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SERAFIM NIKOLAEVICH ZHURKOV

(on his sixtieth birthday)

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SERAFIM Nikolaevich Zhurkov, corresponding member of the USSR Academy of Sciences, director of the Laboratory of the Physics of Strength at the A. F. Ioffe Physico-technical Institute of the USSR Academy of Sciences was sixty years old on May 29, 1965.

Zhurkov belongs to the type of scientists who devote their entire scientific life to one large problem. For Zhurkov this was the problem of the physical nature of the mechanical properties of solids and above all their strength. Until the last few decades there was no substantial progress in solving this problem which has a history of thousands of years. A physical approach was needed for the study of the mechanical properties of real solids and for the study of such changes which take place in solids under loading.

Zhurkov started his scientific activity at the Physico-technical Institute in 1930 (after completing his studies at the physico-mathematical faculty of the Voronezh State University) in a crucial period of development of the science of strength. The theoretical strengths of solids had already been calculated at that time (on the basis of data from atomic and molecular theory of structure and of ideal defect-free structure), and the gap between the mechanical possibilities with which nature provided solids and their actual properties became clear. The problem arose of explaining the reason for such a large (up to a hundredfold) discrepancy, and of considering the possibility of bringing the actual strength closer to the theoretical strength. Following A. F. Ioffe, Zhurkov together with A. P. Aleksandrov showed that by suitable treatment of solids (removal of defects from their surface) one can come closer to the theoretical strength. The results of the experiments carried out by Zhurkov on quartz and glass fibers, in which strengths of 1300 and 600 kg/mm^2 were obtained for quartz and glass respectively, became a classical contribution to the study of the mechanical properties of solids.

Thus Zhurkov solved in his first important work a fundamental problem—he showed that it was possible to attain the theoretical strength. This was of extreme importance, since it stimulated the development of investigations leading to a search for means of increasing the technical strength of materials.

In the middle Thirties an important event occurred: there appeared sufficiently large quantities of synthetic polymers, among whose properties the mechanical properties are of great scientific and practical interest. A strong group of scientists of the Physico-technical Institute (P. P. Kobeko, A. P. Aleksandrov, E. V. Kuvshinskiĭ, Yu. S. Lazurkin, and others) turned to a study of these most interesting objects. Zhurkov belonged to this group. The fundamentals of the science of physico-mechanical and relaxation properties of polymers were established at that time at the Physico-technical Institute.

The properties of polymers are unusual for solids: their enormous reversible deformations, the strong temperature dependence of the elastic properties, the gradual transition from the solid to the liquid-like state all led to the initiation of profound systematic investigations.

Zhurkov started to investigate the role of intermolecular interactions in the determination of the mechanical properties of polymers. He posed the problem of explaining the molecular mechanism of "softening" of polymers with increasing temperature. In studying the *plastification* (introduction into the polymer of low molecular weight compounds) on the softening temperature of polymers, Zhurkov established the important equivalence law: the introduction into the polymer of equimolecular quantities of various compounds results in equal shifts of the temperature interval of softening. The analysis of this law led Zhurkov to a conception of hardening of polymers as a process of formation of relatively strong bonds between active groups and the side chains of polymer chains interconnecting these chains at certain points. The effect of the plasticizer consists in "screening" of these active groups.

In Kazan during World War II Zhurkov applied successfully the laws governing the action of plasticizers to the solution of serious defense problems: increasing the frost-resistance of lubricating oils and improving the exploitation of the properties of rubber based on synthetic rubbers.

After the war, continuing the development of the investigations on polymer softening, he carried out exceptionally elegant experiments, measuring the temperature dependence of the heat capacity in the region of softening of polymers. These calorimetric investigations were the basis of an estimate of the "knot" concentration in a hardened polymer. However, Zhurkov was not satisfied with all these data. He sought a method for a direct confirmation of the hardening mechanism he proposed. This is a feature characteristic of Zhurkov—not to confine himself merely to phenomenological investigations, but to prove the reality of the particular molecular process by means of suitable microscopic experiments.

The clear proof of the hardening theory developed by Zhurkov was the direct measurement of the ratio between free radicals and those bonded to each other, which was carried out with the aid of infrared spectroscopy. The study of the absorption spectra of various polymers with hydrogen bonding showed that the number of free and bound hydroxyls changes sharply in the region of softening. These experiments fully confirmed the molecular mechanism of vitrification of simple and polymer compounds.

Summarizing the second main period of his scientific activity, one should note that it was devoted to the fundamental problem of polymer physics—the molecular mechanism of hardening (or softening)—and that it was crowned by a theory generally accepted at present. For Zhurkov's further creative path the circumstance was important that the change in the mechanical properties of polymers and simple amorphous solids was related by him, at this point, to molecular processes of a kinetic, activational nature, i.e., the mechanical properties of solids were then already closely tied to the thermal motion of the molecules. This profoundly physical direction was characteristic of the entire school of A. F. Ioffe and his students, P. P. Kobeko, A. P. Aleksandrov, and others.

At the end of the Forties a new, very important period began in Zhurkov's work—the period of study of the fracture mechanism of solids.

