Analysis and Optimization of Bending Performance of Mental Heat Exchanger Plate Structure

Minghan Duan, Yihao Fu, Kui Wang, Mingxing Chu, Meng Chang

Department of Engineering Mechanics, School of Civil Engineering and Architecture, Henan University of Science and Technology, Luoyang 471023, China

Abstract

As a common production equipment of energy enterprises, the heat dissipation capacity of the plate heat exchanger should not only be considered in the process of its use, but also the bearing performance of the structure is very important for the unobstructed gas flow channel. Taking a plate metal heat exchanger as the research object, the bending bearing capacity of the heat exchanger is studied by numerical analysis. Firstly, a four-point bending model of structural analysis was established based on ABAQUS software, and the influence of several different support strips on its bending performance was analyzed. On this basis, the optimal design of the structure with the least deformation was carried out, and the plate heat exchanger with better bending performance was obtained. The research results provide references for the design of such structure.

Keywords

Metal Heat Exchanger Plate; Support Strips; Bending Bearing Capacity; ABAQUS; Numerical Simulation.

1. Introduction

In modern engineering structure, heat exchanger is a very important machine equipment, which has great application in the field of food, medicine, agriculture, petroleum, light industry, electric power, machinery manufacturing, energy industry, smelting metal and many other engineering technology fields. Accidents caused by the damage of heat exchanger plate also occur frequently, causing huge economic losses and casualties, and the safe operation of machinery and equipment has been paid more and more attention. As a new type of heat exchanger structure, the heat dissipation capacity of metal plate heat exchanger should not only be paid attention, but also the structural bearing performance can not be ignored. If the bearing capacity is weak, it is easy to make the deformation of the heat exchange plate sheet too large, affecting the unobstructed gas flow channel. Therefore, it is very important to study the bearing capacity of sheet metal structure to ensure the normal operation of plate heat exchanger.

The metal plate heat exchanger structure can be regarded as a typical sandwich plate structure, and scholars at home and abroad have paid extensive attention to the study of the load-bearing performance of such structures. A metal dot matrix material studied by Zeng[1] and others can be understood that this material not only has a periodic structure but also has a high porosity, which is a relatively advanced material. Li[2] studied a cross-shaped lightweight dot matrix sandwich structure, which has many excellent features and has been applied in a large number of fields related to aircraft and rockets, transportation, manufacturing and mining. Duan[3] designed a normal temperature in-plane shear test for FRP honeycomb sandwich conformal load bearing antenna structure, using sandwich panel theory and separated solid modeling method, established its finite element model with ABAQUS to match the test, and defined the honeycomb core failure criterion using USDFLD. The simulation method can accurately simulate the stiffness and strength of the structure, thus verifying the adaptability of such structures under in-plane shear loading. Wen[4] designed a lightweight octahedral sandwich structure based on a one-system multifunctional concept, and studied the structure through experiments and finite element software simulations. Ge[5] redesigned a connection method of lightweight composite dotted sandwich panel and verified its mechanical properties. Fan[6] et.al made a very detailed analysis of the load-bearing properties of three-dimensional octagonal dot matrix as well as sandwich dot matrix materials. Zhang[7] et al. analyzed the flat compression and shear properties of pyramidal dot matrix structures by establishing them with finite element software. Lin[8] introduced the current status of research on the impact resistance of several sandwich structures mainly applied in aerospace, which provides reference for the design and research on the impact resistance of aerospace sandwich structures. Qin[9] established a simplified model for strength analysis of single-layer plate-bubble structure in the study of plate-bubble heat exchanger plates, and applied the finite element numerical simulation method to verify the analysis of this model. Zhao[10] studied the effect of the size of the outer plate reinforcement pavement on the mechanical behavior and load-bearing capacity of the honeycomb sandwich structure, based on experiments, combined with theoretical analysis and finite element simulation results. Han[11] studied the impact resistance of honeycomb sandwich structures and analyzed the effects of impact energy, punch shape and punch diameter on the failure mode, damage characteristics, load carrying capacity and energy absorption of honeycomb sandwich structures.

