A comparison of the static and cyclic lives of various polymers shows that, whatever the loading regime, fracture may be regarded from the standpoint of the thermal-fluctuation theory. Under comparable test conditions the lifetimes in different loading regimes coincide. The experimentally observed cases of a reduced cyclic as compared with static life do not conflict with the kinetic theory of fracture and can be attributed to hysteresis heating effects or to differences in the structural changes that take place in the test material in different loading regimes.

There have been numerous studies of the cyclic fatigue of polymers and other solids (see, for example, [1-5]). The extensive experimental material has been examined by various authors from various standpoints, theoretical and practical.

However, one of the latest developments, based on a consideration of the phenomenon from the standpoint of the kinetic theory of strength, has not yet received much attention in the reviews [6]. The number of studies, in which this theory is applied to polymer fatigue, is increasing all the time [6-46]; accordingly, it is now desirable to summarize the first results of this research, emphasize the special aspects of the kinetic approach, enumerate the principal results obtained so far, and note certain problems that have arisen. This is the subject of the present review.

We shall not consider the many recent studies of polymer fatigue (for example, [47-58], etc.) that do not raise the question of the interpretation of the data from the standpoint of the kinetic theory. Neither shall we include studies of the fatigue behavior of polymers in the high-elastic state, including rubbers, since fatigue in elastomers is complicated as compared with fatigue in the glassy and oriented polymers, with which this review will be concerned. Research on vibrocreep, which has recently been the subject of special reviews [59, 60], will also be omitted.

The discussion will chiefly revolve around the research recently conducted in the Physics of Strength Laboratory of the A. F. Ioffe Physicotechnical Institute, Academy of Sciences of the USSR, although due allowance is naturally made for the work of other authors who have approached the fatigue problem from a similar standpoint.

Although the basic principles of the kinetic theory of the strength of solids are quite well known (see, for example, [61-67]), we will start by briefly reviewing them, in order to formulate the problem with maximum clarity and emphasize the particular features of the kinetic approach.

The general organization of the material will become apparent from the statement of the problem and in the course of the subsequent discussion.

1. Basic Principles of the Kinetic Theory of Strength

From the standpoint of the kinetic theory, fracture is regarded as a certain process that develops in a body under load and not as a critical event that occurs when a critical stress — ultimate strength — is reached.
In the kinetic theory the elementary events of the fracture process are thermal-fluctuation breakages of interatomic bonds. For polymers these bonds may be chemical or intermolecular. Successive breakages lead to the macroscopic failure of the specimen: to the formation and growth of cavities and cracks and eventual disintegration.

From the standpoint of the kinetic theory, fracture, as a time-dependent process, cannot be characterized by a critical stress. Like any kinetic process, it must be characterized either by the rate of the process (number of bonds broken per unit time, rate of crack growth, rate of damage accumulation, etc.) or by its reciprocal—the time required for a certain amount of damage to accumulate or the total life of the specimen under load.

These ideas are based on a systematic study of the temperature-time dependence of the strength of a broad range of materials and have now received direct confirmation in a number of experiments based on the use of modern physical methods capable of registering the elementary fracture events [68-74].

The empirical expression of the dependence of the life \( \tau \) on stress \( \sigma \) and temperature \( T \)

\[
\tau = \tau_0 \exp \left( -\frac{U_0 - \gamma \sigma}{kT} \right),
\]

obtained by Zhurkov and coworkers [61-67], is interpreted as an equation reflecting the nature of the fracture process. As a rule, the coefficient \( \gamma \), with a value close to \( 10^{-2} \) sec, is associated with the period of the natural vibrations of the atoms in the solid. \( U_0 \) is the activation energy of the fracture process. Experience has shown that it is closely correlated with the energy of the interatomic bonds.

In most cases it has proved possible to neglect the theoretically predicted weak dependence of the pre-exponential coefficient in (1) on temperature \( T \) and stress \( \sigma \) and, moreover, the dependence of \( U_0 \) on \( T \). In other words, the coefficients \( \tau_0 \) and \( U_0 \) may be assumed constant and structure-insensitive for a given material.

The only structure-sensitive coefficient in Eq. (1) is the coefficient \( \gamma \), whose physical significance has still to be finally determined. On the one hand, this coefficient may reflect the degree of nonuniformity of the stress distribution in the investigated solid and thus characterize the local stress concentration at the points at which fracture develops; on the other hand, \( \gamma \) may characterize the activation volume, in which the unit thermal-fluctuation fracture event takes place. All the complicating factors that must be taken into account in calculating the total time required to fracture the specimen should, in fact, affect the quantity \( \gamma \).

Since the coefficient \( \tau_0 \) and \( U_0 \) in Eq. (1), which reflects the macroscopic fracture process, are the same as in the equation for the breakage of a single bond, i.e., in the equation of the microprocess, it is clear that on transition from the microprocess (elementary fracture event) to the macroprocess the coefficient \( \gamma \) plays the part of a complex integral characteristic that averages all the changes in the conditions affecting the fracture of the individual bonds. It may be assumed that any changes in the loading conditions, including a transition from static to cyclic loading, will primarily affect precisely this structure-sensitive coefficient.

2. Formulation of the Problem

According to the kinetic theory, a change in the loading regime, for example, a transition from static to cyclic loading, should not radically affect the nature of the fracture process. In both static and cyclic loading fracture should be based on the identical elementary bond rupture events. In both cases failure is the result of a process of successive accumulation of elementary events, i.e., the superposition of breakages, and should be characterized by the rate of this process (the rate of damage accumulation). From this standpoint it is incorrect to contrast the temporal nature of cyclic fracture with the apparently time-independent critical nature of fracture under static loading. For a correct understanding of the relationship between static and cyclic fracture and certain features of the cyclic as compared with the static fracture process it is necessary to compare the rates of the process (rates of damage accumulation) in different loading regimes or their reciprocals, i.e., lifetimes. In other words, in order to compare the processes of fracture under static and cyclic loading it is necessary to compare the time dependence of the cyclic strength with that of the static strength.

This means that, from the standpoint of the kinetic theory, the phenomenological investigation of cyclic fatigue should be based on experiments to compare the cyclic and static lifetimes or experiments to compare the rates of crack growth in different loading regimes.