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Development of an Innovative High Temperature Compact Heat Exchanger for the Coupling of VHTR and Hydrogen Production System

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1. Introduction

Very high temperature gas cooled reactor technology and IS cycle technology are being developed in KAERI for a nuclear hydrogen production system [1]. One of the important components in the nuclear hydrogen production system is a process heat exchanger of the SO_3 decomposer (hereafter PHE) which generates SO_2 gases at the highly elevated temperature conditions. The materials used for PHE require excellent mechanical properties at an elevated temperature as well as a high corrosion resistance in SO_2/SO_3 environment. A ceramic heat exchanger with a strong corrosion resistance has difficulties in the manufacturing and the thermal shock resistance because of its low fracture toughness. KAERI has implemented the ion beam mixing surface modification technology to solve this technical problem. Based upon aforementioned design requirements, a hybrid heat exchanger is designed. The design concept of the developed heat exchanger is introduced in this paper. By using of the temperature profile obtained from the thermal sizing, the local stress fields are calculated to confirm the structural integrity of the heat exchanger. Also, the manufacturing technology of the PHE is briefly described.

2. Design Concept Development

2.1 Shape design

The design requirement of the process heat exchanger is listed as four important items. First, the material of PHE should have enough corrosion resistance and high temperature strength. Second, PHE should withstand the pressure difference between VHTR (Very High Temperature Gas Cooled Reactor) system and hydrogen production system. Third, enough catalyst space should be available in the sulfur-gas side flow channel. Finally, it must be easy to manufacture. In order to satisfy these technical requirements, the hybrid type PHE design was developed [2]. As shown in Fig.1, the flow channel shapes of the He side and the sulfur gas side are different. The He and the sulfur gas flow path have similar shapes to that of the printed circuit type heat exchanger and the plate fin type heat exchanger respectively.

2.2 Ion beam mixing

The SiC coating is known to improve the lifetime and the performance of the metallic substrates when exposed to an aggressive corrosive environment. At the extremely high temperature, the delamination and/or transverse cracking of the coating layer results from the difference between the thermal expansion coefficients of the coating ceramic material and the base metal, thus an additional treatment of the base materials before or after the coating is necessary to maintain the integrity of the corrosion-resistant coated layer. Ion beam mixing technology is applied to develop a highly adherent coated layer and to reinforce the base metal [3]. These two effects reduce the abrupt interface between the film and the substrate effectively so as the film to experience less stresses.

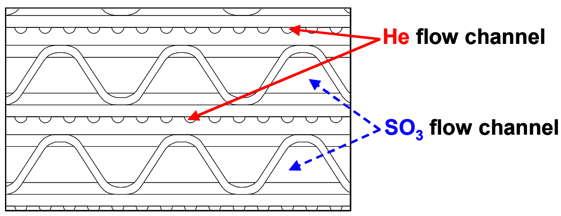

Fig. 1 Flow channel of hybrid PHE

2.3 Thermal Sizing

Based on the developed concept, the thermal sizing of a 10kw PHE is done for the test in the gas loop. The endothermic chemical reaction of the sulfur gas is considered in the heat balance equations of the thermal sizing calculation [4]. The temperature profile along the flow channel is shown in Fig. 2 in which the effect of the catalyst on the temperature distribution is given.

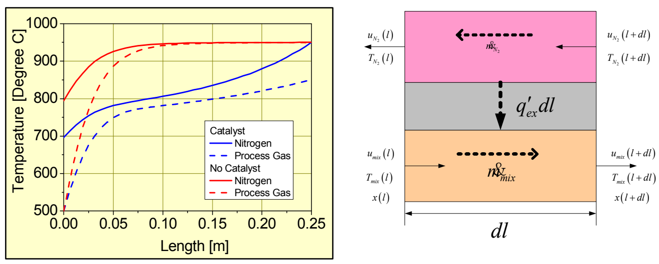

Fig. 2 Temperature profile along the flow channel

3. Stress Analysis

Finite element stress analysis for the PHE is carried out to confirm the structural integrity by using of the temperature profile obtained from thermal sizing. Two-dimensional analysis and three-dimension analysis were done in sequence.

