Development of welding technology for TBM First Wall fabrication without permanent backing strip using laser welding

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ABSTRACT: Korea has developed a helium cooled ceramic reflector test blanket module for fusion reactors. An advanced reduced activation alloy has been developed as a structural material and various joining methods such as electron beam welding, tungsten inert gas (TIG) welding, laser welding, and hot isostatic pressing have been applied to establish its fabrication method and procedure. Based on the current design of the TBM and breeding blanket, TIG and laser welding were selected as the main joining methods, and the U-shaped first wall (FW) was adopted. For welding of the breeding blanket, a special joining technique without a permanent backing strip with simultaneous full penetration welding in accordance with the design rules of class $N2_{RX}$ of RCC-MRx is required for the pressure vessel. For the U-shaped FW, a permanent backing strip should not be formed when joining the front plate and the cover plate. In this study, laser welding conditions were checked to determine the bonding method without a permanent backing strip, and small mock-ups were fabricated using these conditions. The manufactured small mock-ups were subjected to a non-destructive inspection using radiographic test (RT) and a visual inspection on the weld surface of the joint after cutting. The results of the visual observation of laser welding show that the welding is normally done without a permanent backing strip on the joint surface, and the proposed fabrication method is applicable to the development of the FW fabrication procedure. Currently, Korea are discussing with EU the research topics and development of a TBM jointly. The welding method without permanent backing strip used in this paper will also be applied to the Korea-EU joint TBM production in the future.

Fabrication procedure of the HCCR TBM First Wall

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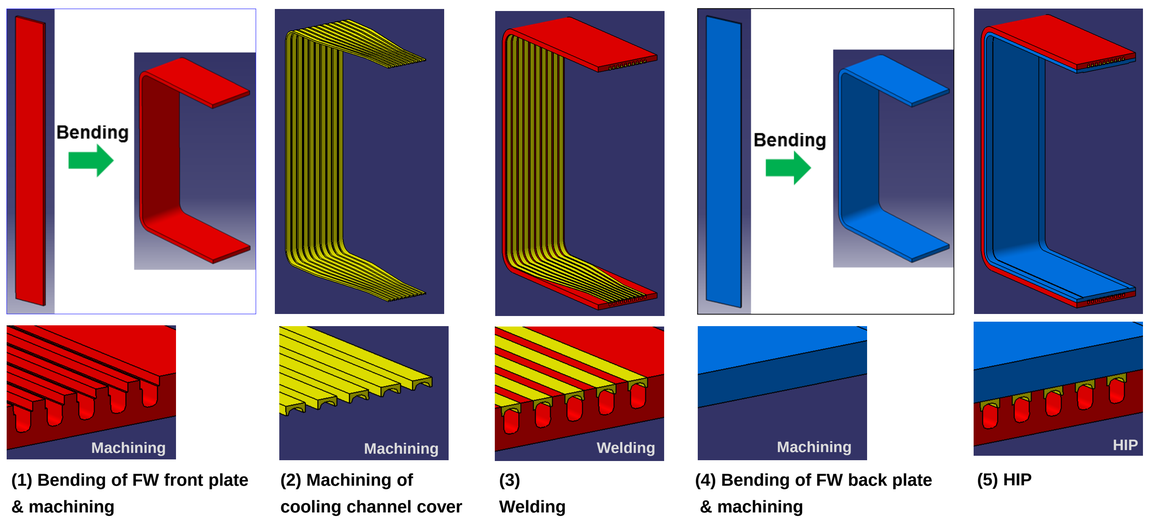
- The HCCR TBM First Wall is composed of
  - FW front plate;
  - FW cooling channel cover plate;
  - FW back plate.
- The main fabrication sequence of FW is ; 1) Bending of FW front plate & machining, 2) Machining of cooling channel cover, 3) Welding cooling channel cover plate to front plate machining, 4) Bending of FW back plate & machining, 5) HIP



(1) Bending of FW front plate & machining | (2) Machining of cooling channel cover | (3) Welding | (4) Bending of FW back plate & machining | (5) HIP

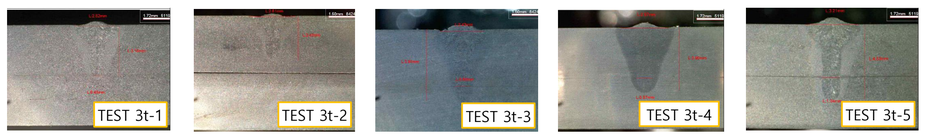
Fabrication procedure of HCCR TBM FW

Welding conditions of the FW small mock-up

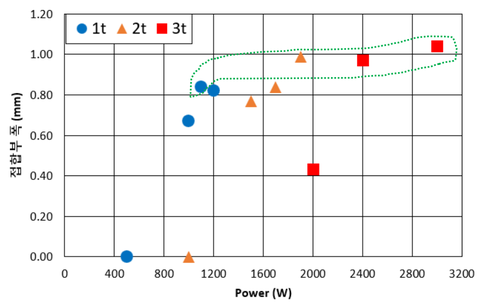
◆ Laser beam welding Condition for manufacturing FW small mock-up