In this paper, a model of metal plate heat exchanger was studied. Firstly, a four-point bending model was established for the structural analysis of the heat exchanger plate based on ABAQUS software. The influence on the bending performance was analyzed for four types of support strips, namely square tube, T-type, I-type and Ω-type. Then the cross-sectional properties of the support strips of the plate structure are used as the structural optimization parameters to obtain the optimal design of the heat exchanger plate sheet structure, under the condition of meeting the structural load-bearing performance requirements. The results of the study provide a reference for the design of such structures.

2. Modeling of Bending Analysis

The analysis model is designed with 1000mm long and 200mm wide (as shown in figure 1), and the board thickness is 0.8mm. This paper studies and analyzes the bending deformation performance of the metal heat transfer plate when the support strip with four different cross-sectional shapes, while keeping the structural quality unchanged, that is, the cross-sectional area of the support strip is the same.

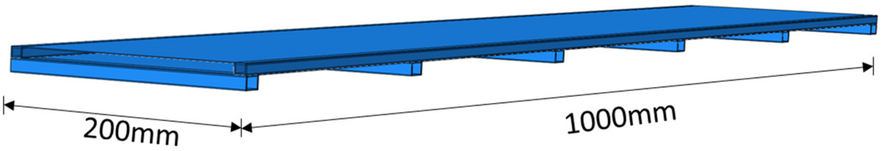
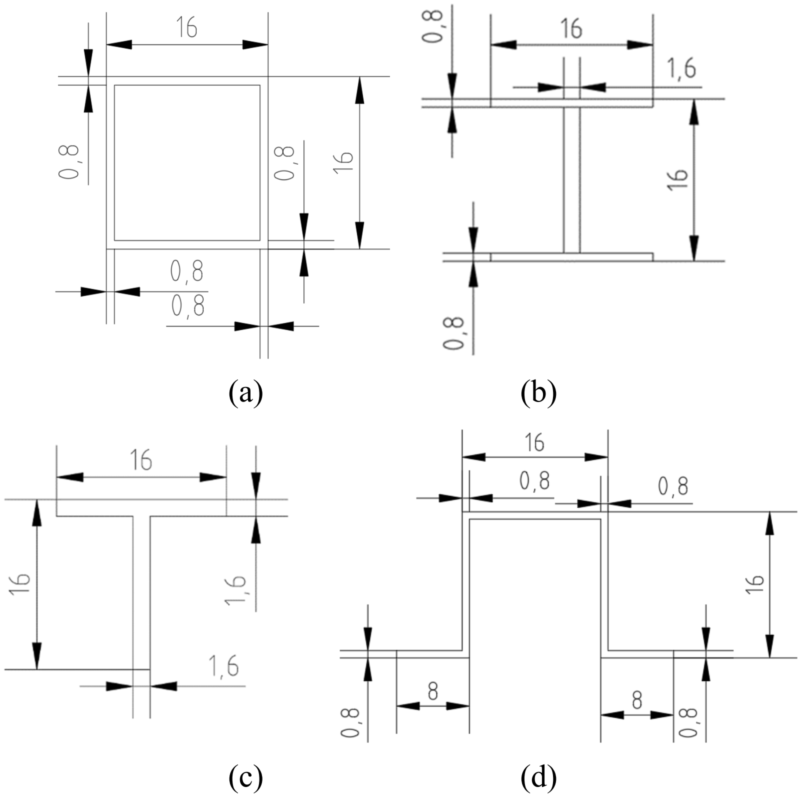


Figure 1. Analysis model of the metal plate heat exchanger

The cross-sectional shapes of each support strip are square tube, T-type, I-type and Ω-type, as shown in figure 2 respectively, and their cross-section parameters are also shown in the figure.

The standard four-point bending method for measuring the bending properties of non-enhanced and reinforced plastics and electrical insulation materials is used in reference [12]. In this paper, the same approach is used, and the four-point bending analysis model of the metal heat exchanger plate is established, as shown in the figure 3. In the figure 3, the cylindrical bottom surface is a circle with a radius of 40mm, a height of 200mm, and the loading plate is 300mm*200mm*0.8mm. Regarding the central axis symmetry of the model, the distance between the central axis of the upper two cylinders is 300mm, and the distance between the central axis of the lower two cylinders is 900mm.



