Research on the Response Characteristics of Bio-Inspired Composite Sandwich Structure under Low Velocity Impact

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Abstract. In order to research the impact mechanical response characteristics of the bio-inspired composite sandwich structure, the hemispherical impactor is preloaded with different energy to impact bio-inspired and conventional composite sandwich structure, the stress distribution and dynamic response characteristics of composite sandwich structure under impact load are studied. The results show that the main damage of the upper panel is fiber shear fracture, while crushing fracture for the core, and the main damage of the lower panel is fiber tensile tearing under different impact load. The bio-inspired composite sandwich structure shows better impact resistance in terms of damage depth and maximum impact load under the same impact energy. From the perspective of energy consumption, the bio-inspired structure absorbed more energy than conventional structure under high energy impact.

Keywords. Bio-inspired composite, impact response, finite element.

1. Introduction

The composite sandwich structure is an important structure used in the aerospace industry and other fields of modern engineering [1-2]. Such lightweight structures are also applied increasingly to the field of civil, transportation engineering [3-4]. The rapid increase of demand for composite sandwich structure have accelerated the development of analysis and study of such advanced materials. Many works have been performed using theoretical analysis, numerical studies and experimental investigations [5-12].

The ability to calculate precisely the characteristic of composite sandwich structure under axial loading requires to build the right models that represent several kinds of mechanical properties. There are many different failure mode of composites, including matrix failure [13-15], fibers failure [16-18], delaminated failure [19, 20] and others. Panigrahi et al. [21] assessed the mechanical properties of laminated composite bonded double support tee joint by 3D non-linear finite element analyses. Then several numerical studies have been carried out for different interfacial failure in order to obtain the most important effect of functional graded adhesive. Lau et al. [22] introduced the use of energy absorbing composite. The failure mode which significantly affected the mechanical properties has been investigated under axial impact loading by numerical simulations. Lamanna et al. [23] studied structural behavior of composite laminates. They adopted a new modeling method under compression loading by taking into account the impact and the damage after impact. Liu et al. [24] studied the
dynamic response of composite sandwich structures under different impact energy, impactor mass and inclination.

Although the mechanical behaviors of composite sandwich structure has been extensively investigated during the last decades, but few studies research the bio-mimetic composite sandwich structure. Du et al. [25] observed the internal microstructure of beetle elytra, then proposed a macro scale sandwich structure with a composite laminates. The pole canal in the biological layers of beetle elytra has been firstly revealed and discussed by building a micron-scale FE model [26]. They [27, 28] also proposed a novel bionic honeycomb structure named as BHS. The crushing behavior properties of several bio-inspired structures were studied [29].

As show in figure 1, the stacking angle of the beetle elytra was identified, and the stacking sequence was [0/60/-30/30/-60/0/90/-30/60/-60]. Then, the composite sandwich structure inspired by beetle elytra was proposed. The dynamic response of bio-inspired and conventional composite sandwich structure is investigated, and the stress distribution and deformation mode of the model are studied by numerical simulation.

![Figure 1. Schematic of the beetle elytra and the model of the composite sandwich structure. (a) The crosssection view SEM images of beetle elytra; (b) The schematic diagram of laminated composite skins; (c) Schematic of the composite sandwich structure subjected to the axial impact.](image)

2. Finite Element Model

The FE model of bionic composite sandwich structure is established based on ABAQUS, including the composite skins, the Nomex honeycomb core and impactor, as show in figure 2. In order to compare with the traditional composite sandwich structure, all composite skins designed in this study are laid up with 16 layers. The conventional composite skins were plied [0/90]s, and the bio-inspired composite skins were plied [0/60/-30/30/-60/0/90/-30/60/-60/30/90/0/60/-60/30]. The thickness of each ply is 0.22mm. The material of composite skins is carbon fibre epoxy face sheets, and the composite material parameters are listed in table 1. The FE model of hemispherical impactor is given a concentrated mass of 8.79 kg. The impact energies used were 10, 30, 50, 100 and 150J. The corresponding impact velocities were 1.51, 2.61, 3.37, 4.47, and 5.84 m/s, respectively.

