Current Activities on Design and Development of ITER Blanket Shield Block

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Abstract. The conceptual design of blanket shield block has been completed in the framework of BIPT (Blanket Integrated Product Team) since the redesign of blanket system was recommended by 2007 ITER design review. As a part of blanket conceptual design tasks KO DA (Domestic Agency) has participated in the blanket electromagnetic benchmarking activity, coordinated by ITER organization, to verify the analysis methodology and to compare the calculation results. In addition the thermo-hydraulic and thermo-mechanical analyses of the in-board conceptual model were carried out to ensure the thermal performance. Regarding manufacturing technologies, fundamental fabrication techniques such as drilling, machining and deep electron beam welding were successfully developed in the close collaboration with industries. Based on the developed techniques a quarter mock-up was manufactured and fabrication feasibilities of the blanket shield block were also identified. This paper presents recent activities and progresses on the design and fabrication of the ITER blanket shield block in Korea.

1. Introduction

The role of the ITER blanket system is to shield and absorb the radiation from the plasma to the vacuum vessel and superconducting magnets. The shield block is a modular system whose function is to provide thermal and nuclear shielding of outer components and to supply the FW (First Wall) panel with cooling water.

Since the decision of blanket redesign by 2007 ITER design review, the blanket system has been developed in the framework of BIPT composed mainly of IO (ITER organization) and procuring parties. KO DA has supported the electromagnetic, thermo-hydraulic and thermo-mechanical analyses to complete the conceptual design of blanket shield block.

For the manufacturing of a blanket shield block conventional fabrication techniques based on drilling, milling and welding of forged stainless steel block have been adopted. As a consequence of the manufacturing feasibility study, key fabrication techniques to be verified in advance were identified and successfully developed with related industrial companies. Based on the developed techniques a quarter mock-up was recently manufactured. This paper describes recent activities and progresses on the design and fabrication of the ITER blanket shield block in Korea.

2. Design and Analysis

The blanket design shall accommodate EM loads defined in load specification. According to recent updates of ITER blanket design, electromagnetic loads during the plasma disruption are being evaluated to verify the mechanical confidence and reliability. As a course of such evaluations, a benchmark activity for the electromagnetic analysis, coordinated by ITER Organization, is underway between ITER parties to compare the calculation results for disruption loads on the blankets.

We have completed the calculation of electromagnetic loads on the simplified but practical model of ITER shield blankets with respect to six representative disruption scenarios of which ITER distributes simulation results based on the DINA code as a reference of the design and analysis. Commercial finite element method software, ANSYS/EmagTM, was employed to evaluate the eddy current on the blanket modules with the 40 degree sector model for major conducting structures of the tokamak including double-walled vacuum vessel, triangular support, and vertical targets of divertors. An interface between ANSYS/EmagTM and plasma simulator was implemented with a conversion tool assigning the plasma current density on the ANSYS elements corresponding to the current filaments in DINA outputs. Fig. 1 presents the principal concept of the conversion code. [1] Fig. 2 shows the comparison between ANSYS results and DINA outputs of VV shell for the downward VDE 16ms ECQ case to validate the analysis methodology and procedures. As can be seen these figures, the magnitude and distribution of induced current in VV matches well with those of DINA outputs.

