Comparison of FEA Responses between Brick and Tetrahedron Elements of Mini Heat Exchanger for Generation IV Reactors Subjected to Pressure and Thermal Loads

Bong Yoo, Man-Sik Myung, Yun-Jae Kim,
Mechanical Engineering Department, Korea University, Anam-dong, Sungbuk-ku, Seoul 136-701, Korea,
byoo3@korea.ac.kr

1. Introduction

In the development of a power conversion system using S-CO_2 Brayton Cycle for Generation IV Reactor Systems, like Liquid Metal-Cooled Fast Reactors[1], various types of mini heat exchangers(MHE) have been considered as a promising candidate for the advantages in compact size and economic benefits over a conventional shell-tube type[2,3]. One of the mini heat exchangers, the Printed Circuit Heat Exchanger (PCHE) is whether this concept can be applicable to nuclear systems. Some structural evaluations for the mini heat exchangers were attempted to investigate the structural integrity and function[4,5].

The objective of this paper is to compare the stress results between three dimensional brick element and tetrahedron element model of the mini heat exchanger in the HTR (High Temperature Recuperator) with the normal operation condition of the S-CO2 Brayton cycle. Numerical models of the heat exchanger for Lead Fast Reactors have been developed for analysis with the ABAQUS finite element code. Stress analyses for the simple analytical models of the heat exchanger subjected to pressure and thermal loads are performed using the heat exchanger design parameters.

2. Analytical Modeling of S-CO_2 Heat Exchanger

Under normal operation of the S-CO_2 Brayton cycle, the design pressures for the hot and the cold channels of the HTR are 7.463 and 19.99 MPa, respectively. The design temperatures for inlet and outlet of hot channel are 435.8 C and 186.8 C, respectively, and those for inlet and outlet of cold channel are 180.6 C and 402.1 C, respectively. The average heat transfer coefficients in the hot channels and cold channels are 0.548 Kw/m2-K and 0.629 Kw/m2-K, respectively. The dimension for the hot and cold channels were determined to be the same size, which was 1.0 mm diameter with 1.3 mm pitch to diameter with semi circular cylinder shape.

The simplified numerical models using both three dimensional brick element and tetrahedron element for the heat exchanger for Lead Fast Reactors have been studied using ABAQUS version 6.4.

To obtain solutions the size of the finite element model had to be further reduced down to a mesh that had 2 layers of 5 passageways in a side and 1 layer of either 4 passageways in the other side. The remainder of the layers was considered to be solid material. The number of the elements and nodes modeled are 40,160 and 48,849 for brick element, 66,894 and 99,912 for tetrahedron element, respectively, as shown in Fig.1.

The loadings applied to the heat exchanger are the pressures in the passageways and the temperature distribution in the model. In modeling, material properties of the heat exchanger are shown in Table 1. The structural boundary conditions applied to the models at the level of the operating floor considers one corner to be fully constrained from translations (i.e., no motion in the horizontal x, vertical y or horizontal z directions), one corner constrained from motion in the y- and z-directions, one corner constrained in the x- and y-direction and one corner constrained in the y-direction.

3. Analyses Results and Discussion

Structural analyses of the models subjected to different pressures and temperatures at hot and cold channels respectively were performed. The temperature distribution due to thermal loading and a cutoff view are shown in Figure 2. The stress contours for each model due to pressure and thermal loads are shown in Figure 3, and those due to combined loads in Figure 4.

The calculated maximum stresses for the tetrahedron and brick models are 164.2 and 86.94MPa, due to pressure loads, and 229.9 and 136.7MPa due to thermal loads, and 271.5, 162.8MPa due to combined loads, respectively as given in Table 2. With the ASME Section VIII, Division 1 design, the calculated maximum stresses for the both models subjected to pressure and thermal combined loads are within the maximum allowable stress of 330 MPa for SS316.

4. Conclusion

With the limited computational models of the mini heat exchanger, the following conclusions are drawn:

- The stresses calculated by the brick element model with fine mesh can reduce the stress peaks calculated by the tetrahedron element model resulting in much less stress.
- The calculated maximum stresses induced by the combined pressure and thermal loads are well within the ASME Section VIII, Division 1 allowable stress for the 5x4 model.