- ARAA welded specimens for the bead width and penetration depth according to the Laser beam welding current and welding speeds

TEST	Power (W)	Velocity (mm/min)	Beam interval	Bead width (mm)	Penetration depth (mm)
TEST 3t-1	2000	1000	CW	2.62	3.16
TEST 3t-2	2000	800	PW	2.61	2.43
TEST 3t-3	3000	800	PW	2.43	3.9
TEST 3t-4	2400	1000	CW	2.97	3.9
TEST 3t-5	3000	1000	CW	3.21	4.53



Welding condition of welding penetration depth of 3 mm using ARAA plates



Variation in junction width according to the change in the amount of heat input of laser

Thickness (mm)	Power (W)	Velocity (mm/min)	Beam interval
TEST 3t-1	1100	1000	CW
TEST 3t-4	1900	1000	CW
TEST 3t-5	3000(2400)	1000	CW

Design rules of class $N2_{RX}$ of RCC-MRx

◆ Design rules of class $N2_{RX}$ of RCC-MRx

- For welding of the breeding blanket, a special joining technique without a permanent backing strip with simultaneous full penetration welding in accordance with the design rules of class N2RX of RCC-MRx is required for the pressure vessel
- HCCR-TBM is shell type, Cat. IV (ESPN), $N2_{RX}$ in RCC-MRx code, which does not permitted permanent backing strips (welded assembly category (a))

Table RB 3334.4a: definition of types welded joints

Examples	Definition of types welded joints				
	I.1	butt welding	full penetration	two sides accessible	back welding
	I.2	butt welding	full penetration	two sides accessible	gaseous back protection with or without insert
	I.3	butt welding	full penetration	two sides accessible	on temporary backing strip can be inspected after removal of the strip
	II.1	butt welding	full penetration	back side inaccessible	gaseous protection with or without insert
	II.2	butt welding	full penetration	back side inaccessible	permanent backing strip

Welding conditions of the FW small mock-up

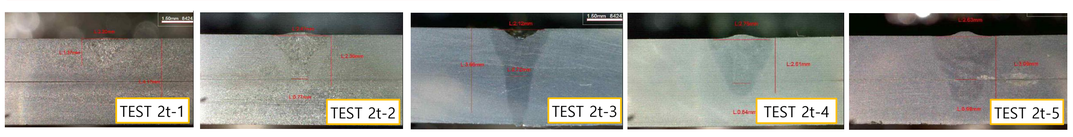
◆ Laser beam welding Condition for manufacturing FW small mock-up

- ARAA welded specimens for the bead width and penetration depth according to the Laser beam welding current and welding speeds
- Welding condition of welding penetration depth of 1 ~ 3 mm using ARAA plates
- Influence of the penetration depth and weld width was investigated according to different weld currents
- Laser beam lining according to the welding power and welding speeds → Fine welding at determined conditions

TEST	Power (W)	Velocity (mm/min)	Beam interval	Bead width (mm)	Penetration depth (mm)
TEST 1t-1	500	1000	CW	1.91	0.83
TEST 1t-2	1000	1000	CW	2.3	1.37
TEST 1t-3	1700	800	PW	1.85	2
TEST 1t-4	1200	1000	CW	2.43	1.88
TEST 1t-5	1100	1000	CW	2.34	1.59

Welding condition of welding penetration depth of 1 mm using ARAA plates

TEST	Power (W)	Velocity (mm/min)	Beam interval	Bead width (mm)	Penetration depth (mm)
TEST 2t-1	1000	1000	CW	2.2	1.37
TEST 2t-2	1500	1000	CW	2.47	2.36
TEST 2t-3	2200	800	PW	2.12	3.88
TEST 2t-4	1700	1000	CW	2.75	2.61
TEST 2t-5	1900	1000	CW	2.63	3.09