(a) (b)

(c) (d)

Figure 2. Cross-sectional shapes of support strips (unit: mm)

(a) square tube, (b) T-type, (c)I-type, (d) Ω-type

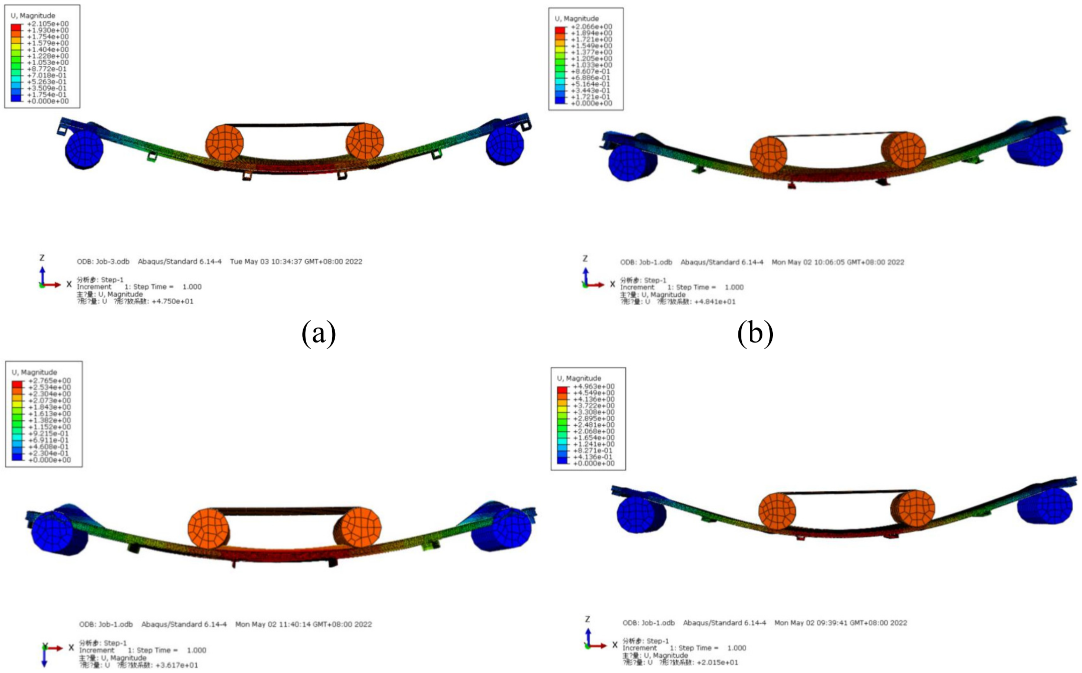
Figure 3. Four-point bending analysis model of the metal heat exchanger plate

3. Heat Exchanger Plate Bending Performance Analysis

The material of the structure during the analysis is Q235 steel, whose material properties are elastic modulus E=210GPa, and the Poisson ratio is ν=0.3. Each model is assembled up and down, and the interaction and constraints are set to make the assembly a related whole. A distributed load of 0.01MPa is applied on the surface of the structure to calculate the bending deformation of the metal heat exchange plate. The deformation of the heat exchange plate structure under different support strips are shown in Figure 4.

By comparing the displacement cloud diagram of the metal heat exchange plate of each section, it can be found that the displacement in the middle is the largest. From the figure, it can be seen that the maximum displacement of the metal heat exchange plate with different support strips is 2.105mm, 2.066mm, 4.963mm and 2.765mm under the load of 0.01MPa.

Among them, the displacement deformation of the metal heat transfer plate of the T-shaped and Ω-type support strips are not the smallest, but also the depression of the metal plate are found through the deformation diagram, which has the greatest impact on the performance of the metal plate. Howevere, the maximum deformation of the metal heat exchange plate of the I-shaped support strip is 2.066mm, and the depression of the metal heat exchange plate is not obvious. The maximum deformation of the metal heat exchange plate of the square tube is 2.105mm, which is close to the I-shaped deformation. Therefore, in order to get better performance, it is necessary to change the cross-section size of the square tube and I-shaped support strip for the metal heat exchange plate and compare them to find the optimal design.



