Mechanical Design for Key Dimensions of Printed Circuit Heat Exchanger

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1. Introduction

The plate type heat exchanger with electrochemical etched channels is called PCHE (printed circuit heat exchanger). The heat transfer plates are assembled using the diffusion bonding technology to make a module. PCHE is widely used for industrial applications because of its compactness, cost efficiency, and serviceability at the high pressure and/or temperature condition. However, one of significant technical tradeoffs of the PCHE is the difficulty in in-service inspections including even pre-service inspections. Several modules are used for the large PCHE type heat exchangers because the maximum size of single PCHE is limited by the capability of the diffusion bonding equipment having compressive press. Rules for design and fabrication of PCHE are specified in ASME Section VIII [1] but not in ASME Section III of nuclear components.

In this study, mechanical design procedure of PCHE has been studied on the basis of ASME section VIII. The calculation procedure of mechanical design was established and programmed for the easy use in the PCHE design [2]. The effect of assumptions used for the key dimension calculation on the stress value is investigated.

2. Key Dimension Calculation

The flow channel of PCHE is a semi-circular shape. Semi-circular flow channels are assumed to be a rectangular cross section in the formula based dimension calculation as shown in Fig. 1. The effective heat transfer region of PCHE is defined by several key dimensions such as flow channel radius R, edge width t_1, wall thickness t_2, and ridge width t_3. The radius of flow channel is mainly influenced by thermo-hydraulic performance and other parameters are dominated by the strength criteria and the manufacturability.

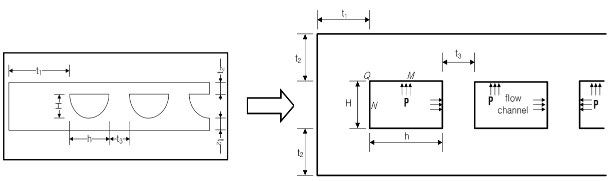


Fig. 1 Assumption of flow channel shape for key dimensions determination.

According to ASME section VIII, the membrane stress across the thickness S_m should be less than allowable stress of ASME Section II Part D [3]. Also, total stress S_T should be less than 150% of allowable stress. The joint efficiency of diffusion bonding is 0.7 along the diffusion bonded direction. The membrane stress and the total stress across thickness t_1 are expressed as equation (1), (2), and (3).

$$S_m = \frac{Ph}{2t_1}\left\{3-\left[\frac{6+K(11-\alpha^2)}{3+5K}\right]\right\} \quad (1)$$

$$(S_T)_N = \frac{Ph}{2t_1}\left\{3-\left[\frac{6+K(11-\alpha^2)}{3+5K}\right]\right\}+\frac{Pc}{24I_1}\left[-3H^2+2h^2\left(\frac{3+5\alpha^2K}{3+5K}\right)\right] \quad (2)$$

$$(S_T)_Q = \frac{Ph}{2t_1}\left\{3-\left[\frac{6+K(11-\alpha^2)}{3+5K}\right]\right\}+\frac{Ph^2c}{12I_1}\left(\frac{3+5\alpha^2K}{3+5K}\right) \quad (3)$$

Where P, I, c, α, and K are design pressure, moment of inertia, distance from neutral axis, rectangular vessel parameter, and vessel parameter, respectively. Similar equations shall be used for the determination of the wall thickness t_2 and ridge width t_3 [2]. It is a straight forward to check whether the designed key dimensions satisfy the strength criteria or not. However, six coupled nonlinear equations should be solved to obtain minimum t_1, t_2 dimensions for a given material strength. A program has been developed to solve these nonlinear equations. This procedure is also used for determination of key dimensions of built-in header and external header with different equations.

3. Comparative Studies

3.1 Effect of shape assumptions on stress values

Stress values of flow channels with semi-circular cross section have been compared with those of flow channels with rectangular cross section as shown in Fig.2. Stress analysis was done by using of commercial finite element analysis program ABAQUS [4].

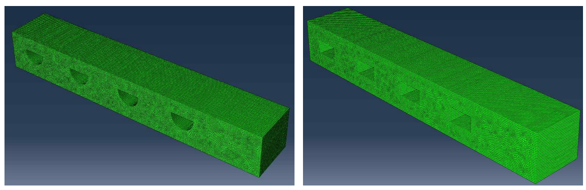


Fig. 2 Finite element models of semi-circular cross section and rectangular cross section.

