Development of HCCP TBM Fabrication Procedure and Design of Small mock-up for Fabrication

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1. Introduction

Korea is developing a helium-cooled ceramic reflector (HCCR) breeding blanket as part of its efforts to develop a Korean fusion demonstration reactor and fusion power plant [1]. As part of this initiative, Korea, in collaboration with Europe, is developing the Helium-Cooled Ceramic Pebble (HCCP) Test Blanket Module (TBM) for installation and testing in ITER. Reduced-activation ferritic/martensitic (RAFM) steel is being considered as a candidate structural material for fusion reactors, and various countries have developed RAFM steels such as EUROFER [2] and F82H [3]. Korea has developed an advanced reduced-activation alloy (ARAA), which is used to manufacture HCCP TBM components for ITER [4-7]. The HCCP TBM consists of a TBM box and a TBM shield structure. The TBM box contains the breeding material that generates tritium, while the TBM shield provides structural support and neutron attenuation. The TBM shield requires materials that can withstand high temperatures, neutron irradiation, and mechanical loads. South Korea has selected nuclear-grade stainless steel SS316L(N)-IG as the primary material for the TBM shield due to its excellent mechanical properties and corrosion resistance. The successful development of the TBM shield is essential not only for contributions to ITER but also for the future construction of a fusion demonstration reactor.

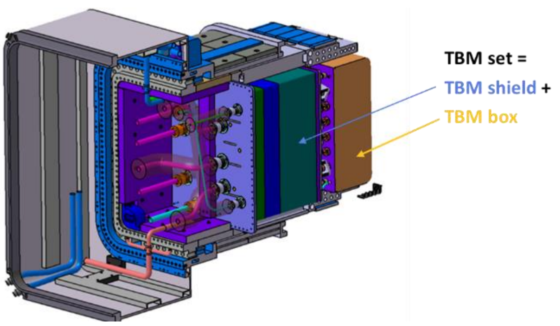

Fig. 1. HCCP TBM geometry diagram

The HCCP TBM box is made of RAFM steel (EUROFER-97), while the TBM shield is fabricated using SS316L(N)-IG. The fabrication of the HCCP TBM for ITER is jointly carried out by Korea and Europe. Korea is responsible for the TBM box's internal components (breeding unit) and TBM shield, whereas Europe is responsible for the TBM box outer casing and manifold structure. The final assembly will be conducted in Europe. The structure and configuration of the HCCP TBM are shown in Fig. 1.

2. Design of a Small Mock-Up for HCCP TBM Shield Fabrication

The HCCP TBM design was developed in Europe, and Korea and Europe have agreed on joint production. The HCCP TBM set consists of a TBM box and a TBM shield, with Korea responsible for manufacturing the breeding unit and TBM shield, while Europe is in charge of the TBM box main body, manifold structure, and final assembly. The overall fabrication schematic of the HCCP TBM shield is shown in Fig. 2. The structure of the HCCP TBM shield consists of a pipe and casing structure, incorporating five shield blocks along with three additional blocks at the front, bend, and rear. The pipe and casing include cooling water inlet/piping, helium inlet/piping, purge gas inlet/piping, and NAS I&C piping, all of which are connected to the TBM manifold. To verify the performance of the TBM, design and structural analysis must be conducted, and manufacturing feasibility must be confirmed by reviewing the fabrication procedures and methods. The existing HCCP shield design presents challenges in welding and fabrication due to multiple reinforcement plates. In this study, the welding processes were simplified and manufacturing procedures improved by reviewing the characteristics of the HCPB TBM shield and WCLL TBM shield developed in Europe, as well as the HCCR TBM shield developed in Korea. The improved HCCP TBM shield design includes geometric design and fabrication procedures, with an assembly process diagram shown in Fig. 3. The HCCP TBM shield can be fabricated using Tungsten Inert Gas (TIG) welding, and both visual inspection and non-destructive testing (NDT) can be applied to the weld joints. This study focused on designing a small mock-up for TBM shield fabrication. The small mock-up design targets the fourth and fifth shield blocks, where the pipe structure passes through the bending section. The fabrication procedure diagram for the designed small mock-up is shown in Fig. 4. The geometry of the inlet casing, by-pass casing and outlet casing of the HCS applied to the small mock-up is shown in Fig. 5. The geometry of the purge gas inlet and outlet casing applied to the mock-up is shown in Fig. 6. The design of the mock-up was centered around the following main objectives Developing a systematic design framework for the TBM shield mock-up, analyzing the applicability of various welding techniques, including TIG welding, applying non-destructive testing techniques such as X-ray inspection, ultrasonic testing (UT), magnetic particle testing (MT), and penetrant testing (PT), and verifying the fulfillment of the design requirements for fabricating the TBM shield mock-up based on the designed model.

This research provides important information for the design and testing of fusion reactor components and contributes to the ITER project and the advancement of fusion technology. The design established in the study will be directly utilized during the actual fabrication of the TBM shield mock-up. The goal is to perform pre-production validation and weld quality assessment of the prototype, as well as to identify and address any issues that may arise during production.

