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Stress Analysis for Process HX of VHTR Hydrogen Production System

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1. Introduction

To produce hydrogen with the economic efficiency, the coolant outlet temperature of very high temperature gas cooled reactor should be elevated up to 950°C [1]. The process heat exchanger is a sulfuric-acid gas decomposer which shall be used to transfer heat generated from VHTR to the hydrogen production system at the elevated temperature conditions. The heat exchanger is a printed circuit type heat exchanger in which the Ni-based plate is coated with SiC to enhance corrosion resistance [2]. Thermo-mechanical finite element stress analysis was done for the process heat exchanger. The structural integrity of process heat exchanger is evaluated based on ASME procedure [3].

2. Finite Element Modeling

Thermal analysis and stress analysis were done in sequence by using of commercial finite element program ABAQUS [4]. Temperature dependent material properties were used for the thermo-mechanical analysis. It has been assumed that the dimensional change caused by the thermo-mechanical loading does not have an influence on the thermal analysis. The coated region, which has a negligible influence on the overall stress distribution, is not simulated in the finite element model. Process heat exchanger model is shown in Fig. 1 where 1,474,267 nodes and 962,274 elements are used for the thermo-mechanical analysis.

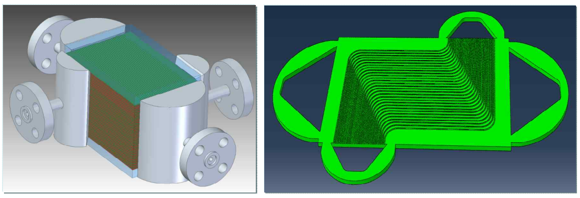

Fig. 1 Process heat exchanger and unit section view.

2.1 Modeling

A single heat transfer unit, which consists of the helium flow channel plate and the sulfuric acid gas flow channel plate, is modeled for the analysis. A single heat transfer channel is divided into 400 sections to input the heat transfer coefficient and the coolant temperature profile. Three dimensional continuum element DC3D10 is used to obtain temperature distribution. Stress analysis is carried out by using of C3D10 continuum solid element.

2.2 Loading and Boundary condition

In order to obtain temperature distribution of heat exchanger, helium temperature and sulfuric acid gas temperature are applied to each flow channels. Temperature profile obtained from thermal analysis and coolant pressure are used for the input of thermal stress analysis. As for the boundary condition of the stress analysis, thickness directional displacements (z-dir.) of all the nodes on the plate top surface are coupled by using of the equation command in ABAQUS. The pressure of helium coolant channel and sulfuric acid gas channel are 2.5Mpa and atmospheric pressure, respectively.

3. Thermo-mechanical Stress Analysis Results

3.1 Thermal Analysis

Temperature distribution along the flow channel obtained from the finite element analysis is shown in Fig. 2. The difference between coolant temperature and solid surface temperature is compared in Fig. 3. Solid temperature of the HX is more close to the helium coolant temperature than that of sulfuric acid gas temperature.

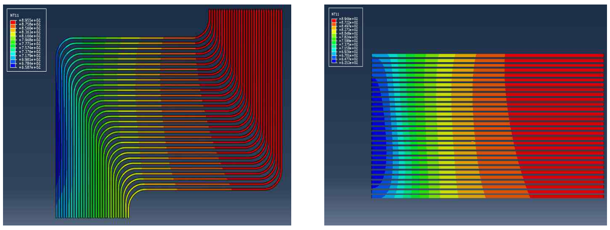

Fig. 2 Flow channel surface temperature distribution.

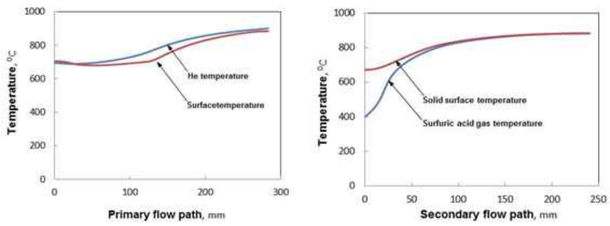

Fig. 3 Temperature difference between coolant and channel surface.

3.2 Stress Analysis

Finite element stress analysis is done for three loading cases separately; pressure loading, thermal loading, thermal and pressure loading. Stress distribution is calculated by applying thermal loading and pressure loading. Von-Mises stress distribution is shown in Fig. 4 along the helium flow path.

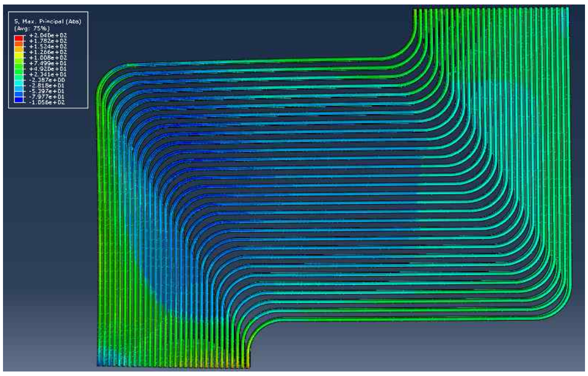

Fig. 4 Von-Mises stress distribution along the He flow path

3.3 Evaluation based on ASME

In order to evaluate structural integrity of the process heat exchanger, stress linearization module of ABAQUS is used. The stress distribution at the ligament between channel 1 and 2 is shown in Fig. 5. By using of stress linearization technique, membrane stress P_m, bending stress P_b, local stress P_L, and thermal stress Q are calculated. The equations (1), (2), and (3) are used to determine whether the aforementioned ASME stress indices and deformation exceed the allowable limit of ASME.

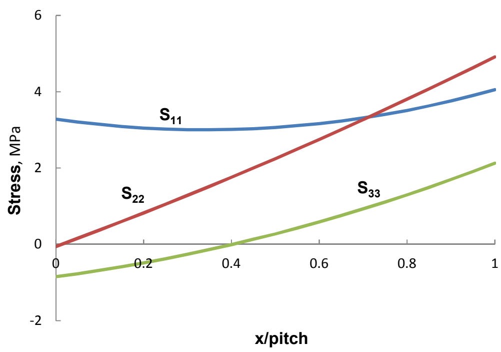

Fig. 5 Stress linearization for helium flow channel

$P_m \leq S_{mt}$ (900℃, 1000hr) (1)

$P_L+P_b \leq K \cdot S_m$ (2)

$K_t=(K+1)/2$

For rectangular cross section K=1.5

$X+Y \leq 1$ (3)

$X=(P_L+P_b)/S_y$(900℃, yield stress), P_m/S_y

$Y=Q/S_y$

ASME stress categories are calculated for all of the channel ligaments and primary and secondary header. Among these points, maximum deformation has occurred at the secondary header inlet which has a large temperature gradient.

Table I ASME stress evaluation for header

	Primary header Outlet	Secondary Header Inlet	Allowable
P_m	0.7 Mpa	0.5 Mpa	20 Mpa
P_L+P_b	2.5 Mpa	2.4 Mpa	160.5 Mpa
P_L+P_b/K_t	2.14 Mpa	2.02MPa	20 MPa
X+Y	0.45	0.84	1

Time dependent failure is not evaluated since time history operation condition of the process heat exchanger is not defined in the current design stage.

4. Conclusions

Stress state of process heat exchanger is evaluated according to ASME procedure. Temperature and stress distribution are calculated from finite element analysis. Membrane stress, bending stress, local stress are much less than the allowable stress but the deformation caused by thermal stress is less than 16% than the allowable limit. Stress state of the process heat exchanger has satisfied ASME criteria.

Acknowledgement

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