Stress category has been defined as shown in Fig. 3. Stress values normalized by the internal pressure do not have much difference as shown in Fig. 4. The stress contour of semi-circular cross sectional flow channels are compared with that of rectangular cross sectional flow channels in Fig. 5.

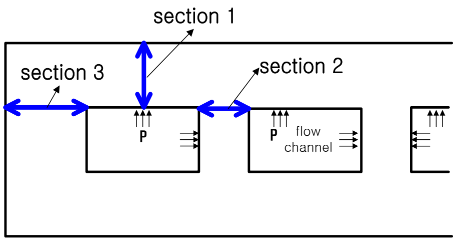
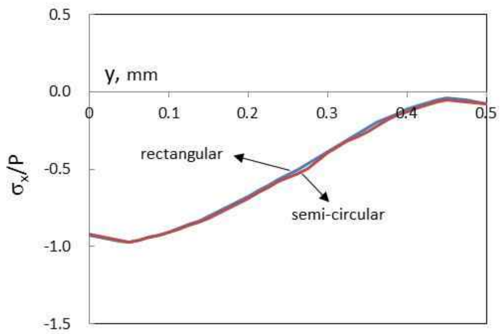
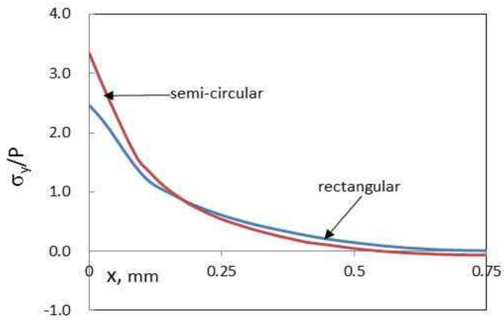


Fig. 3 Section definition to classify ASME stress category.



(a) Section 1



(b) Section 3

Fig. 4 Stress distribution of semi-circular and rectangular cross section flow channels

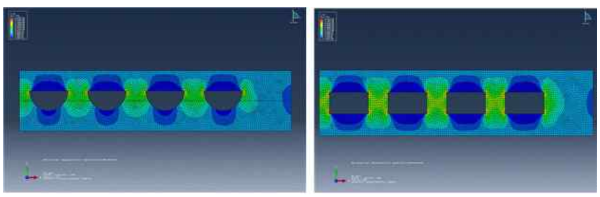


Fig. 5 Thickness direction stress (σ_y) contour of semi-circular and rectangular cross section flow channels

3.2 Effect of $t_1 \gg t_2$ assumption on stress values

The assumption that t_2 is much smaller than t_1 is often used to determine key dimensions to avoid the complex iterative calculations of coupled equations [5]. A comparative calculation has been done to investigate the effect of this assumption. If t_2 becomes much smaller than t_1, K can be assumed zero. Equations (1), (2), (3), and other equations related to determine key dimensions became simple explicit equations of t_1 and t_2. Total stress at location M and Q with K=0 assumption are compared with those without assumption in Fig. 6. If t_1/t_2 is larger than 5, K=0 assumption can be used without much error.

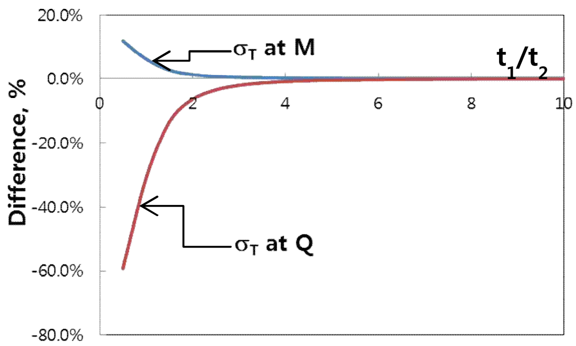


Fig. 6 Effect of K=0 assumption on total stress values

4. Conclusions

Key dimension determination procedure for effective heat transfer zone has been presented based on ASME section VIII. The calculation procedure is programmed in order to use for the design of flow channels and headers. The cross section of flow channel can be assumed to have rectangular shape in the formula based dimension calculation since the finite element analysis does not show much difference between ASME stress category values of semi-circular cross section and rectangular cross section. The simplified equations that t_2 is much smaller than t_1 can be used with negligible error when t_1/t_2 is larger than 5.

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