PERSONALIA

Serafim Nikolaevich Zhurkov (on his seventieth birthday)

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May 29, 1975 was the seventieth birthdy of Academician Serafim Nikolaevich Zhurkov, chief of the Strength Physics Laboratory of the A. F. Ioffe Physico-technical Institute of the USSR Academy of Sciences.

Zhurkov devoted his scientific career for the most part to a single major problem—determination of the physical nature of strength. In the development of this problem, whose history spans a thousand years, Zhurkov succeeded in bringing about radical reforms that made possible further successful development of the science of strength.

One can cite two basic problems on which Zhurkov concentrated his attention in his studies in the physics of strength for over 40 years: 1) experimental attainment of the theoretical strength of materials, 2) ascertaining the atomic-molecular mechanism of the failure of solids.

Zhurkov began his scientific career in 1930 at the Leningrad Physico-technical Institute (after graduating from the Physicomathematical Faculty of Voronezh State University). By that time, theoretical values of the strengths of solids had already been calculated (on the basis of data on the interatomic cohesive forces and for an ideal defect-free structure, by M. Born, F. Zwicky, and others). The questions arose as to whether the enormous ultimate strengths predicted by the theory could ever be achieved in practice, and as to the causes of the disagreement (by tens and hundreds of times) between the theoretical strength and the ordinary strength determined in experiments.

A. F. Ioffe's classical experiments of the 1920's on sodium chloride had shown that the strength of the specimens can be increased by many times by eliminating defects from their surfaces. Working with A. P. Aleksandrov, Zhurkov extended these studies to glass and quartz filaments. He etched the surfaces of filaments in hydrofluoric acid, which removed superficial cracks. The tensile-strength values obtained under these conditions were unheard-of at the time: up to 1300 kg/mm^2 for quartz and 600 kg/mm^2 for glass. These values were comparable with the theoretical strengths of the materials studied.

The results of another series of Zhurkov's experiments supported the hypothesis that local defects are responsible for the low practical strength values. He stated the manner in which the strength of the filaments depends on their diameter: strength increased with decreasing diameter.

These data formed the basis for later statistical theories of strength, in which the strength of the body was related to the probability that dangerous defects are present both in the interior and especially on the surface of the body. Naturally, this probability decreased with decreasing volume. Miniaturization of the specimens was also another device that made it possible to move closer to the theoretical strength.

Thus, Zhurkov solved a fundamental problem in his very first studies in strength physics: he demonstrated the real possibility of attaining theoretical strength. This was extremely important, because confirmation of the existence of tremendous strength reserves in solids stimulated the development of research aimed at finding ways to improve the technical strength of materials.

Production of synthetic polymers, which have important and specific mechanical-property features, began to develop rapidly in the mid-1930's. A group of FTI scientists headed by P. P. Kobeko and A. P. Aleksandrov and including Zhurkov addressed itself to the study of these most interesting objects.

Zhurkov began to study the role of intermolecular interactions in the hardening (or softening) of the polymers. He investigated the influence of plasticizing (introduction of low-molecular-weight compounds into the polymer) on the hardness of the products and their softening temperatures. The Second World War interrupted the "academic" progress of these studies. At Kazan', Zhurkov successfully applied his observations of plasticizer effects to the solution of important defense problems: improving the stability of lubricating oils at subfreezing temperatures and oxidative plasticizing of synthetic rubbers.

On his return to Leningrad after the war, Zhurkov completed his studies of the hardening and devitrification of polymers, the results of which were summarized in his doctorate dissertation "A Study of the Mechanism of the Transition of Polymers from the Solid to the Rubber-like State" (1947).

On the basis of the results of his studies, Zhurkov developed a theory of the hardening of polymers as a process of formation of local "bridges"—links that secure the polymer chains to one another at certain places. These nodes are formed at radicals appended laterally to the chain molecules. The plasticizer works by "screening" active radicals.

To obtain a quantitative determination of the number of "bridges," Zhurkov resorted to measurement of heat capacity vs. temperature curves, developing a new and extremely clever low-lag technique for measurement of heat capacity.

