FAILURE RESISTANCE IN TITANIUM-ALLOY JOINTS UNDER BIAXIAL LOADING WITH TENSION

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On the basis of the criteria of the linear and non-linear distruction mechanics new quantitative characteristics of changing the parameters of ciclic distruction resistance depending upon the relationship of biaxial nominal stresses, crack inclination angle and tension in the joint were obtained. On the basis of the numerical analysis of the "cross" - type specimen having a central hole into which a pin with preload was adjusted imitating the insertion of a bolt into a smooth hole, the machanisms of the influence of loading conditions on the coefficients of intensities of the stresses were obtained.

INTRODUCTION

Modern tendencies in the world and domestic machine-building industry prove the reliability, strength and ervice life to be of dominant role in providing the increased quality and competitiveness of products. Detachable high-loaded joints being the most widely used type of structural joints in gas-turbine engines define strength, service life and reliability of structures as a whole. In operation, such joints are effected by the action of biaxial static and alternating loads of different intensities.

CONTENTS

Advanced methods of calculating longevity and survivability under cyclic loading are based primarily on taking into account the material plastic properties in the area of the crack tip, the deformation process inside the plastic zone being described by Manson-Koffin small-cycle fatique equations and by models for smallsclale fluidity state. The investigation of crack growth under biaxial cyclic loading has got a number

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of pecularities based on the type and geometry of the specimen to be tested. In this case the given ratio σ_1 / σ_2 is to be realized and the uniform field of stress-deformed state in the specimen operating zone is to be provided.

Numerical Methods. Stress-deformed state determination in specimen operating zone being studied was carried out by finite element method with the help of ANSYS 5.1 computer complex in Windows NT 3.51 (1) working medium.The principal solution equation of finite element method is to be(2):

$$\{R\} = [K][q] \qquad \text{where} \qquad [K] = \int_V [B]^T [D][B]\, dV \qquad (1)$$

Finite element model fragments applied for calculating stress-deformed state and defining the failure indensity parameters in the form of stress intensity coefficient are shown in Figure 1 and contain 1338 nodes, 1254 elements and 1390 degrees of freedom. Intensity and shear stress distribution given in Figure 2 shows that the highest density of isometric lines is in concentration zones: in places of bolt insertion into smooth hole and in zones of the radius interference nteraction of load tabs in specimens. Calculations of force parameters of fracture in plane stressed state were made by formulas:

$$K_1 = \frac{\sigma\sqrt{\pi h}}{2} F_1 Y_1 \qquad \text{and} \qquad K_2 = \frac{\sigma\sqrt{\pi h}}{2} F_2 Y_2 \qquad (2)$$

where $F_1 = (1+\eta)-(1-\eta)\cos2\alpha$; $F_2 = (1-\eta)\sin2\alpha$.

Figure 3 shows graphs in the form of K-calibrations obtained by finite element method on finite-element models, in Figure 1.

Experimental Procedures. Figure 4 shows a geometry of four-tab specimens made of material OT4 (σ_b = 766..810MPa, $\sigma_{0,2}$=550..650MPa, δ=18,2..21,8 %) and D16AT(σ_b = 435..462MPa, $\sigma_{0,2}$=282..339MPa, δ=11,9..21,6 %) which have been used for nvestigations. Stress relationship applied to specimens in testing were taken to be equal to $\eta = P_2/P_1 = 1$; 0,5; 0,2. The crack orientation angle was chosen to be: $\alpha = 25^0$; 45^0; 65^0; 90^0. Experimental investigations on cyclic resistance were carried out according to specifications (normative documentation) for testing (3).

It was defined that the crack growth trajectories under ciclic biaxial loading for OT4 alloy not depending upon the type of the stressed state, are similar to each other and always aimed at their normal to be of the highest nominal stress.It was defined that the biaxiality of stress-deformed state effects first of all through the zone of plasticity of the crack tip, and the capacity of stress distribution in the material is defined by its deformatiom properties.

The main feature of testing materials with initial sloped crack is that the crack is growing in arbitrary direction which differs from the initial and curved trajectory.The error in testing measurements will be basically defined by the curvature of the crack growth trajectory, since not the real length of trajectory segment is measured but the length of the straight line segment which is the projection of the given curve section on the axis of the optical device measurement.The tests were carried out till the final fracture of the cross-type specimen. The test pieces having failure on grips or along the radius of arms passes have not been taken into account and considered in the analysis.

