FATIGUE DAMAGE IN LIGHT ALLOYS UNDER BLOCK LOADING, WITH STRESS CONCENTRATION AND FRETTING CORROSION

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The investigation was performed into the laws of high-cycle fatigue of aluminum and titanium alloys under regular and block loading in the presence of stress concentration and fretting-corrosion. It is shown that in accordance with the linear damage summation hypothesis the magnitudes of relative accumulated damage under block loading with stress concentration and fretting-corrosion are equal to or exceed those for smooth specimens, which is defined by the degree of the influence of the processes initiated on the block high step upon those of fatigue damage accumulation on the block low step.

INTRODUCTION

In the literature, fatigue damage accumulation under block loading is often evaluated using the linear damage summation hypothesis, which is written in the following form:

$$\sum_{1}^{S} \frac{n_i}{N_i} = 1 \qquad \text{classical hypothesis} \qquad \sum_{1}^{S} \frac{n_i}{N_i} = a \qquad \text{modified hypothesis}$$

where n_i is the number of load cycles at stress σ_{ai}, N_i is the number of load cycles to fracture under regular loading at stress σ_{ai}, S is the number of stress steps in a block, a is the relative accumulated fatigue stress at fracture. As is shown by the data from the literature, the a value varies within a wide range for different materials and loading conditions ($0.02 \leq a \leq 10$).

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MATERIALS AND EXPERIMENTAL PROCEDURE

The materials chosen for the investigation were aluminum, D16AT and AMg6, and titanium, VT14, alloys. Mechanical properties of the materials studied are listed in Table 1. Here $\sigma_{\max R}$ is the maximum stress in a cycle which corresponds to the fatigue limit at 10^7 cycles.

TABLE 1- Mechanical Properties of the Materials

Material	Yield stress MPa	Ultimate strength MPa	Elasticity modulus $E \times 10^{-4}$ MPa	Relative elongation %	$\sigma_{\max R}$ MPa
Aluminum alloy D16AT (4.4% Cu, 1.5% Mg, 0.6% Mn)	322	424	7.29	10	170
Aluminum alloy AMg6 (6.3 %Mg, 0,65%Mn)	157	360	7.20	19	190
Titanium alloy VT14 (4.5 % Al, 3.0 % Mo, 1.0% V)	980	1040	11.0	6	490

The investigations were performed on sheet specimens 25 mm wide and 2.8 mm thick (alloys D16AT and AMg6) and 20 mm wide and 2.0 mm thick (alloy VT14). Stress concentrator was a hole drilled along the specimen axis. For D16AT alloy specimens, the theoretical stress concentration factor was $\alpha_\sigma = 2.73$, for AMg6 alloy specimens $\alpha_\sigma = 2.3$ and $\alpha_\sigma = 2.9$. The tests were carried out under axial loading at a frequency of 45 Hz. The influence of fretting-corrosion was studied using 10 mm-base bridge-shaped pads pressed against the specimen with a clamp with a force inducing contact stresses of 50 MPa. Bridge-shaped pads and the test specimen were made of the same material. The magnitude of the applied force was monitored using strain gauges mounted on the clamp and was maintained constant during the test.

The nucleation and propagation of cracks in smooth specimens and in specimens with stress concentrators were studied by an optical microscope with a scale factor of 0.014 mm. Under fretting-corrosion conditions a surface crack was located by heating the specimen to the temperature when the colour of its surface changed. This made it possible to study the crack front after the specimen fracture. The program loading was realized in two-step blocks with the stress ratio, R, in a cycle being 0, 5, 0 and -1. The stress ratio in a cycle on both loading steps was similar. The number of cycles on the program loading block steps was taken such that the number of blocks to the specimen fracture was no less than 10...15.

