Study on compression load and energy absorption characteristics of glass fiber honeycomb tube

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Abstract. In terms of the deficiency of the existing research on the compression load and energy absorption characteristics of composite structures, a glass fiber honeycomb tube with different thickness and different cell number was proposed. The static compression test was carried out by universal testing machine. The results show that the failure forms of honeycomb tube are fiber fracture damage, fiber layer delamination and their composite forms. The peak compression load and total energy absorption increase with the increase of cell number and thickness, and the specific energy absorption increase only with the increase of thickness. The compression peak load of single-cell honeycomb tube with wall thickness of 0.4 mm is the smallest, which is 2.21 KN; and the compression peak load of eight-cell honeycomb tube with wall thickness of 1.2 mm is the largest, which is 91.48 KN. The corresponding total energy absorption is 25.16 J and 2257.57 J respectively; the corresponding specific energy absorption is 8.38 J/g and 45.06 J/g respectively.

1. Introduction

Compared with metal materials, fiber materials have been widely used in aerospace, civil construction, shipbuilding and other fields because of their high specific strength, good safety, good corrosion resistance and designability. Fiber materials have good energy absorption characteristics at the same time, they are widely used in engineering as energy absorption components. However, fiber composites are sensitive to compressive load. Therefore, it is significant to study the compressive load and energy absorption characteristics of fiber composites.

Roozbh Kalhor[1] proposed hybrid square tubes made from composites and 304 stainless steel with different fiber orientation, stacking sequence, and thickness. Yifan Wang[2] studied the energy absorption capability of composite tubes with different fiber orientation and wall thickness. Sun G[3] studied the effects of winding angle and thickness on the crashworthiness of carbon fiber reinforced plastics. Nguyen T B H [4] Studied the mechanical properties of glass fiber honeycomb. The researches above show that the winding angle and thickness have significant effects on the failure mode, energy absorption capability and crushing characteristics. ABM S[5] studied the influence of winding direction on energy absorption capacity and crashworthiness through quasi-static compression load, which proved that the energy absorption performance of the hybrid material was better than that of glass fiber composite pipe. Duan S Y[6] established the finite element model of composite with sinusoidal specimen, optimized the composite with specimen under axial impact load which improved the specific energy absorption and peak impact load. Liu Q[7] Conducted compression tests on the impact capacity and energy absorption characteristics of carbon fiber reinforced tubes, the results show that the number of layers is the key factor affecting the structural damage, energy absorption and
specific energy absorption. Xu J[8] Studied the effects of compression speed, fiber angle and thickness on the energy absorption characteristics of composite, the research shows that fiber reinforced composites absorb energy in the form of fiber fracture, matrix cracking and delamination failure. Jamal O M[9] Proposed a new type of transverse corrugated pipe, the results show that the cross-section shape of corrugated pipe has a significant impact on the energy absorption and failure mode. Andrews B[10] Carried out quasi-static compression tests on new composite reinforced pipes under two impact speeds, the results show that the knitted tubular fabric has a great influence on the energy absorption properties of the composites.

To sum up, the researches above are mostly fiber-reinforced laminates, fiber-reinforced alloy laminates and fiber-reinforced circular tubular structures, and the load direction is mostly vertical to the laminate surface. There is little research on the energy absorption characteristics of multi-cell glass fiber honeycomb structures. In this paper, the damage morphology, compressive load and energy absorption characteristics of honeycomb tube are studied by the static compression test, which provides a reference for the design of composite energy dissipation structures.

2. Manufacture process and samples of glass fiber honeycomb tube
The glass fiber honeycomb tube is produced by molding method, and (0°/90°) alternating layers are adopted for honeycomb tube whose single layer fiber thickness is 0.2mm. Figure 1 (a)–(f) shows the process of honeycomb tube. (a) Cut the glass fiber prepreg with thickness of 0.2 mm into a thin plate with length of 300 mm and width of 100 mm (b) stack the prepreg film neatly on the isolation film (c) place the paved prepreg on the lower mold and cover the upper mold (d) place the clamp on both sides of the mold and tighten the bolts to make the prepreg stick in the groove of the mold (E) put the mold into the drying oven at 140℃ for 90 minutes. After drying, cool it in the air for 2 hours (f) paste the sample symmetrically with SYE13001 epoxy resin adhesive, and then put it in the air for 48 hours. By cutting different sizes of fiberboard and bonding 2, 4 and 6 layers respectively, then three kinds of glass fiber honeycomb tubes with different wall thickness and different number of cells were obtained. The compression speed is 5 mm/min, the glass fiber honeycomb tube and testing machine are shown in figure 2 and the parameters of honeycomb tube samples are shown in table 1.

| Mass/g | 0.4mm | 0.8mm | 1.2mm |
|--------|-------|-------|-------|
| 1-cell | 3.0   | 6.2   | 8.4   |
| 3-cell | 9.1   | 18.2  | 21.9  |
| 5-cell | 12.3  | 23.8  | 32.5  |
| 8-cell | 22.3  | 36.7  | 50.1  |

Figure 1. Manufacturing process of glass fiber tube
Figure 2. Sampes of glass fiber honeycomb tube and testing machine
3. **Compression process and failure mode analysis**

Table 2. Compression process and failure mode of glass fiber tube

| Compression Process | Failure Mode | Compression Process | Failure Mode |
|---------------------|--------------|---------------------|--------------|
| front | back | front | back |
| 2-1 | 2-3 | 2-5 | 2-8 |
| 4-1 | 4-3 | 4-5 | 4-8 |
| 6-1 | 6-3 | 6-5 | 6-8 |

**Notes:** the samples in the table are marked as A-B, A represents the layers of honeycomb tube, and B represents the cell number of honeycomb tube.

