Nature Inspired Optimal Composites

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Biological tissues are mostly presented by composites with optimal mechanical properties including low specific weight at high strength and durability. These properties are also desirable for the technical and biomedical materials, which can be composed basing on the Nature inspired optimal solutions.

Bone biomechanics initiated the mechanics of adaptive materials that can remodel their microstructure according to the applied external load. The bone tissue is formed by osteons (multilayered cylindrical shells) and trabeculae (small beams) composed from collagen and calcium. The trabeculae of the sponge bone form two orthogonal families corresponding to the principals of the stress tensor. As a result the bone works resisting compression and extension thanks to the two families of trabeculae elongated properly. When the external load is changed, the inner structure is adapted according to the stress distribution produced by the varying load.

Plant cells differ from the animal cells by the rigid cellular walls. The inner structure formed by a continuous system of cell walls also corresponds to the principals of the stress tensor. The cell walls are elongated in radial, tangential and axial directions in the normal tree trunks and branches. When a tree is grown at a certain wind load, the cell walls form spiral grains resisting the twisting of the trunk and the branches.

Blood vessel wall is formed by layers with different anisotropy type produced by reinforcing fibers and cells. The inner structure of skin is produced by collagen fibers of different thickness, orientation and interlacing types depending on the bearing loads. As a result the skin exhibits different extensibility according to the principals of the stress tensor controlling the fiber orientation and thickness. The classification of the mechanical structures of the skin is given and analyzed from a biomechanical viewpoint.

The reinforcement by a complex system of tubes is proper to different animal and plant organs. The branching systems of blood vessels and airways exhibit some regularity between the diameters and branching angles of the tubes in bifurcations. The identical regularities have been found in the tree crowns and in the conducting systems of plant leaves of different size, shape, venation type and evolutionary age. The obtained regularities correspond to an optimal pipeline providing delivery of water and substances to the distributed system of live cells at minimal total energy expenses. Besides the blood vessel systems and airways serve as mechanical cages for the soft inner organs, as well as the venation system provides mechanical reinforcement of the leaves keeping their orientation to the sun against gravity, wind and rain loads. The optimization principles implemented in the leaf reinforcement by conducting elements can be proposed as a Nature inspired solution for the heat and mass exchangers, biomedical applications and MEMS technology. The numerical results for the round and rectangular plates with different reinforcing structures are presented and discussed.