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Macroscopic High-temperature Structural Analysis on an Alloy800HT PCHE prototype

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1. Introduction

Hydrogen is considered a promising future energy solution because it is clean, abundant, and storable, and has high-energy density. One of the major challenges in establishing a hydrogen economy is how to produce massive quantities of hydrogen in a clean, safe, and economical way. Among the various hydrogen production methods, nuclear hydrogen production is garnering worldwide attention since it can produce hydrogen, a promising energy carrier, without an environmental burden.

In the intermediate loop, the IHX (Intermediate Heat Exchanger) of the VHTR transfers 950℃ heat generated from the VHTR to a hydrogen production plant through a hot gas duct, while the PHE (Process Heat Exchanger) is a component that utilizes the nuclear heat from the nuclear reactor to produce hydrogen. A PCHE (Printed Circuit Heat Exchanger) is considered a candidate of the IHX of the nuclear hydrogen system in the ROK. Recently, the Korea Atomic Energy Research Institute (KAERI) has established a helium experimental loop (HELP) for a performance test of VHTR components, as shown in Fig. 1, and has manufactured a lab-scale PCHE prototype made of Alloy800HT to be tested in HELP.

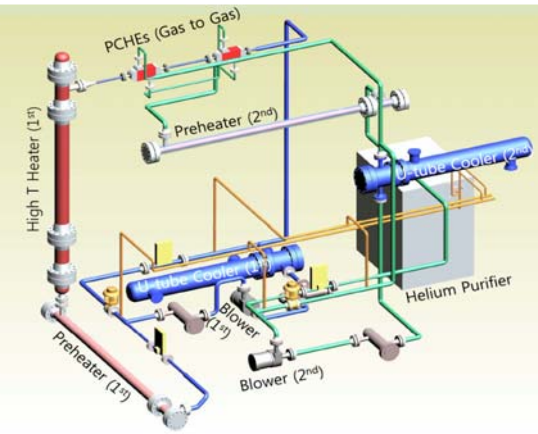

Fig. 1 Helium Experimental Loop (HELP)

In this study, to investigate the macroscopic structural characteristics and behavior of a lab-scale Alloy800HT PCHE prototype under the test conditions of HELP, FE (finite element) modeling, a thermal analysis, and a structural analysis on the PCHE prototype have been conducted as a precedent study for a performance test. The results obtained in this study were compared with the test results of the lab-scale Alloy800HT PCHE prototype.

2. FE modeling

A schematic view of a lab-scale Alloy800HT PCHE prototype, which was generated from a finite element (FE) model, is illustrated in Fig. 2. The FE model of the PCHE prototype is formulated with 3,255,685 linear 3D elements including 128,726 linear tetrahedron elements and 330,103 linear wedge elements. The maximum node number of the FE model is 3.823,819. All parts of the PCHE prototype and inlet/outlet pipelines are made of Alloy800HT. Thermal boundary conditions at primary and secondary flow plate, as shown in Fig. 3, are used as input data for a thermal analysis. Based on the finite element model of the PCHE prototype, as shown in Fig. 2, analyses such as thermal and structural analyses are carried out using ABAQUS Ver. 6.11-1 [6] with thermal insulation on the outside of the lab-scale PCHE prototype.

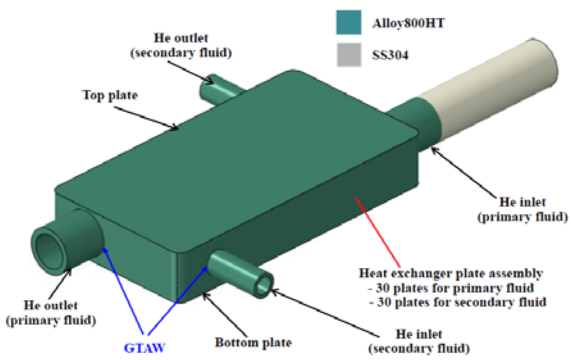

Fig. 2 FE model of a PCHE

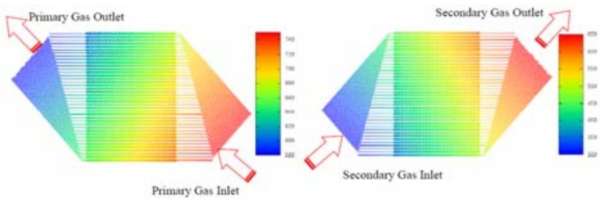

Fig. 3 Thermal Boundary Conditions

3. Analysis

A thermal analysis on the Alloy800HT PCHE prototype under free convection/radiation on the outside of it was performed to compare analysis results with measured temperature contours. When compared the temperature contours from analysis and test, good similarities between them are observed. Consequently, present analysis model seems to be reliable. Fig. 4 shows temperature contours under insulation on the outside of the PCHE prototype.