EXPERIMENTAL RESULTS

Stress concentration reduces substantially fatigue strength of the alloys studied. The results of the investigation of the D16AT alloy given in Fig. 1 are typical. Here K_σ is the effective stress concentration factor equal to the fatigue limits ratio of smooth and notched specimens, N is the number of cycles to fracture. 1 refers to $\alpha_\sigma = 2.73$, $R = -1$; 2 refers to $\alpha_\sigma = 2.73$, $R = 0$; 3 refers to $\alpha_\sigma = 2.73$, $R = 0.5$. As is evident from Fig. 1, K_σ increases with the number of cycles to fracture and with the cycle stress ratio. A decrease in the fatigue strength during fretting-corrosion as compared to smooth specimens can be inferred from the results of the investigations given in Fig. 2. Here K_F is the ratio between the fatigue limits of smooth specimens and those under conditions of fretting-corrosion. 1, 2 and 3 are for alloy D16AT, 4 is for alloy AMg6, 5 is for alloy VT14 (1-$R = -1$; 2, 4 and 5 - $R = 0$; 3-$R = 0.5$).

The results of the investigation of the scattering zones of the magnitudes of the relative accumulated fatigue damage, a, calculated by the number of cycles to the initiation of a crack (dotted vertical lines) and by the number of cycles to complete fracture (solid vertical lines) for different stress ratios in a cycle for smooth specimens and specimens with stress concentrators are given in Fig. 3 (a is for alloy D16AT and b is for alloy AMg6). Similar results for smooth specimens and specimens subjected to fretting-corrosion are presented in Fig. 4 (a is for alloy D16AT and b is for alloy VT14). In these figures the areas bounded by a single horizontal line correspond to smooth specimens, whereas those bounded by double horizontal lines correspond to specimens with stress concentration (Fig. 3) and fretting-corrosion (Fig. 4), respectively. Different vertical lines obtained for smooth specimens correspond to different values of the ratios $\sigma^{I}_{\max}/\sigma_R$ and $\sigma^{II}_{\max}/\sigma_R$ and to different stress ratios in a cycle. The characteristics of the regimes and blocks of program loading for specimens with stress concentrators and for those subjected to fretting-corrosion are listed in Table 2. Enumeration of the blocks corresponds to the notations in Figs 3 and 4.

TABLE 2- Characterization of Program Loading Regimes and Blocks

			Characteristics of the program loading blocks						
№	Mate-rial	R	$\sigma^{I}_{\max}$ MPa	$\frac{\sigma^{I}_{\max}}{\sigma_R}$	$\sigma^{II}_{\max}$ MPa	$\frac{\sigma^{II}_{\max}}{\sigma_R}$	$n_I \times 10^3$ cycles	$n_{II} \times 10^3$ cycles	α_σ
				Stress concentration					
1		-1	60	0.8	120	1.6	70	10	2.73
2		-1	100	1.3	120	1.6	18	8	2.73
3							20 min		2.73
	alloy	-1	0	0	160	1.6	interval	14	
4	D16AT	0	60	0.6	160	1.6	98	14	2.73
5		0	120	1.2	160	1.6	22	10	2.73
6		0	130	1.3	180	1.8	50	10	2.73
7		0.5	160	1.2	210	1.6	10	4	2.73
8	alloy	0	100	0.9	140	1.3	70	10	2.30
9	AMg6	0	110	1.1	140	1.3	30	8	2.30
10		0	140	1.3	170	1.5	20	6	2.90
				Fretting-corrosion					
1		0	340	1.1	400	1.3	25	8	-
2	alloy	0	340	1.1	500	1.6	40	6	-
3	VT14	0	400	1.3	500	1.6	10	5	-
4		0	440	1.4	500	1.6	10	6	-
5		0	60	0.7	160	1.8	105	15	-
6	alloy	0	120	1.3	160	1.8	22	10	-
7	D16AT	0	160	1.8	220	2.1	15	15	-
8		-1	70	1.3	100	1.8	20	8	-

DISCUSSION OF RESULTS AND CONCLUSIONS

In tests of smooth specimens of D16AT and VT14 alloys the mean values of a were close to 1 for all the test regimes realized. For alloy AMg6 those values were close to 0.5. When analyzing the test results for alloy AMg6, account should be taken of the fact that this alloy is cyclically hardening with a very low value of $\sigma_{0.2}$ and that its high-cycle fatigue curve lies in the range of stresses exceeding $\sigma_{0.2}$ (Table 1), i.e. intensive structural changes take place in this alloy under high-cycle loading. From the results presented in Figs 3 and 4 it follows that for all the materials and loading regimes studied there is no essential difference in the values of a calculated by the number of cycles to crack initiation and to complete fracture.

