Simulation Study on Stress Analysis of Double-etched Type Printed Circuit Heat Exchanger

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1. Introduction

Heat Exchanger is one of important components in a nuclear reactor. A high temperature operating environment gives a very critical rule of a heat exchanger. The newest heat exchanger type is printed circuit heat Exchanger (PCHE) which has been coming up with a promising because its ability to withstand several advantages such as large area density, pressure, and temperature capability. *(Asadi et al., 2014; Minghui et al., 2016)* High-efficiency compact heat exchanger is needed and widely developed as an important issue these days. The target of this efficiency is for economically improvement and safety increase. In this case a high thermal hydraulic performance should be supported by high mechanical integrity to ensure the target of efficiency.

Some research has been conducted to enhance the high thermal hydraulic performance *(Sang et al., 2013)* conducted a study to assess the optimal shape and to enhance the thermal and hydraulic performance by considering the ratios of the fillet radius, wavelength, and wave height to the hydraulic diameter of the channels. According to some previous study, *(Youho Lee et al., 2014)* the stress concentration occurs in the sharp corner's region of traditional one-sided etched PCHE plate. In order to deal with the stress problem, a new double-sided etched PCHE with an additional elliptical channel is proposed to reduce the stress concentration.

The main purpose of this study is to propose a new design which is called as double-side etched heat exchanger which has additional elliptical upper channel. The radius of additional elliptical channel is employed as the design variable. It will vary from 0 mm, 0.234 mm, 0.33 mm, 0.512 mm and 0.6 mm. Finite Element Method (FEM) with COMSOL Multiphysics is applied to observe the effect of additional channel radius to the stress distribution along the surface of heat exchanger unit.

2. Methods and Results

2.1 Model and Approach

The double-etched channel heat exchanger consists of two main channels. An additional elliptical channel will be added to a half-circle common channel as shown in Fig. 1. Fabrication process will be done by using two times chemical etching method.

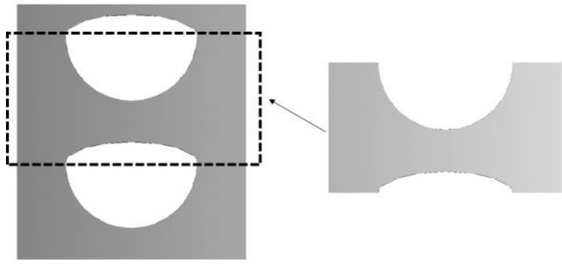


Fig. 1 Channel configuration of Double-side Etched PCHE.

First etching will form the half circle channel while the second etching will form the smaller additional elliptical channel. All the formed plate will be stacked into one compact plate heat exchanger as shown in Fig.2.

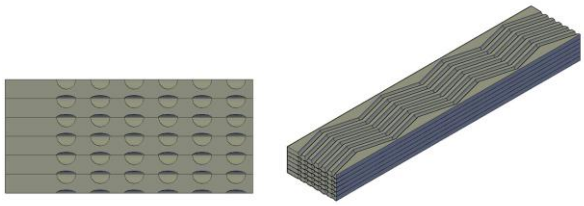


Fig. 2 Stacked layers of PCHE

2.2 Boundary Condition

Finite Element Method is used to observe the effects of the elliptical channel diameter factor to the stress distribution along the geometry. To conduct this study, a certain geometry is chosen. A half circle channel with 0.755 mm of radius will be supported by an additional upper elliptical channel. The variables of elliptical channel radius vary from 0 mm, 0.234 mm, 0.33 mm, 0.512 mm and 0.6 mm. Heat exchanger has cold and hot channel. Cold channel will be flown by 20 MPa of pressure and 503 °C while the hot channel will have 0.5 MPa and 528.5 °C of temperature. These pressure conditions are applied to the finite element method. COMSOL Multiphysics is utilized for simulation. A stress distribution and displacement result will be plotted. The result will be compared to the yield strength of material to find the safety factor enhancement of proposed geometry.

In simulation, material properties of stainless steel 316 is employed with plasticity behavior simulation. The plasticity was modeled by taking into account the non-linear plastic behavior which was plotted by considering study conducted by Hayhurst et al.

(2003). The plastic stress-strain behavior of SS316 at 550°C was obtained by using the power-law plasticity model as shown in fig. 3.

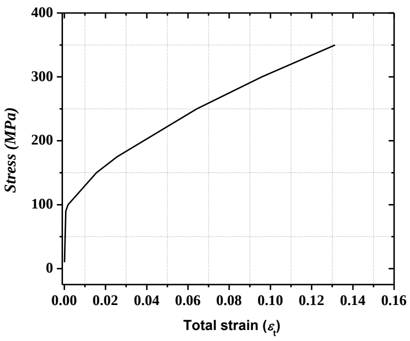


Fig. 3 Stress-strain graph for SS316 material under temperature of 550 °C

Two stipulations were added into account. The first is "fixed H/W" model. This model is considered for the restriction of height and width of completed assembled heat exchanger. In this stipulation, the pitch dimension decreases with the increment of elliptical shape factor d.

