Three-layer composite panel with discrete layer and bionic principles

I A Mayatskaya*, B M Yazyev, V D Eremin

Don State Technical University, Socialisticheskaya str., 162, Rostov-on-Don, 344022, Russia

E-mail: irina.mayatskaya@mail.ru

Abstract. A very interesting direction in bionics, which uses the properties of natural, complex in design structures. The purpose of these studies is to increase strength, thermal insulation and sound insulation by changing the shape and thickness of the intermediate layer and using composite materials in a lamellar structure.

1. Introduction

Three-layer structures are widely used in aircraft and helicopter construction. The use of thin ones, for example, plates and shells, in conditions of bending deformation are the most rational from the point of view of strength and rigidity. The use of lamellar structures in construction and mechanical engineering is also relevant [1-5]. Lamellar structures, which are three-layer panels with discrete cores of low density, make these objects lighter [6-8].

When creating modern structures, the issues of increasing strength, thermal insulation and sound insulation by changing the shape and thickness of the intermediate layer and using composite materials in a layered structure are relevant. The paper considers a three-layer structure with two outer layers, which are unidirectional polymers with mutually perpendicular directions and an intermediate spongy core layer.

2. Bionics and Building Structures Using Lamellar Plates and Shells

Currently, when designing, the latest composite materials and intermediate layer models are preferably used. Lamellar plates and shells are widely used in aircraft and helicopter construction in the manufacture of wings, empennage and fuselage skin, one of the variants of which is a three-layer shell with a honeycomb core made of a composite material (Figure 1).
The use of thin three-layer skins with a lightweight filler with a low density or in the form of honeycombs makes these structures lighter. High strength and resistance to vibration and acoustic loads determine the growth in the use of lamellar structures as load-bearing elements of the fuselage. Three-layer plates with a ribbed intermediate layer (Fig. 1) are also used in construction as thermal insulation cladding of buildings and for sound insulation inside the structure.

The disadvantage of three-layer plates and cladding shells is the constancy of the intermediate layer thickness and the impossibility of using more complex geometric shapes and anisotropic polymeric materials for the outer and inner layers.

The closest technical solution to a bionic structure in the form of a three-layer structure with a discrete intermediate layer is a three-layer shell with a spongy structure of the intermediate layer. At present, much attention is paid to bionic principles in structures design [5, 9, 10]. Let us consider the bones of a human skull. It is a three-layer shell with different thickness, surface shape and material properties. The outer and inner thin layers of the shell element represent an anisotropic structure, and the intermediate one has a spongy structure of two types: porous and rod with variable thickness. It is this structural feature of the bones that determines its increased strength, heat and sound insulation of the inner part of the skull.

The paper investigates the problem of increasing the strength of a three-layer structure with a discrete intermediate layer and proposes to use a discrete intermediate layer in the form of cylindrical blocks of variable thickness. This discrete layer of a three-layer structure has a structure for which each block is a cylindrical shell or a rod with a circular cross-section of variable thickness (Figure 2).

Figure 1. Discrete-filled three-layer plates

Figure 2. Three-layer plate with discrete aggregate in separate blocks

A three-layer structure with two outer layers, which are unidirectional polymers with mutually perpendicular directions, and an intermediate spongy core layer works as a structure with isotropic properties, which is more rational [5].

The specified technical result is achieved by the fact that the intermediate layer has a block structure. Each block is a cylindrical shell or bar with a circular cross-section of variable thickness with a curved surface. This surface can be in the form of a rotating hyperboloid, which has a continuous surface or the rectilinear agents of which are the intermediate layer’s fibers. A catenoid can be used as a block. This is a
body which surface is formed by the rotation of a chain line \( y = ach(x/b) \). This surface belongs to the minimum surfaces. One of the examples is a soap film obtained by tension on two rings, the planes of which are perpendicular to the rotation axis. This block may resemble an hourglass shape, which is quite common in engineering structures, or two cones in contact, it is possible to see both a truncated cone and a hexagonal cross section. These blocks can have different sizes, and a similar shape, only its height should be constant for panels with constant thickness. If the thickness of the structure changes, then for a given structure of the intermediate layer, the change in height does not cause difficulties.

In spar structures of helicopters, the bending moment is perceived mainly by the longitudinal elements – spars, and the skin (lamellar panels) perceives local loads, shearing force and torque. And in a monoblock structure, the skin, together with the frame elements, also perceives normal forces from bending moments. The load on the panel is quite varied and it is desirable that the properties of the plate react less to the material properties in different directions.

As blocks in the intermediate layer, cylinders or thin-walled cylindrical shells with a constant radius, a rotating hyperboloid or a thin-walled shell of rotation formed by an algebraic curve, for example, of the second order, circular cones or thin-walled conical shells, as well as the bodies of variable thickness with a cross-section in the polygons form.

The device works as follows. The blocks included in the intermediate layer of a three-layer structure are loaded differently and the block system starts operating as a structure in which the influence of material properties in different directions in the outer and inner layers is reduced.

