한국핵융합에너지연구원
KOREA INSTITUTE OF FUSION ENERGY

Development of Joining Technologies for the Cooling Plate and Breeder Unit in HCCP Breeding Blanket Fabrication

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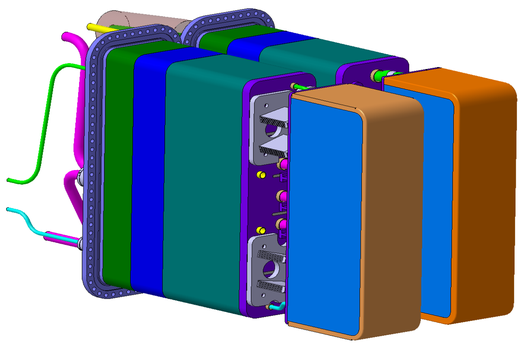
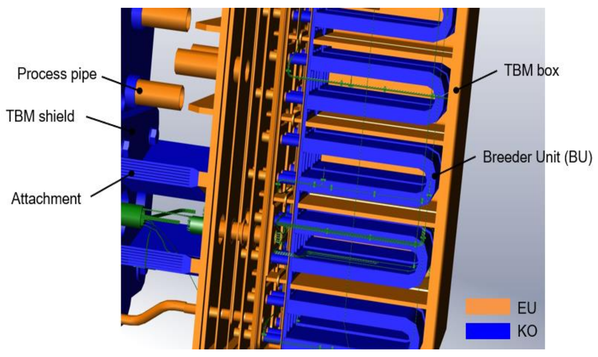
Introduction

- ITER decided to reduce the number of ports dedicated to TBM testing from three to two, and resulted in the reduction of TBM concepts from six to four
- KO negotiated with EU for a joint development of Helium-Cooled Ceramic Pebble TBM, and formed Partnership Arrangement between KO/EU signed March 2023
- TBM-set consisting of TBM box, process pipes, TBM shield including attachment
- F4E responsible for TBM box except of Breeder Unit (BU), Procurement of EUROFER97, ITER KOREA responsible for TBM shield including attachment, TBM-set integration, Procurement of SS316L(N)-IG (F4E/ITER KOREA: 50%/50%)



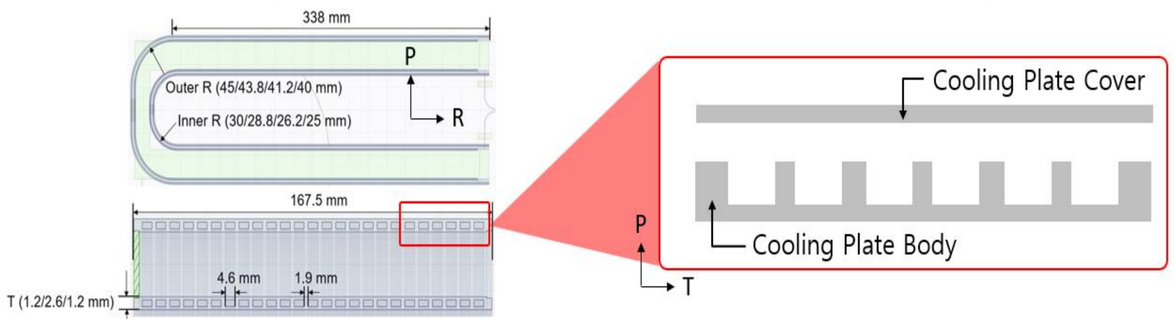
[HCCP TBM-set global views]



[Work package sharing for the TBM-set manufacturing]

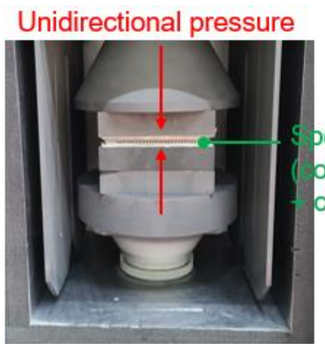
Fabrication of the Cooling Plate

- The Breeder Unit (BU) is a key component of the TBM for neutron multiplication and tritium breeding and Cooling Plate (CP) needed to remove the nuclear heating generated from the neutron reactions
  - A total length of the CP over 800 mm (not feasible with conventional machining)
  - Small/rectangular shaped cooling channels (requiring high-precision machining)
- Investigating fabrication method using combination of conventional machining and diffusion bonding to replace the special EDM developed for fabricating the CP

