Effect of Fatigue Crack Path on Statistical Distribution of the Fatigue Lifetime

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ABSTRACT. *The influence of the fatigue crack path on the fatigue life distribution was studied. The fatigue data of some aluminum alloys were analyzed from a statistical viewpoint taking into account the discontinuity region of the fatigue curves. The Weibull distribution and the log-normal distribution were applied. Relationship between the fracture probability and the changing the crack path was shown.*

INTRODUCTION

In recent years much attention has been given to the problem of the gigacycle fatigue. It was proved that gigacycle fatigue failure in many alloys with high strength can appear beyond 10^9 cycles and S-N curve has a distinct transition region within $N=10^5$-10^6. So, the fatigue life limit determined without taking into account such property cannot provide the safety design data.

Many researchers, which observed earlier such a transition region or a discontinuity region on fatigue curves at testing alloys with low strength related it to scatter of experimental data. The first who discovered the fatigue curve discontinuity of the aluminum alloy was V. I. Shabalin (1958) [3]. He connected it with the cyclic yield strength of material. Later Porter [4] and then Bathias [1] and Nakajima [2] showed that a slope of fatigue lifetime distribution changes at the discontinuity stress. Therefore, they used a double log-normal distribution of fatigue life to describe experimental data.

The main aim of our work was to analyze the effect of crack path in specimens from aluminum alloys AK4-1T1 and D16T, tested by V.N. Shabalina [5] on different statistical distributions of fatigue lifetime. These alloys are widely used in aircraft industry and analogous by composition to alloys 2618 and 2024.

CHANGING THE FATIGUE CRACK PATH

Probability curves were considered taking into account fracture mode and fatigue crack path which depended on geometry of specimens and stress amplitude. As it has been shown by Shabalina, increase in stress amplitude was accompanied by turning a fracture surface of the smooth samples due to increasing a contribution of shear stresses in fracture.

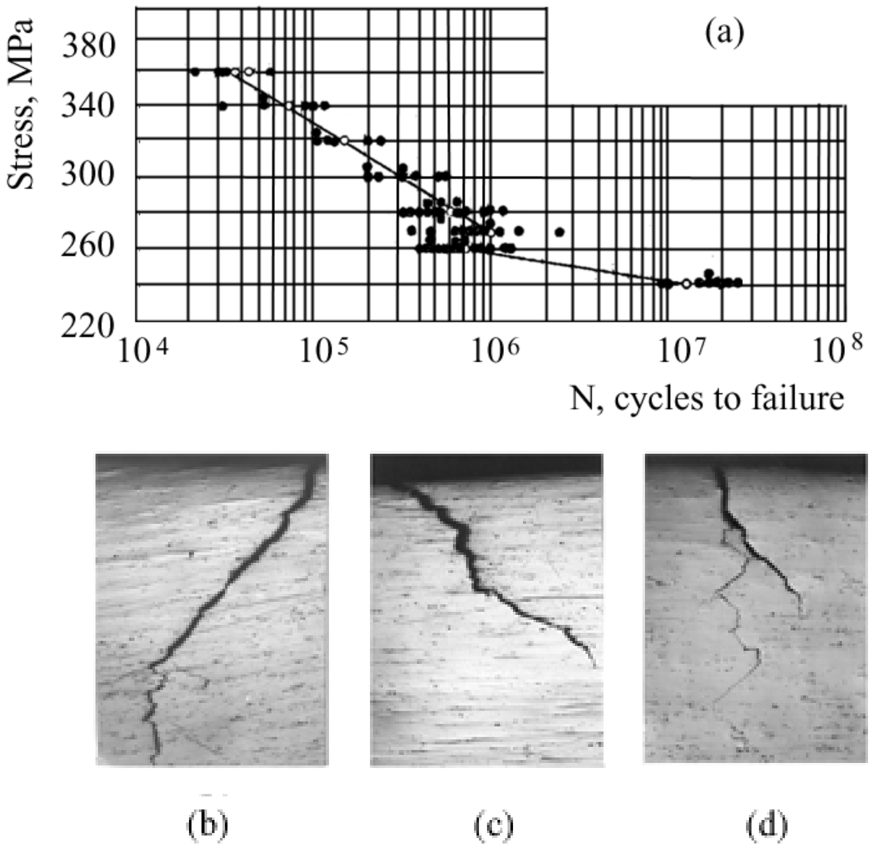

Figure 1. Fatigue curve of alluminium alloy D16T (a) and fatigue crack path changing at 320 MPa (b), 280 MPa (c), 260 MPa (d).

