FATIGUE CRACK GROWTH IN MAGNESIUM ALLOY MA12 IN AIR AND A VACUUM

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It was established earlier that the stage of fatigue crack growth accounts for most of the service life of metal alloy MA12 (T6) under cyclic strain in air [1]. The present work attempts to explain the macroscopic characteristics of crack growth in this alloy and the associated microscopic features of plastic strain and the fracture mechanism. Since a vacuum has an appreciable effect on the fatigue properties of different metals and alloys [2-4], we also studied its effect on crack growth in the above alloy.

Materials and Experimental Procedure

Specimens of magnesium alloy MA12 (2.9% Nd, 0.44% Zr) were stamped from a sheet heat-treated according to the mode specified for T6 (quenching from 540°C, 2 h, aging at 200°C, 16 h). The trapezoidal working section of the specimen presented uniform resistance to cantilever bending [1]. We notched (r = 2.0 mm and h = 0.8 mm) the side of the specimen to fix the site of crack nucleation and growth. The specimens were mechanically and electrolytically polished before testing.

The tests were conducted on a commonly used unit [5] in cyclic, symmetrical cantilever bending at a frequency of 750 cycles/min in air and in a vacuum of 1.10^-6 mm Hg at a stress of 15 kgf/mm^2 (ε = 0.0034). The initial length of the crack was recorded after it crossed the first grain boundary. Crack length was measured to within 5 μ on an optical microscope.

The plastic zone formed around the crack during its growth was studied by the methods of optical microscopy of specimen surfaces and x-ray crystallographic analysis of fracture surfaces. The diffraction patterns were made on unit URS-60 in chromium radiation by the Debye method, with a collimator slit diam. of 0.4 mm and exposure of 5 h. To determine the depth of the plastic zone, we used electrolytic polishing to remove a layer 10-15 μ thick from the fracture surface, and then conducted repeated sight x-ray diffraction analyses.

The macro- and microstructure of the fracture surfaces were studied by means of optical microscope MBS-2 and electron microscope UEMV-100V (by the method of carbon replicas), using the same specimens on which we measured crack growth rate.

Results and Discussion

The rate of crack growth in air and the vacuum at separate stages of the process is shown in Fig. 1 and Table 1. As is apparent, the vacuum retards all stages of fatigue fracture, beginning with the nucleation of cracks. The stage of crack growth, both in the vacuum and in air, occupies most of the life of the specimen. This stage consists of three periods characterized by different accelerations of the crack. The first period is marked by a low rate of crack growth and little change in this rate during the deformation process. In this period, the crack growth rate is substantially less in the vacuum than in air and the period is longer by about one order. The second period is characterized by sudden increases in crack growth rate in both media, although the growth rate in air is appreciably higher than in the vacuum. It should be noted that, in both media the length of crack corresponding to the end of the first period is 0.5 mm, and is 3.5 mm for the end of the second period.

It has been established [6] that the propagation of a fatigue crack is most fully described by means of stress intensity factor K, which is a parameter of linear fracture mechanics characterizing the stress field at the crack tip [7]:

where $Y = f(l/b)$ is a correction factor; $\sigma$ is the applied stress; $l$ is the length of the crack; $b$ is the width of the specimen.

Here we used the value of $Y$ cited in [8] for a sheet, subjected to bending, with a single notch on its edge.

To analyze the test data on the rate of fatigue crack growth in air and the vacuum, we plotted the relation $dL/dN = f(K_{\text{max}})$ in double log coordinates (Fig. 2). As can be seen, the rate of fatigue crack growth in both media can be expressed in the form of Paris' well-known relation:

$$dL/dN = C (\Delta K)^n,$$

where $C$ and $n$ are constants within a certain range of stress intensity factors. In the present case, due to the symmetrical loading cycle, the range of the stress intensity factor $\Delta K = 2K_{\text{max}}$. In contrast to Paris' formula this relation consists of three separate regions for which the coefficients $C$ and $n$ are constants and are dependent on the medium. For example, at $4.5 \text{ kgf/mm}^{3/2} \leq K_{\text{max}} \leq 9.5 \text{ kgf/mm}^{3/2}$, $n_{\text{atm}} = 0.5$; $n_{\text{vac}} = 0.17$; at $9.5 \text{ kgf/mm}^{3/2} \leq K_{\text{max}} \leq 35 \text{ kgf/mm}^{3/2}$, $n_{\text{atm}} = 1.2$; $n_{\text{vac}} = 1.7$; at $35 \text{ kgf/mm}^{3/2} \leq K_{\text{max}} \leq 61 \text{ kgf/mm}^{3/2}$, $n_{\text{atm}} = 8$; $n_{\text{vac}} = 8$. Here coefficient $C$ is less in a vacuum than in air. The data shown for alloy MA12, in agreement with the results of studies of other alloys, is evidence of the fact that the relation $dL/dN = f(K_{\text{max}})$ consists of three separate regions, each of which is characterized by certain values of $n$ [9].

It follows from the data obtained that, in the initial period of fatigue fracture, the rate of crack growth and its change in a vacuum is significantly less than in air. In subsequent stages, the crack growth rate in the vacuum is less than in air, although its change in the former medium is greater than in the latter. Analyzing the relation $dL/dN = f(K_{\text{max}})$ (Fig. 2), we may note that the sudden changes in crack growth rate in the investigated alloy occur at the same critical values of stress intensity factor for both media.

It follows from the laws of linear fracture mechanics that the rate of growth of a crack is determined by the plastic zone at its tip. In this connection, it is of interest to determine the character and degree of plastic strain in the investigated alloy and their dependence on the medium. It turned out that, in the initial period of crack growth, when the crack length is no greater than 0.5 mm, a zone is formed ahead of the crack having slip bands 0.2 mm in size in both air and the vacuum. The zone with slip bands widens with an increase in the length of the crack. For example, with a crack of 3 mm, the length and width of this zone in air are equal to about 2 mm. The zone is somewhat larger in the vacuum. Metallographic studies show that the slip bands in the plastic zone are larger in the vacuum than in air both in the initial stage of crack growth and at