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On the Strength Evaluation of the Lab-Scale PHE Prototypes

a Keenam Song[a*], S-D Hong[a], and H-Y Park[b]
[a]*Korea Atomic Energy Research Institute, P.O.BOX 105 Yusong, Taejon, Rep. of KOREA*
[b]*AD solution*
[*]Corresponding author: *knsong@kaeri.re.kr*

1. Introduction

Researches demonstrating the massive production of hydrogen using a very high temperature reactor (VHTR) have been actively carried out worldwide. In the intermediate loop of a nuclear hydrogen program, a process heat exchanger (PHE) is a key component to transfer high heat generated in a very high temperature reactor to a chemical reaction that yields a large quantity of hydrogen [1]. Recently, the Korea Atomic Energy Research Institute (KAERI) established a small-scale nitrogen gas loop [2] for the performance test of the VHTR components, and manufactured welded lab-scale PHE prototypes made of Hastelloy-X [3].

In this study, to understand the mechanical behavior of theses lab-scale PHE prototypes in detail, strength analyses considering the weld mechanical properties recently obtained [4] by an instrumented indentation technique were performed, and the analysis results were compared with the previous research using the parent material properties.

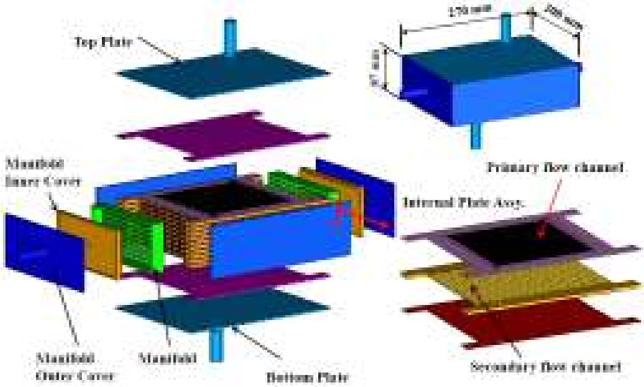
2. Lab-Scale PHE prototypes

Fig. 1 shows the overall dimensions and each part of two lab-scale PHE prototypes, which were designed for operation at up to 850℃ in the gas loop at KAERI. All parts of the lab-scale PHE prototypes are made of Hastelloy-X. Grooves 1.0 *mm* in diameter were machined into the flow plate for the primary coolant (nitrogen gas). Waved channels were bent into the flow plate for the secondary coolant (SO_3 gas). Flow plates for the primary and secondary coolants were stacked in turn, and bonded along the edge of the flow plate using a solid-state diffusion bonding method. After stacking and bonding the flow plates, the outside of the lab-scale PHE prototypes was covered with the 3.0 *mm* thick Hastelloy-X plate and is welded along its edges using tungsten arc welding with argon as a shielding gas.

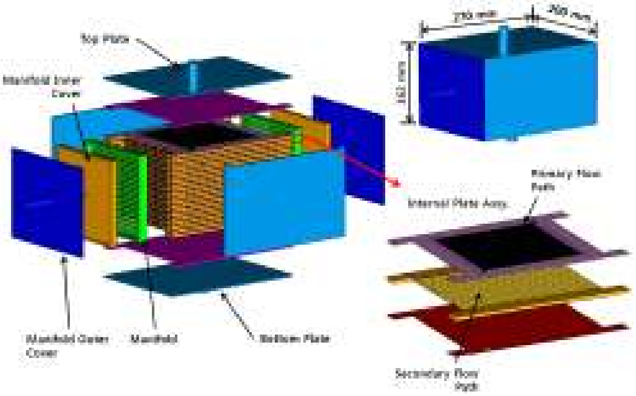
3. Measurement of Weld Properties

An instrumented indentation method is known to be a remarkably flexible mechanical test to obtain the mechanical properties with minimal specimen preparation [5] by continuously measuring the load and depth if an indentation is made. An additional advantage of the indentation is the ability to obtain the mechanical properties in a narrow or inaccessible region through other methods such as uni-axial tension or a compression test.

