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INFLUENCE OF THE CONFIGURATION OF CRAZES ON THE FRACTURE OF PMMA

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1. INTRODUCTION

During long-time loading of amorphous thermoplastics, crazes generally appear before fracture. The density of the crazes is a function of the stress history. Low loadings lead to the formation of solitary large crazes while with high stresses, accompanied by high rates of deformation at the beginning of the experiment, dense configurations of crazes become visible [1, 2]. The main objective of the present paper is to investigate the influence of the configuration of the crazes on the failure by fracture.

2. EXPERIMENTAL

In these investigations, long time experiments and short time tensile tests following a pre-loading in creep have been carried out. By a variation of the creep stress, different configurations of crazes could be investigated. For all these experiments, the development of crazes has been observed microscopically, and statistically evaluated. The high molecular PMMA investigated can be considered as a material almost free of orientation and internal stresses. In this case the crazes and cracks always start from the surface of the specimen.

3. THE DIFFERENT CONFIGURATIONS OF CRAZES

With regard to their influence on fracture, in a simplified way the crazes can be divided into two groups: crazes which grow freely and crazes which hinder each other. The mutual hindrance of crazes is to be attributed to a local disturbance of the stress state, caused by the formation of a craze in the material. In the investigated PMMA, this disturbance has nearly disappeared at a distance of about 80 μm from the failure-point. For this reason, crazes well separated in the loading direction, can develop without mutual influence. With increasing density of crazes, i.e., with a decrease of the distance between crazes, the growth of adjacent crazes becomes more limited. This leads to a limitation of the length of crazes visible on the surface of the specimen (Figure 1). In earlier investigations [3], it was possible to show that a limitation of the length of crazes should not lead to a total restriction of the growth of crazes. In this case, the crazes grow, at nearly constant length, in the form of tongues, into the material. Figure 2 shows a craze, which, as a result of free growth, has the form of a semicircle (A) and crazes with mutual hindrance of the growth (B).

With increasing density of crazes, the probability that adjacent crazes would lie in the same plane, perpendicular to the loading-direction,

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increases. In the course of the experiment such crazes join and form a larger one.

With high stresses, the number of crazes reaches a peak after a short time, and then decreases slightly. This is because the development of new crazes is stopped soon after the application of stress, but then later some crazes grow together. This effect is shown in Figure 3 for a stress of 48 MPa.

4. THE INFLUENCE OF THE CONFIGURATION OF CRAZES ON THE FRACTURE

The fracture failure is strongly influenced by the configuration of crazes developed during the long-time experiment. In short time experiments of specimens with solitary crazes which have been measured before the test, the fracture always starts from the largest craze. Thus the length of crazes, visible on the surface of the specimen, has a decisive significance in the release of the fracture. Therefore the fusion of crazes is to be considered as an effect which accelerates the fracture. However, in the experiments already carried out, the opposite effect of mutual hindrance of crazes has the predominant influence on the fracture of the specimens.

At free growing crazes, a decrease of the obtained fracture strain in the short-time test following a long-time creep experiment, is observed for increasing pre-loading times t_V (i.e., for increasing length of crazes). On the contrary, dense configurations of crazes with mutual hindrance lead to higher fracture strains with increasing t_V (Figure 4). The different influence of the pre-loading time shows that the higher fracture strains obtained in the case of dense configurations of crazes are to be attributed not only to stronger dissipation of energy due to a larger number of crazes, but also to another mechanism of fracture. At dense configurations of crazes, the length of crazes which is important for the release of the fracture is limited by a mutual influence of the crazes.

We may conclude that the often-used method for the design of plastic parts by extrapolation of the long-time fracture curve to the desired duration of use, is to be seriously questioned. For amorphous thermoplastics, the long-time fracture curves are mostly obtained with stresses $\sigma > 40$ MPa for fracture times shorter than 1000 hours, i.e., for the investigated PMMA at strongly hindered configurations of crazes. In the practical use of plastic parts, the fracture results mostly at essential lower stresses, which have led to the development of unhindered configurations of crazes before the fracture failure.

The doubt concerning the extrapolation of long-time fracture curves is also confirmed by some particular creep experiments with fracture times longer than one year. With these experiments, the reached fracture strains are, in part, essentially smaller than the extrapolated values.

