiment for Thermal-hydraulic and Thermo-mechanic Characteristic of Pebble Bed

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Performance of a fusion reactor using pebble bed in its blanket depends on averaged properties such as packing density of the bed. On the other hand, crucial phenomena that affect safety issues, e.g., stress concentration in the pebble bed, blockage of flow area and the outset of a heat spot caused by thermal creep of constituent particles, depend on local properties of the bed. Conventional researches for pebble bed have been done in terms of average operation or coarse graining of the bed and can never capture the above local phenomena. In this study, the pebble bed is not coarse-grained but is treated such that small scale phenomena are treated as they are. For the purpose of constructing a mathematical model of the pebble bed without empirical derivation as much as possible, we generate the pebble bed in a computational space and simulate its thermomechanical properties.

Thermal Particle Dynamics (TPD) is used in the simulation. TPD is a kind of the discrete element method (DEM) and treats one particle as one element. In this method, force exerted on each particle is estimated by Hertz contact theory while temperature of particle is calculated by using thermal contact conductance model.

Fig. 1 shows the numerical result when a Aluminum pebble bed with particle diameter of 3.5 mm packed in a cylindrical vessel of 49 mm diameter and 60 mm height was tested on stress-strain properties. The maximum loading was 4 MPa and the loading-unloading cycle was repeated 3 times. It is found from the result compared to experimental data that the numerical data shows good agreement with experimental one in the loading process but in the unloading process of the experiment, plastic deformation that is assumed to occur might make strain keep as it is whereas in the simulation not taking the plasticity into account the strain is largely relaxed.

Effective thermal conductivities obtained from the simulation are depicted in Fig. 2. They are compared to experimental data and the both are in good agreement for not only rigid ceramic pebble case but rather deformable Aluminum pebble case. Compared to a theory in which contact area of particles is not considered, however, the theory shows large difference from numerical data in the deformable pebble case where the contact area of pebbles plays an important role in heat transport through the bed.

In addition, effective thermal conductivity of pebble bed with volumetric heating is estimated numerically and compared to an analytic solution. Fig. 3 shows numerical temperature distributions of Li_2TiO_3 pebble bed with particle diameter of 2±0.2mm packed in a cylindrical vessel of SUS304 with 10 mm diameter and 20 mm height which generates volumetric heat of 10MW/m^3 compared to the analytical solution using the effective thermal conductivity obtained from the case without volumetric heating. Because the both are in good agreement, the effective thermal conductivity of the pebble bed does not depend on whether the bed experiences the volumetric heating or not.

Thermomechanical properties of pebble bed were well re-created in a computational space by means of the numerical model used in this study. We plan to incorporate plastic deformation, thermal creep and convectional heat transfer into the model

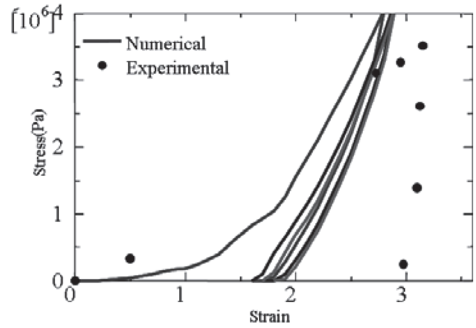

Fig. 1 Stress-strain relation in uniaxial compression test

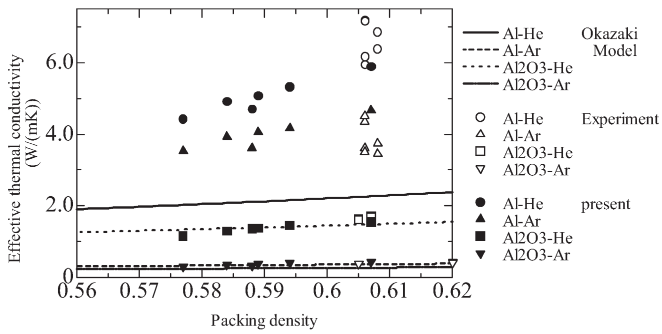

Fig. 2 Relation between packing density and effective thermal conductivity

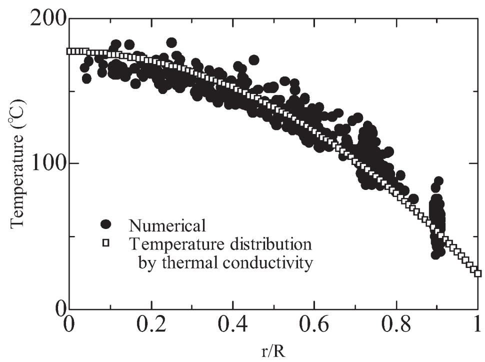

Fig. 3 Temperature distribution in the case with volumetric heating