# FRACTURE OF PLATES AND SHELLS WITH CRACKS WITH ACCOUNT FOR THE LOCAL STABILITY LOSS

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ABSTRACT

The present paper deals with the results of experimental studies of the local stability loss, the stress-strain state and fracture of plates and shells with cracks and crack-like defects under various loading conditions. Critical stresses corresponding to a stability loss for a wide range of materials have been determined. The form of the stability loss and the postcritical deformation has been studied. The influence of tested specimen types, defect types and their orientation as to the stress field, upon the characteristics to be defined has been found out. The dependence of the stress-strain state from local buckling near the crack has been studied. The dependence of the values of stress-strain concentration factors from the stability loss is shown. It is shown that a local stability loss near cracks and crack-like defects influences upon fracture kinetics, the main characteristics of fracture and residual strength. The influence of stress concentration types and external loads on the determined fracture characteristics has been also found out.

KEYWORDS

Fracture, stability, plate, shell, crack, stress, strain.

INTRODUCTION

In the study of fracture of thin bodies (plates and shells) with cracks in tension,it is necessary to take an account of specific deformation of such bodies. It consists in that fact that due to the presence of compressing forces, localized along crack edges, in case definite relations between the crack length and the thickness of a body exist, a local stability loss will precede the beginning of fracture. The resultant stress-strain state is different from the normal one (in case we suppose that the tested specimen retains its form until fracture begins) that leads to changes of the main fracture haracteristics. Many authors for many years (e.g.Dixon and Stranningan,1969; Fuimoto and Sumi,1987; Goltsev et al.,1969; Zielsdorf and Carlson,1972 etc) carried out experimental studies of stability and fracture of thin plates with cracks. Individual specific problems concerning mainly the phenomenon of local buckling of a thin plate with a rectilinear crack have been considered by them. For many years already the authors of the present paper have been also carrying out investigations in this sphere. They are studying not only plates with rectilinear cracks but also plates and shells with cracks and crack-like defects (e.g.two rectilinear cracks, elliptic and arced cracks, cracks stretching up to contour of the circular opening etc) under different loadings (cracks arranged under different angles to the external loads; uniaxial and biaxial loadings). Special attention was given to the influence of local stability loss on the material fracture characteristics. Some of the results are given in (Guz' et al.,1981) and in numerous papers, published in recent years (e.g.Guz' and Dyshel', 1985; Dyshel',1988; Dyshel',1990 etc).

In the present paper,we shall present results of the complex experimental study of the local stability loss, the stress-strain state and fracture of plates and shells weakened by cracks and crack-like defects in different loading conditions. This study may be divided into two parts: 1.The study of only the local stability loss in order to find out critical stresses. Here we may determine whether or not we should take an account of the process of the local stability loss in studying fracture processes in plates and shells. 2.The study of fracture of plates and shells with account for the preliminary local stability loss. The influence of a local stability loss on its stress-strain state, the main characteristics of fracture and strength are determined.

## LOCAL STABILITY LOSS

To determine critical stresses $P_{cr}$ corresponding a local stability loss of a plate with a crack, diagrams of deformation reflecting dependence of one of the parameters characterizing the buckling of the plate (deflection $W$ , the change of surface curvature $\Delta æ$, the deformation difference $\Delta \varepsilon$ on both sides of the plate)from the applied load were presented. A typical diagram of deformation is shown in fig.1. In contrast to theoretical studies, in experiment,due to various imperfections (e.g. the initial curvature of a plate, nonhomogeneous of material, eccentricity of the applying load etc), the bifurcational form of transition to the contiguous equilibrium state is not realized. However, since the diagram of deformation has special sections (two rectilinear sections $OA$ and $BC$ connected by the $AB$ curvelinear section), we can determine the value $P_{cr}$ . One method consists in determining $P_{cr}$ as abscissa of $M$ point of intersection of rectilinear sections $OA$ and $BC$. To determine $P_{cr}$ we may use other methods, in particular, the Southwell method, but all results are similar. The values of the critical stresses depend on geometric



parameters of a plate and mechanical properties of materials and are determined by expression (1), where $E$ - the elasticity modulus, $h$ - the thickness of a plate, $\ell_o$ - the semilength of a crack, $K$ - a factor of proportionality. Values $K$ for plates from different materials - steels, aluminium and titanium alloys have been determined. The values $K$ varies in the limits of 1.05-1.20.