At the same time, Zhurkov was looking for ways to confirm his hardening mechanism more directly. Using infrared spectroscopy, he succeeded in obtaining direct estimates of the ratio between the free radicals and the radicals that are bound to one another. A study of the absorption spectra of polymers with hydrogen bonds at various temperatures showed that the numbers of bound and free hydroxyls change sharply in the softening range. These experiments provide full confirmation for the molecular mechanism of the gas transition in polymers that Zhurkov had proposed.

Having successfully solved a fundamental problem of polymer physics—that of establishing the mechanism by which polymers harden (or soften), Zhurkov returned to the problem that interested him most: that of determining the physical nature of the strength of solids.

The late 1940's saw the beginning of a new phase in Zhurkov's work: a period in which he studied the atomic-molecular mechanism of the failure of solids. Prior to that time, concepts in which failure was regarded as a purely mechanical process had been generally accepted. It was assumed that the external tensile load is distributed among the interatomic bonds and pulls the atoms apart. If the external force is large enough, the atoms are disconnected and the body fails. From this standpoint, it was quite natural to solve the problem of the strength of a solid on the basis of comparison of the forces loading the bonds and the interatomic cohesive forces. The concept of "ultimate strength"—the critical external stress an excess over which causes an abrupt loss of stability of the body in the sense of its resistance to failure—is quite consistent with these conceptions.

Zhurkov began by questioning the existence of the ultimate strength as a real physical characteristic of materials. These doubts arose from data to the effect that bodies can also fail under loads smaller than the ultimate strength. In these cases, of course, failure does not occur at once, but only after a certain time, which is longer the smaller the applied load. At that time, such data were comparatively rare, scattered, and unsystematic. No serious physical importance was attached to such observations, and it was assumed that they represented side effects of miscellaneous factors (such as corrosion, aging, etc.) that eventually lowered the ultimate strength. However, Zhurkov saw in them an opportunity to develop a general physical aspect of failure.

First of all, Zhurkov made careful and systematic measurements of the longevity of bodies under tensile loads, i.e., of the time between the application of the load and the failure of the body. Machines developed in his laboratory made it possible to perform these measurements over an enormous range of longevity values (spanning ten orders of magnitude, from thousandths of a second to many months). The tensile stresses and temperature were varied widely from one experiment to the next. Many of the experiments were carried out in hard vacuums. Over a hundred substances, representing all of the basic types of solids, were tested: metals, alloys, glasses, polymers, crystals with various types of interatomic bonds, composition and heterogeneous materials. It was found that the ability to fail under any load is a property common to all of the materials studied. Moreover, the functional relationship for the dependence of longevity (τ) on the external conditions at failure—stress (σ) and temperature (T) also proved to be surprisingly consistent. Analytical reduction of an enormous amount of experimental material led Zhurkov to a universal formula for the temperature-force dependence of longevity (universal except at very small stresses):

$$\tau=\tau_0 \exp\left(\frac{U(\sigma)}{kT}\right),$$

where $U(\sigma) = U_0 - \gamma\sigma$, k is Boltzmann's constant, τ_0 has the same (in order of magnitude) value ($\sim 10^{-13}$ sec) for all solids in all of their states, U_0 is a constant for a given substance irrespective of its structural state and processing, but varies from one substance to another, and γ depends on the prior treatment of the given material and varies in a broad range as the structure of the material varies.

First, Zhurkov drew attention to the fact that the longevity of a body depends equally on both the applied mechanical force (tensile stress σ) and its temperature. Both of these quantities appear in the argument of the exponential. This permitted a conclusion of very important physical content: thermal motion (of whose intensity the temperature T is a measure) is an important factor in the failure process.