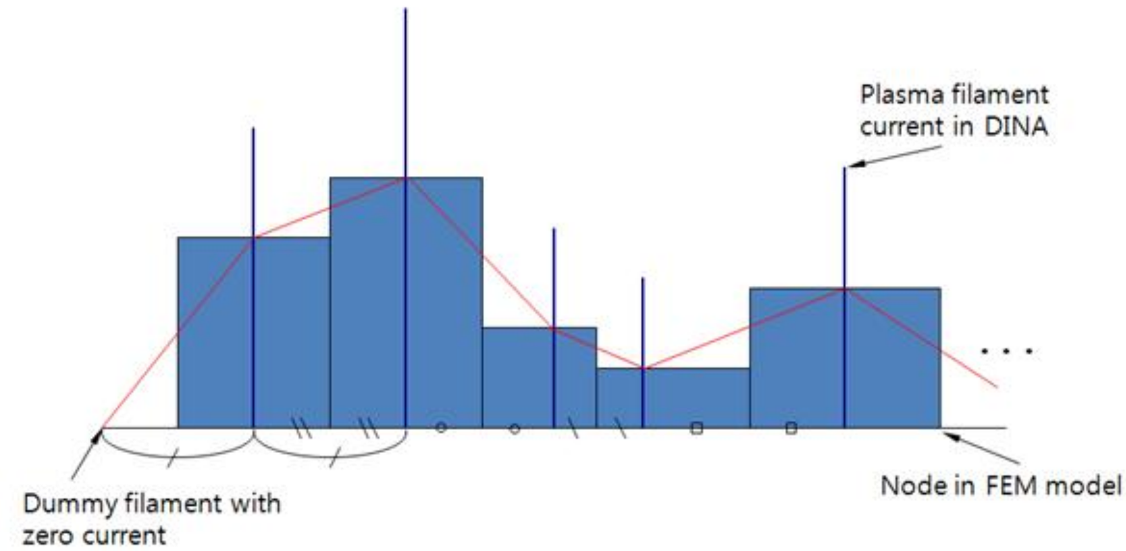
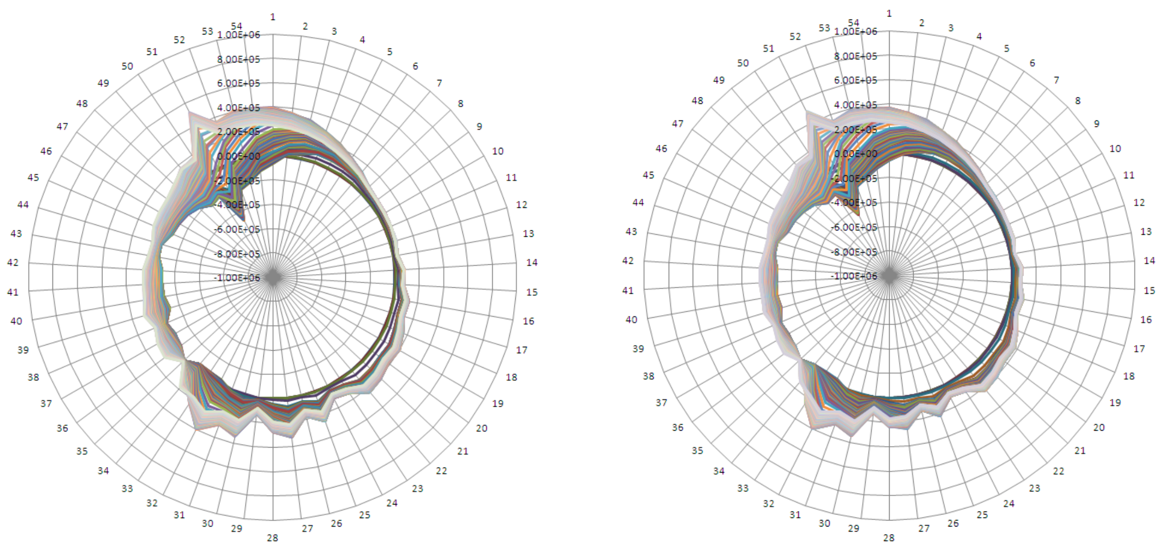


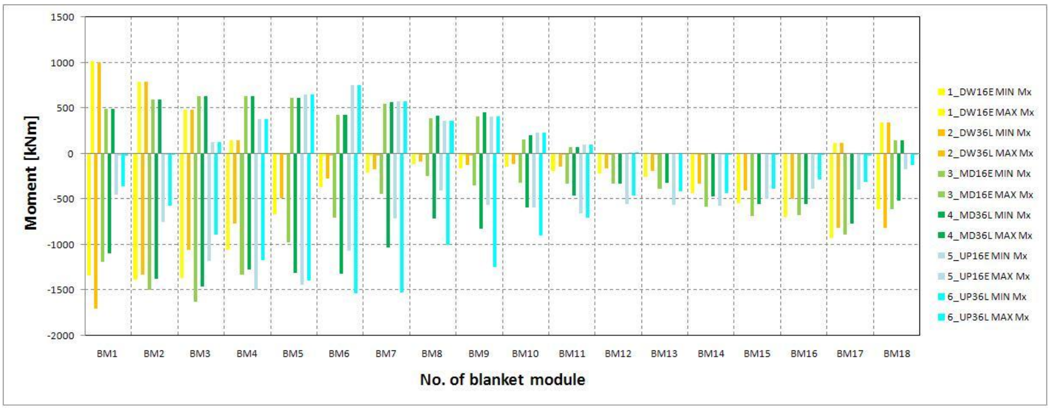
FIG. 1 Concept on conversion program for transferring plasma filament current of DINA output to ANSYS input.



