

Design and Fabrication Procedures of the HCCP TBM Shield and Its Small-Scale Mock-up

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1. Introduction

One of the principal objectives of the ITER Test Blanket Module (TBM) program is to demonstrate tritium breeding and heat extraction under fusion-relevant operating conditions [1–3]. Korea and the European Union are jointly developing the Helium Cooled Ceramic Pebble (HCCP) TBM by integrating the principal features of the Korean HCCR and European HCPB concepts [3,4]. The HCCP TBM-set comprises a TBM box, a water-cooled shield, process pipes, and attachment structures. Under the Korea–EU work-share arrangement, Korea is responsible for the design and fabrication of the TBM shield, its attachments, breeder units, and TBM-set integration, whereas the European Union is responsible for the TBM box structure and process pipes.

The TBM shield constitutes a pressure boundary and contains five shield blocks, a front plate, internal plates, pipe casings, a rear flange, and multiple penetrations for helium coolant, purge gas, shield cooling water, and instrumentation. The earlier HCPB-based configuration required numerous full-penetration welds among the internal plates, side walls, and pipe casings. In addition, modification of the process-pipe layout reduced the clearance between adjacent casings, creating possible overlap of weld regions and heat-affected zones and limiting access for welding and non-destructive testing (NDT). The present work therefore establishes a fabrication-oriented HCCP shield design and a sequential manufacturing procedure, and develops a small-scale mock-up concept for verifying weld accessibility, inspectability, and the preliminary welding procedure specification (pWPS).

2. Design and Fabrication Procedure of the HCCP TBM Shield

The shield design was revised using manufacturability as a primary constraint while retaining the required structural performance. First, the number of internal plates was reduced and their spacing was increased to decrease the number of pressure-boundary welds and improve access for welding torches and inspection equipment. Plate and wall thicknesses were adjusted to compensate for the reduced number of stiffening elements. Second, the full-penetration joint between each internal plate and pipe casing was

eliminated by adopting a monolithic internal-plate concept. In this concept, the plate is machined to form the required recesses and penetrations, after which the pipe-casing joint can be completed from the accessible side. This change removes an interference-prone joint from the crowded internal region.

Orbital-welding requirements were reviewed with an industrial partner. The clearance around the pipe casings was checked against the welding-head envelope, and the widths of individual shield blocks were redistributed to provide the required tool approach without changing the overall functional envelope. The modified block arrangement and the corresponding structural-assessment result are shown in Fig. 1. The modified configuration was assessed under representative pressure and thermo-mechanical loads, and the assessment indicated that the change in block widths and internal-plate arrangement did not impair the structural integrity of the shield. The resulting design thus links structural verification directly to fabrication constraints rather than treating weld access as a downstream issue.

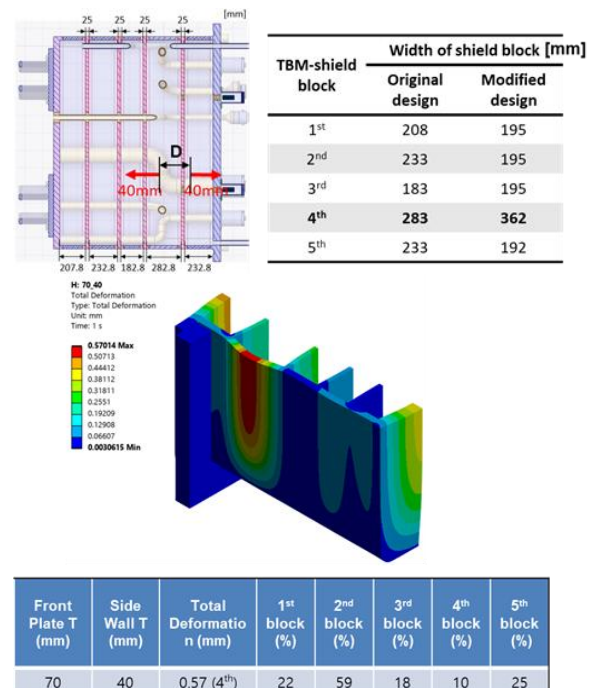


Fig. 1. Modification of the HCCP TBM shield for orbital-welding access (top) and structural verification (bottom).