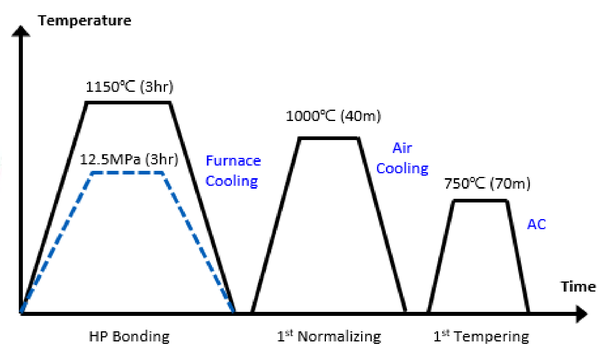


[Cooling Plate fabrication method using diffusion bonding]

- The fabrication method for the cooling plate using the combination including diffusion bonding
  - Machining a cooling plate body including channels and a cooling plate cover
  - The Cooling Plate Body and Cover joined by diffusion bonding using a hot press
  - Bending the cooling plate after the diffusion bonding
  - Inspection through visual inspection and Non-Destructive Testing

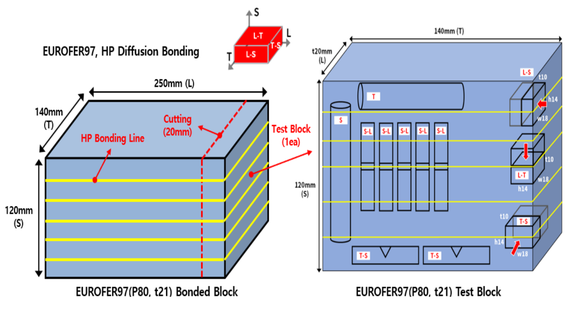


[Hot Press diffusion bonding]



[Diffusion bonding and heat treatment conditions]

- Optimization of the post heat treatment conditions for EUROFER97
  - Performing diffusion bonding by stacking six specimens (250 x140 x 21 mm) based on the diffusion bonding condition (1150℃, 12.5MPa, 3hr)
  - The HP-bonded specimen cut into 20 mm-thick sections, which were used to evaluate mechanical properties and analyze microstructures
  - Test specimens per 1 test block: tensile, impact, microstructure specimens



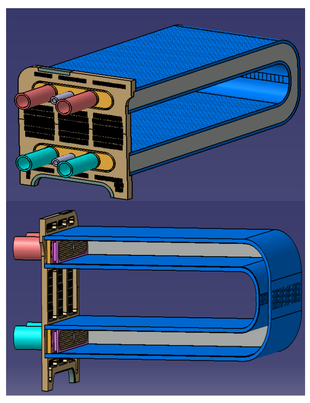
ITEM	Specimens Condition (DB, Heat Treatment)	Charpy Impact Absorbed E (J), -20℃		Tensile Strength		Hardness	Grain index
		Notch	Avg.(J)	Avg.(MPa)	EL(%)	HV	ASTM
EUROFER97 (base metal)	Base Material	S-L	370	671	28	156	10.0
		T-S	377	664	27	176	10.0
As-Bonded	1150℃(3hr),12.5MPa	S-L	9	1234	13	380	4.0
		T-S	13	1245	13	384	4.0
EUROFER_HT-01	1000(40m), 750(70m)	S-L	300	615	29	205	7.0
		T-S	329	632	26	201	7.0
EUROFER_HT-02	1000(2h), 680(2h), 1000(2h), 720(2h), 750(2h)	S-L	247	606	31	202	7.0
		T-S	347	611	29	203	7.0

