APPLICATION OF BIOMECHANICAL PRINCIPLES FOR DESIGN OF COMPOSITE STRUCTURES

A. Malakhov*, A. Polilov
Department of Strength, Survivability and Safety of Machines, Institute of Machines Science named after A.A.Blagonravov of the Russian Academy of Sciences, Moscow, Russia
* Corresponding author (anmaviko@gmail.com)

Keywords: composites, concentration stress, curvilinear fibers, biomechanics

A weak point of composite structures remains fastening joints owing to the traditional perforation technology for rivets or bolts. Nature suggests an alternative making of joints without cutting fibers and using curvilinear reinforcement structure in places of junction such as, for example, “branch-trunk” or “trunk-root”.

The paper describes modeling of wood structure, namely fiber distribution in a “branch-trunk” junction. The area around the knot is simulated by the orthotropic plate with a hole under tensile stress. In this research a hypothesis is used that the fibers are located along the force-flow lines, that is, along the trajectories of maximum principal stress [1]. Trajectories of the force flow created on the ground of this hypothesis show a qualitative similarity with the inside knot structure (Fig.1).

On the basis of created trajectories the structure is simulated by means of finite element method. Each element of this structure is allocated its own mechanical properties depending on the distribution of the fibers. The fiber direction is modeled by means of assigning its own local coordinate system for each element. The local coordinate system is directed along maximum principal stresses that corresponds to the direction of the axis of greatest stiffness. A change of the volume fraction of fibers depends on the obtained distribution of fibers. The elastic material constants change according to the fiber-volume fraction. Thus, the created discrete model takes into account the change of direction and the volume fraction of fibers. The similar models were described in papers [1,2], but the latter did not consider a variation of fiber-volume fraction.

The stress state in the new structure changes after each element is assigned local material properties depending on the distribution of fibers. The new structure has other trajectories of fibers conforming to the new stress state. A solution of this problem has iterative character and this process will end, when the field of stresses from iteration to iteration is not practically changed. Using of the mentioned above hypothesis implies the fact that shear stresses in the structure are minimized along fibers. It is described in the paper that in the created structure not only shear stresses decline, but stresses along fibers in the concentration stress zone are also reduced. This in turn leads to the increase of load-carrying capability. According to the maximum stress failure criterion the strength is defined taking into account fiber-volume fraction. It appears that in the created structure with curvilinear trajectories of fibers there is only a slight increase in the value of failure criterion (~ 20%), while in the structure with rectilinear trajectories of fibers the value of failure criterion increase by 5-7 times.

Thus, it is obvious that a decrease of stress concentration and growth of strength can be achieved by special distribution of fiber structure consistent with the field of stresses. Studying and understanding of biomechanical principles helps find new approaches to creating optimal composite structures. The methods developed on the basis of biomechanical principles make it possible to design composite structures and places of junction more efficiently.

Fig.1. The distribution of fibers around a knot.

References