A NUMERICAL SIMULATION OF THE EFFECT OF CORE DENSITY AND PANEL THICKNESS ON VIBRATION OF THREE-LAYER HOURGLASS LATTICE SANDWICH STRUCTURE

Yalun Dong, Lihong Yang and Lei Sui
College of Aerospace and Civil Engineering, Harbin Engineering University, Harbin, China
e-mail: jokersama@hrbeu.edu.cn

The traditional steel structure has many disadvantages, including excessive mass and high density. Owing to the characteristics of low density, high strength-to-weight ratio and excellent energy absorption, metallic sandwich structures with cellular core have attracted tremendous attention in recent years and become significant protective structure in transportation industry, aerospace structures and marine structures fields. The design of the core layer plays an important role in damping and noise reduction of the overall structure, and the panel thickness variation of the structure also has an important effect. In this paper, the effects of core density and panel thickness are considered. The configuration of three-layer hourglass lattice sandwich structure is designed. The relative density of each core layer is changed with sectional dimension of core truss members to establish four gradient models; three thickness ratios are employed for the front and rear panels of four gradient models in order to compare when keeping the total thickness of the front and rear panels of the model constant. The commercial software ABAQUS was used to simulate the vibration of 12 models to obtain the first to ninth natural frequencies of each model, and the results were compared to probe the influence of core density and thickness ratio of the front and rear panels on overall structural vibration.

Keywords: Hourglass lattice sandwich structure  Core density  panel thickness ratio  Vibration characteristics  numerical simulation

1. Introduction

Lightweight sandwich structure is widely used in aviation, aerospace, automotive, transportation and other important fields due to its excellent mechanical properties such as high specific strength and high specific stiffness. The periodic lattice structure not only has light weight and high load-bearing characteristics, but also realizes multi-functional development in its internal space, thus becoming the most promising new generation of lightweight high-strength structure. With the rapid development of modern transportation technology, the engineering field has put forward higher design requirements and technical requirements for structural lightweight and multi-functional integration, which promotes the rapid development of new lightweight sandwich structures. The lattice structure can be divided into two types: the
tensile dominant type and the bending dominant type according to the relationship between the number of cell nodes and the number of rods. Among them, the tensile dominant lattice structure [1-2] converts the shear force of the core into the tensile force or pressure of the rod due to the rod in the core. Therefore, the overall mechanical properties of the structure are significantly improved compared with the bending dominant sandwich structure [3-4], and the connectivity between the lattice cells makes it extremely advantageous in the field of structural functional integration design [5-6]. As a new generation of advanced lightweight structural materials, scholars have carried out extensive and in-depth research work on the design, preparation, statics and dynamic properties of such structures. Recently, in view of the mechanical performance defects of traditional lattice structures, scholars have designed a new type of hourglass lattice structure through topology optimization [7-8]. The hourglass lattice sandwich structure increases the slenderness ratio of the rod, so that the buckling resistance of the rod is greatly improved compared with the traditional lattice structure (such as pyramid, tetrahedron, etc.). Reducing the spacing between the nodes increases the local buckling resistance of the structure [7]. It is well known that in the case of long-term vibration, most of the structure has problems of reduced work accuracy and reliability, as well as a significant reduction in fatigue life and service time, and may even lead to irreparable damage caused by premature failure. Therefore, it is necessary to carry out systematic research on its vibration characteristics [9-10], and provide reference for the related design and application of such structures.

On this basis, the natural frequency of the structure is compared by changing the relative density of the core and the thickness ratio of the front and rear panels, thereby obtaining a better structural design method in this paper.

2. Numerical Simulation

In this paper, three-layer hourglass lattice sandwich structure models with four different gradient combinations and three-layer pyramid lattice sandwich structure models for comparison are designed. The effects of different gradient combinations and different front and rear panel thickness ratios on the natural frequencies of the three-layer hourglass lattice sandwich structure are analysed.

The material parameters used in the numerical simulation are aluminium, $E=70 \text{GPa}$, $\nu =0.33$, $\rho = 2.7 \times 10^3 \text{ kg} \cdot \text{m}^{-3}$. The structural model has three cores, each core has $2 \times 12$ cells in two directions. The size of the core unit cell is shown in Fig.1. The total height of the models showed in Fig.2 are 96 mm, the dimension of each panel is $100 \text{ mm} \times 560 \text{ mm}$, the sum of the thickness of the front and rear panels is 6 mm, and the thickness of the panels between the three cores are 1.5 mm. The horizontal cross section of the core rod in the interlayer core is square, and the specific dimensions are shown in Table 1.

![Fig.1. The size of the core unit cell (a) hourglass lattice structure (b) pyramid lattice structure](image-url)
Fig. 2. The overall models (a) hourglass lattice structure (b) pyramid lattice structure

Table 1. Hourglass lattice structure and pyramid lattice structure unit cell geometry size

<table>
<thead>
<tr>
<th>geometry size</th>
<th>$L / \text{mm}$</th>
<th>$c / \text{mm}$</th>
<th>$\omega$</th>
<th>$h / \text{mm}$</th>
<th>$h_f / \text{mm}$</th>
<th>$h_p / \text{mm}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>hourglass</td>
<td>45.2</td>
<td>2.546</td>
<td>45°</td>
<td>27</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>pyramid</td>
<td>45.2</td>
<td>2.546</td>
<td>45°</td>
<td>27</td>
<td>1</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Under the condition that the total mass and other geometric parameters of the model are not changed, four different density gradient combination models can be obtained by adjusting the cross-section side lengths of different core layers, which are respectively recorded as H1~H4. H1 is a uniform model, H2 is a strong-weak phase model, H3 is a weak-strong phase model, and H4 is a fade-out model. In the model, the core layer with a large cross section of the core rod is strong, and the short cross section of the core rod is weaker, and C1~C3 respectively represent the first, second and third cores. The H2~H4 models are shown in Fig. 3. The core rod dimensions of the four models are shown in Table 2.

