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Fatigue cracks growth features in aluminum alloy D16AT

This paper investigates the description of the fatigue cracks growth in sheet aluminum alloy D16AT by exponential dependence. The results show that the propagation of all investigated fatigue cracks can be satisfactorily described by this dependence with grate values of the determination coefficient.

Changing of the fatigue crack length a on the number of loading cycles N in a wide size range has a number of unique features. The development of short cracks is not considered in this paper because the scale of the stress intensity factor (SIF) ΔK for them is less than the threshold value ΔK_{th} and it is determined mainly by microstructure factors. The growth of long cracks at $\Delta K > \Delta K_{th}$ is characterized by kinetic diagram of fatigue fracture. The second portion of it is described by the regression Paris' equation:

$$\frac{da}{dN} = C\Delta K^m , \quad (1)$$

where C and m – the regression coefficients that are not associated with materials physical properties (for most metallic materials m varies from 1.5 to 4).

From equation (1) should be dependent a on N, which can be represented implicitly as a

$$\int_{a_0}^{a} \frac{dx}{\Delta K^m(x)} = C(N - N_0) , \quad (2)$$

where a_0 – the length of the initial crack, which was formed at N_0 loading cycles; x – the integration variable.

Function (2) in the approximate shape describes the propagation of a fatigue crack on the number of load cycles, including the stage of its rapid growth (with $m > 2$). However, the regression equation (1), on the basis of which the function (2) is obtained, are not always adequately reflect the characteristics of the crack growth in the early stages and the period of rapid growth is not practically significant in predicting of the structure limit state.

Based on the analysis of methods for describing of fatigue cracks propagation, it is asserted that it is impossible to describe the dependence of crack length on the number of cycles in the whole range of durability until the destruction by a single dependency [1]. Generally, the functional dependencies that describe the propagation of cracks at different stages are different. For example, numerous studies have shown that the initial fatigue crack growth stage, and period of its rapid propagation satisfactorily approximated by an exponential relationship [1]:

$$a = a_o \exp(hN) , \quad (3)$$

where h – the kinetic coefficient that depends on the fracture geometry, material properties, and effective stress. It should be noted that the random crack growth, according to the formula (3) is determined by a value of random coefficient h.

Equation (3), which is a special case of regression equation (1) when $m = 2$, well describes the propagation of fatigue cracks in the sheet metal aviation structures at operational loading, that is reflected in an exponential model of fatigue cracks growth (Frost-Dugdale model) [2,3].

In this paper it is investigated the description of the fatigue cracks growth in sheet aluminum alloy D16AT by dependence (3).

Experimental studies conducted on flat samples, with thickness 1.5 mm, which had 14 holes with a diameter of 4 mm, which are arranged in three rows. Samples were tested at unidirectional loading cycles with a maximum stress value in the cycle $\sigma_{max} = 80$ MPa, 100 MPa and 120 MPa. Methods of fatigue tests, monitoring of the cracks behavior and crack length measuring are given in [4].

There are three characteristic regions on the typical dependence of a crack length on the number of cycles, which was received as a result of aluminum alloy D16AT fatigue test (Fig. 1). They are linear region (I), which is implemented at the initial stage of crack growth, exponential region (II), which is described by the function (3) and takes up most of the crack propagation time, and accelerated crack growth region (III).

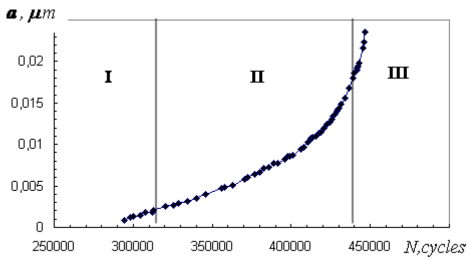

Fig. 1. Typical dependence of crack growth on the number of cycles

The obtained experimental data on the growth of fatigue cracks in the aluminum alloy D16AT samples presented in semilogarithmic coordinates according to the relation (3):

$$\ln a = p + hN, \tag{4}$$

where p – the regression coefficient (Fig. 2). In an ideal exponential growth of cracks $p = \ln a_0$, however, value of the coefficient p is not related uniquely to the initial crack size a_0 because of the natural variation of the experimental data from the exponent.