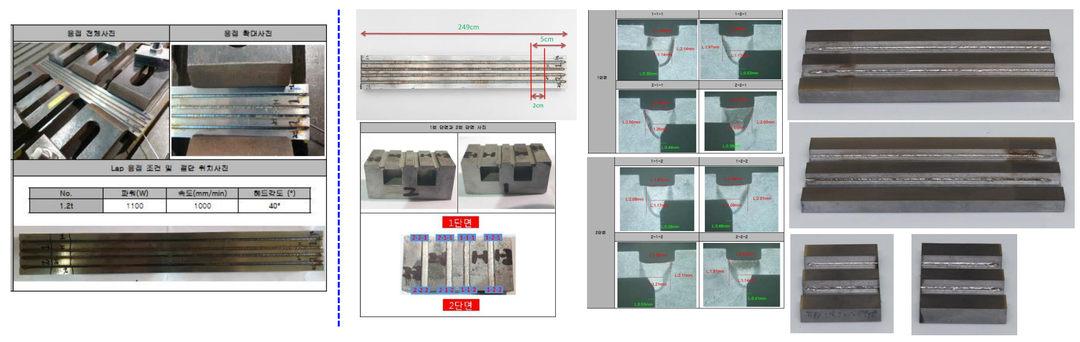


Welding condition of welding penetration depth of 2 mm using ARAA plates

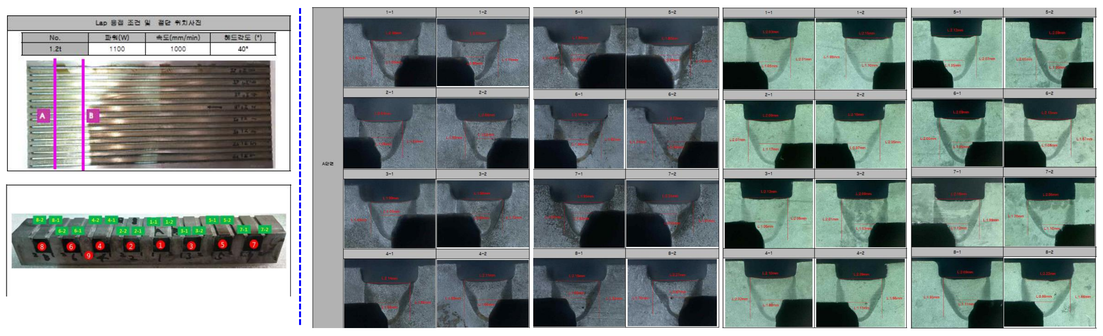
Laser welding without permanent backing strip for the small mock-ups

◆ Laser welding without permanent backing strip for the small mock-ups

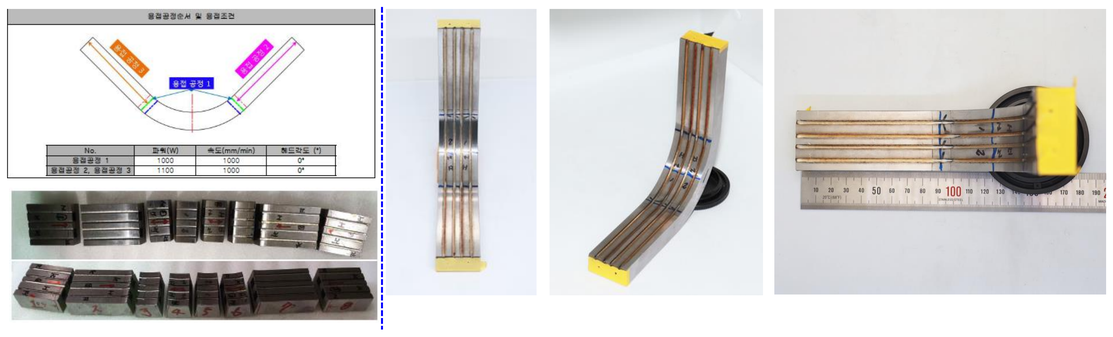
- 2 CH straight small mock-up with 1.2 mm depth and 0.3 mm offset width
- 8 CH straight small mock-up with 1.2 mm depth and 0.3 mm offset width
- 2 CH curved small mock-up with 1.2 mm depth and 0.3 mm offset width

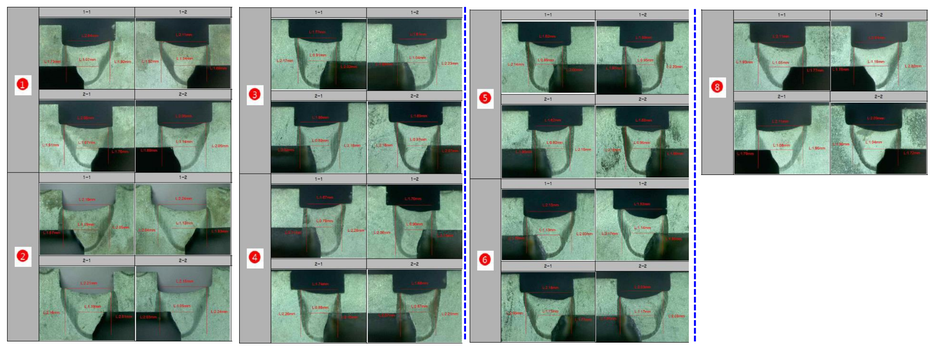


2 CH straight small mock-up with 1.2 mm depth and 0.3 mm offset width



8 CH straight small mock-up with 1.2 mm depth and 0.3 mm offset width





2 curved small mock-up with 1.2 mm depth and 0.3 mm offset width

Conclusions:. A welding method without a permanent backing strip was developed and confirmed by fabricating the straight and curved mock-ups. We found that there is no permanent backing strip by visual observation after cutting of the welding region for both mock-ups. Some unstable region will be tested and then the method will be applied to ITER TBM production.

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