The initial fatigue curve of the alloy D16T is shown in Fig. 1. The photos of the fatigue crack on its initial stage of growth from specimen's surface (Fig. 1, b-d), taken at different stress levels, show the changing of the crack path with decrease in stress amplitude. At high stress amplitude, the fracture was observed to occur at about 45 degrees to specimen axis

(Fig. 1b) and at low amplitude it occurred at 90 degrees. So, the transition from shear to rupture occurs at decrease in stress amplitude (Fig. 1d). The changing the crack path is observed at 280 MPa, which corresponds to the discontinuity stress (Fig. 1c).

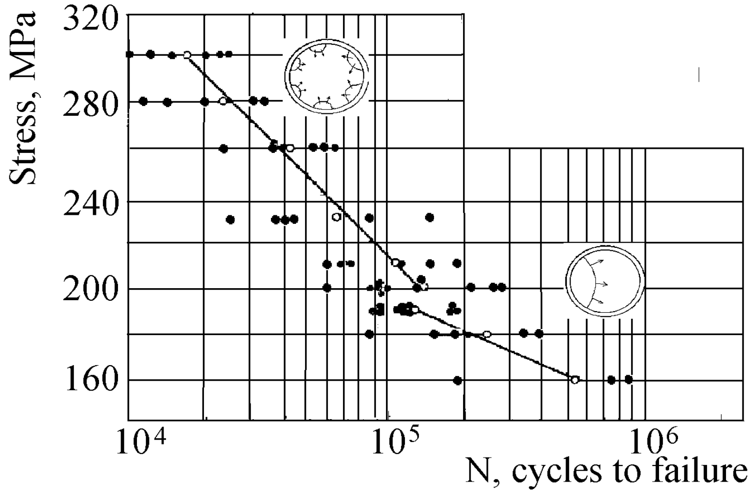

Figure 2. Fatigue curve of D16T aluminium alloy notched speciments, tested at 0.67 Hz.

Another situation is observed at testing of notched specimens from alloy D16T (Fig. 2). In this case, the rupture zone on the fracture surface shifts to the specimen center with the stress increasing due to a crack development from numerous origins in the notch tip. At low stresses the crack develops from the only origin. The discontinuity region of the fatigue curves is observed at the cyclic yield strength, corresponding to the changing the fatigue crack path.

The fracture surfaces of specimens from AK4-1T1 were studied. In Fig. 3 change in both the crack path and the depth of the plastic deformation zone under fracture surface above (Fig. 3a) and below (Fig. 3d) discontinuity stress are shown. Discontinuity region corresponds to 270 MPa (Fig. 3b). At low stress amplitude, close to fatigue limit, the angle of inclination of the fracture surface is about zero along stable crack. The angle increases up to 22 degrees after transition to high stress level, with plastic deformation zone increasing. Thus, the appearance of the discontinuity region is connected with plastic zone increasing and crack path changing. The photos of fracture surface at the stress above (280 MPa) and below (260 MPa) the discontinuity stress are presented in the Fig. 3b, e. At higher magnification the fatigue striations are well observed on the fracture surface (Fig. 3 c, f). The striation spacing becomes higher with stress increasing.