(a) (b)

(c) (d)

Figure 4. Deformation of the heat exchange plate structure (unit: mm)
(a) square tube, (b) T-type, (c)I-type, (d) Ω-type

4. Heat Exchanger Plate Optimization Design

4.1 Optimization of Metal Heat Exchanger Plates with Square Tube Cross-section

Under the condition that the cross-sectional area remains unchanged, it is found that the height of the cross-section has a greater influence on the displacement after changing its height to width ratio several times.

For example, the cross-sectional size of the long support bar is 12mm*6.8mm, the thickness of the long side is 0.8mm, the thickness of the short side is 1.6mm, and the rest of the conditions remain unchanged, the displacement cloud can be obtained by loading in the original way, as shown in figure 5. The maximum displacement of the metal heat exchanger plate with the square tube support is 5.569mm in the middle, the deformation of the metal heat exchanger plate is not reduced but increased when the height of the cross section is reduced. Therefore, it is necessary to maintain the same height while appropriately increasing the thickness of the upper and lower sides of the section.

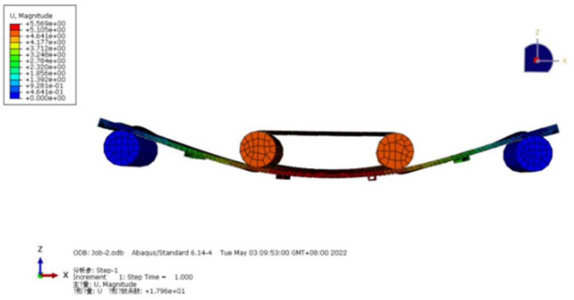


Figure 5. Deformation of the square tube supported plate with low height

After several parameter optimization, it is found that when the cross-sectional size of the support strip is b=8mm, a=17.6mm, t=0.8mm, r=1.6mm, as shown in figure 6. The maximum displacement of the metal heat exchanger plate is 1.787 mm in the middle (shown in figure 7), and the deformation of the metal heat exchanger plate is much reduced and the cross-sectional size of structure is optimal.

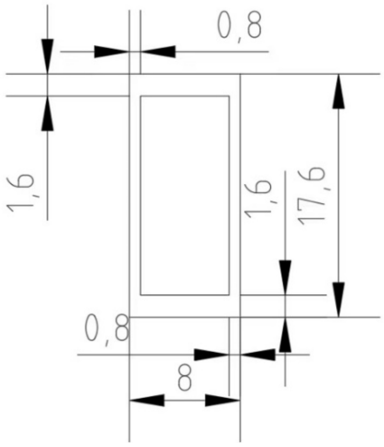


Figure 6. The optimal section size parameters of the square tube support

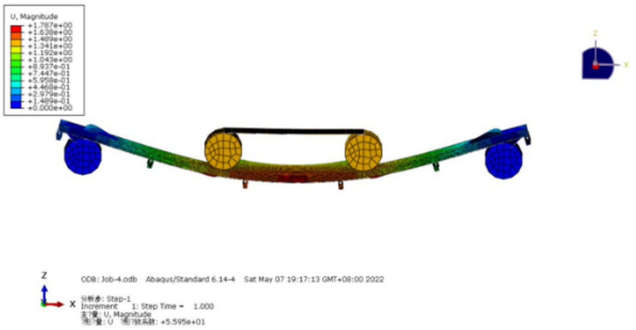


Figure 7. The optimal displacement of the metal heat exchanger plate with square tube

4.2 Optimization of Metal Heat Exchanger Plates with I-shape Cross-section

In the case of ensuring the cross-sectional area remains unchanged, the cross sectional dimensions of the I-shape support cross-section are optimized several times to obtain a cross-section that minimizes the deformation of the metal heat exchanger plate. The cross-sectional dimensions are shown in figure 8, the cross section data of the support strip is t=2mm, b=0.8mm, h=9.28mm, L=18.4mm.

The displacement of the metal heat exchanger plate is shown in figure 9. In the displacement figure, it can be observed that the maximum deformation of the metal heat exchanger plate is 1.434 mm in the middle when the load is 0.01 MPa, the deformation of the metal heat exchanger plate of this structure is the smallest.