The proposed fabrication begins with procurement and acceptance of SS316L(N)-IG material, followed by machining of the front plate, five shield-block frames, monolithic internal plates, pipe casings, and rear flange. The front pipe casings are prepared and welded to the front plate. The first shield-block frame and first internal plate are then installed in sequence. The remaining block frames and internal plates are alternately fitted and welded while dimensional control is maintained. Process pipes are inserted after sufficient internal access has been secured; the bent casing sections are joined to the front sections, followed by the rear casing sections. The fourth internal plate and fifth block frame are then assembled, and the rear flange is welded last. Intermediate dimensional inspections, visual examination of both weld sides through dedicated access holes, and applicable surface or volumetric NDT are incorporated before access is closed by the next block.

3. Design and Fabrication of a Small-Scale Mock-up

A small-scale mock-up was defined to reproduce the fabrication features that govern qualification of the shield rather than its full external dimensions. The mock-up includes representative portions of the front plate, a monolithic internal plate, a shield-block side wall, and pipe casings with the minimum practical spacing. Its geometry preserves the relevant plate thicknesses, joint preparations, tool approach directions, and inspection paths. The change from the conventional internal-plate route to the monolithic concept adopted for the mock-up is shown in Fig. 2. Interchangeable casing locations can be used to examine the most restrictive HCS and instrumentation penetrations and to confirm whether the orbital-welding head, fixtures, and endoscope can be positioned without interference.

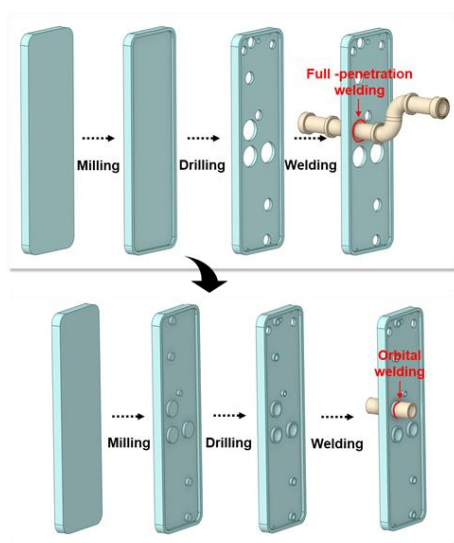


Fig. 2. Manufacturing routes for the conventional internal plate (top) and monolithic internal plate (bottom) used to define the mock-up.

Mock-up fabrication follows the intended production sequence. A plate blank is first milled to form the monolithic recess, followed by drilling and finish machining of the casing penetrations. The front plate, casing, internal plate, and side-wall specimens are inspected before fit-up. Dedicated jigs then establish casing position, angular alignment, root gap, and stand-off distance. Welding is performed using candidate parameters from the pWPS, with the sequence arranged to minimize distortion and to retain access for subsequent joints. Dimensional changes are recorded after each weld group. Where applicable, post-weld heat-treatment conditions are evaluated together with their effect on distortion and surface condition.

The mock-up inspection plan combines direct visual examination, endoscopic inspection of the reverse side through access holes, and applicable NDT of the representative joints. Particular attention is given to incomplete penetration, lack of fusion, distortion, and interaction between adjacent heat-affected zones. The trial also provides practical information on torch manipulation, orbital-welding-head clearance, jig stiffness, inspection coverage, and the order in which temporary supports should be removed. These results will be used to refine the assembly sequence, establish acceptance criteria, and support welding-procedure qualification and preparation of the pWPS for the full-scale shield.

4. Conclusions

A fabrication-oriented design and manufacturing procedure were developed for the HCCP TBM shield. The proposed design reduces internal full-penetration welds, introduces monolithic internal plates, and redistributes shield-block widths to secure orbital-welding access while maintaining structural adequacy. A stepwise fabrication sequence was established so that welding, dimensional control, and NDT can be performed before each region becomes inaccessible. In addition, a representative small-scale mock-up was defined to verify critical joint fabrication, tooling access, distortion control, and inspectability. The mock-up program provides the experimental basis needed to refine the production sequence and qualify the welding procedure for subsequent full-scale manufacturing.

Acknowledgments

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