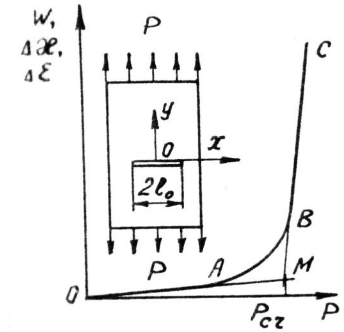


Fig.1.Diagram of deformation

For plates with crack-like defects the values $P_{cr}$ have been determined by analogue. Diagrams of deformation had the same form as for the plate with rectilinear crack, and values $P_{cr}$ depended on the type of defect and its orientation in the field of external forces. The value $P_{cr}$ in each concrete case has been determined using the expression (1), and the value of the factor $K$ varied depending on the defect type. Some regularities of the critical stress variation in depending on the defect type pre-

$$P_{cr} = KE\left(\frac{h}{\ell_o}\right)^2 \qquad (1)$$

sented below. For plates with rectilinear crack located under an arbitrary angle $\alpha$ to the load action the factor $K_\alpha = K/\sin^3\alpha$ . At certain values of the angle $\alpha$ even for maximal possible crack length for the given plate the local stability loss will not occur since the fracture of the plate will precede to it. In case of biaxial loading of the plate the values $K_q = K(1+q/P_{cr})$, where $q$ - the load applied along a crack. In case of two parallel cracks the distance between them practically does not influence on the value $P_{cr}$ . In case of two cracks on a single line the decrease of the gap between them reduces significantly the value $P_{cr}$. For plates with an elliptical crack the value $P_{cr}$ is influenced by the form of a crack contour - the least value $P_{cr}$ is observed for a rectilinear crack; for a circular opening the value $P_{cr}$ approximately exceeds 1.7-2 times the value $P_{cr}$ for a rectilinear crack. For an arced crack the distortion of the crack (change of an arc arrow) effects significantly on the value $P_{cr}$ . When the distortion increases the critical stress increases on the concave edge of a crack and decreases on a convex one. For the circular opening with two radial cracks stretching up to its contour the value $P_{cr}$ depends on the relationship between the crack length and the opening radius. For a curvelinear opening with three points of return the value $P_{cr}$ is influenced by the position of a defect in the external forces field. First of all, a stability loss occurs near that side of the opening for which the angle of inclination to the line of a load is the least.

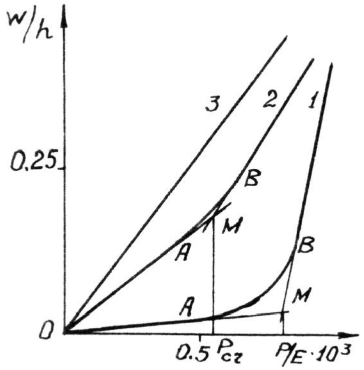


Fig.2. Diagrams of deformation of panels and shells

In studying stability panels and closed shells with cracks deformation diagrams were similar in form as in the case of plates deformation diagrams. The curve 1 (Fig.2) relates to the cylindrical panel of the radius $R$ =4000 mm. It allows to determine critical loads corresponding to a stability loss using analogous procedures. Due to decrease of the panel or shell radius, the deformation curve is rectificating (curve 2 corresponds to radius $R$ =1000 mm) until it does not turn into a straight line (curve 3 corresponds to radius $R$ =250 mm). For shells with similar deformation the determination of critical stresses is impossible. Hence, we cannot speak about the stability loss in the strict sense of this word. To determine the critical stresses we may use expression (1), however, in this case (in contrast to a plate where factor $K$ depends only on the Poisson's ratio and does not depend on geometrical parameters of a plate) the value of factor $K$ depends also on geometrical parameters of a shell - its radius $R$ , thickness $h$ and crack length $2\ell_o$ . Numerical values of the factor $K$ increase with a decreasing crack length and an increasing shell radius. The value $K$ has maximal value for a plate with similar geometrical parameters as well as for the shell.

## STRESS-STRAIN STATE

The influence of the local stability loss of plates with cracks on their stress-strain state is shown in fig.3-6. To estimate this influence plates with similar geometrical parameters were tested in two types of experiments - with and without free buckling. In the latter case the buckling was prevented by attaching two rigid slabs to both sides. The gap between them was wide enough to provide linear deformation of the plate. Fig.3 shows the distribution of tensile stresses $P_y$ along section $Ox$ passing through the crack. Curve 1 corresponds to the buckling case, curve 2 - to the case when buckling is absent (this notes are valid for all other figures). The presence of buckling leads to increase of stress $P_y$ at the crack tip. The stress concentration factor increased approximately by 17%. Fig.4 shows the dependencies of compressible $P_c$ and tensile $P_{max}$ stresses measured correspondingly on the crack middle edge and at the tip of it, of the applied load. In the presence of buckling an absolute value of the stress $P_c$ decreases and the stress $P_{max}$ rises with the increase of the load. The influence of buckling on stress increase $P_{max}$ may be expressed by the empirical rela-



