Plots of p_u and p_* and the region of experimental critical loads p_{exp} [5, 6] are presented in Fig. 2.

We note in conclusion that the load p_* found depends upon the shell thickness and agrees over a wide range of variation of h with the lower limit of the region of the derived and experimental critical loads. Other experimental facts find explanation within the framework of the proposed mechanism of stability disruption. In particular, the large scatter of the experimental data can be explained by a difference in the initial conditions, the nature of the loading, and random dynamical effects, and the decrease of this scatter at small thicknesses is related to an increase in the number of resonance relationships, along with the increase in 1/h.

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FIELD OF ELASTOPLASTIC STRAINS IN THE MOUTH ZONE OF A CRACK

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When establishing the criterion of failure, the knowledge of the strain and force conditions in the mouth zone of the crack is of great importance. Dependent on the model of elastoplastic strain of this zone, different concepts are proposed for the choice of the failure criterion [1]. At the same time it is necessary to take into account the fact that a real failure process on the macro scale in the majority of cases has a mixed character [2]. Hence experimental and theoretical investigation of the field of elastoplastic strain (EPS) in the mouth zone of the crack [3] is of great importance. In [4-6] an experimental analysis of the EPS fields in the mouth zone of a crack is carried out by methods of photoelasticity, Moiré and holographic interferometry. In [7-9], by numerical methods, analysis of EPS fields is carried out for plane stress and plane strain states. A paper should be mentioned [10] in which by the holographic interferometry method, the field of elastic and residual components of strains is determined for a plate loaded by internal pressure.

1. The Method of Investigation. The investigation was carried out under the normal external conditions on flat testpieces of alloy steel 38KhNVA. The testpieces were heat treated according to typifying conditions. Hardness HRC = 50.

In Fig. 1 we have shown the geometry of the testpieces. The origin of the coordinate system is connected with the crack tip. The work zone of the testpieces was mechanically polished, and was then lapped under a load $P_0 \sim 2kN$ to obtain a maximum flatness and a satisfactory coefficient of light reflection. The testpieces had an initiated fatigue crack. The thickness of testpieces t = 2.0 mm. The loading was carried out on a testing machine provided with a laser holography system. The loading regime was stepped monotonic tension with the load step Δp = 981 H.

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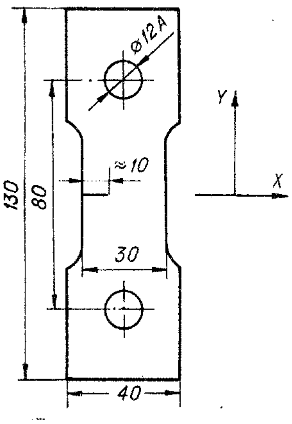


Fig. 1

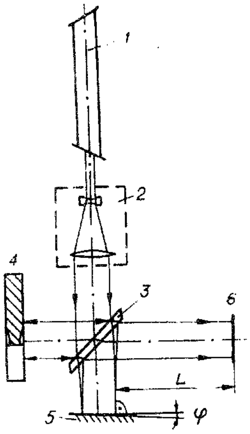
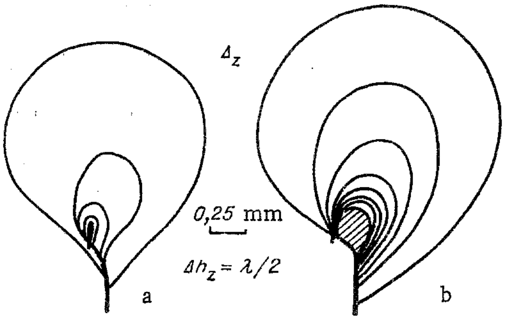


Fig. 2

In Fig. 2 we have shown the optical scheme of the holographic interferometer. It consists of an He–Ne laser 1 of the LG 75 type, a collimator 2, a dividing mirror 3, the testpiece 4 under investigation, a base mirror 5, and a screen 6 for the observation of holograms. The given scheme to some degree is similar to the scheme proposed in [11]. It allows us to measure fields of displacements both along the normal to the surface Δ_Z and in the plane of the object Δ_{XY}. The step h_Z, h_{XY} between the equipotential lines of displacements equals approximately $\lambda/2$. The basic instrumental error (as a result of the angle φ, Fig. 2) of a real installation is estimated by a quantity less than or equal to 5%. The measurement of the displacements Δ_Z is based on the principles of classical interferometry. The theory of the method of measurement of the displacements Δ_{XY} is presented in [12]. At the basis of the method there lies the phenomenon of diffusive reflection of light from the surface of a metal and its interference with the base ray.

During the investigation the unit of measuring head, consisting of the components 3 and 5 (Fig. 2), was adjusted relative to the surface of the testpiece in such a way that a homogeneous field of illumination was obtained on the screen. Then tensioning of the testpiece took place with the photography of the holograms at each stage of loading.