A significant difference between the a values for smooth specimens and those obtained in testing specimens with stress concentrators and under fretting corrosion is observed at $R = 0$ and $R = 0.5$ when the maximum stresses on low and high loading steps exceed considerably the fatigue limit.

The performed analysis, whose procedure and results are described in detail by Dragan and Semenyuk (1) and by Troshchenko et al. (2), revealed that for specimens with stress concentrators at the above loading regimes residual compressive stresses are initiated on the high step of the loading block in the stress concentrator zone, which result in essential variation of the cycle stress ratio on the low loading step. If the calculation is performed with the account taken of the real stress ratio in a cycle on the low step of the loading block, the a values are close to those for smooth specimens.

The analysis of the results obtained in the investigation of the materials under conditions of fretting-corrosion was less detailed. That analysis was made by changing the ratio of low and high steps duration in the block. It revealed that at the loading regimes for which an increase in the a value is observed (regime 7 in Fig. 4a and regimes 2,3,4 in Fig. 4b), the contribution of low block steps after loading on the high step is rather small. This suggests that under loading at high stresses the processes take place in surface layers in the zones of fretting-corrosion (residual compressive stresses are probably initiated as well) which lower considerably the intensity of damage accumulation on the low loading step.

REFERENCES

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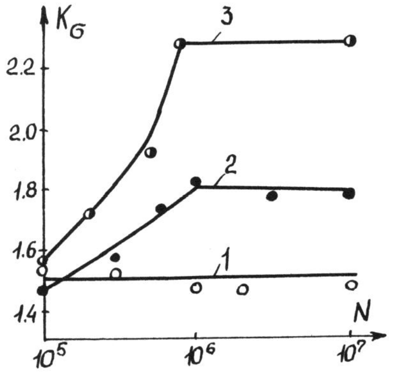

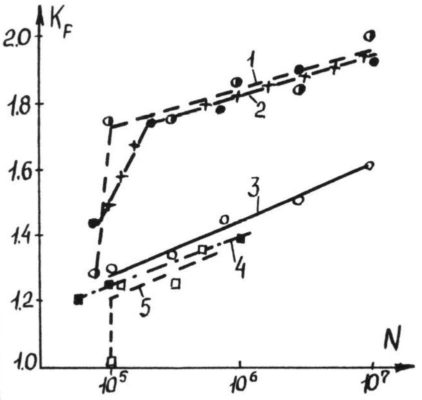

Fig.1 K_σ *vs* N relations for alloy D16AT

Fig.2 K_F *vs* N relations for alloys D16AT (1,2,3),AMg6(4) and VT14 (5)

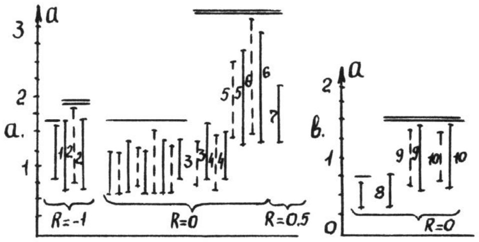

Fig. 3 Variation of *a* values at stress concentration

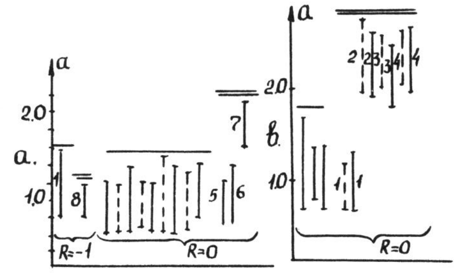

Fig.4 Variation of *a* values at fretting-corrosion