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Overview of Japanese Water-Cooled Ceramic Breeder Test Blanket Module Manufacturing and Assembly Technologies

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The Water-Cooled Ceramic Breeder (WCCB) blanket is considered a promising and reduced-risk technology for fusion reactors, owing to its extensive operational experience in pressurized water fission reactors and the well-established understanding of material behavior under neutron irradiation [1,2]. This blanket concept offers a viable pathway for the early realization of energy conversion and tritium self-sufficiency, both of which are essential for the development of sustainable fusion energy systems.

As part of the ITER Test Blanket Module (TBM) project, which aims to experimentally validate breeding blanket technologies for future demonstration reactors, Japan is preparing to test a WCCB-TBM. The Japanese module employs high-temperature, high-pressure water at 15.5 MPa/280℃ as the coolant, and incorporates pebble-type materials for tritium breeding (Li_2TiO_3) and neutron multiplication (Be) [3,4]. The structural material is F82H, a reduced-activation ferritic/martensitic steel developed from 9Cr heat-resistant steel, selected for its favorable mechanical properties and radiation resistance [5].

To ensure both safety and thermal performance under fusion-relevant conditions, the Japanese WCCB-TBM adopts a cylindrical structural design with its radial axis serving as the major axis. This configuration enables stable containment of high-pressure coolant even in the event of internal leakage and facilitates rapid heat dissipation to the vacuum vessel or surrounding structures in case of cooling system failure [6]. The design reflects a careful balance between structural integrity, manufacturability, and functional performance [7-9].

This work provides a comprehensive overview of the manufacturing and assembly technologies developed for the WCCB-TBM. Key manufacturing processes include machining of F82H components, assembly, joining and pebble packing. [10]. From the perspective of pressure resistance and vacuum compatibility, welded joints are required in the blanket structure. Since F82H is a tempered martensitic steel, post-weld heat treatment is necessary to restore mechanical strength. However, if this heat treatment is performed after the functional materials have been filled, it may promote the formation of reaction layers at the contact interfaces between F82H and the functional materials. Moreover, repeated heat treatment can also lead to degradation of the weld metal strength. Therefore, careful consideration of the assembly sequence is essential.

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