![Figure 2. Composite sandwich structure.](image)
Table 1. Mechanical properties of the carbon fibre epoxy face sheets.

| Parameters | Value  |
|------------|--------|
| $E_1$ (GPa) | 55.8   |
| $E_2$ (GPa) | 55.8   |
| $G_{12}$ (MPa) | 3650   |
| $\nu_{12}$ | 0.06   |
| $X_c$ (MPa) | 630    |
| $X_t$ (MPa) | 630    |
| $Y_t$ (MPa) | 550    |
| $Y_c$ (MPa) | 550    |
| $S_{12}$ (MPa) | 100    |
| $S_{13}$ (MPa) | 100    |

3. Results and Discussion

3.1. Force-Displacement Curves

As shown in figure 3, the trend of the crushing force was predicted well along with the displacement. When using low energy impact, it has an unloading stage and the impactor rebounds, so the load-displacement curve corresponding to this stage fluctuates and decreases along the negative direction of the x-axis. From the crushing force-displacement curves, it can be seen that the impact process is divided into three stages: (I) the impactor starts to contact the sandwich panel until it breaks through the upper panel. In this process, the load quickly reaches the first peak. With the shear fracture of the upper panel, the load value decreases rapidly; (II) failure stage of core. At this stage, the core is gradually destroyed, the load oscillates in a low level and small range, and the curve is serrated; (III) When the impact energy is higher than 100J, the load displacement curve can enter load homogenization.

![Crushing force-displacement curves](image1)

(a) Bio-inspired composite sandwich structure      (b) Conventional composite sandwich structure

Figure 3. Crushing force-displacement curves for the bio-inspired and conventional composite sandwich structure.

3.2. Energy Absorption

As shown in figure 4, energy absorption of the two types of composite sandwich structure during impact was compared. It can be seen from the figure that the absorbed energy of the two sandwich structures increased to a certain value with time, and then decreased slightly. Due to the rebound of the impactor, the energy absorption of the structure was reduced. Therefore, the rebound of the impactor corresponds to the reduction value. Absorbing the same energy, the bionic composite structure took less time than the traditional composite structure. From the perspective of energy consumption, the bio-inspired structure absorbed more energy than conventional structure under high energy impact.
Figure 4. Absorbed energy-time curve of the bio-inspired and conventional composite sandwich structure.

3.3. Stress Distribution

| Impact energy | Front face-sheet of BCSS | Front face-sheet of CCSS | Back face-sheet of BCSS | Back face-sheet of CCSS |
|---------------|--------------------------|--------------------------|-------------------------|-------------------------|
| 10J           | ![Stress nephogram 10J BCSS](image1.png) | ![Stress nephogram 10J CCSS](image2.png) | ![Stress nephogram 10J BCSS](image3.png) | ![Stress nephogram 10J CCSS](image4.png) |
| 30J           | ![Stress nephogram 30J BCSS](image5.png) | ![Stress nephogram 30J CCSS](image6.png) | ![Stress nephogram 30J BCSS](image7.png) | ![Stress nephogram 30J CCSS](image8.png) |
| 50J           | ![Stress nephogram 50J BCSS](image9.png) | ![Stress nephogram 50J CCSS](image10.png) | ![Stress nephogram 50J BCSS](image11.png) | ![Stress nephogram 50J CCSS](image12.png) |
| 100J          | ![Stress nephogram 100J BCSS](image13.png) | ![Stress nephogram 100J CCSS](image14.png) | ![Stress nephogram 100J BCSS](image15.png) | ![Stress nephogram 100J CCSS](image16.png) |
| 150J          | ![Stress nephogram 150J BCSS](image17.png) | ![Stress nephogram 150J CCSS](image18.png) | ![Stress nephogram 150J BCSS](image19.png) | ![Stress nephogram 150J CCSS](image20.png) |

Figure 5. Stress nephogram of front and rear panels of bionic and traditional composite sandwich structures.
Figure 5 shows the stress nephogram of the front and back face-sheet. It can be used to compare the stress distribution of bionic and traditional composite sandwich structures. Through comparison, the bio-inspired composite sandwich structure shows better impact resistance in terms of damage depth and maximum impact load under the same impact energy.

4. Conclusion and Discussion
This study was dedicated to studying the impact behaviour of the bio-inspired and conventional composite sandwich structure. The conclusions can be drawn as follows:

1. The main damage of the upper panel is fiber shear fracture, while crushing fracture for the core, and the main damage of the lower panel is fiber tensile tearing under different impact load.

2. The load response process of sandwich panels can be obviously divided into three stages, and the energy absorption of bionic composite sandwich structure is better than that of the conventional composite sandwich structure, which are related to the lamination mode of composite panels.

Acknowledgments
This study is funded by the National Natural Science Foundation of China (Grant No. 12172251, 11572218), the Fundamental Research Funds for the Central Universities (Nos. xjh012019033, xxj022019019 and 3122018D041).

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