Summary

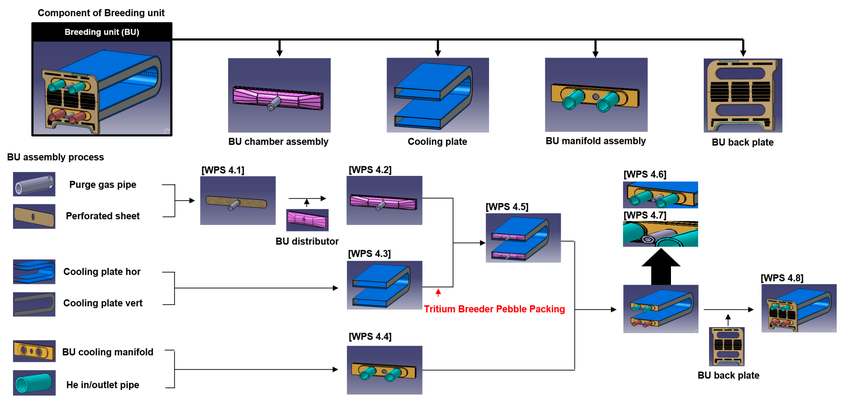
- A novel fabrication technology for Cooling Plates using diffusion bonding is under development as an alternative to the previously applied Special EDM process.
- Post-heat treatment conditions for EUROFER97 are being investigated to optimize the microstructure and to achieve mechanical properties equivalent to or exceeding those of the base material.
- For the Breeder Unit, welding groups have been defined to develop welding procedure specifications. The feasibility of laser welding was examined for each joint through bead-on-plate tests.
- Even under identical laser power and speed, bead shape and penetration depth varied, confirming that welding motion and shielding method are critical factors for Breeder Unit welding.
- The applicability of the wobble function was assessed using AARA plates, demonstrating that its implementation improves weld quality and mitigates defects

Fabrication of the Breeder Unit

- The BU composed of various components requiring many different WPSs
  - Small and thin weld joints (requiring high-precision machining and welding)
- Investigation of the assembly sequence and welding groups of the BU
  - A total of eight welding groups defined in order to develop the pWPS



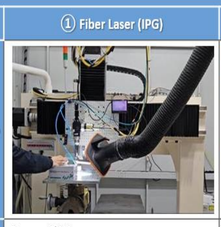
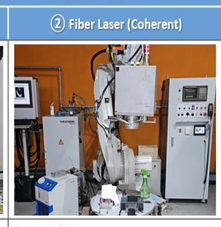
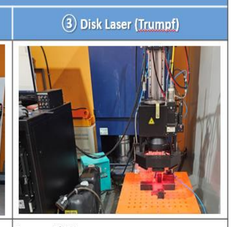
[Breeder Unit]



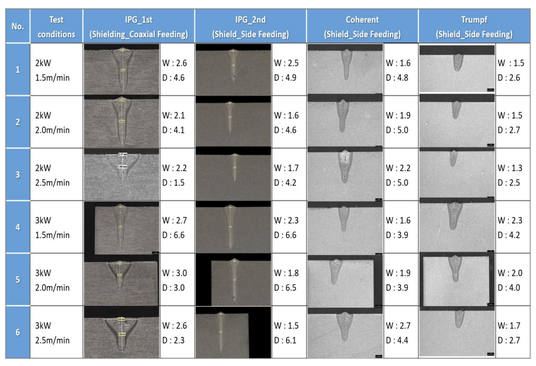
[Assembly Sequence of the Breeder Unit]

- Defining details like joint types, specimen sizes for each welding group (WPS 4.1 – 4.8)
- Three different systems used to investigate the feasibility and process parameters of laser beam welding

