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Strength and Fatigue of Natural and Artificial Materials

Alexander Berlin*

Semenov Institute of Chemical Physics of the Russian Academy of Sciences, Department of Chemical Physics, Russian Federation

***Corresponding author:** Alexander Berlin, Semenov Institute of Chemical Physics of the Russian Academy of Sciences, Department of Chemical Physics, Russian Federation, Tel: + 79035234004; E-mail: berlin.a@yandex.ru

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Commentary

Material strength is a complex concept that includes the material resistance to various types of loading. Often the improvement of strength in one type of load leads to deterioration in the other. For example, the ordinary window glass is quite durable material under the pseudo-static slow loading, but it is easily broken upon impact. In solid mechanics, there are conceptions of the static strength and fracture toughness characterizing resistance to the crack growing in a material. The glass has very low fracture toughness: A crack propagates easily in it. Metals can possess both high strength and high fracture toughness. These characteristics are largely determined by the possibility of dislocations movement. The easier the dislocations move, the lower the static strength, but the higher the fracture toughness, the harder the crack propagates. Therefore, the introduction of special additives impeding the movement of the dislocations (for example, carbon in iron) leads to an increase in the static strength, but also to rising in brittleness and facilitating the crack propagation [1-3].

Nature and human beings, following to it, found a way out of this contradiction by creating composite fibrous materials such as wood or glass-reinforced plastics. In this case, a crack arising from a fiber break encounters an adjacent fiber and turns along the fiber due to the large difference in the strength of the fibers (high) and the binder or interphase between them (low). Thus, the crack propagation across the loading direction becomes less dangerous, being located along the straining. This occurs when stretching of the unidirectional fibrous material happens along the fibers (the reinforcement direction). Selecting the desired reinforcement scheme, i.e., the location of the different layers depending on the external loading, the equal-strength material can be got, which cannot be obtained from anisotropic material [4,5]. A pipe operating at high internal pressure is a typical example. In this case, the radial stresses are approximate twice the axial stresses. This means that a pipe made of an isotropic material (metal, polymer, ceramic) always breaks along the pipe axis due to the radial stresses. To protect a pipe in this mode we would thicken its walls using too much material. From a unidirectional anisotropic material, we can construct an equal-strength structure by placing along the axis half of layers in comparison with radial direction. In the same way we can design other, more complex parts, forming equal-strength products. This is an example of how we can use two different strength characteristics-the static strength and fracture toughness [6,7].

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Another characteristic of the material strength –is the fatigue strength under cyclic bending. It is well known that a metal wire is readily broken after a few bending. The same thing will be happened, for example, with a plastic comb. The fact is that solids accumulate defects (dislocations in crystalline materials, dilatations in glasses, crazes in polymers, etc.) under large plastic deformations. These defects turn into cracks leading to material destruction. Unlike solids, in liquids, during defects are not accumulated with deformation (flow) or they quickly relax and the body returns to an equilibrium state. For large bending deformations of, say, bones, nature invented a special "device" as articulations containing the liquid lubricant, which is able to support large deformations. Similarly, lubrication works in bearings [8,9].

A tree is especially interesting. The liquid juice in the living branches, apparently, takes over large bending deformations. If a tree or branch dries up, it becomes brittle and breaks easily when bent. At low temperatures, the liquid juice seemingly should freeze and a tree should become brittle. Yes, it is the truth. However, in such trees as larch, which can survive even at Siberian frosts, its juice is an aqueous solution of a polysaccharide (arabinogalactan), freezing at very low temperatures (eutectic). Elastomers and rubbers are other materials that do not accumulate defects during deformation. These materials are in the liquid state under normal conditions ($T>T_g$, T is the operating temperature, T_g is the glass transition temperature) and relaxation times of their structure are relatively low. The muscles of animals and humans or tires, as well as rubber products that man has created, are arranged in the same manner.

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