The pressure loadings of the He side and the sulfur gas are 1.1MPa and 0.1MPa respectively. Four different finite element models, in which the number of meshes ranges from 832 to 5306, are studied in order to confirm the validity of the finite element modeling. IDEAS-TMG and ABAQUS are used for the analysis to compare the temperature calculation modeling methods of each codes. The meshing shape and the pressure loading are shown in Fig.3. A cyclic symmetric condition is used to simulate multi channels. The temperature and the Von-Mises stress distribution for a single channel model are given in Fig.4. The maximum stress exceeds 17MPa in the contact edge of the fin. However, the membrane stress is around 6~7MPa.

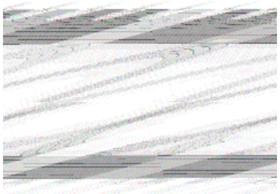

Fig. 3 Finite element meshing

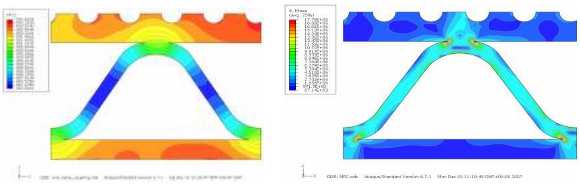

Fig. 4 Temperature and V-M Stress contour

A three-dimension analysis is also performed in order to investigate the temperature profile and the stress distribution along the flow path. The results shows the PHE can withstand the differential pressure up to 2Mpa when the plate temperature reaches 940°C.

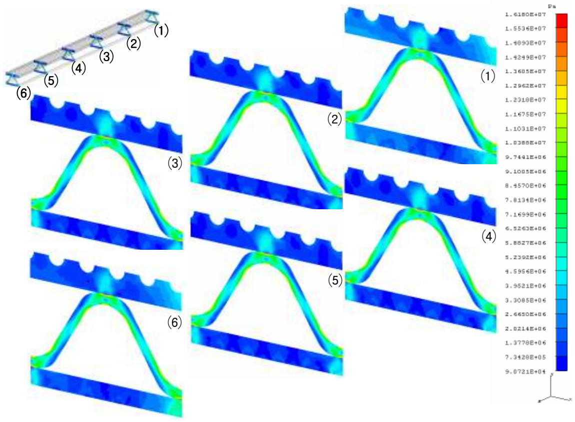

Fig. 5 V-M Stress along the flow path

4. Manufacturing of Test HX

A small heat exchanger is being manufactured in order to test in a high temperature gas loop. The ion beam surface modification is done only for the sulfur gas flow channel. As shown in Fig. 6, diffusion bonding is applied to stack the effective heat transfer region. The flow path of the plate is machined by the milling method instead of the etching process. The manufacturability of metal could be maintained by the ion beam mixing technology with the enhanced corrosion resistance.

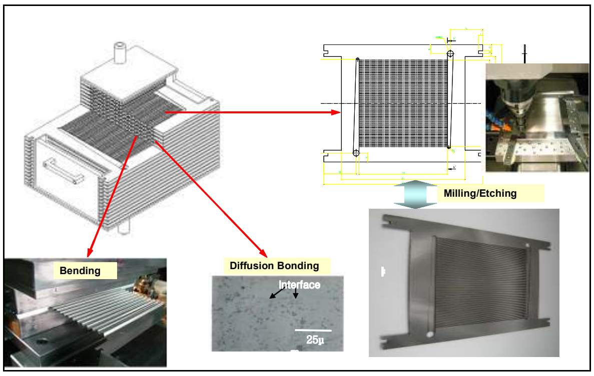

Fig. 6 Manufacturing of PHE for test

4. Conclusion

An innovative high temperature heat exchanger is developed for the coupling PHE between the VHTR system and the hydrogen production system. The hybrid design and the surface modification technology are implemented into the developed HX. It has been shown that the developed PHE can withstand high temperature and pressure difference. As a next step, the mock up PHE will be tested in the gas loop.

ACKNOWLEDGEMENTS

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