Design and Simulation of Sandwich Structure of Exoskeleton Backplate Based on Biological Inspiration

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Abstract. The backplate is the main skeleton of the exoskeleton robot, and its structural strength and lightweight design are very important to the body structure of exoskeleton. In this paper, a design scheme of grille reinforced foam sandwich structure based on biological inspiration is presented. By analyzing the influence of core thickness on the mechanical properties of the sandwich structure, a new sandwich structure of exoskeleton backplate with a surface thickness of 2mm and a core thickness of 15mm was designed. Based on finite element software ABAQUS, the simulation calculation was carried out. The results show that the maximum stress of the sandwich structure is 298.5Mpa and the maximum strain value is $2730\mu\varepsilon$, which is less than the allowable value. This meets the structural strength design and lightweight design requirements.

1. Introduction
Exoskeleton robot is a wearable robot developed by imitation human bones, which can be used in emergency rescue, carrying burden, material handling and other fields [1-4]. The backplate is the main skeleton of the exoskeleton robot, which is used to secure the arms mechanism while transmitting the force acting on the upper limb to the lower limb. And its structural strength and lightweight design are very important to the body structure of the exoskeleton. In this paper, a design scheme of grille reinforced foam sandwich structure based on biological inspiration is presented. The grille, foam and surface of plate of the reinforced sandwich structure were prepared by titanium alloy, polyurethane and carbon fiber respectively. The influence of the thickness of core layer on the mechanical constants of sandwich structure was studied, and the finite element calculation and analysis were carried out on the backplate.

2. Backplate design of exoskeleton

2.1. Backplate design of the grille reinforced foam sandwich structure based on biological inspiration
The origins of common composite sandwich structures can be traced back to “biomimetic” science, as shown in Figure 1. The micro cross sections of grass blades and sandwich structures have obvious sandwich features, that is, the upper and lower layers are fiber panels with high strength, high stiffness and small thickness, and the core layer is porous and light core layer. The face layer is the main bearing part of the sandwich structure, and the mechanical properties of the sandwich structure can be greatly improved by placing the surface material with high strength and stiffness on both sides of the sandwich structure. The core layer plays the role of connecting the upper and lower surface layers to
improve the flexural and torsional rigidity of the structure. And it also provides a variety of functions, such as thermal insulation, muffling, wave absorption and impact resistance.

In Figure 1, the lotus leaves have a relatively regular micro-vein sandwich structure. In other words, regular lattice micro-veins are distributed on the basis of surface layer-porous core structure. These veins are mainly composed of fibers with high stiffness and strength, and the diameter of veins is much larger than the thickness of the fiber panel, which can fully improve the stiffness and strength of the structure. The sandwich structure with higher mechanical properties can be obtained compared with the grass blade. Therefore, lotus leaves can obtain higher mechanical properties of the sandwich structure compared with grass leaves.

![Fig. 1. The sandwich structure in nature.](image)

Inspired by the microstructure vein-mezzanine of lotus leaves tissue, a grille reinforced foam sandwich structure was designed, as shown in Figure 2. In this grille-reinforced foam sandwich structure, the orthogonal grille is equivalent to the lattice veins in the lotus leaves tissue, which is responsible for improving the stiffness and strength of the structure. The foam acts as a porous core in the tissue and is responsible for providing functionality and structural flexural performance. Grille and foam together constitute the core of the sandwich structure. In the backplate forming scheme, TC4 titanium alloy, polyurethane foam and T700 carbon fiber were selected to prepare the grille-reinforced foam and surface layer of sandwich structure respectively.

![Fig. 2. Design diagram of grille reinforced foam sandwich structure.](image)

2.2. Influence of core thickness design on mechanical properties of sandwich structure

The core layer adopts titanium alloy grille to enhance polyurethane foam, as shown in Figure 3. Because the material of the core layer is light, the increase of a certain thickness is very small for the overall mass of the structure, but the overall sandwich structure obtains a higher moment of inertia.
Considering the cubic relation between the section thickness of sandwich structure and the bending stiffness, it can be seen that the thickness of core layer is a key parameter for the bending performance of sandwich structure. According to the testing standards of bending properties, sandwich structures with different thickness were designed and were screened by the method of simulation calculation.