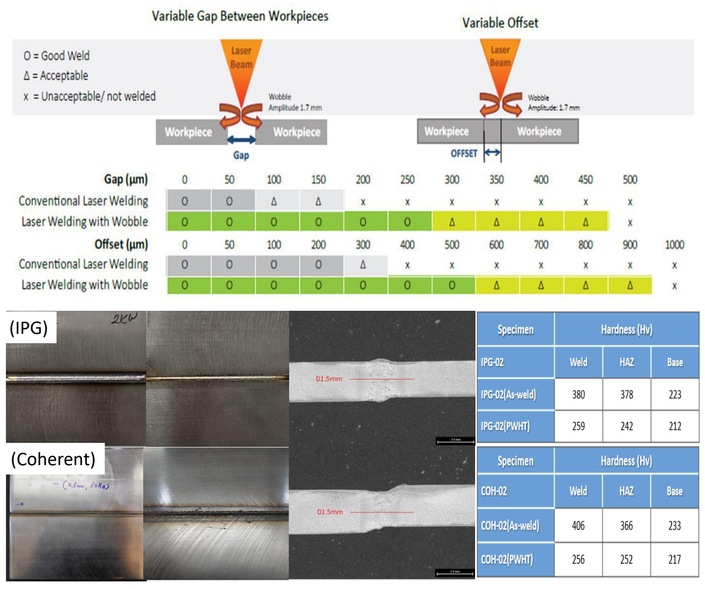
WPS Development Specification				
No.	Details of WPS	Joint type (PQR)	Joint size (mm)	Component Size
1	Purge gas pipe + Perforated sheet	Pipe + Plate	**t1**, ø10	Plate : t1 x 152 x 19.8 Pipe : t2.5 x ø12 x 63
2	BU distributor + Perforated sheet BU distributor + Purge gas pipe	**Plate + Plate** Pipe + Plate	**t1**, 19.8x152 **t10**, ø12	Plate : t20 x162.4 x 24.5 Pipe : t2.5 x ø12 x 63
3	CP hor + CP vert	**Plate + Plate**	**t2.5**, 383x131 61xR29.5 61xR40.5	Plate : t2.5 x 383x131 Cooling Plate Hor : t5 x U 383 x 167.5
4	Helium pipe + BU cooling manifold	Pipe + Pipe	**t2.5**, ø12.5x57.5	Tube : t2.5, ø12.5x57.5
5	BU distributor + CP (hor & vert)	Plate + Plate	**t2**, 162.4x24.8	Plate : t20 x 162.4 x 24.8
6	BU cooling manifold + CP (hor & vert)	**Plate + Plate**	**t2**, 164.9x32.4 **t2**, ø12	Plate : t18.5 x 164.9 x 32.4
7	BU cooling manifold + Purge gas pipe	Pipe + Plate	t2, ø12	Plate : t18.5 x 164.9 x 32.4 Pipe : t2.5 x ø12 x 63
8	BU cooling manifold +BU back plate	**Plate + Plate**	**t3**, 164.9x32.4	Plate : t18.5 x 164.9 x 32.4 Plate : t10 x 185 x 181

LBW Applicability Test			
LBW	① Fiber Laser (IPG)	② Fiber Laser (Coherent)	③ Disk Laser (Trumpf)
Test Setup			
Main Specifications	Power : 6kW Focal Length : 300mm Single Beam : ø300μm Machine : Stage Type Shielding Gas : Ar (Coaxial Feeding)	Power : 10kW Focal Length : 460mm Dual Beam : ø280/700μm Machine : Robot + Scanner Shielding Gas : Ar (Side Feeding)	Power : 8kW Focal Length : 300mm Dual Beam : ø300/1200μm Machine : Scanner Shielding Gas : Ar (Side Feeding)
Weld conditions	2~4kW, 1.5 ~ 3.0m/min	2~4kW, 1.5 ~ 3.0m/min	2~4kW, 1.5 ~ 3.0m/min

- Bead On Plate (BOP) test carried out with power of 2 ~ 4 kW, Speed of 1 ~ 3 m/min, using ARAA plate
- Bead shape and depth varied depending on equipment and shielding gas supply, even under the same laser power and speed, welding motion and shielding method to be critical factors



[X-sectional analysis on the BOP tests]



[Results of the wobble tests with two LBW systems]

- Considering applying the wobble function to improve the weld quality by compensating for the gap deviation and removing pores inside the weld bead
- No defects such as pores or cracks near the welds and HAZ in both laser systems
- The applicability of Wobble to RAFM steel (ARAA) confirmed although optimization still needed

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