
KINETICS OF DAMAGE CUMULATION IN MATERIALS OF FLEXIBLE VACUUM ELEMENTS

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An analysis is made of the process of damage cumulation in flexible elements of a wave transmission in cyclic loading used in vacuum technology systems. A kinetic diagram of cyclic damage is proposed and their relationship is determined within the rate of damage, the stress, and the specific flow. New parameters characterizing the individual stages of damage cumulation are evaluated. The results show that defects in the form of pores or microcracks build up along the grain boundaries of flexible elements of the wave transmission.

The need to ensure reliability and endurance of vacuum technology systems and to expand the area of application of vacuum technology increases requirements on materials and characteristics of components of equipment including vacuum inlets of motion which contain thin-walled metallic membranes, bellows, and wave shells which separate the vacuum medium and the atmosphere. In transferring or transforming motion into vacuum, the elastic elements of the wave transmission are subjected to cyclic loading during which damage cumulates in them which leads to a loss of their leak tightness and failure.

Since the loss of leak tightness takes place prior to the initiation of a macrocrack, the efficiency of a material must be determined by analyzing the kinetics of multiple failure or short cracks whose growth rate is higher than that of the macrocracks [1]. In this case, the conventional fracture mechanic methods cannot be used to evaluate the efficiency of flexible vacuum components. In this work, investigations were carried out into the kinetics of damage cumulation in thin-walled metallic flexible elements of a wave transmission working at the boundary between the atmosphere and vacuum, in cyclic loading.

Fatigue tests were carried out on flexible elements of the wave transmission. The geometry of the specimens, materials, and loading conditions are given in Table 1. The following test method was used [2]. A wave shell or a tubular element was placed in a vacuum chamber with a rarefaction of $10^{-4}$ Pa. The flexible elements of the wave transmission were cyclically deformed by working loads: the wave shell by the atmospheric pressure and loading from a generator, the tubular element with an internal excess pressure of 1-4 atm. In loading, measurements were taken of a gas flow generated by inleakage through microdamaged areas in the specimen. The flow was measured by the calibrated resistance method using two pressure gauges. Tests were completed when the gas flow reached $10^{-1}$ W. No macrocracks formed in this case. A JSM-U3 scanning electron microscope was used to examine the side surfaces of tested flexible elements of the wave transmission on the side of the vacuum and atmosphere.

TABLE 1. Loading Conditions and Dimensions of Tested Flexible Elements of Vacuum Inlets of Motion

<table>
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<tr>
<th>Types of flexible elements of wave transmission</th>
<th>Amplitude of equivalent stresses $\sigma$ (MPa) for steels</th>
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<tr>
<td>Wave shell</td>
<td>Kh18N10T 36NKhYu</td>
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<tr>
<td></td>
<td>128 160 176 146 160</td>
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<tr>
<td>Tubular element</td>
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The content of impurity elements in the zones of local fracture was determined using a SMU3-DDS x-ray microanalyzer.

The efficiency of the flexible element of the wave transmission is characterized by the value of the gas glow $Q$ which changes with an increase of the number of load cycles $N$ in accordance with the dependences* given in Fig. 1. The angle of the slope of the curves in Fig. 1 determines the rate of increase of the gas flow which increases with an increase of the applied stress amplitude. The form of the dependences of the gas flow and the number of load cycles is identical with the dependences of the fatigue crack length of the number of load cycles obtained at constant acting stress amplitudes. The form of these dependences is determined by stages of the fatigue crack growth which consists in a general case of three phases: initial failure under the effect of shear stresses; stable crack propagation under the effect of normal stresses, and the third in crack propagation made into final fracture of the specimen. The length of stable crack propagation $Z_s$ determines the length of the zone of crack propagation with rate close to constant for the given stress. When the crack reaches the length $Z_s$, its growth rate increases, the crack changes into an unstable crack and its propagation ends in final fracture. The value of $Z_s$ is used to determine the endurance $N_g$ and the critical value of stress intensity factor $K_s$ which characterizes the cracking resistance of the material at the end of the stage of stable crack propagation [3]. The parameters $Z_s$, $N_g$, and $K_s$ are used as criteria for selecting and comparing materials and also as characteristics which determine the conditions of transfer from stable (and, consequently, safe) crack propagation to unstable.

In accordance with these considerations, we determine the critical flow $Q_s$ which represents the value of the flow corresponding to completion of the stable stage of damage development and the number of load cycles $N_g$. We also determine the parameters $Q_s$, i.e., the flow corresponding to the start of the stable process stage, and $Q_f$, i.e., the flow corresponding to the completion of the stages of stable and accelerated development of the damage process in the start of propagation of a microcrack in the examined element. The value $Q_s$ is determined by the background flow of vacuum equipment and sensitivity of the system. The permissible value of the gas flow $Q$ is determined by the requirements of technological process carried out using the given vacuum equipment, and by the range of application of the flexible element of the wave transmission. In less important structures, the permissible value of the gas flow can be represented by $Q_f$, in more important structures by $Q_s$.

*Experimental dependences $Q = f(N)$, presented by A. I. Danilov, were determined by A. I. Mel'nikov and V. A. Belyakin.