Another stipulation is "fixed pitch (p)". This stipulation causes a bigger design of heat exchanger. The pitch is consistently maintained with the increment of the elliptical shape factor d. In this simulation the pitch dimension is 0.705 mm.

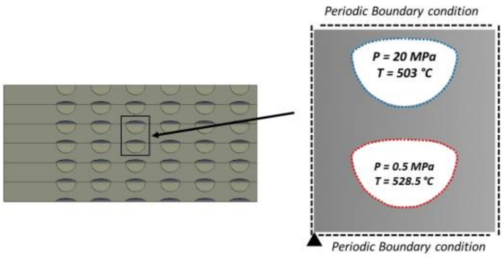
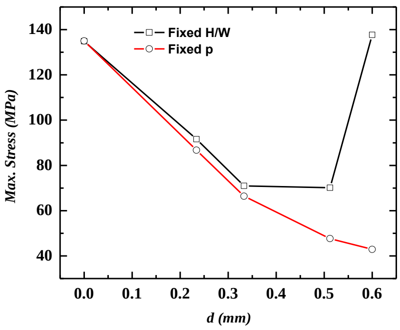


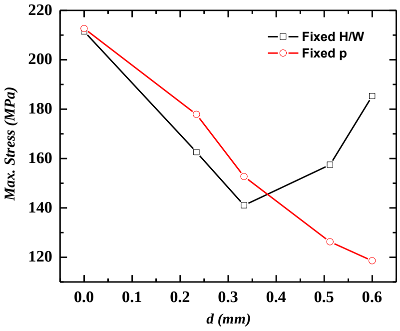
Fig. 4 Applied Pressure and temperature Boundary Condition

2.3 Result

A FEM simulation is conducted to observe the effect of additional elliptical radius to the stress distribution at the stacked cold and hot channels. 20 MPa boundary pressure is applied to the cold channel and 0.5 MPa is applied to the hot channel. Outer side of simulated geometry is simulated as periodic boundary condition.



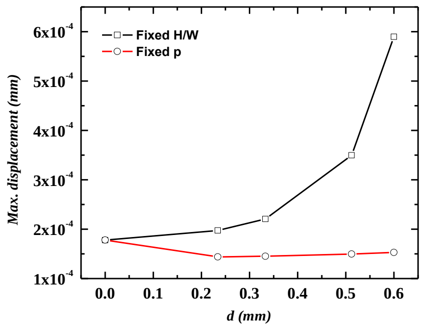
(a)



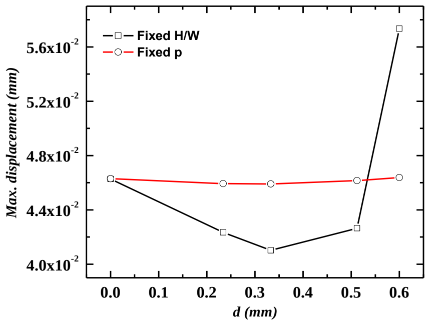
(b)

Fig. 5 Effect of additional ellipse surface to the stress intensity **(a)** Stress Intensity under pressure load only **(b)** Stress intensity under pressure and thermal load

In the fixed p stipulation, the maximum stress intensity is 213 MPa at the d = 0 mm which is located at the tip area of the channel. A high stress can be observed at the area between cold and hot channel. At d = 0.234 mm, the maximum stress intensity is 178 MPa. It is 16% less than the condition without additional elliptical channel. The stress distribution pattern between cold and hot channel is almost similar to d= 0 mm condition. It shows a higher stress intensity at that area. At d = 0.333 mm radius condition, the maximum stress intensity is 153 MPa which is 14% less than the condition of 0.234 mm. Simulation also resulted 126 MPa and 119 MPa of maximum stress for condition of d=0.512 and d=0.6 mm respectively. Maximum stress intensity decreases with the increase of elliptical shape factor d which is shown in fig.5.



(a)



(b)

Fig. 6 Effect of additional ellipse surface to the total displacement **(a)** Total displacement under pressure load only **(b)** Total displacement under pressure and thermal load

The factor of safety (FOS) of the proposed geometry can be 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, it can be studied by using a FOS approach (*Jianye C., 2009*). By observing the stress intensity resulted by FEM simulation, safety factor can be seen by using equation:

$$S_f = \frac{y_s}{\sigma_{\max}}$$

3. Conclusions

Stress analysis has been conducted for double-faced printed circuit heat exchanger. This study is conducted by using FEM simulation with COMSOL Multiphysics software. The stress concentration at the tip area of half circular channel can be reduced by adding the elliptical etched channel. The stress intensity reduces with the increase of elliptical shape factor. To be concluded, the fixed p stipulation is the nearly realistic one for the design. In this case, elliptical shape factor can reduce the stress intensity around 40% lower compared to the condition without addition of elliptical shape. The displacement value of fixed pitch stipulation is also shown under consistent value.

Acknowledgement

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