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Fragmentation behaviors and mechanical properties of the tritium breeder pebble bed for fusion blanket

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Abstract:
During the operation of the fusion reactor, the tritium breeder pebbles packed into the tritium breeding blanket formed a tritium breeder pebble bed. Under the influence of the severe environment such as irradiation swelling, thermal expansion, alternating stress, and so forth, the tritium breeder pebbles will be broken and pulverized, accompanied by changes in the thermomechanical properties and packing structures of the tritium breeder pebble bed. With the increase of the operation time, the fragmentation behaviors will become more and more serious, which may affect the tritium breeding efficiency and the heat transfer performance of the tritium breeding blanket. Therefore, in this work, the packing structures, fragmentation behaviors and mechanical properties of tritium breeder pebble bed were investigated utilizing experiments and numerical simulations, as well as the flow characteristics of the purge gas in the pebble bed.
The packing behaviors of tritium breeder pebble beds and neutron multiplier pebble beds are important to estimate the thermal properties of pebble bed, the thermal-mechanical of pebble bed, the flow characteristics of purge gas and the tritium breeding ratios of the blanket. In this work, the packing experiments and the DEM simulations were conducted to investigate the packing behaviors and mechanical properties of the mono-sized and binary-sized pebble beds, respectively. Owing to the tritium breeding zone of the typical solid breeder blanket can be simplified to prismatic containers. Thus, we investigated the widths' influences (Lx/d=5~60) on the average packing factors and porosity distributions in pebble bed with and without vibration. The results obtained in this study show that the packing factors and the porosity can be significantly influenced by walls and widths as shown in Fig.1. The average packing factors increase with the ratio of bed widths to pebble diameter and the vibration process can increase the average packing factor. In the area near the wall of the pebble bed, the porosity gradually oscillates and damping with the increasing distance from the wall. In further, the effect of pebble size distributions on the packing structures of pebble bed was explored experimentally and numerically. By optimizing the pebble size component, a higher packing factor can be obtained by using binary-sized pebbles and polydisperse pebbles. The maximum packing efficiency state appear at the volume fraction 70% of larger pebbles.

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Besides, the mechanical properties of compressed pebble bed and the fragmentation characteristics of ceramic pebbles inside the pebble bed were investigated by the DEM simulation and the X-ray computed tomography (x-ray CT). The fragmentation characteristics of pebbles inside pebble bed under different compression loads were investigated experimentally. The Schematic of the pebble crushing experiment based on the x-ray CT and the Uniaxial compression test (UCT) as shown in Fig.3. The results show that the breakage rate of the tritium breeder gradually increased with the increase of the compressive load. The x-ray CT can characterize the fracture characteristics of pebbles inside the pebble bed.

Figure 1: Schematic of the pebble Fragmentation experiment based on the x-ray CT and the UCT.

Moreover, the packing behaviors of pebble beds under vibration were investigated experimentally. The influences of the vibration amplitude and frequency on the packing fraction were analyzed to optimize the pebble packing techniques for the helium-cooled ceramic breeder blanket. In addition, the flow characteristics of the fluid distribution and the pressure drop along the pebble bed were analyzed by the DEM-CFD method. The effects of the bed lengths, the diameter ratios of the cylinder to the pebbles, and the contact point treatment between the pebbles on the velocity distribution and pressure drop of the purge gas were investigated. The results in this work will provide some technical support for the optimal design of the solid tritium breeder blanket.

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Keywords: Packing behaviors; Fragmentation behaviors; Mechanical properties; solid tritium breeder blanket; Discrete element method; X-ray computed tomography

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