![Diagram of titanium alloy grille reinforced foam core structure.](image)

**Fig. 3.** Diagram of titanium alloy grille reinforced foam core structure.

The core layer thickness is selected as 5mm, 7mm, 9mm, 12mm, 15mm, 17mm and 19mm respectively, and the surface layer thickness is fixed as 2mm. Figure 4 shows the load-displacement curves of sandwich structures with different thickness under three-point bending load. The linear relation between load and displacement of sandwich structure with different thickness indicates that sandwich structure has linear elastic relation and geometric nonlinear characteristic is not obvious. It is found that when the thickness of core structure exceeds 12mm, the stiffness of sandwich structure increases significantly and when the thickness of sandwich structure exceeds, the stiffness of sandwich structure increases slowly.

![Load-displacement curve of sandwich structure under bending load.](image)

**Fig. 4.** Load-displacement curve of sandwich structure under bending load.

Figure 5 shows the stress distribution of sandwich structure with different thickness. Under the same displacement load, with the increase of sandwich structure thickness, the maximum stress increases significantly, which is mainly attributed to the increase of the stiffness of sandwich structure.
Fig. 5. Stress diagram of different core thickness under bending load.

Considering the lightweight requirements of the backplate, it is necessary to comprehensively compare the bending stiffness and specific bending stiffness of sandwich structure. With the increase of the core thickness, the bending stiffness of the structure increases rapidly, but the increase of the core thickness causes the core material to suffer from stiffness failure and the surface layer to produce great stress. Taking the above factors into consideration, the sandwich structure thickness was selected as 15mm. The backplate prepared by the grille reinforced foam sandwich structure is shown in Figure 7.

Fig. 6. Stiffness of sandwich structure with different core thickness.
3. Finite element analysis

3.1. Constraint condition
In this paper, the simulation software ABAQUS is used for the finite element calculation of the sandwich structure. A torque of 350Nm was applied at the end of the unilateral arm, and the lower end of the back structure was threaded to the lower extremity structure. Material parameters: the grid is made of TC4 titanium alloy; the foam is polyurethane; the surface layer is T700 carbon fiber. The surface thickness is 2mm, and the core thickness is 15mm.

3.2. Stress and strain analysis of backplate
As shown in Figure 8, the maximum stress of the surface layer is 207.6Mpa and is located at the connecting hole of the supporting structure, which is less than the tensile and bending failure strength of the T700/epoxy resin composite material. The maximum stress of the core layer is 298.5Mpa and is located at root of the connecting hole of the supporting structure, which is less than the failure strength of titanium alloy. The maximum stress of surface layer and core layer is less than the failure strength of material.

Figure 9 shows the strain analysis of surface layer and core layer. The maximum strain values of surface layer and core layer are $1490 \mu \varepsilon$ and $2730 \mu \varepsilon$ respectively, which do not exceed the damage strain of the material [5, 6].
4. Conclusion
In this paper, the effect of core thickness on the mechanical properties of sandwich structure is analysed for a new type of sandwich structure of exoskeleton backplate based on biological inspiration. Based on finite element software ABAQUS, it was simulated and analysed, and the following conclusions were obtained:

1) The results show that the sandwich structure has a linear elastic relationship. With the increase of core layer thickness, the maximum load of sandwich structure increases under the same displacement load.

2) With the increase of core layer thickness, the bending stiffness of the sandwich structure increases rapidly, but the increase of core layer thickness will accelerate the damage of sandwich structure.

3) It is found through simulation that the maximum stress value of the new designed sandwich structure is 298Mpa, the maximum strain value is 2730με, and both values are less than the allowable value.

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