2. Experiment. The results of the experiment have been represented in the form of holograms processed from photographs. In Fig. 3 we have shown holograms connected with the field of displacements Δ_Z. Fig. 3a corresponds to a quasistatic growth of the zone of EPS under a load p = 3.92 kN under conditions close to a plane stress state. In view of smallness of the geometrical dimensions of this zone it was not possible to investigate fully its fine structure. It should be noted that the external contour of the zone agrees with the hypothesis about its shape in accordance with [13]. Under a load p = 7.84 kN there occurred the first discrete increment of the crack of the magnitude (for the given testpiece) Δl_{T_1} = 0.125 mm. Figure 3b shows the field of EPS immediately after the jump of the crack (the shaded region with large displacement gradients). The step between the equipotential lines $h_Z = \lambda/2$. The holograms of the EPS displacement Δ_Z fields after the loads p = 10.78 and 12.74 kN have been reached, are shown respectively in Fig. 4a and b. By dashed lines we have isolated the regions of the EPS zone of maximum intensity of plastic strain. The chain-dotted lines isolate in this region the contour inside which there takes place the basic



a b

Fig. 3

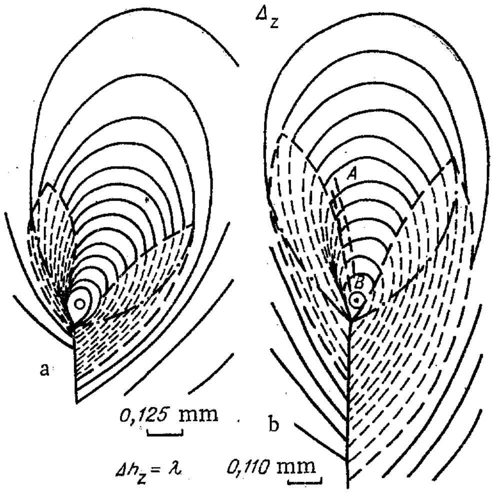


Fig. 4

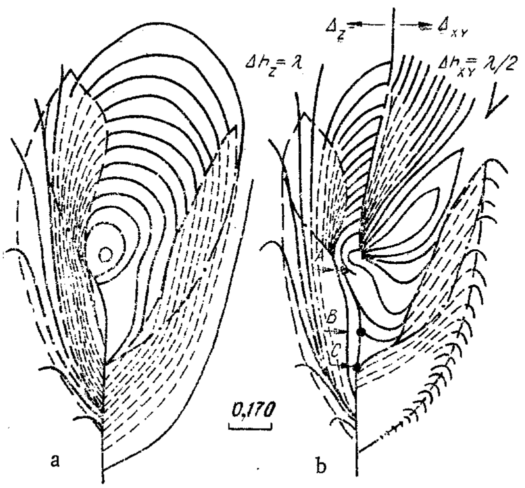


Fig. 5

dissipation of the elastic energy by the zone of plastic strain under the given load. To determine the boundaries of this contour, we have used the feature of changing curvature of the equipotential lines Δ_{XY} (Fig. 5b) with passage from the zone of plastic strain into that of elastic strain. Experimentally, it has been determined that for the given steel in the case of $h_Z = \lambda/2$, for the field of displacements Δ_Z the distance between neighboring equipotential lines equals $\approx$ 17 μm. The field of displacements under a load p = 12.74 kN is connected with the postcritical state, since under p = 13.33 kN there occurred the second jump of the crack, $\Delta l_{T_2} = 0.360$ mm. A comparative analysis of the holograms (Fig. 4) shows that, in addition to the absolute increase of the dimensions (the area) of the contour of maximum intensity of plastic strain, its rotation relative to the crack tip takes place. This basically is connected with the fact that the jump of the crack takes place under the conditions of a plane strain state, while the growth of plastic strain takes place under the conditions of a plane stress state. We know that for a plane strain state precisely such an orientation of plastic strains is characteristic [9]. By the line AB (Fig. 4b) we have shown the place where the shear plane goes out to the surface of the testpiece (although on the macro scale we do not observe a break in the displacement field). On the hologram the line AB is singled out from the contrast of illumination in comparison with the surrounding pattern of the field. In Fig. 5 we have shown holograms of the residual field of displacements in the zone of plastic strains after unloading of the testpiece to p = 1.86 kN. On the left (Fig. 5b) we have shown the field of displacements Δ_Z, and on the right the field of displacements Δ_{XY}. Here also by the points C, B, and A we have denoted respectively the initial position of the crack tip, and after the jumps Δl_{T_1} and Δl_{T_2} of the crack. From the results of measurements obtained we have constructed the graphs (Fig. 6) of the relations $r_r/t = f(p)$, $\Delta l_T/t = f(p)$ (1 and 2, respectively, where r_r is the modulus of the radius vector, numerically equal to the magnitude of the segment joining the crack tip with the remotest point of the contour with maximum intensity of plastic strains.

An analysis of the fields of displacements in the zone of intense plastic strains shows that in the case of a mixed character of the failure process we can single out three characteristic phases of its development. The first phase is a quasistatic growth of the zone of intense plastic strains, which in the first approximation linearly depends on the magnitude of the applied external load. The special feature of the second phase consists of the fact that under loads close to the critical load p_* there occurs localization of plastic strains in the form of a narrow zone in the direction of the continuation of the crack, this being connected with formation and growth of the shear plane into the depth of the material. The basic mechanism of the formation of localized shear is exhaustion of the capacity for plastic deformation in the zone with maximum intensity of strains. At the same time dissipation of the elastic energy is determined basically not by the growth of the volume of the plastically strained zone but by the magnitude of the localized shear (the nonlinear character of the curve 1 in Fig. 6). Development of the localized shear leads to an increase of the concentration of stresses in the central regions of the crack contour, and for $p = p_*$ there occurs a jump of the precritical crack, which is singled out into the third phase of the development of the failure process in the case of its mixed form.

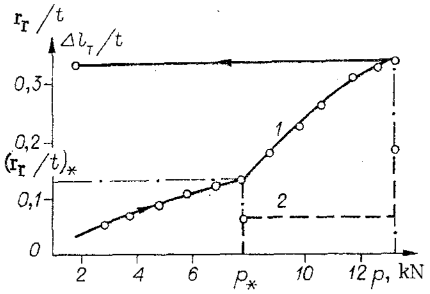


Fig. 6

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