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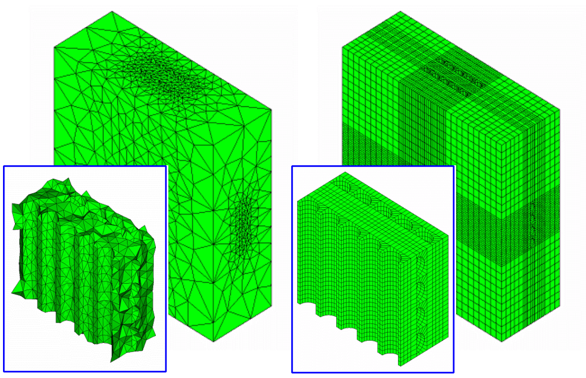
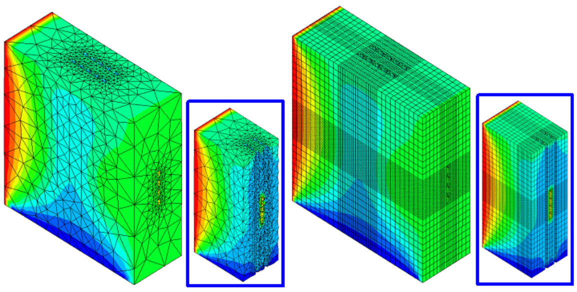
Table 1 Material Properties of SS316

Temp (C/F)	Thermal conductivity (W/mmC)	Modulus of elasticity (KPa)	Thermal expansion (mm/mm/C)
21.1/70	14.93E-3	195.13E6	15.30E-6
93.3/200		190.30E6	16.74E-6
178/350	17.47E-3	184.44E6	18.00E-6
301.7/575	19.37E-3	175.34E6	19.17E-6
426.7/800	21.10E-3	166.17E6	19.98E-6



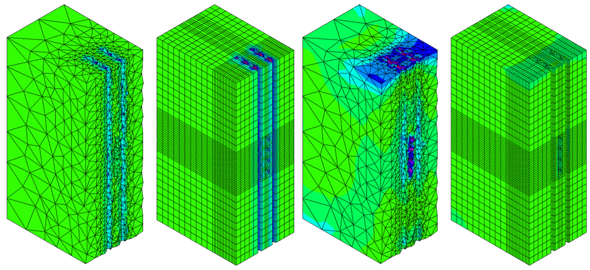
(a) Tetrahedron element (b) Brick element

Fig. 1 Finite element mesh for mini-heat exchanger



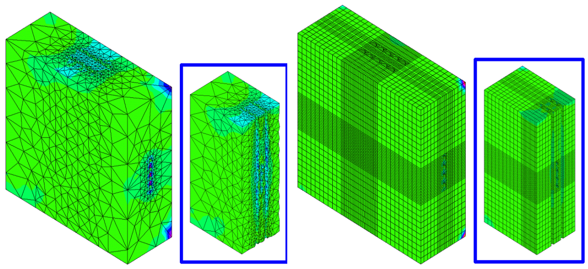
(a) Tetrahedron element (b) Brick element

Fig. 2 Contour of thermal Analysis



(a) Stress by pressure load (b) Stress by thermal loads

Fig. 3 Contour of stress analysis



(a) Tetrahedron element (b) Brick element

Fig. 4 Contour of combined stress analysis

Table 2 Stress results of element type & load type

Element Type	Load Type	Maximum Stress [*MPa*]
Tetrahedron Element	Pressure	164.2
	Thermal	229.9
	Combined	271.5
Brick Element	Pressure	86.94
	Thermal	136.7
	Combined	162.8

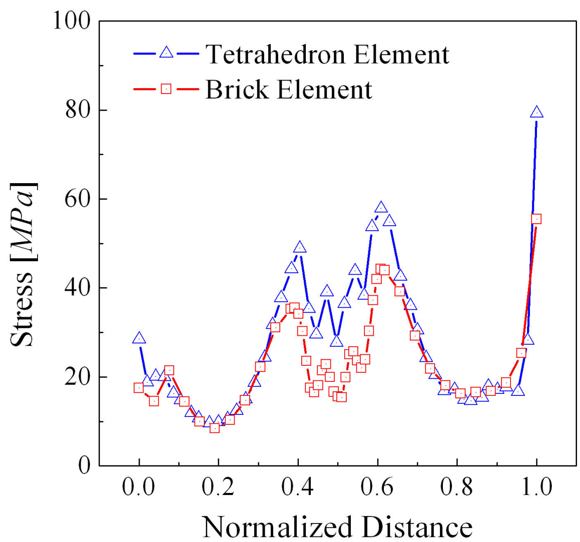


Fig. 5 Stress distribution along the hot channel