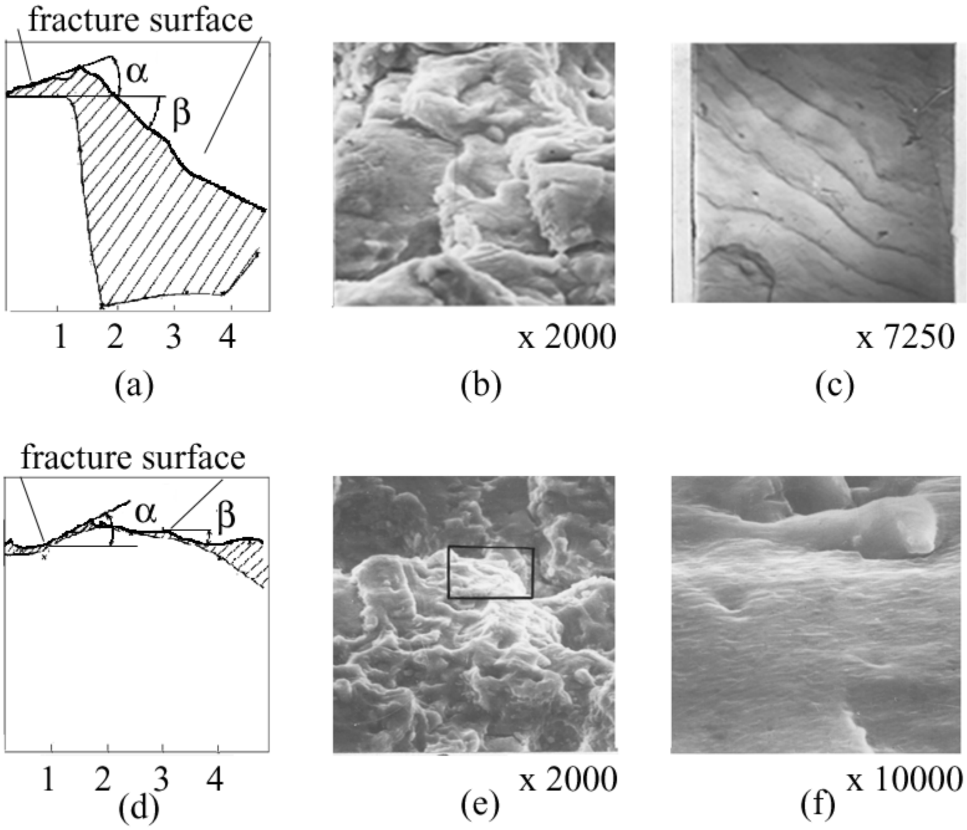

Figure 3. Plastic deformation zone (a, d) and fracture mechanism (b, c, e, f) of alloy AK4-1T1 above (a, b, c) and below discontinuity region (d, e, f)

Results of the Statistical Analysis

The log-normal distribution, the Weibull distribution were used for the statistical analysis. The results obtained were plotted on the probability paper. Both the log-normal and the Weibull distribution showed a good agreement with each other. The discontinuity region of the fatigue curves was observed at the cyclic yield strength, corresponding to the changing of the fatigue crack path.

This change also influences the angle of inclination of probability curves for both the Weibull and the log-normal distributions. The family of these curves of the aluminum alloy AK4-1T1 (Fig. 4 a, b) has the same angle of inclination at high and low stress level, except curve 5 at the stress 270 MPa, corresponding to the discontinuity stress. It deviates to low durability. So, the probability of fracture increases.

For higher (380 Hz) frequency of load, the family of the fatigue curves divides into two parts with different angles for each other. In this case, the fracture probability decreases.

Similar effect was found at plotting the fatigue distributions of the high strength steels. The initial fatigue data for this were taken from the investigation of Okada with his colleagues [6]. In this case, two populations of curves were also obtained. The probability of fracture decreased with stress decreasing.