Based on the measured data using an instrumented indention method, the normalized mechanical properties in the parent material, the weld, and the HAZ of Hastelloy-X were obtained [4].



a) 3 kW class



b) 10 kW class

Fig. 1 Parts of two lab-scale PHE prototypes

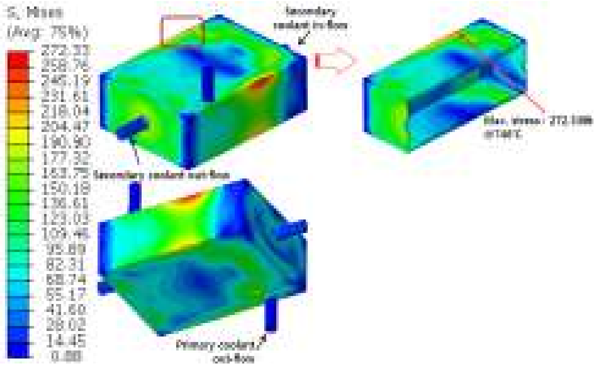
4. Finite Element Modeling and Analysis

Finite Element (FE) modeling using I-DEAS was carried out. For the sake of simplicity and an understanding of the overall mechanical behavior of the lab-scale PHE prototypes, the FE models are composed of 3-D linear solid elements including tetrahedron elements. The weld zones of the lab-scale PHE prototypes are modeled, where the weld beads along the edges and heat affected zone (HAZ) are represented.

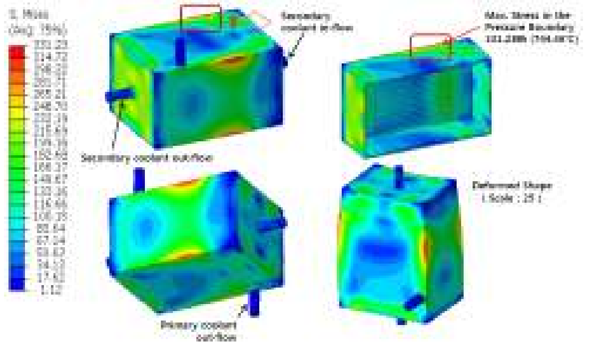
Thermal analyses were carried out using I-DEAS/TMG Ver. 6.1 under the normal test conditions of small-scale nitrogen gas loop. Based on the thermal analysis results [6,7] and the imposing structural boundary conditions considering the pipeline stiffness of the gas loop [6], structural analyses were carried out using ABAQUS Ver. 6.8.

5. Results

Figure 2 shows the elastic stress contours at the pressure boundary of the lab-scale PHE prototypes. For the 3 kW class PHE prototype, the maximum local stress of 272.33 MPa around the edge between the top plate and side plate exceeds the yield stress of Hastelloy-X (239.70 MPa at 746℃) [8] by 13.61%. For the 10 kW class PHE prototype, the maximum local stress of 331.23 MPa around the edge between the top plate and side plate exceeds the yield stress of Hastelloy-X (238.0 MPa at 744.46℃) by 39.17%.



a) 3 kW class



b) 10 kW class

Fig. 2 Stress contours in elastic analysis of two lab-scale PHE prototypes

On the other hand, the degree of exceeded yield stress in the weld (fusion zone) is decreased for the analysis using the weld material properties. For the 3 kW class PHE prototype, the maximum stress of 272.33 MPa exceeds the yield stress of the weld material (269.50 MPa at 746℃) [8] by only 1.05%. For the 10 kW class PHE prototype, the maximum stress exceeds the yield stress of the weld material (263.09 MPa at 744.46℃) by 25.9 %. Thus, a smaller degree of excess yield stress is attributed to a larger yield stress of the weld material than the parent material.

Even though the maximum stresses exceed the yield stress for the lab-scale PHE prototypes, the high-temperature structural integrities of the PHE prototype seem to be maintained under the normal test conditions of the gas loop, owing to the chamfering effect on each edge. That is to say, since the edges of the PHE prototype are chamfered realistically, the maximum stress will be decreased to some extent when considering the chamfered edges.

6. Summary

1. A high-temperature elastic structural analysis on the lab-scale PHE prototypes under the gas loop test conditions was performed.
2. Even though the maximum stress exceeds the yield stress in the weld zone, the degree of excess in yield stress may be different owing to the different yield stresses in the weld zone.
3. As a result of the analyses, high-temperature structural integrities of the PHE prototypes seem to be maintained under the normal test condition of the gas loop, owing to the chamfering effect on each edge.

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