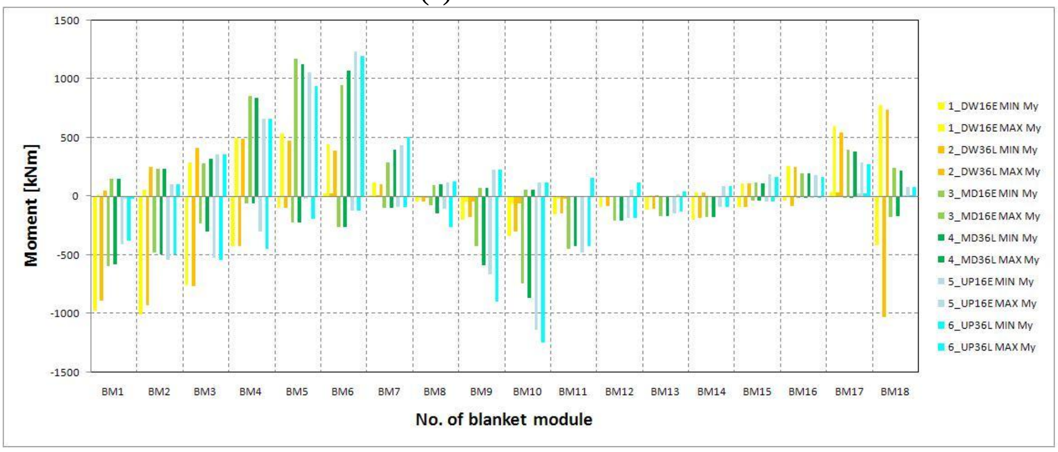
(a) DINA (b) FEM based-ANSYS

FIG. 2. Comparison of induced current in VV obtained from ANSYS and DINA for downward VDE 16 ms ECQ case: Inner wall.

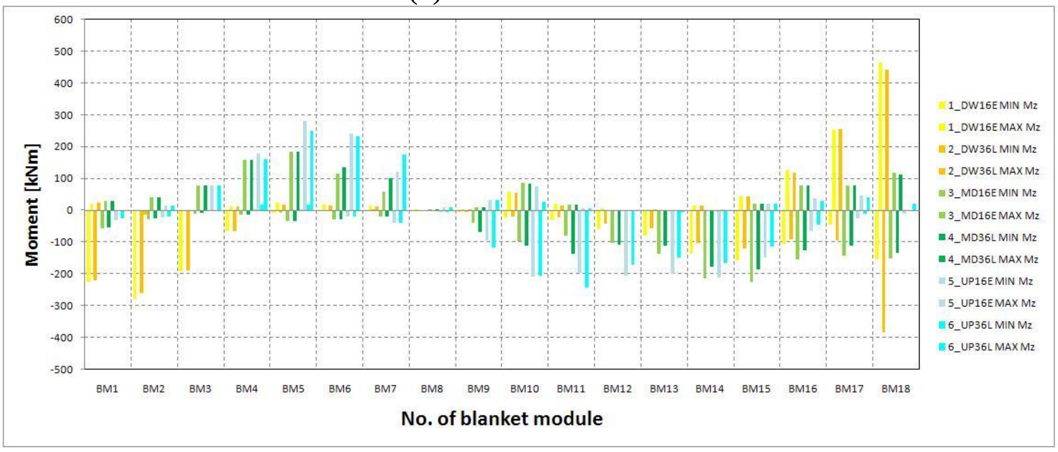
According to the analysis results [2], it seems that there are no big differences between linear and exponential cases even though maximum loadings for relevant events were slightly different. As expected the effect of lower port opening is not so large, and it can be possible to reduce to the 20° sector model. In case of VDE (Vertical Displacement Event) and disruptions, the contribution of first wall panel on electromagnetic loading by eddy current can be considered as small, because it increases the EM loads by several percent. These results could be used as fundamental data for the design of attachments as well as blanket itself even though benchmarking model was already obsolete. In parallel with electromagnetic benchmarking activity the practical investigation of incorporating halo currents in ANSYS disruption simulation is in progress and tangible results are to be presented in the near future.