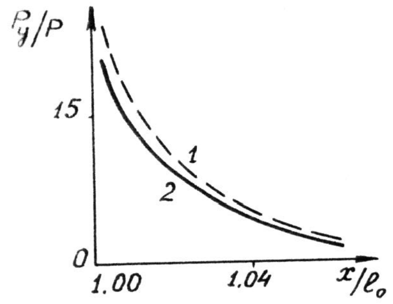


Fig.3. Distribution of tensile stresses

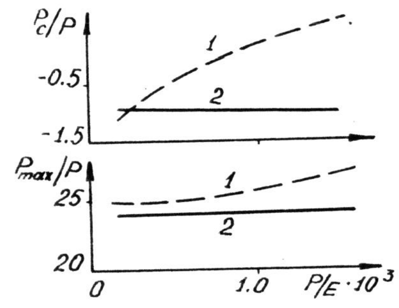


Fig.4. Dependences of stresses on load

tionship (2). In experimental determination of the stress intensity factor taking account for some factors influencing its value (in particular, dimensions of a plate, the form of a crack and a sharpness of a crack tip) by introducing cor-

$$(P_{max})_1/(P_{max})_2 = 1 + 0,14\,(w/h)^2 \qquad (2)$$

rection factors we must take account of the influence of buckling. It has been done with the obtained distribution of stresses $P_y$ along the crack line. The "seeming" value of the stress intensity factor $K_I^*$ with different distances $r$ to the crack tip was found from relation $K_I^* = P_y\sqrt{2\pi r}$ and then the factor $K_I$ was found as $K_I = \lim_{r\to 0} K_I^*$ by extrapolation of the obtained dependences $K_I^*$ from $r$ . The following quantity of

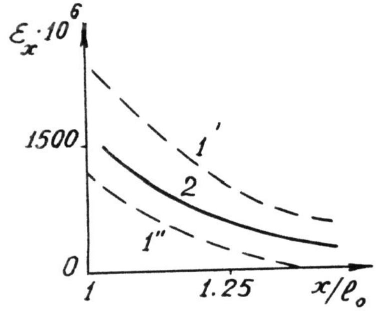


Fig.5. Distribution of deformation $\varepsilon_x$

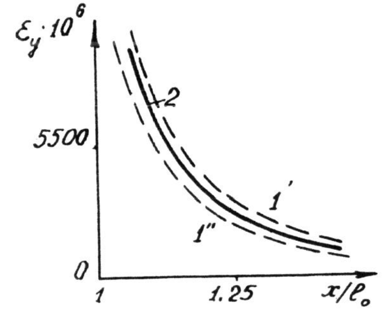


Fig.6. Distribution of deformation $\varepsilon_y$

the correction factor $f$ for plates made of aluminium alloy AMg6M was obtained:

$$f = 1.001 - 0.010\, P/P_{cr} + 0.011\,(P/P_{cr})^2 . \qquad (3)$$

In fig.5 and 6 curves of the distribution of surface deformation $\varepsilon_x$ and $\varepsilon_y$ along the plate section passing throuhg the crack (curves 1' - measurements were made on the convex surface of the plate in buckling, curves 1'' - on the concave side of the plate) are shown. Buckling resulted to concentration of deformations, in comparison with the case no buckling, increased appro-ximately by 16%.

## FRACTURE

The critical crack length $\ell_*$ has been obtained from the equality of the critical load $P_{cr}$ corresponding to the stability loss and fracturing load $P_m$ . In fig.7 the dependences of loads $P_{cr}$ and $P_m$ on the initial crack length for the plate from AMg6M are shown. The dashed part of the curve $P_{cr}$ was