The form of the temperature dependence of longevity enabled Zhurkov to establish the manner in which thermal motion influences the course of failure. The proportionality of the "Boltzmann" multiplier $\exp(U/kT)$ to τ indicates that thermal motion participates in failure in the form of thermal fluctuations—sharp "bursts" of kinetic energy that appear from time to time at atoms of the body. This is given particular stress by the surprising similarity between the expression for $\tau(T)$ and the well-known expression of Ya. I. Frenkel' for the average time τ_{fl} between two successive fluctuations that impart a kinetic energy E_{fl} to a given atom: $\tau_{fl} = \tau_a \exp(E_{fl}/kT)$, where $\tau_a \approx 10^{-13}$ sec is the average period of the thermal oscillations of atoms in condensed bodies. We see that $\tau_0 \approx \tau_a$. Consequently, it is the energy of the thermal fluctuations, and not the energy of the average thermal vibrations, that enables atoms to overcome the interatomic cohesion barriers. Accordingly, the content of $U(\sigma)$ is that of the activation energy of the failure process, and it followed from the established formula that this energy depends on the applied stress, decreasing with rising σ. The value of U_0 (the initial activation energy) is determined from longevity measurements. Comparison of the values of U_0 (those obtained by Zhurkov and his co-workers) with the activation energies of thermal decay of interatomic bonds (the sublimation energy in metals and crystals and the thermal destruction energy in polymers) showed good agreement between these quantities. This agreement definitely confirms the conclusion that the energy of the thermal fluctuations is expended to disconnect atoms in solids under loads, which is the essence of the failure process. But then what is the role of the external mechanical force? In light of the new, kinetic conception of failure, the tensile stress applied to a body has two effects: the first is to reduce the decay energy of the bonds and thereby sharply increase the probability of their fluctuations failure, and the second, an especially important effect, is to lower the recombination probability by moving disconnected atoms farther apart. It might be said that the external force acts as a kind of valve that directs the destructive effects of the thermal fluctuations. Here it is important to stress that the mechanical force in operation directly at the sites at which interatomic bonds decay proves to be much larger than would follow from the average-stress (σ) values. This is indicated by the fact that the value of γ in the longevity equation is tens and hundreds of times larger than the volume of the atom (the approximate value of the activation volume of interatomic-bond decay). These overstresses arise as a result of the structural heterogeneity of real bodies, which results in nonuniform distribution of the external load among the interatomic bonds. It is naturally at these points that thermal-fluctuation bond-breakage processes advance most actively. Failure centers, whose development culminates in the falling apart of the body, are formed here.

Thus, according to the theory developed by Zhurkov, the failure process is an atomic-kinetic process. Moreover, the strength of a body as a measure of its resistance to an external force disturbance is determined not only by interatomic cohesion forces, but also by the intensity of the thermal motion. Hence arose the concept in which the strength of solids is of kinetic nature. Introduction of these new conceptions should be recognized as a very great contribution to the development of strength physics.

The approach to the analysis of failure as a kinetic process consisting of a sequence of elementary interatomic-bond decay events moved Zhurkov to introduce extremely progressive changes into the very nature of experimental research on failure. With the object of confirming the kinetic concepts and following the progress of failure in its details, Zhurkov was the first to bring a wide range of physical and physicochemical methods to bear on the solution of "mechanical" problems in his laboratory. Methods that were "unconventional" in strength research were used: infrared spectroscopy, electron paramagnetic resonance, mass spectrometry, nuclear magnetic resonance, chromatography, small-angle diffraction of light and x-rays, electron microscopy, etc. Using this arsenal, Zhurkov and his co-workers succeeded in obtaining unique data on the true local stresses on the interatomic bonds, on the failure of these bonds, on the secondary molecular-destruction processes initiated by these bond failures, on the generation of embryonic breaks in continuity—extremely minute embryonic cracks, on the kinetics of pregressive enlargement of these cracks, and so forth. The use of precision modern methods made it possible to raise the experimental study of failure to a new level, to make this study genuinely physical. This approach opens broad prospects for the development of strength research in its fundamental aspects—for the construction of a quantitative and detailed theory of strength.

Zhurkov's work has won wide recognition in the USSR and all over the world. It has had a strong influence on the development of the strength-physics research under way in many countries.

This is witnessed by the election of Zhurkov as Vice President of the International Congress on Failure of Materials.

His birthday finds Serafim Nikolaevich Zhurkov, a major scientist and a Communist, embarking on bold new searches and profound new investigations whose aim is to solve the most important problems in the way of development of the ultrastrong materials of the future.

Translated by R. W. Bowers