(a) Radial moment



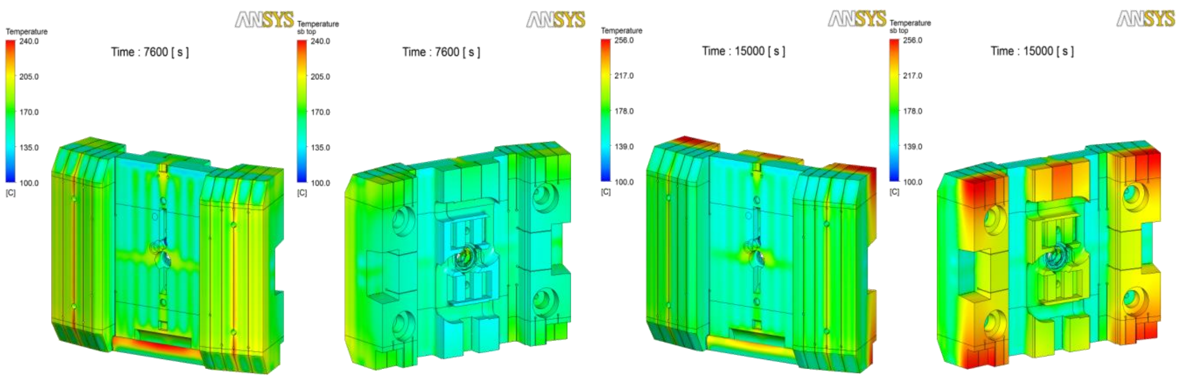
(b) Poloidal moment



(c) Toroidal moment

FIG. 3. Comparison of electromagnetic moments in shield blanket for six enveloped loading cases.

Three dimensional thermo-hydraulic and thermo-mechanical analyses of the blanket shield block 04 for the optimization of cooling structures were performed. A large pressure drop was found to occur at interfaces with inlet or outlet, but the pressure drop in the shield block only was less than 0.1 MPa. Transient thermo-hydraulic analysis was performed under two plasma loading conditions, inductive and non-inductive operations, in accordance with CDR (Conceptual Design Review) specific analysis protocol. Coolant temperature at outlet showed similar tendencies to plasma loadings. The coolant outlet temperatures for inductive and non-inductive operations were 148℃ and 146.4℃, respectively for a coolant temperature rise from inlet to outlet of <10℃.
As shown in Fig. 4, the maximum temperatures in the shield block (at the knuckle) and coolant for inductive operation were 241 ℃ and 164 ℃, respectively. In case of non-inductive operation, the maximum temperatures in the SB (at the rear corners) and coolant were 256 ℃ and 158 ℃, respectively. Table I summarizes the results of the static structural analysis of shield block #4. The maximum displacements under all loading conditions were tolerable for the 10 mm gaps between modules. In addition the stresses were well below allowable limits. In case of non-inductive operation peak stresses over 3Sm occurred at the rear toroidal slit hole and their fatigue lives were identified less than 30,000 cycles. Solutions can be expected in further design evolution. In conclusion, no significant design issue was identified from these analyses.



(a) Inductive operation (7,600 sec) (b) Non-inductive operation (15,000 sec)

FIG. 4 Maximum temperature distributions of shield block.

