Bio-inspired transformable elastic structures with hard covering

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Abstract

The principle of the structural organization of living organisms based on external supporting systems or exoskeletons is widespread in living nature. This structural principle characterizes arthropods, which make up 2/3 of all species of living creatures on Earth, including insects and crustaceans. Characteristic feature of arthropods are their shells (cuticles), located on top of the internal soft resilient tissues, which work together as complex elastic envelopes.

Constructive shell systems based on biological principles were studied since the late 1960s in the Laboratory of Architectural Bionics in Moscow [1]. The studies have shown that natural shells are usually designed not only for compression, but also for bending and stretching. Forms of natural shells successfully combine tension, rigidity and stability. An example would be a hen's egg shell with a variable cross section, a crab shell, a scallop shell, etc.

The results of the studies were based on experiments with models of elastic structures with a hard covering. In these experiments, transformable woven structures made of an elastic continuous closed rod in the form of cyclic knots, were used for the creation of the frame base of the shells [2].

The woven frame shells of an elastic continuous closed rod have a variable spatial rigidity due to a change in its geometry from flat to elliptical shape. The transformation of the structure occurs continuously in accordance with the changing of inclination of the tangent to the horizontal plane. The calculation of such structures can be carried out on the basis of a universal spatial highly flexible rod nonlinear finite element.

The spatial rigidity of a transformable elastic woven shell depends on its shape. It is non-linear in nature and increases from the minimum value, in the initial flat stage of transformation, to its maximum, as it approaches to the ultimate elliptical stage. Knowing the material characteristics of the elastic rod, its cross-sectional diameter, the applied load and its anchorage points, allows calculating such structures and completely determine their deformation.

The outer hard covering, similar to the structure of the shell of arthropods, is attached to the inner woven elastic shell to create a multilayered structure, where the outer shell has greater rigidity than the inner bearing and formative framework.

Rigid outer plates are attached to an elastic inner structure, stabilize its shape and transmit forces to it. Such a complex construction allows the outer shell to be made as light as possible, which is observed in the similar systems of living nature.

References

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