Measurement and Analysis. On the basis of the test result the graphs of dependencies of crack length on load cycle number in the area of crack lengths up to 1 mm were developed. Herein, both the inclination angle and the degree of biaxial load were changed. Such dependancies are given in Figure 5. It was found out that there were some effects of the degree of biaxiality $\eta = \sigma_x/\sigma_y$ and inclination angle α_0 of the initial concentrator upon the kinetics of crack growth in materials OT4 and D16AT.

The received experimental data show that the initial crack orientation angle α has more effects on the crack growth rate than the relationship of nominal stresses η.Figure 5 shows experimental diagrams of cyclic crack resistance of cross-type specimens with their holes filled in. The law of the crack growth starting from the hole with the inserted bolt was described by the equation:

$$dh / dN = C\left(K_{eqv}^{max}\right)^{m} \quad \text{or} \quad dh / dN = \left(\frac{dh}{dN}\right)^{*}\left(\frac{K_{eqv}^{max}}{K^{*}}\right)^{m*} \qquad (3)$$

Richard failure criterion was chosen as the basis for producing failure diagram [5]:

$$K_{eqv} = \alpha K_{I} + 0{,}5\sqrt{K_{I}^{2} + 4\alpha K_{2}^{2}} \qquad (4)$$

where $\alpha = K_I/K_2$.

The test pieces made of alloys D16AT and OT4 have different trajectories of crack growth with similar load conditions which can also be explained by various plastic properties in the crack tip zone. Figure 5 shows diagrams of fatique failure under different relationships of nominal stresses η and tension in joint Δ. It is seen that the difference in diagrams of fatique failure for biaxial loading under $\eta = 0{,}5$ and $1{,}0$ is not large for materials D16AT and OT4. The difference in crack growth rates is defined not only by relationship of loads on axis η, but also by tension in joint Δ.

It may be concluded from the failure diagram (Figure 5) that tension in joint Δ results in some increase of crack growth in initial section of the failure diagram and practically does not effect in case crack length "h" becomes more than 0,3 mm, when the loaded hole becomes fully unloaded. The results given show that the initial crack orientation angle and tension in the joint greatly effect the crack growth rate. The lowest crack growth rate from all the studied variants of mixed types under cyclic loading was observed to be for parameters $\eta = 0,5$; $\alpha = 0$; $\Delta = 0,1\%$.

CONCLUSION

The effect of the crack orientation angle α, the relationships of nominal stress on axes of both the pecimen and the tension values in joint Δ on diagrams of cyclic crack resistance have been defermined in this work by investigating complex stressed state in cross-type specimens with filled-in holes as an example.

It has been stated that the failure process may be defined mostly by the angle of the initial crack orientation and, in the least degree, it depends on relationship of loads put on the specimen axes. Tension in joint Δ due to applied residual technological stresses can also slower down the failure process in the initial section of the failure diagram.

SYMBOLS USED

C, m, K^* = are experimentally defined material constants

$(dh/dN)^*$ = 10^{-7} (m/cycle)

h = half-length crack in the specimen (m)

K = calibrations obtained by finite element method ($MPa \cdot m^{1/2}$)

{R} and [q] = node stress vector and displacement matrix in finite element model nodes, correspondingly

V = finite element volume (m^3)

$Y_{1,2}$ = calibrating functions, taking into account the joint geometry anc load scheme, and calculated by finite element method (4)

Δ = tension in joint(%)

σ = nominal stress in the direction of axis OY (MPa)

REFERENCES

(1) Ansys User's Manual Revision 5.1, Swanson Analysis Systems, Inc. December 23, 1992.

(2) Irons, B.M. " A frontal solution program." Jnt. J. Num. 3. Eng., 1970, v. 2, pp. 5-32.

(3) Methodical Instructions (Manuals). Calculations and strength tests. Methods of mechanical metal testing. Definition of crack resistance characteristics (destruction viscosity) under cyclic loading. RD-50-345- 82. Standards Publications, Moscow,1983, 96 p.

(4) Morosov E.M., Nikishkov G.P. Finite elements method in failure echanics. Chief edit., phys.-math. lit.,Moscow,1980, 256 p.