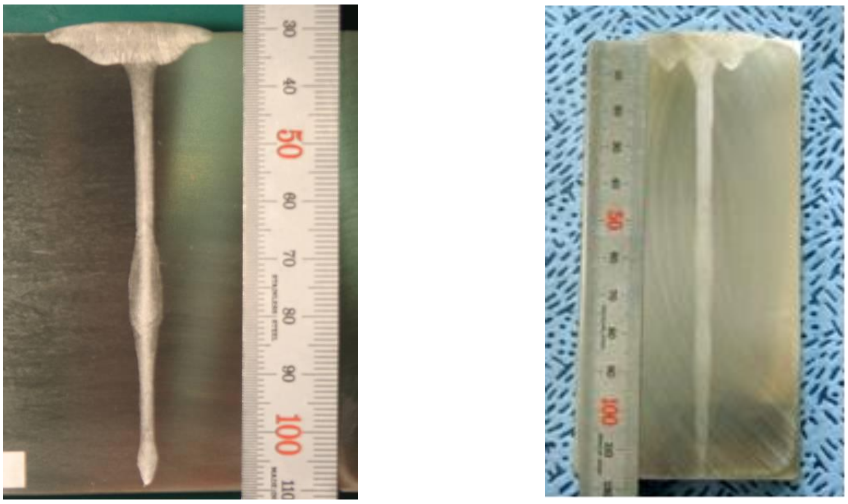
TABLE I: SUMMARIZED RESULTS OF STATIC STRUCTURAL ANALYSIS

Loading conditions	Stress Category	Von-Mises Stress (MPa)	Allowable Stress (MPa)	Maximum Displacement (m)
Coolant Pressure	P_m	6	147	-
	P_m+P_b	46	221	-
	P_m+P_b+Peak	46	-	0.306 E-4
Coolant Pressure + Gravity + Assembly Load	P_m	35	147	
	P_m+P_b	95	221	
	P_m+P_b+Peak	146	-	0.348 E-4
Coolant Pressure + Gravity + Assembly Load + Thermal (Inductive)	P+Q	65	363	
	P+Q+Bending	119	363	
	P+Q+F	296	-	0.0011
Coolant Pressure + Gravity + Assembly Load + Thermal (Non-inductive)	P+Q	102	363	
	P+Q+Bending	272	363	

After blanket CDR KO DA has supported the post CDR activities to deal with the arising issues and is now actively collaborating for the implementation of blanket preliminary design.

3. Manufacturing Techniques Development

The ITER blanket shield block is to be fabricated by the conventional process based on drilling, milling and welding of forged stainless steel blocks. For the adaptation of conventional method, one of the most important tasks to be verified is to develop the electron beam welding (EBW) technologies for the block to block joint. In addition, after drilling and milling for cooling passages, plugging techniques satisfying the requirements for the welding section should be developed. Three joining technologies for the blanket reference design, the electron beam welding for thick blocks, joining of lids and plugs, and attachment of flow drivers, were investigated and the results are briefly summarized in this paper. [3-5]
The electron beam welding parameters for 70 or 110 mm thickness blocks satisfying the requirements in accordance with ASME code were established as presented in Fig. 5 and Table II. It was also found that slower welding speed plays an important role in the suppression of the formation of voids and porosities in weld metal.



(a) 70 mm thickness (b) 110 mm thickness

FIG. 5. Macroscopic cross section through the fusion and heat affected zones (HAZ) of thick longitudinal weld.

TABLE II: WELDING PARAMETERS FOR THICK BLOCKS

Welding Parameters	70mm Blocks	110 mm Blocks
Acceleration voltage (kV)	120	120
Welding current (mA)	140	245
Chamber pressure (torr)	5×10^{-5}	5×10^{-5}
Welding speed (mm/min)	100	100

After drilling and milling the coolant passage, header lids and plugs for closure are attached by welding. EB or laser welding to attach the header lids and plugs were suggested. From the feasibility study, however, it was found that using EBW for plug attachment is very expensive although EB or laser welding is attractive for minimizing distortions and high productivity. For this reason two mock-ups were made in order to check these welding methods and to verify the appropriate weld design. The joint setup and welding parameters for achieving full penetration on the back side should be verified since the open crevice between two adjacent bodies could be vulnerable to corrosion cracks due to the coolant. Fig. 6 shows the front header mock-up of the reference design for the EBW and narrow gap welding. For joining 20 mm thickness lid, TIG welding with 16 passes was performed. The welding current was in the range of 100-250 A. The soundness of all mock-ups was verified under the helium leak rate of 10^{-9} - 10^{-10} Pa m^3/sec and the pressure of 3.5 MPa. A deformation of EBW mock-ups for the front header lid was measured less than 1 mm. The maximum deformation of front header mock-up by narrow gap welding, however, was about 4 mm. It seems that post-machining would be needed if front header lid is joined by narrow gap welding. The plug welding tests were also implemented as shown in Fig. 7. All welding conditions for both mock-ups were very similar to those of front header mock-up.

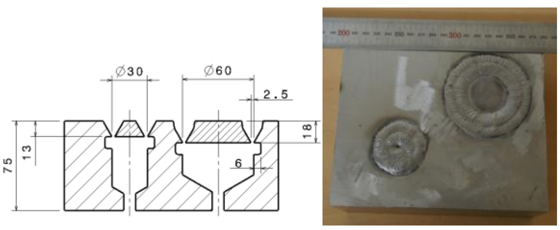
A quarter mock-ups as shown in Fig. 8 were successfully fabricated for the verification of developed techniques in accordance with related code and standards.