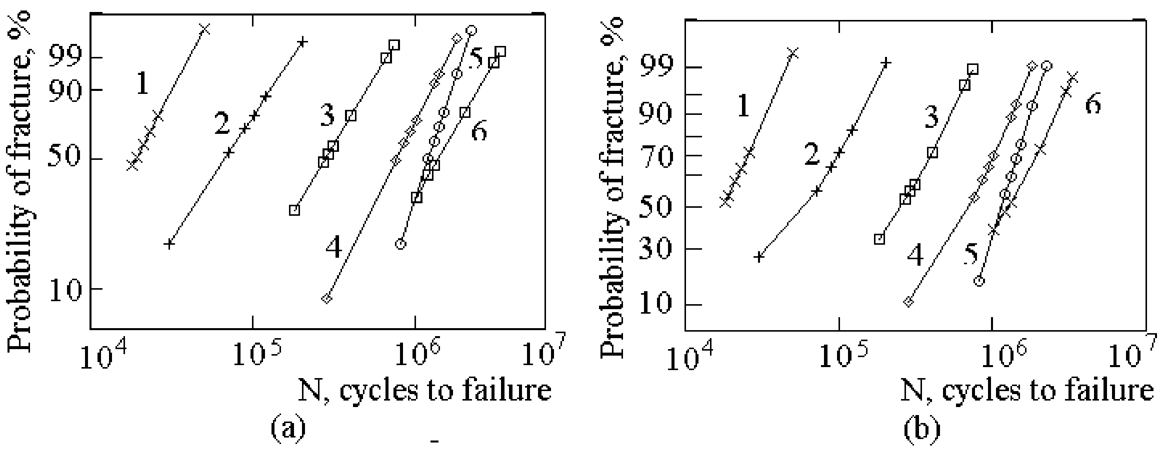

Figure 4. Probability of fracture of alloy AK4-1T1, tested at frequency 200 Hz and stress amplitudes (1) 340 MPa, (2) 320 MPa, (3) 300 MPa, (4) 280 MPa, (5) 270 MPa, (6) 260 MPa and using the Weibull (a) and the log-normal distribution (b).

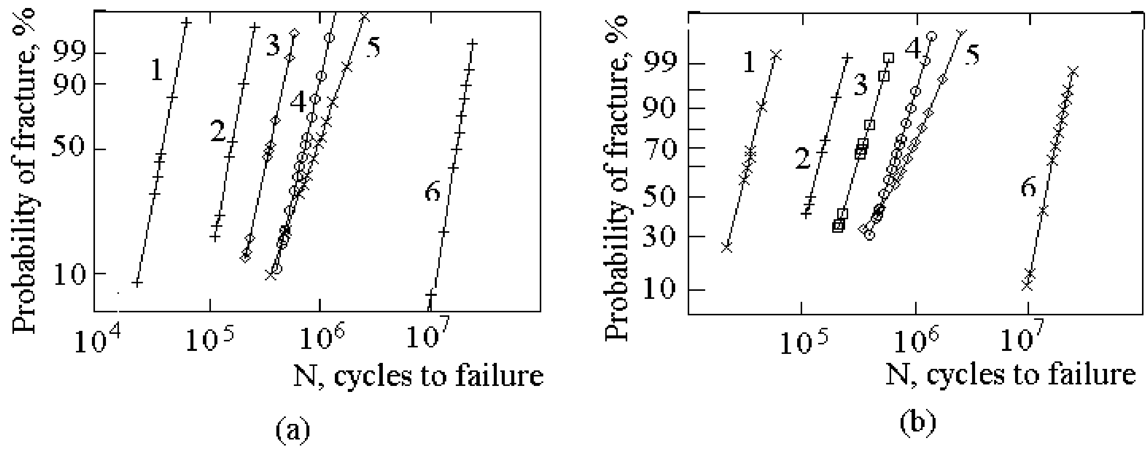

Figure 5. Probability of fracture of alloy D16T, tested at 380 Hz and stress amplitudes: (1) 360 MPa, (2) 320 MPa, (3) 300 MPa, (4) 270 MPa, (5) 260 MPa, (6) 240 MPa and using the Weibull (a) and the log-normal distribution (b).