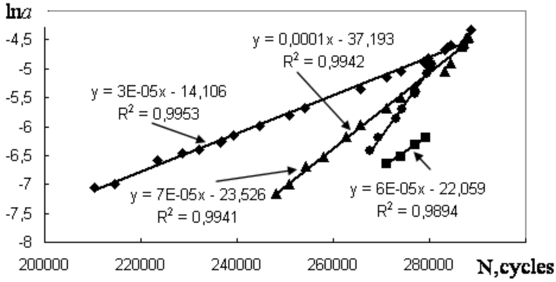

Fig. 2. Dependences of the logarithm of the fatigue cracks length on the number of load cycles with a maximum stress in the cycle $\sigma_{max} = 80$ MPa

Presented in Fig. 2 dependences shows that crack growth is satisfactorily described by an exponential function (3). Linearity regression (Fig. 2) is characterized by relatively high values of the determination coefficient (R^2). Similar results were obtained for cracks when $\sigma_{max} = 100$ MPa and $\sigma_{max} = 120$ MPa (Table 1).

Table 1.

Values of the coefficients p , h and R^2 for cracks in experimental specimens

p	h	R^2	p	h	R^2
$\sigma_{max} = 80$ МПа					
-23,526	0,00007	0,9941	-44,852	0,0001	0,9992
-30,537	0,00009	0,9998	-13,517	0,00003	0,9986
-22,059	0,00006	0,9894	-18,42	0,00004	0,9996
-37,193	0,0001	0,9942	-14,106	0,00003	0,9953
-37,43	0,0001	0,9818	-10,905	0,00002	0,9968
-25,358	0,00006	0,9926	-27,674	0,00005	0,9961
-11,357	0,00002	0,9934			
$\sigma_{max} = 100$ МПа					
-11,427	0,00003	0,9998	-22,002	0,00006	0,9888
-9,264	0,00002	0,9993	-37,515	0,0001	0,9893
-14,593	0,00004	0,9843	-34,022	0,00009	0,9965
-12,873	0,00003	0,9983	-23,631	0,00006	0,9941
-10,686	0,00003	0,9856	-11,689	0,00002	0,9783
-15,518	0,00005	0,996	-13,517	0,00004	0,9965
-12,619	0,00003	0,9759	-11,328	0,00002	0,9936
-12,812	0,00003	0,9926	-14,233	0,00003	0,9986
-13,458	0,00003	0,9921	-27,863	0,00009	0,9945
-10,258	0,00001	0,891	-23,725	0,00008	0,9986
-15,539	0,00003	0,9607	-20,629	0,00007	0,9972
-20,42	0,00005	1,0000			

$\sigma_{max} = 120$ МПа					
-10,99	0,00005	0,9993	-24,276	0,0001	0,9954
-15,545	0,00009	0,9985	-16,881	0,00007	0,9845
-18,996	0,0001	0,9954	-15,078	0,00006	0,9913
-14,14	0,00006	0,9987	-15,462	0,00006	0,9985
-23,965	0,0001	0,9900	-22,273	0,0001	0,9942
-24,246	0,0001	0,9311	-24,83	0,0001	0,9964
-12,93	0,00005	0,9982	-19,029	0,00008	0,9997
-17,365	0,00008	0,9946	-13,39	0,00005	0,9967
-18,239	0,00008	0,9987	-13,813	0,00005	0,9987
-14,981	0,00006	0,9990			

Conclusions. The results show that the propagation of all investigated fatigue cracks can be satisfactorily described by an exponential dependence of the length on the number of load cycles. The values of the determination coefficient for the exponential dependence of all cracks is not less than 0.9, and the average value of R^2 is equal to 0.99075.

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