Fig. 3. Schematic diagram of H2~H4 models

Table 2. Core rod dimensions of the four models

<table>
<thead>
<tr>
<th>Configuration</th>
<th>$d_1$</th>
<th>$d_2$</th>
<th>$d_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
</tr>
<tr>
<td>H2</td>
<td>2.643</td>
<td>1.83</td>
<td>2.643</td>
</tr>
<tr>
<td>H3</td>
<td>2.06</td>
<td>2.976</td>
<td>2.06</td>
</tr>
<tr>
<td>H4</td>
<td>2.795</td>
<td>2.4</td>
<td>1.935</td>
</tr>
</tbody>
</table>
On the basis of the above four models, the thickness ratio of the front and rear panels is changed while ensuring that the total thickness of the front and rear panels is constant. Among them, the thickness ratio is defined as:

$$\eta = \frac{d_f}{d_r}$$

$d_f$ is the thickness of the front panel, and $d_r$ is the thickness of the rear panel. The thickness of the front and rear panels is shown in Table 3.

<table>
<thead>
<tr>
<th>$d_f$/mm</th>
<th>3</th>
<th>4</th>
<th>4.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>$d_r$/mm</td>
<td>3</td>
<td>2</td>
<td>1.5</td>
</tr>
<tr>
<td>$\eta$</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

The unit type used for numerical simulation is C3D8R, and the end face of the core is connected to the adjacent panel by "Tie". Set clamped edges as boundary conditions at the shorter ends of the structure. A linear perturbation analysis step is created, and the Lanczos solver is used for natural frequency extraction.

After obtaining the simulation results of each model, the first six natural frequencies of each model were extracted for analysis.

### 3. The effect of different variables on the natural frequency

After simulating the sandwich structure of the two configurations, the first six natural frequencies of each model were obtained. Taking the uniform model $H_1$ as an example, the first six natural frequencies corresponding to different thickness ratios are shown in Fig.4.

![Fig.4 First six natural frequencies of uniform models of hourglass lattice structure and pyramid lattice structure](image)

It can be seen from Fig.4 that the natural frequency of the hourglass lattice structure is higher than the natural frequency of the same-order pyramid lattice structure. In the high frequency band above the fourth order, the difference between the natural frequency of the hourglass lattice structure and the natural frequency of the pyramid lattice structure is significantly increased.

It can be seen that the hourglass lattice structure has a higher natural frequency than the pyramid lattice structure, and the vibration isolation performance is stronger.
3.1 Different density gradient

During the vibration process, the first-order frequency is the easiest to occur, so the first-order frequencies of the four models are compared, as shown in Fig.5.

![Graph showing first order natural frequencies of H1~H4 models with different thickness ratios.]

Fig.5. First order natural frequencies of H1~H4 models with different thickness ratios

It can be seen from Fig.5 that the first-order natural frequencies of the four models show the same variation law in different panel thickness ratios. The H3 model has the smallest first-order natural frequency and the H1 model has the largest first-order natural frequency. Because the relative density of the three cores in the H1 model is the same, the mass distribution in the overall structure is more uniform, resulting in a higher natural frequency.

3.2 Thickness of front and rear panels

Change the thickness ratio of the front and rear panels so that the front panel is a thicker panel and the rear panel is a thinner panel. The first six natural frequencies of the four models are plotted in terms of thickness ratio, as shown in Fig.6.

![Graphs showing first natural frequencies of H1~H4 models with different thickness ratios.]

(a) (b)
It can be seen from Fig. 6 that the natural frequencies of the H1~H4 models decrease as the thickness ratio of the front and back panels increases. Since the H1~H3 models are symmetrical structures, when the thickness ratio is 0.5 and the thickness ratio is 2, the structures of the models are the same. Therefore, when the front and rear panels of the structures are equal, the four model structures have the largest natural frequency. The main reason for this phenomenon is that the same thickness of the front and rear panels will make the overall mass distribution of the structures more uniform, which is closer to the mass distribution of the solid board.

It can also be seen from the above figures that when the four models are at the third or fourth natural frequency, the natural frequencies of each model are very close at the same thickness ratio. That is to say, density gradient has no significant effect on the natural frequency of the model at this time.

4. Conclusion

In this paper, the effects of density gradient and thickness ratio of front and rear panels on the vibration characteristics of hourglass lattice sandwich structures are discussed. The following conclusions are obtained:
(1) In the case where the relative density of three layers of cores is the same, the hourglass lattice structures have higher natural frequencies than the pyramid lattice structures, and the frequency difference in the high frequency band above the fourth order gradually becomes larger.

(2) In the case where the thickness ratios of the front and rear panels are the same, the uniform model has the largest natural frequency, and the weak-strong phase model has the smallest natural frequency.

(3) All four models have the maximum natural frequency when the front and rear panels are equal in thickness, and the natural frequency gradually decreases as the thickness ratio of the front and rear panels increases.

(4) The density gradient has little effect on the third and fourth natural frequencies of the models.

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REFERENCES


