Study of Local Heating at the Crack Tip of a Cyclically Deformed Polymer Specimen

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The cyclic loading is known to be more dangerous than the static one. As a rule solid bodies under cyclic load fracture more rapidly. This is due to several reasons (1). One of them is heating of the investigated material under the action of cyclic load. The temperature of the specimen increases due to mechanical hysteresis. Along with the total increase in the temperature of the specimen there are the seats of higher local heating throughout the whole volume. Such seats can exist near the stress concentrators, i.e., near defects and cracks. It is quite natural, therefore, that the study of heating in these seats is of particular interest, as it is these seats that determine the kinetics of the fatigue fracture process.

However the local heating has not been studied experimentally until now. The aim of this study is to work out the experimental procedure for investigation of heating of a material at the crack tip to elucidate its role in the process of the fatigue fracture of polymers.

Experimental Procedure

The kinetics of crack growth in the nylon-6 and polyvinylalcohol (PVA) films was investigated by the microfilming method. The specimens were in the form of double spade with the working part of 15.5.0.15 mm. Before the experiment the specimen was cut by a sharp blade. The depth of the cut was 400 microns. After this the specimen surface was covered by a thin layer of the mixture of liquid cholesteryl crystals several microns thick. Then this specimen was cyclically loaded with frequency 16-200 cycles/sec in a special apparatus at room temperature. The microfilming was carried out in reflected white light at oblique illumination. Black-and-white and colour 35mm films were used. The available liquid crystals changed their colours from red to violet in definite temperature ranges. The range of transition from one colour to another for different crystals was from 1.5 up to 30°C. The set of crystals covered the temperature range from room temperature up to 123°C. The study of the kinetics of crack growth under static and cyclic load with liquid crystals and without them showed that their application does not influence the kinetics of fracture.

Observation of Heating at the Crack Tip

As the experiments have shown under cyclic load a region is observed at the crack tip the colour of which differs from the colour of the rest of the sample. (Such region is not observed under static load) The region at the crack tip changes its colour successively from red to violet and its geometric size with time. The coloured region appears at different time from the moment of cyclic load application which depends on the crack size, the applied load, frequency of loading and the sample thickness. Besides, the maximum observed temperature of heating depends on the polymer itself and conditions of heat removal. In our experiments we succeeded in registration of heating up to 70°C. The temperature of the specimen at large distances from the crack tip remained close to room temperature. The least registered size of the coloured spot at the crack tip was about 40 microns. Fig. 1 presents a black-and-white picture of the crack tip with a heated region in the nylon-6 specimen; the frequency of loading is 25cps and the amplitude of stress is 12kg/mm^2.

Local Heating and Kinetics of Fatigue Fracture

In Fig.2 is shown the curve of the change of the crack

growth rate plotted by the microfilming data. A coloured heated region at the crack tip was observed at the end of portion II. The temperature of the material in this region was about 56°C. The use of the additional heat removal by air blowing at this stage resulted in the decrease of the crack growth rate approximately by the order of magnitude. (portion II). In this case the temperature at the crack tip dropped to 32°C which was indicated by the change of the colour of the region at the crack tip from violet to red. After the forced heat removal had been stopped (portion III) the rate of the crack growth corresponded to initial conditions.

The following fact is of particular interest. As it was mentioned above the appearance of the heated region is registered not from the very beginning of the loading but well after it. The time, size and colour of the heated region do not change the linear character of the dependence lgV(l). We may think that this is explained by the existence of the region at the crack tip which is far less than the visually observed region and has the same temperature of heating. The latter is based on the established earlier (3) fact of linear dependence lgV(l) at constant temperature of test. Because of the bad resolution of liquid crystals we have not still succeeded in registration of this small initial heated region by the usual microfilming.

However one can attempt to evaluate the least possible size of this region from the dependence of the heated region size on time. As one can see in Fig.3 this size of the overheated region is not more than 10 microns.

The results of the study are the following:
First, it turned out that liquid crystals enable us to detect relatively small regions where the temperature exceeds the temperature of the rest of the sample by a few tens of degrees.

Second, the local heating registered in the experiments is one of the causes of considerable accaleration of the fracture process as one passes from static loading to cyclic one.

The solution of the problem of fatigue fracture requires further and more detailed study of the regularities of local heating.

References

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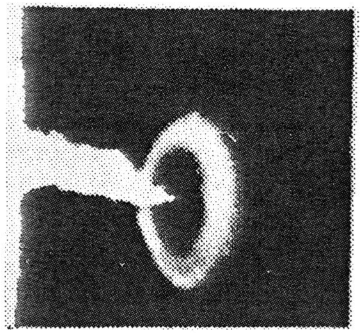

Fig.1 Crack tip with heated region in nylon-6. Temperature inside the ring is 56°C, at large distance from the tip - about 32°C.

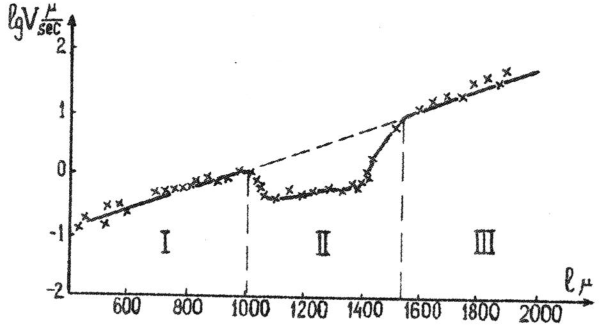

Fig.2 Dependence of crack growth rate on its length. Regions I and III correspond to natural conditions of heat removal, region II - to forced heat removal by air blowing.

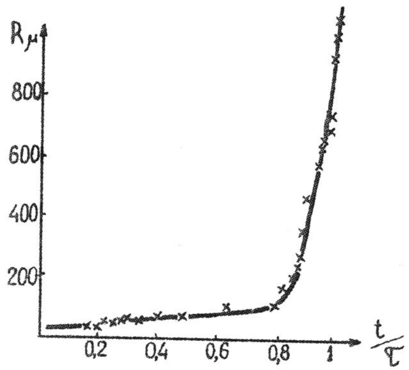

Fig.3 Dependence of geometric size of heated region at the crack tip on time.
t-is run time, τ-is lifetime