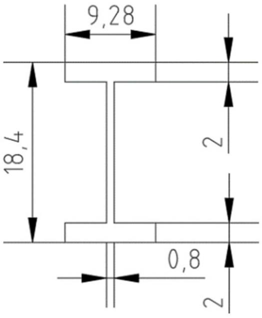


Figure 8. The optimal section size parameters of the I-shape support

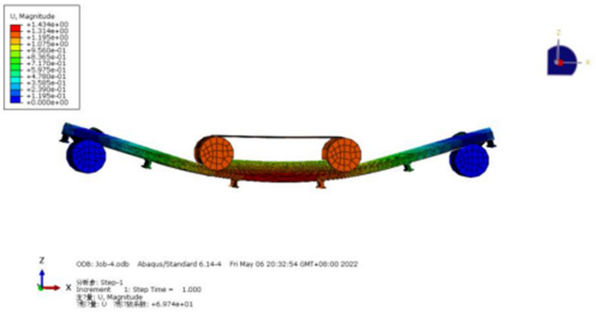


Figure 9. The optimal displacement of the metal heat exchanger plate with I-shape

5. Conclusion

In this paper, the bending performance of the plate metal heat exchanger is analyzed and optimized. The computational models of four different cross-sectional support bar metal heat exchanger plate models are established to numerically analyze the deformation of four-point bending of different cross-sectional support bar metal heat exchanger plates. Through comparative analysis, it was found that:

(1) The deformation of the heat exchanger plate is relatively small when the cross section of the support bar is mouth-shaped and T-shaped, which can meet the performance requirements of the heat exchanger plate.

(2) By optimizing the design of the metal heat exchanger plate with the support bar of the mouth-shaped and T-shaped cross-section, it is found that the metal heat exchanger plate with the support bar of T-shaped cross-section has the best deformation resistance under the condition of meeting the load-bearing capacity.

Acknowledgments

This research was supported by Innovation and Entrepreneurship Training Program for University Students of Henan Province (202210464022), Student Research Training Program of Henan University of Science and Technology (2022149).

References

[1] Zeng Song, Zhu R, Jiang W, et al. Research progress of metal dot matrix materials [J]. Materials Guide, 2012(5):18-23. (In Chinese)

[2] Li Q. Energy absorption effect of discontinuous cross-shaped dot matrix sandwich structure [D]. Dalian University of Technology, 2012. (In Chinese)

[3] Duan Miaomiao,Jia Kunrong,Song Qianguang. Experiment and simulation of shear performance of honeycomb sandwich conformal bearing antenna structure [J]. Engineering Plastics Applications, 2017, 45(07):61-64+72. (In Chinese)

[4] Wen Zhihui. Study on acoustic properties of lightweight closed-cell cubic sandwich structures [D]. Harbin Institute of Technology, 2019. (In Chinese)

[5] Ge Qi. Joint design and performance characterization of lightweight composite dot matrix sandwich panels [D]. Heilongjiang: Harbin Institute of Technology, 2015. (In Chinese)

[6] Fan Hualin,Yang Wei. Lightweight and high-strength dot matrix materials and their mechanical properties [J]. Progress in Mechanics, 2007, 37(1):99-112. (In Chinese)

[7] Zhang Zheng,Wu Huaping,Li Xianghui,et al. Analysis and optimization of mechanical properties of pyramid dot matrix composite structure[J]. Light Industry Machinery, 2013, 31(1):74-79. (In Chinese)

[8] Lin Xiaohu,Yang Qingsheng. Status of research on impact resistance of aerospace sandwich structures [J]. Aerospace Manufacturing Technology, 2013, (10):71-74. (In Chinese)

[9] Jiang Qin. Strength Study of Plate Bubble Heat Exchanger Plate Structure [D]. Jiangsu:Nanjing University of Technology,2008. (In Chinese)

[10] Zhao Junfeng,Zhang Qiao. Influence of outer panel reinforced layup on the mechanical properties of honeycomb sandwich structures [J]. Helicopter Technology, 2017, (03):26-29+33. (In Chinese)

[11] Han Chaochao. Study on the impact resistance of composite honeycomb sandwich structures under different punch impacts [D]. Jiangnan University, 2022. (In Chinese)

[12] Xu Fangfang. A standard experimental method for determining the bending properties of unreinforced and reinforced plastics and electrical insulation materials by the four-point bending method [J]. Science and Wealth, 2018, (13):175-176. (In Chinese)