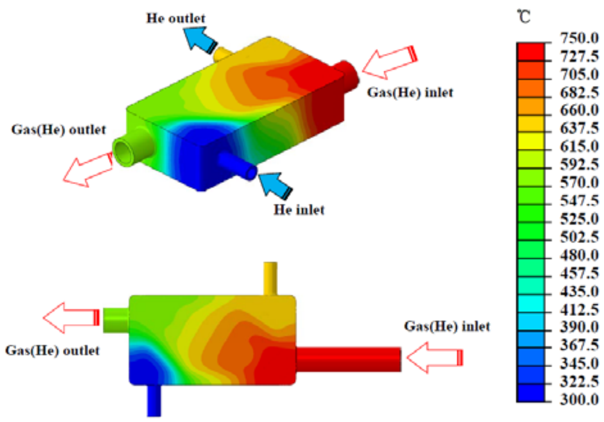

Fig. 4 Temperature contour

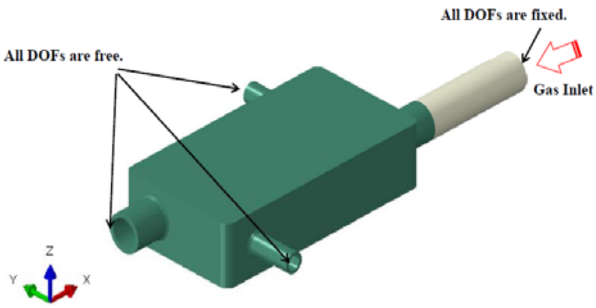

Fig. 5 BC for structural analysis

Based on the structural boundary conditions shown in Fig. 5 and the temperature contours shown in Fig. 4, an elastic structural analysis of the PCHE prototype was carried out considering the primary/secondary coolant pressures of 3.0 MPa. Figure 6 shows the overall stress distributions of the PCHE prototype. According to Fig. 6, a maximum stress of 160 MPa occurred near the weld connection of the main body of the PCHE prototype and 2nd in-flow pipeline. Considering the temperature contours in Fig. 4 and stress contours in Fig. 6, considerable plastic deformation seems to occurred on the outside of the PCHE. In order to carry out the performance test of the PCHE prototype in HELP without considerable plastic deformation on the PCHE prototype, some measure, such as a flexible pipeline designing, should be taken.

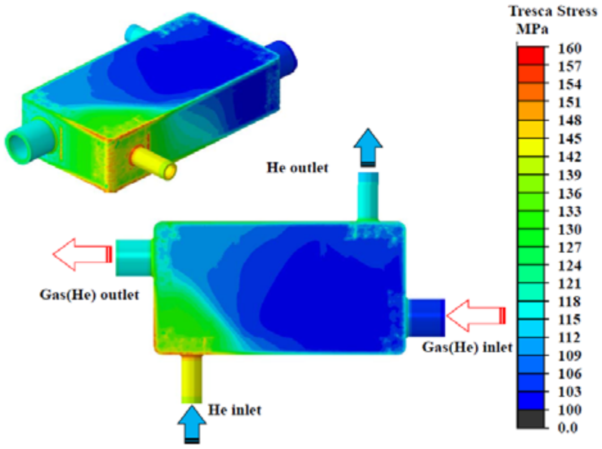

Fig. 6 Stress contour

4. Summary

In an effort to investigate the macroscopic structural characteristics and behavior of a lab-scale PCHE prototype made of Alloy800HT under the test conditions of HELP prior to an actual performance test, FE modeling, a thermal analysis, and a high-temperature structural analysis on the lab-scale PCHE prototype were carried out. A summary of the analysis results is as follows:

1. Under the test conditions of HELP, the maximum local stress occurring at the pressure boundary of the PCHE prototype was about 160 MPa.
2. Some measure to reduce the plastic deformation on the PCHE prototype should be taken.

Acknowledgements

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