Such three-layer shells, as, for example, the structure of the human cranium or the structure of a turtle can be met in nature. The tortoise shell can withstand very significant loads and has a block structure (Figures 3, 4).

**Figure 3.** Turtle species

The carapace consists of shields in the form of curved polygons: quadrangles, pentagons, and hexagons with variable thickness and a slightly convex surface. This natural construction is very durable. But most often in the shell structure is the hexagonal shape of the blocks. This structure is very strong and reliable. Octagons can also be used as blocks.

**Figure 4.** Types of block structure of turtle shells
In the three-layer structures’ design, a block structure with three-layer hexagonal blocks can be used, each layer of which has different mechanical properties. The outer layer should be strong, and its strength is increased due to variable thickness and convex shape, which is widely used in natural objects of rational shape. The intermediate layer should have shock absorption damping properties. The inner layer is made of an elastoplastic material with shape memory or a material with improved thermal insulation properties.

For the intermediate layer of a three-layer structure, the elements that are encountered when constructing semiregular polyhedrons should be considered, for example, a truncated cuboctahedron (Figures 5, 6).

![Figure 5. Types of semiregular polyhedron](image)

![Figure 6. Truncated cuboctahedron view](image)

Three-layer panels are used in the construction of residential buildings. This is a three-layer “sandwich” of two layers of reinforced concrete or metal sheet and a modern light intermediate layer between them, as well as a decorative layer that can take on any texture (Figure 7). During construction, the slabs are joined together with minimal seams at the joints.

![Figure 7. Types of three-layer panels in building structures](image)

The multi-layer structures using spherical elements or thin-walled spheres in the intermediate layer can be applied in construction, although this direction in the multilayer structures design is not sufficiently developed. Development of new types of three-layer structures with an intermediate discrete filler, the possibility of using them in structures with complex geometry is possible. There is an opportunity to construct a three-layer panel with a discrete filler in the form of rods of both rectilinear and curved shapes.
Currently, one of the important tasks is the development of software for performing such calculations and automation of the design process, creation and assembly of a three-layer structure with a discrete filler of complex shape. Such structures could be used much more widely than the structures with honeycomb and corrugated or lightweight cores.

3. Summary
The proposed three-layer structure with two outer layers, which are unidirectional polymers with mutually perpendicular directions, and an intermediate spongy core layer operates as a structure with isotropic properties. It is also possible to use a panel with an intermediate discrete layer in the form of separate blocks in the form of rotating hyperboloids or two touching frustums of a cone.

When designing thin-walled structures, a problem arises, which consists in determining the parameters of a rational and optimal structure for a given load. To solve the problems of optimal design, it is necessary not only to analyze the optimality conditions for thin-walled shell structures and an algorithm for determining the optimal parameters for different types of shells and loading schemes, but also to pay attention to the structural structure.

Determination of the best design solution is an extremely complex process, consisting of work to ensure the best operating conditions for loading, the choice of rational schemes, shapes of parts and effective materials that contribute to obtaining the minimum mass of the structure, taking into account manufacturability and cost. To find the correct design solution that ensures the optimal design, you can use the methods of bionic research.

Further research is needed to improve structures’ design using the bionic principles. Using these principles, it is possible to create the objects of amazing shape using the layered shells and to design the structures with a rational form [5, 9, 10].

References
[1] Mayatskaya I A, Demchenko D B, Demchenko B M 2018 The theory calculation of plates (Publishing house Don State Technical University).
[2] Mayatskaya I A, Krasnobaev I A 2011 Fundamentals of calculation for the output of thin rigid plates (Publishing house Rostov State University of Civil Engineering).
[3] Mayatskaya I A, Krasnobaev I A, Smirnov I I, Yazyev B M 2012 Plate and shell theory (Publishing house Rostov State University of Civil Engineering).
[4] Mayatskaya I A, Demchenko D B 2020 The fundamentals of the theory and calculation of thin-walled open profile rods (Publishing house Don State Technical University).
[5] Mayatskaya I A, Eremin V D 2019 Bionics and the choice of rational structural form E3S Web of Conferences 110 01042.
[6] Mayatskaya I A, Krasnobaev I A, Vitols O E 2017 On the issue of calculating three-layer structures with light filler Scientific works of the National University of Architecture and Construction of Armenia 3 (66) 67-73.
[7] Mayatskaya I A, Krasnobaev I A 2016 Calculation of rounded three-layer plates under the influence of a uniformly distributed load Scientific works of the National University of Architecture and Construction of Armenia 2 (61) 94-99.
[8] Mayatskaya I A, Krasnobaev I A 2016 Strength calculation of three-layer cylindrical under the action of axial force Scientific works of the National University of Architecture and Construction of Armenia 3 (62) 35-40.
[9] Mayatskaya I A, Demchenko B M, Shvetsov P A 2016 On the possibility of improving the meshy plates and shells based on bionic principles Regional architecture and construction 2 (27) 137-145.
[10] Mayatskaya I A 2016 On the possibility of improving building structures based on bionic principles. *Bulletin of the Volgograd State University of Architecture and Civil Engineering. Series: construction and architecture* 45 (64) 27-36.