It can be seen from table 2 that when the wall thickness is 0.4 mm, the single-cell honeycomb tube is seriously deformed with broken fiber; the honeycomb tube with multi-cell deform more lightly than those with less cells and tends to appear delamination damage. When the wall thickness is 1.2 mm, the deformation and fiber fracture damage of honeycomb tube become more light, and the delamination of fiber layer is more obvious. The inner fiber layer is folded towards the center of honeycomb tube, the outer fiber layer is folded towards the outside of the honeycomb tube, and the fiber layer is dispersed in petal shape.

4. **Analysis of compression load and energy absorption characteristics**

The compression load and energy absorption of glass fiber honeycomb tube are shown in figure 3, figure 4 and table 3.

![Load-displacement curve of honeycomb tube](image)

(a) 0.4mm  
(b) 0.8mm  
(c) 1.2mm  

Figure 3. Load-displacement curve of honeycomb tube
As can be seen from the load-displacement curve in figure 3, the compression load increases from 0 to the maximum with the increase of compression displacement, then decreases to a certain value, and fluctuates slightly up and down. The compression load and peak load increases with the increase of the number of cells and thickness. When the wall thicknesses are 0.4 mm, 0.8 mm and 1.2 mm, the corresponding compression peak loads of single-cell tube are 2.21 KN, 9.17 KN and 16.2 KN respectively; the corresponding compression peak load of three-cell tube are 9.2 KN, 25.06 KN and 36.69 KN respectively; the corresponding compression peak load of five-cell tube are 11.2 KN, 40.56 KN and 60.5 KN respectively; the corresponding compression peak load of eight-cell tube are 18.8 KN, 55.89 KN and 91.48 KN respectively.

![Figure 4](image)

**Figure 4. Energy-displacement curve of honeycomb tube compression**

As can be seen from the energy-displacement curve in figure 4, the total energy absorbed by the honeycomb tube increases approximately linearly with the increase of compression displacement, the total energy increases with the increase of the number of cells and thickness. When the wall thicknesses are 0.4 mm, 0.8 mm and 1.2 mm, the corresponding total energy of single-cell tube are 25.16 J, 127.7 J and 183.3 J respectively; the corresponding total energy of three-cell tube are 192.1 J, 525.5 J and 639.6 J respectively; the corresponding total energy of five-cell tube are 277.2 J, 973.6 J and 1391.7 J respectively; the corresponding total energy of eight-cell tube are 456.1 J, 1425.4 J and 2257.57 J respectively.

| Items   | PCF/KN | EA/J | SEA/(J/g) |
|---------|--------|------|-----------|
| THK/mm  | 0.4    | 0.8  | 1.2       |
| 1-cell  | 2.21   | 9.17 | 16.2      |
| 3-cell  | 9.2    | 25.06| 36.69     |
| 5-cell  | 11.2   | 40.56| 60.5      |
| 8-cell  | 18.8   | 55.89| 91.48     |

| THK/mm  | 0.4    | 0.8  | 1.2       |
| 1-cell  | 25.16  | 127.7| 183.3     |
| 3-cell  | 192.1  | 525.5| 639.6     |
| 5-cell  | 277.2  | 973.6| 1391.7    |
| 8-cell  | 456.1  | 1425.4| 2257.57   |

**Notes:** THK is the wall thickness of honeycomb tube, EA represents total energy absorption and SEA represents specific energy absorption.

As can be seen from table 3, the specific energy absorption increased only with the increase of wall thickness, and had no obvious correlation with the number of cells. The specific energy absorption (SEA) of single-cell honeycomb tube with wall thickness of 0.4 mm is the smallest, which is 8.38 J/g; the specific energy absorption (SEA) of eight-cell honeycomb tube with wall thickness of 1.2 mm is the largest, which is 45.06 J/g.

5. Conclusions
In order to study the compression load and energy absorption characteristics of composites structures, the glass fiber honeycomb tubes with different wall thickness and different cell number were compressed by using the universal testing machine, the conclusions are as below:

(1) The main damage form of those honeycomb tubes with thin wall and less cells tends to be fiber fracture, and the damage form of those honeycomb tubes with thick wall and multi-cell tends to be fiber delamination and fiber fracture failure.
(2) The inner fiber folds to the center of the honeycomb tube and the outer fiber folds to the outside of the honeycomb tube with the increase of compression displacement. Finally, the damaged glass fiber honeycomb tube is scattered in petal shape as a whole.

(3) The peak load and total energy absorption of glass fiber honeycomb tube increase with the increase of wall thickness and cell number. The specific energy absorption of honeycomb tube increases only with the increase of wall thickness, and has no obvious correlation with the number of cells.

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