In addition the industrial assessment for the recent blanket design is in progress. The objective of the assessment is to evaluate the proposed blanket shield block design from a manufacturing perspective using industries within the KO DA. The assessment is to be used to provide feedback to the design from a manufacturer’s perspective, identify areas of the design that will require R&D to establish feasibility of the concept. Based on these results, the semi-prototype fabrication as a course of the pre-qualification program is launched within the near future.

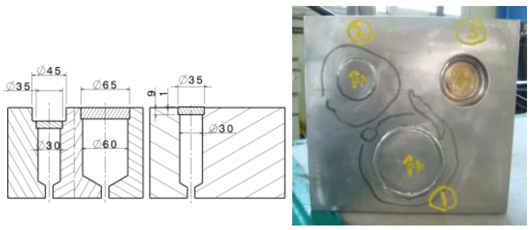
(a) Narrow gap welding

(b) Electron beam welding

FIG. 6. Front header mock-ups manufactured by EBW and narrow gap welding.

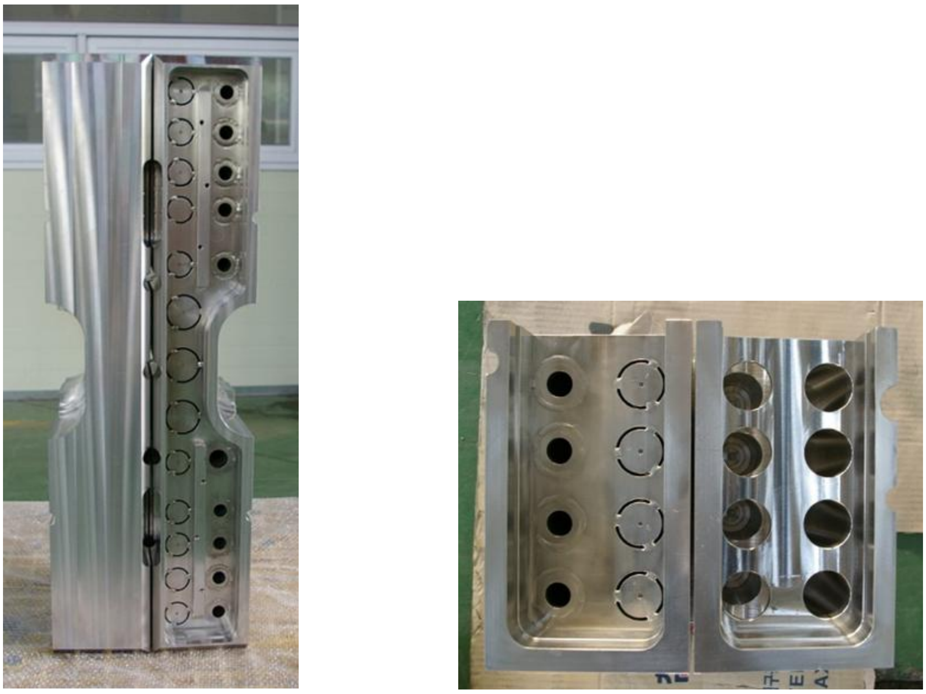


(a) Narrow gap welding



(b) Electron beam welding

FIG. 7. Plug mock-ups based on EBW and narrow gap welding.



(a) Central part (b) Lateral part

FIG. 8. A quarter mock-up of reference blanket shield block.

4. Conclusions

This paper describes recent activities and progresses on the design and fabrication of the ITER blanket shield block in Korea. As a part of blanket conceptual design tasks ITER Korea has participated in the blanket design & analysis activities such as electromagnetic, thermo-hydraulic and thermo-mechanical calculations, etc.

To verify the adequacy for the manufacturing of a blanket shield block by using conventional methods and to establish the fabrication process, several welding tests such as EBW for thick SS blocks, joining of lid or plug, and attachment of flow driver, were performed based on the reference design. The single side EBW techniques for 70 and 110 mm thickness blocks were successfully developed by KO industries. The EBW parameters for achieving requirements of relevant codes and standards were found, and appropriate welding conditions to suppress the growth of voids and porosities in fusion metal were also identified. For the weld design of front header lids and plugs, small mock-ups using EBW or narrow gap welding were manufactured. A quarter mock-ups were fabricated for the verification of developed techniques. These developed manufacturing techniques are contributing to the evolution of blanket design.

At present we are participating in the blanket preliminary design and collaborating with the concerned industries for the industrial assessment to the proposed design and the semi-prototype fabrication preparation.

Acknowledgments

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The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

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