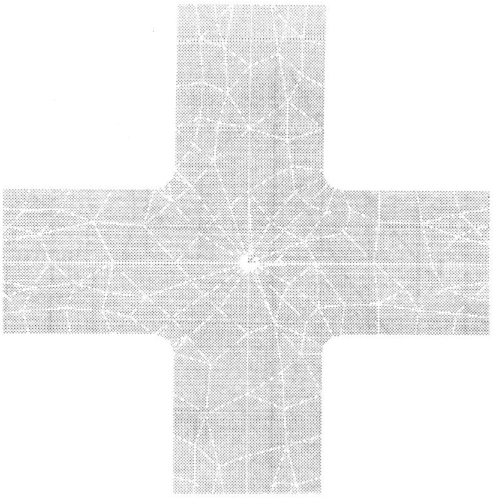

Figure 1 Finite element model

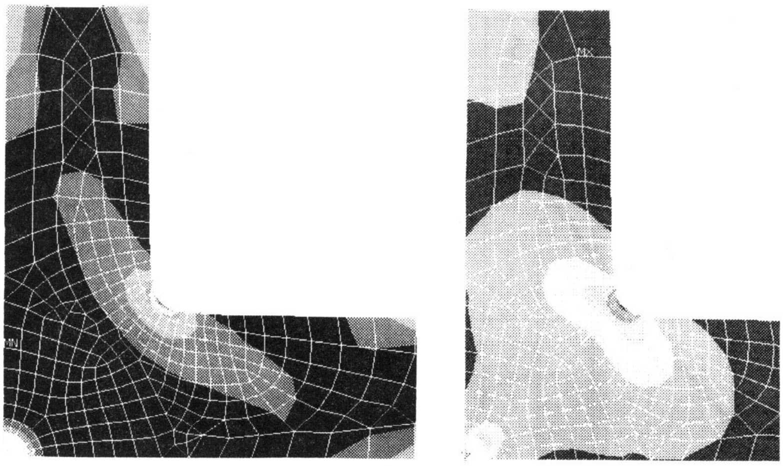

Figure 2 Stress -deformed state

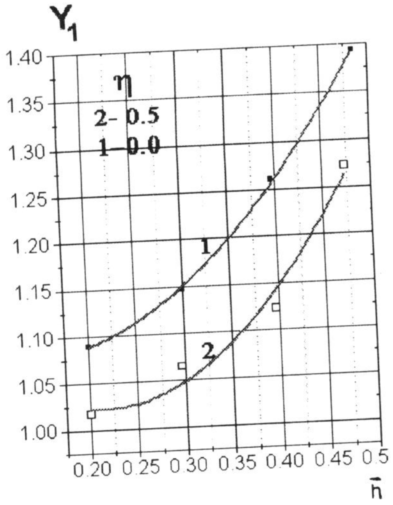

Figure 3 Stress intensity coefficient

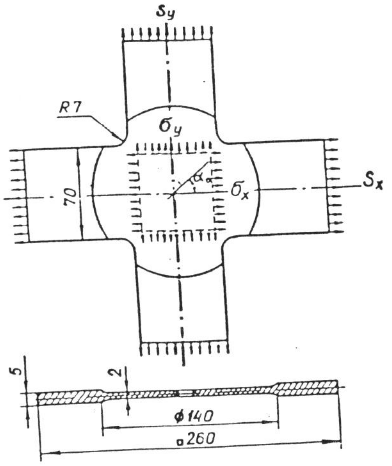

Figure 4 Geometry of four-tab specimen

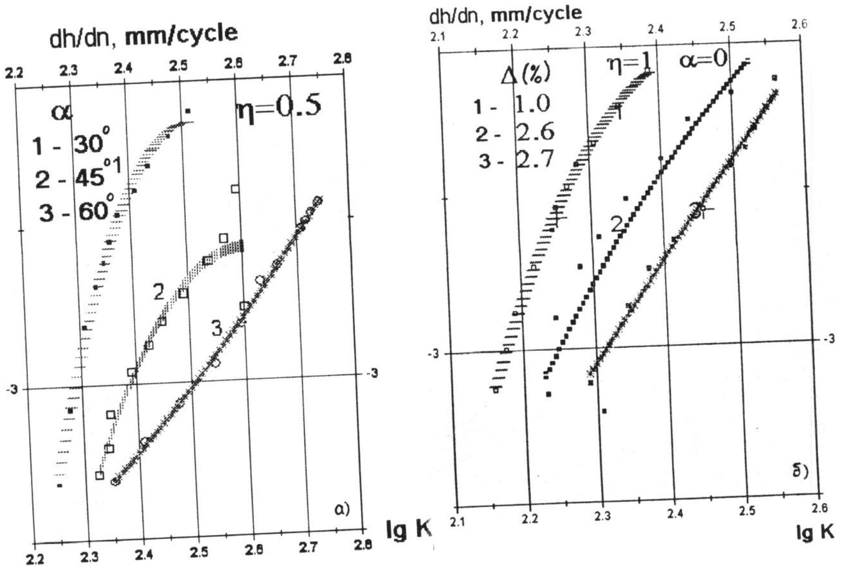

Figure 5 Experimental diagrams