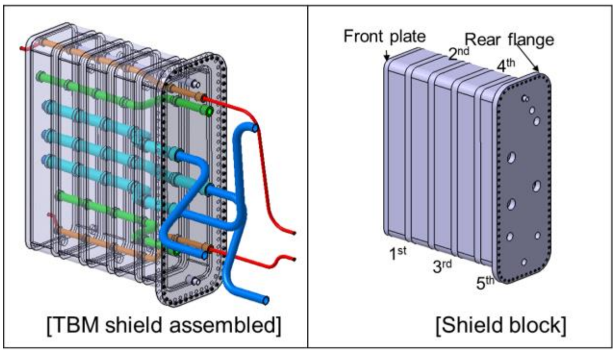

Fig. 2. Schematic of HCCP TBM Shield fabrication

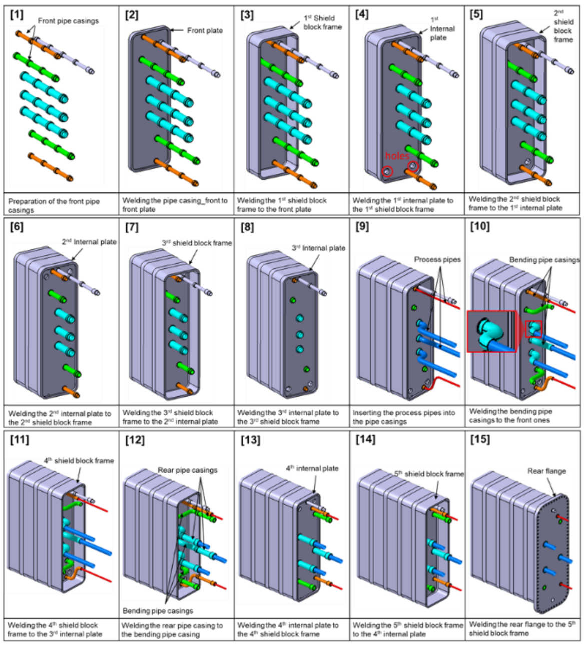

Fig. 3. Schematic of HCCP TBM Shield assembly procedure

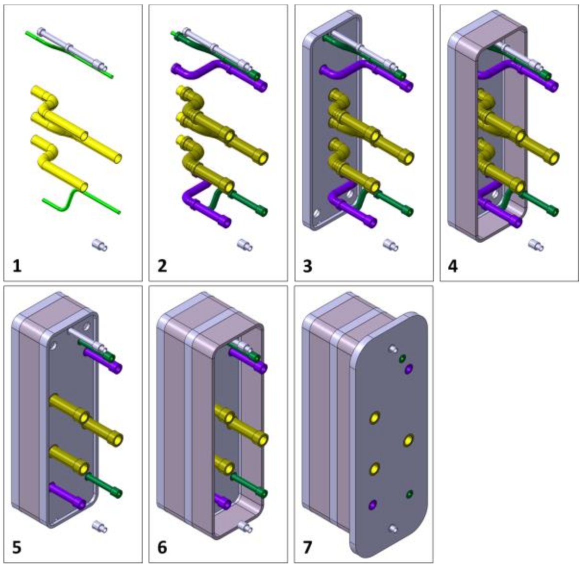

Fig. 4. Assembly procedure of small mock-up of HCCP TBM Shield

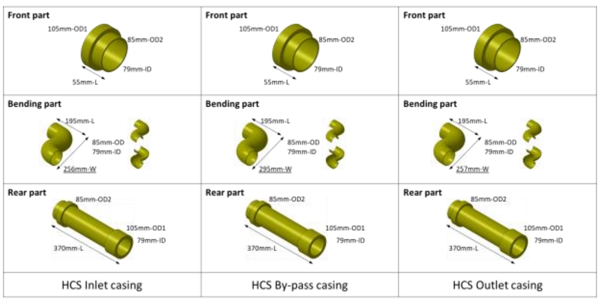

Fig. 5. Schematic of the inlet casing, by-pass casing and outlet casing of the HCS

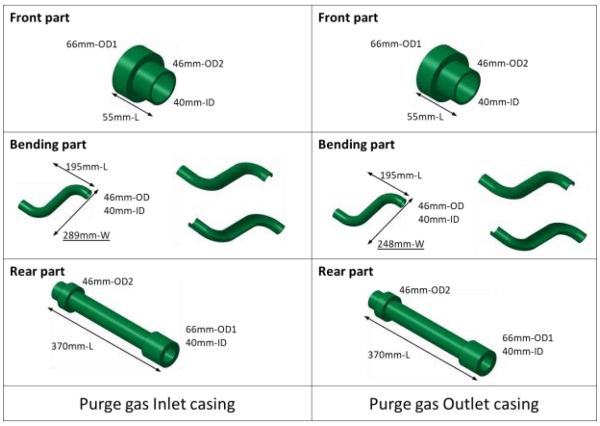

Fig. 6. Schematic of the inlet and outlet of the Purge gas casing

3. Conclusions

HCPB TBM shields and WCLL TBM shields developed in Europe and HCCR TBM shields in Korea are expected to face difficulties in welding and inspection due to multiple reinforcement plates. To solve this problem, this study designed an HCCP TBM shield that simplifies the welding process and improves the fabrication procedure. A small mock-up was designed to examine the fabrication of the improved TBM shield and the application of non-destructive testing, and a small mock-up will be manufactured to examine the manufacturability and non-destructive testing of this product.

Acknowledgments

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