The probability curves of both distribution functions for the alloy D16T (Fig. 5 a, b) have the same angle of inclination for all stress levels, except one at the discontinuity region (curve 5), where an anomalous changing of the density function is observed.

At the same time for the notched specimens (the alloy D16T Fig. 6 a, b) populations of curves for both distributions divide into two groups with different angle of inclination at high and low stress levels. This division occurs at higher stress than the discontinuity stress.

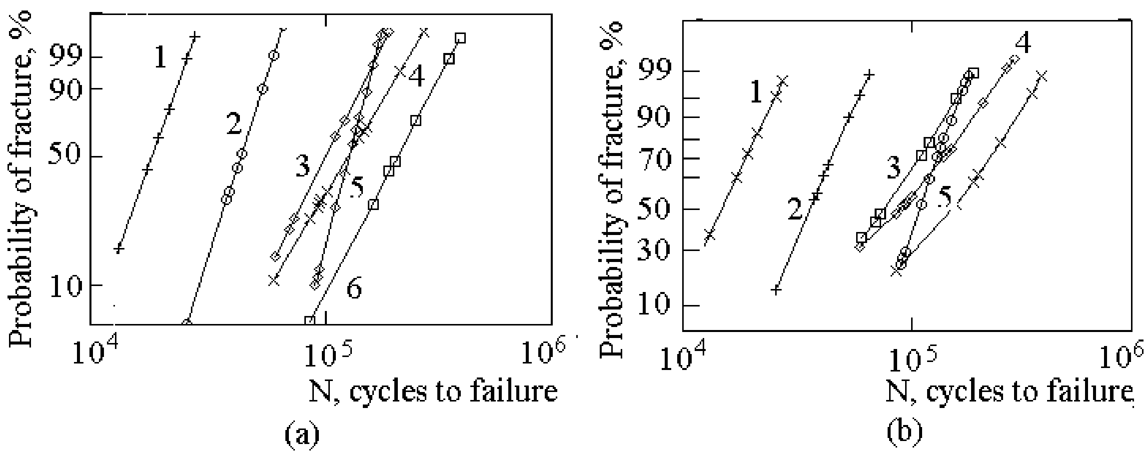

Figure 6. Probability of fracture of notched specimens from alloy D16T, tested at 0.67 Hz and stress amplitudes: (1) 300 MPa, (2) 260 MPa, (3) 220 MPa, (4) 200 MPa, (5) 190 MPa, (6) 180 MPa and using the Weibull (a) and the log-normal distribution (b).

CONCLUSIONS

1. Fatigue crack path changes with stress amplitude decreasing.
2. Changing the fatigue crack path and fracture mechanism influence on fracture probability.
3. Probability curves for the log-normal and the Weibull distributions change the angle of inclination in discontinuity region for all materials studied.
4. Fracture probability depends on a change in fracture mode. Transition from flat to slant crack growth (for smooth samples) and transition from many origins to the one cause decreasing the fracture probability.
5. Changing the crack path is necessary to take into account at prediction of fatigue lifetime.

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REFERENCES

1. Bathias, C. and Bonis, J. (1998) *Fracture from Defects*, Proc. of ECF12, (Eds. M.W. Brown, E.R. de los Rios and K.J. Miller), EMAS Publishing, **1**, 321-326.
2. Nakajima, M., Tokaji, K. and Shimizu, T. (2000) Effect of humidity on long fatigue life more than 10^7 cycles in high strength steel, *Proc. of 13 ECF*, Spain, 2000, *CD ROM*.
3. Shabalin, V.I. (1958) *Reports of USSR Academy of Sciences.* **122,** 600- 604.
4. Porter, J. and Levy, J.C. (1960) *J. of the Inst. of Metals* **89**, 86-89.
5. Botvina, L.R. and Shabalina, V.N. (1986) *Problems of strength* **9**, 62-67.
6. Okada, K. and others (1999) *Progress in Mechanical Behaviour of Materials, Proc. of ICM 8*, (Eds. F.Ellyin, J. W. Provan), Fleming Printing ltd, **1,** 231-236.