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Development of Joining Technologies for the Cooling Plate and Breeder Unit in HCCP breeding blanket fabrication

The Korea Institute of Fusion Energy (KFE), in collaboration with Fusion for Energy (F4E), has been actively engaged in the development of manufacturing technologies for the Helium-Cooled Ceramic Pebble (HCCP) Test Blanket Module (TBM) under the ITER program. A key focus is the fabrication and joining of the Cooling Plate (CP) and Breeder Unit (BU), critical components responsible for removing nuclear heat and responsible for tritium breeding. These components pose unique joining challenges due to their complex geometries, high precision requirements, and use of Reduced Activation Ferritic Martensitic (RAFM) steel, EUROFER97. To overcome the limitations of conventional Electrical Discharge Machining (EDM) and costly specialized processes, we have explored an alternative fabrication route using diffusion bonding via hot press techniques. This method involves machining CP channels in separate plates and subsequently joining them at 1150℃ and 12.5 MPa for 3 hours. A comprehensive post-heat treatment (PHT) optimization was conducted to evaluate mechanical integrity and microstructural evolution. Microstructural analysis confirmed sound bonding with no visible bonding line; however, the joints showed up to 9% reduction in tensile strength and 18% in impact energy compared to the base metal, indicating a need for further optimization of heat treatment.
Regarding welding of the BU, the BU features multiple small and thin joints requiring precise joining. We are developing preliminary Welding Procedure Specifications (pWPS) for eight BU welding groups. Laser Beam Welding (LBW) was identified as a suitable method given joint dimensions below 3 mm. Bead-on-plate and wobble function feasibility tests using different laser systems (IPG, Coherent) confirmed acceptable weld quality under optimized parameters, with no observable defects post-weld heat treatment. Since many weld joints in the BU are below 3 mm in thickness, difficulties are anticipated in performing standard PQR (Procedure Qualification Record) tests. To address this, alternative approaches such as the use of sub-sized specimens are under consideration. These outcomes are contributing directly to the qualification of manufacturing processes not only for the TBM, but also for future fusion breeding blanket applications.

Speaker's title

Mr

Speaker's email address

hsgwon@kfe.re.kr

Country/Int. organization

Korea, Republic of

Affiliation/Organization

KOREA INSTITUTE OF FUSION ENERGY

Author: GWON, Hyoseong (KOREA INSTITUTE OF FUSIOIN ENERGY)

Co-authors: Dr AHN, Mu-Young (KOREA INSTITUTE OF FUSIOIN ENERGY); PARK, Yi-Hyun (Korea Institute of Fusion Energy)

Presenter: GWON, Hyoseong (KOREA INSTITUTE OF FUSIOIN ENERGY)

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