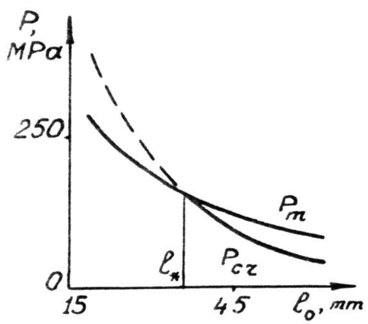


Fig.7.Critical crack length

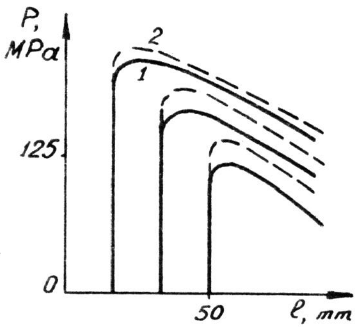


Fig.8.Diagrams of fracture

constructed by using expression (1). Point $A$ of the curves $P_{cr}$ and $P_m$ intersection corresponds to the critical crack length. In case when the initial crack length $\ell_o$ in the plate exceeds $\ell_*$ , the local stability loss precedes the fracture. In the study of fracture of plates and shells with cracks and crack-like defects the length was taken so that the buckling preceded to the beginingof fracture. Using measurement results the diagrams of fracture reflecting dependence of fracture parameters (the crack length, the crack growth rate etc) on loads, the stress intensity factor and the crack propagatoin time were constructed. The typical diagrams of fracture for plates from AMg6M with different lengths of the initial crack are shown in fig.8. Curves 1 as in the previous figures



relate to plates which have the stability loss before fracture, curves 2 - to plates with no buckling. In all diagrams curves 2 are placed over the corresponding curves 1. On the basis of the diagrams the main fracture characteristics were determined. For plates with buckling all fracture characteristics are lower (excluding crack growth rate) than for plates with no buckling. Thus,the value of the crack start stress decreases up to 20% for different materials; the critical crack length and the critical stress corresponding to the transition to unstable fracture decrease up to 15%; the crack growth rate increases up to 30%. On the basis of fracture diagrams for plates with and without buckling the main crack resistant characteristics have been also determined - force (the stress intensity factor $K_I$ ), deformation (the opening in the crack tip $\delta$ ) and energy ( $J$ -integral) parameters of elastic-plastic fracture. Without taking account for the complex three-dimensional stress state near the crack, related to buckling, and formulas have been also used which did not account of buckling. It was obtained that all characteristics of crack resistance of the plates with the stability loss are significantly smaller than those for the plates with no buckling. The maximal difference is 18% and it is bigger for plates for which the initial crack length is bigger. The buckling also reduces the residual strength of plates. This value is influenced by geometric parameters of plates and mechanical properties of the material - The influence of buckling increases with increasing crack length and decreasing plate thickness. Also more significantly the strength of plates decreases for materials with high elastic characteristics. Among the tested materials the biggest decrease of strength has been observed for plates from AMg6M - about 24%. This decrease may be approximated by the expression

$$P_{m_1} = P_{m_2}\,(1 - 0.00065\; 2\ell_o/h) \qquad (4)$$

For plates with cracks and crack-like defects in different conditions of loading for each case the influence of buckling on various characteristics has been estimated. For the incline placed crack the buckling leads to the increase of the crack growth rate, to the decrease of the critical crack length and maximum load. In biaxial loading of plates the influence of buckling on the value of the fracture load decreases with the load $q$ increases. For an arced crack increase in its curving results in the increase of buckling influence on the load fracture growth (up to 16%). For plates of AMg2P with the circumsential opening and two radial cracks stretching up to its contour the buckling

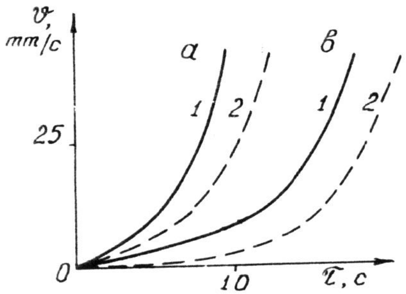


Fig.9.Crack growth rate

results in a decreasing crack start load and in load fracture approximately up to 20%, the increase of the crack growth rate approximately up to 70%. In testing of cylindrical panels, cylindrical and conic shells the fracture diagrams were quantitativly analogous to the diagrams for the plates obtained earlier. Fig.9 shows the dependence of the crack growth rate on the time $\tau$ of its propagation for the cylindrical shells of the thickness 0.3 mm and of the initial crack length 40 mm. Curves1 relate to the shell of diameter 180 mm, curves 2 - 250 mm. The buckling influence on chainging of the main fracture characteristics for shells is similar for those of the plates. Decrease of the crack start load was ~ 15%, fracture load ~ 17%, crack growth rate ~ 30%.

## CONCLUSION

The significant influence of buckling on fracture characteristics of plates and shells with cracks requires to take account of the development of fracture theories which may be applied to the elements of thin wall constructions. In experimental determination of the main mechanical characteristics it is necessary to carry out testing using spesimens of such geometrical dimensions, that their buckling is absent or we must make it artificially. In strength testing of construction elements the correction factors should be introduced when we establish the strength standart taking account of construction materials, their thickness and crack length.

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