Zhurkov drew attention to the separate, disconnected and nonsystematic data indicating that a solid may also fracture at loads smaller than its strength, not at once but after a time which is the longer the smaller the loading. No special physical significance had been previously attached to such observations and it was thought that one is dealing here with the side effects of various factors (corrosion, aging, etc) which decrease the strength in time. Zhurkov, on the other hand, proposed that the presence of a time dependence of the strength indicating a deep physical connection of fracture with time is the very essence of fracture. Experiments carried out on a large number of solids (metals, polymers, glasses, ionic compounds—more than 50 in all) showed that all solids have a time dependent strength. The analytic processing of a large volume of experimental material led Zhurkov to a universal formula for the time dependence of the strength

$$\tau=\tau_0 \exp[(u_0-\gamma\sigma)/kT],$$

where τ is the "lifetime" of the sample (from the moment of loading until fracture), δ is the applied stress, T the absolute temperature, k the Boltzmann constant, and τ_0, u_0, and γ are coefficients; τ_0 is constant for all studied solids regardless of state, u_0 is constant for the given material regardless of its structural state or treatment; γ changes even for the same material on treatment (preliminary heat treatment, mechanical action, alloying, plastification, etc.).

Zhurkov's identification of the coefficients showed that τ_0 has an order of magnitude of 10^{-13} sec and is close to the period of the characteristic thermal vibrations of atoms in solids; u_0 coincides very accurately with the bonding energies of the atoms in the crystal lattice (for metals), or with the chemical bonding energies (for polymers and chain molecules); γ characterizes the extent of the decrease of the potential barrier of interatomic bonds by the applied stress and being as a rule many times larger than the dimensions of the atomic volume reflects the difference between the practical and theoretical strength, i.e., it is an indicator of the imperfection of the material.

The obtained formula is thus not a simple empirical expression describing the experimental results, but has a deep physical meaning shedding light on the fracture mechanism as indicated by the kinetic, "Boltzmann" form of this equation.

What conclusions then did Zhurkov draw regarding the fracture of solids?

1. The fracture of solids is a process which develops in time and not a critical event, as was previously assumed. Fracture is an irreversible process which starts when the load is applied and which is completed by the falling apart of the solid.

The irreversibility of the process was established with the aid of experiments with interrupted loading. The total lifetime of the sample turns out to be equal to the durability of a sample without interruption of the experiment.

2. The physical significance of the limiting strength as a material constant is invalidated. The appearance of this concept is readily explained on the basis of the time dependence of strength when at correspondingly low temperatures the dependence becomes very strong, creating the impression of a threshold stress.

3. The fracture process consists of a sequence of elementary acts—the breaking of interatomic bonds—occurring via thermal fluctuations with the external stress acting as its activator.

4. In a real solid there exist peculiar "levers" which increase greatly the local action of an external force on account of its nonuniform distribution over the interatomic bonds.

Particular attention should be accorded to point 3 where Zhurkov drew a conclusion regarding the fracture mechanism. The interesting fact is not the conception that the fracture consists of a "separation" of atoms (this was naturally also assumed previously), but how the separation occurs and what the role of the external force is. According to Zhurkov this separation is not affected by the external force (a fact which would have seemed obvious previously) but it is effected by the energy fluctuations due to the thermal motion of the atom. The external strength merely provides the conditions for the "fracture" activity of the fluctuations, lowering the barrier and determining the direction of the fracture process.

Without thermal motion the atoms would only be slightly separated through the action of the external force, but they would not be parted. The main work of fracture is thus effected not by the external force, but by the thermal energy averaged over the solid.

Thus, Zhurkov arrived, on the basis of a phenomenological study of the time dependence of the strength, at very radical changes of conceptions about the fracture mechanism. These conclusions marked a new, fruitful era in the study of strength and will undoubtedly serve as a starting point for further development of this science.

Zhurkov's characteristic feature, which has already been mentioned, not to be satisfied merely with phenomenological studies, led to the development in his laboratory of a whole complex of physical methods applicable to the solution of the following two problems:

1. The direct demonstration of the reality of the fracture process as a succession of elementary acts of interatomic raptures, and a study of the specific details of these experiments.

2. A determination of the specific structural conditions of the fracture process, i.e., the elucidation of those features of the structure of real solids which lead to local stresses and accelerate thereby greatly the course of fracture.

The real nature of the successive breaking of interatomic bonds by thermal fluctuations in polymers under load was proved directly by the methods of electron paramagnetic resonance, mass spectrometry, infrared spectroscopy, and a study of the behavior of polymers under the action of ultraviolet irradiation.

The points of the localization of superstresses in solids, i.e., the fracture levers—the boundaries of the mosaic blocks in metals where dislocations accumulate, amorphous, disordered regions of polymers—were established by the use of direct structural methods (x-ray diffraction, infrared spectroscopy, electron microscopy, nuclear magnetic resonance). Direct correlations of the strength with the characteristics of these "dangerous" regions were found. It was shown that in metals the strength (with account of its time dependence) is uniquely determined by the misorientation of the blocks, i.e., by the dislocation density at their boundaries. In polymers a direct connection was established of the strength with the orientation of the chain molecules in the amorphous portions.

All these data allowed Zhurkov to start on a purposeful and well-based solution of a most important problem, the increasing of the strength of solids, in which substantial results have already been attained.

Thus, intensive and fruitful investigations are being carried out in Zhurkov's laboratory by physical methods unique in their elegance; an important feature of these investigations is their firm physical foundation laid down by a study of the time dependence of the strength.

The ideas and results of Zhurkov's work had a greatly stimulating influence on the setting up and development of investigations far beyond the limits of his laboratory and their direct "strength" subject matter.

The works of Zhurkov's school are widely recognized within the Soviet Union and abroad. Numerous students and followers of Zhurkov continue and develop this exceptionally fruitful and promising direction of research.

On July 16, 1955, the Presidium of the Supreme Soviet of the U.S.S.R. awarded Serafim Nikolaevich Zhurkov the Order of the Red Banner of Labor for his achievements in the field of physics and in connection with his sixtieth birthday.

Zhurkov, a great scientist and a communist, is at the peak of his scientific creativity and, undoubtedly, on the verge of new and most interesting discoveries.

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