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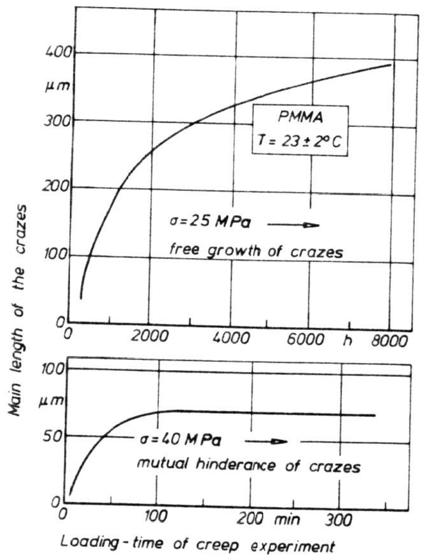

Figure 1 Development of Craze Length in the Case of Free and Hindered Growth of Crazes

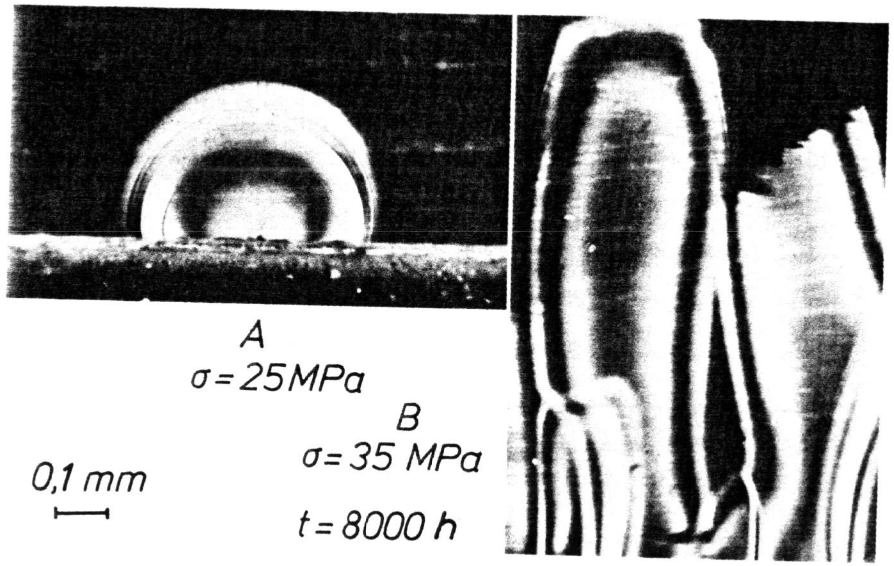

Figure 2 Change in the Shape of Crazes by Mutual Hindrance

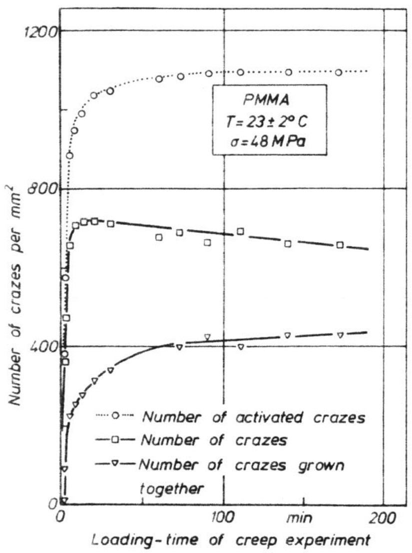

Figure 3 Development of Dense Configurations of Crazes

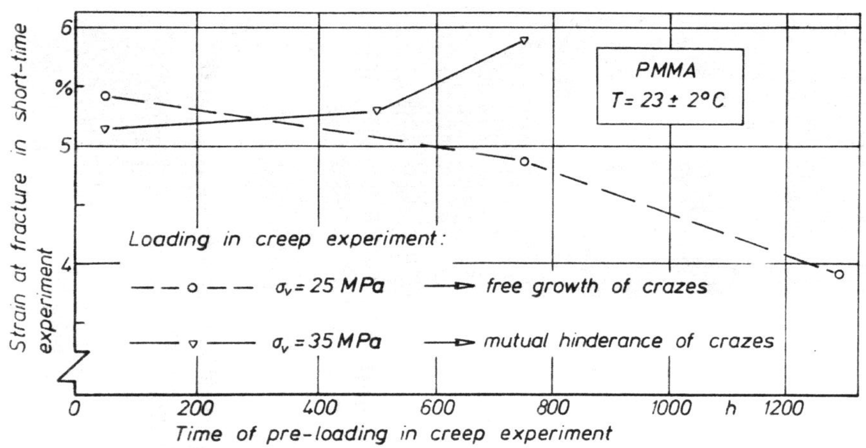

Figure 4 Strain at Fracture in Short-Time Experiment as a Function of Previous Creep Loading