Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 17-18, 2018

Safety Ratio Degradation Due to Channel Misalignment in a PCHE

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1. Introduction

High-efficiency compact heat exchangers are being widely developed and becoming increasingly important. The main target of such development is to improve the efficiency, economics, and safety [1]. Safety is an important feature of the PCHE because some critical issues can occur [2, 3]. Safety has a strong relationship with high mechanical integrity and long operating life.

The present study examined the diffusion bonding or manufacturing misalignment problem limit that can be accepted by the construction code for Class A nuclear service. The misalignment phenomena that may occur in PCHE channels were modeled and simulated. A two-dimensional simulation using COMSOL Multiphysics was conducted to observe the effect of channel misalignment in a PCHE. Five different misalignment conditions were modeled to compare the stress intensities.

2. Methods and Results

2.1 Model and Approach

A two-dimensional simulation was conducted to observe the stress intensity distribution on the surface of the proposed channel. A stationary study was performed by using the solid mechanics module in COMSOL. A linear elastic material with an isotropic solid model was chosen.

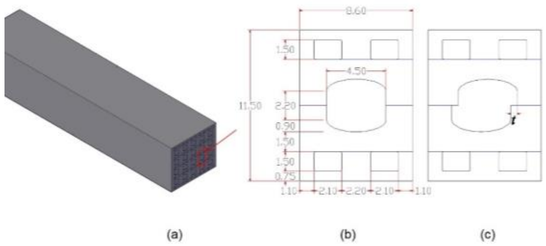

Fig. 1. The schematic illustration of PCHE and observed area which is taken form the surface slice of the PCHE.

Here, a new design for the printed circuit steam generator is proposed. Fig. 1(a) shows a schematic drawing of the geometry, which consists of water and sodium channels. The sodium channel is surrounded by the water channel. The water channel is rectangular with 0.1 mm fillets. The sodium channel is semi-rectangular with an ellipsoidal diameter ratio of 1.8 mm to 4.5 mm. Fig. 1(b) shows the dimensions (in millimeters) to construct of the proposed geometry with a misalignment of 0 mm, i.e., perfectly aligned bonding. Fig. 1(c) shows the bonding line for constructing the stacked layers and the positions of the misalignment value t.

2.2 Boundary Condition

The PCHE is a steam generator and an important component of a sodium-cooled fast reactor. In the steam generator system, a countercurrent flow is formed by the sodium and steam flow. Steam is produced at inlet and outlet temperatures of around 230 and 503.0 °C, respectively, with inlet and outlet pressures of 18 and 16.7 MPa, respectively. Sodium flows at inlet and outlet temperatures of around 528 and 322 °C, respectively, with a pressure of 0.5 MPa [4].

The boundary pressure load was used as the boundary condition. The load-controlled stress limit was analyzed. For comparison to the construction code, only the primary stress produced by a mechanical load was considered. Boundary loads of 18 and 0.5 MPa were applied to the water and sodium channels, respectively.

Table I: Five Simulated misalignment cases (measured as the distance of center to center along x direction)

Case #	Misalignment (t)
Case 1	1 mm
Case 2	0.75 mm
Case 3	0.5 mm
Case 4	0.25 mm
Case 5	0 mm

Symmetry was applied at the horizontal outer sides, and a roller was applied to the vertical outer sides to prevent motion of the rigid body.

2.3 Maximum Stress Intensity

In the five cases, the highest stress was in the tip area of the water channel. This was due to the higher-pressure load on the water channel area. The maximum equivalent surface von Mises stress was as shown in Fig. 5. The highest maximum stress intensity was observed under the misalignment condition of 1 mm, while the lowest intensity was observed under the misalignment condition of 0 mm. This result indicates that the maximum stress distribution increases with the misalignment

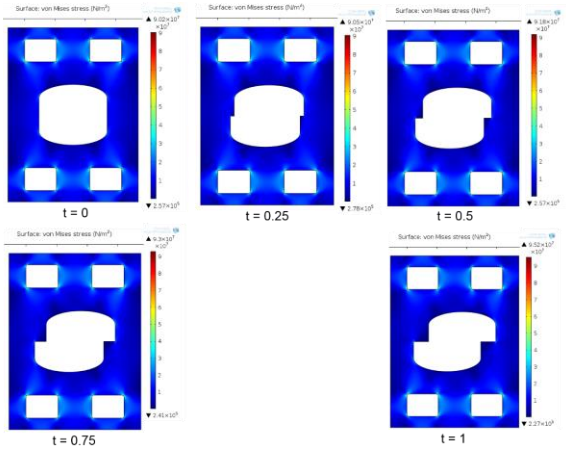

Fig. 2. Stress distribution on each misalignment condition. Stress distribution due to pressure load.

The yield strength or yield stress is a certain stress magnitude at which the material begins to deform plastically. Below the yield stress, the material deforms elastically and returns to its original shape when the applied stress is removed. Once the stress magnitude passes the yield stress, the material deforms permanently, and this cannot be reversed. In this model, stainless steel 316 (SS31600) was set as the material. At a temperature of 550 °C, the yield stress (Sy) of SS31600 is 116 MPa. This indicates that no section in the simulated cases yielded due to the applied pressure load under a working temperature of 550 °C.

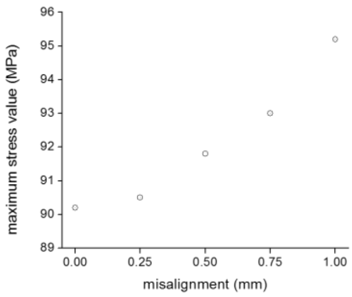

Fig. 3. Maximum stress intensity increases with the increase of channel misalignment

2.4 Factor of Safety Degradation

Even though no section yielded due to the applied pressure load, the factor of safety (FOS) of the proposed geometry decreased with the increasing misalignment of the sodium channel. The FOS is defined as the ratio of the yield stress of the material to the maximum stress caused by the imposed load. The reliability and FOS are equivalent. Thus, the reliability can be studied by using an FOS approach [6]. The FOS can be obtained as follows:

$$FOS = \frac{S_y}{S_{max}} \qquad (1)$$

Increasing the maximum stress can simultaneously decrease the FOS. The maximum stress, which occurred at the tip edge of the water channel, increased in the five simulated cases. This simultaneously decreased the FOS, as shown in Fig. 6. The yield stress (Sy) was determined under a working temperature of 550 °C. Based on the equivalence between the reliability and FOS as described by Ching, the system was most reliable under the misalignment condition of t = 0 mm.

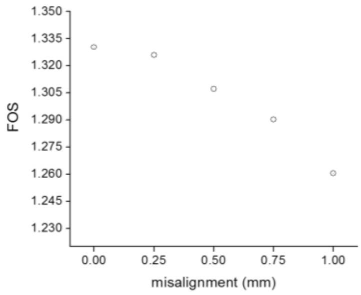

Fig. 4. factor of safety decreases with the increase of channel misalignment

3. Conclusions

In this study, two-dimensional FEM simulations were performed to examine the effect of channel misalignment in the PCHE under five different misalignment conditions.

- The highest stress intensity was located at the tip edge of the water channel because for the higher-pressure intensity compared to that on the sodium channel.
- The stress intensity increased with the misalignment in the five cases. The highest stress intensity, stress point evaluation, and line stress evaluation showed that the stress magnitude increased with the channel misalignment. The increased stress magnitude decreased the reliability of the structure, which is equivalent to the FOS.

Acknowledgement

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIP) (No. 2017M2A8A4018624).

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