POSSIBLE CAUSES OF FRACTURE OF TUBULAR SAMPLES DURING COMPRESSION

M. M. Muzdakbaev and V. S. Nikiforovskii

UDC 539.4

The simplest, and therefore the most widely used, test of materials is uniaxial compression. In many cases spherical, tubular, or rectangular samples — cube, parallelepiped, etc., duplicate or are rather close to the actual shape of the component or structure whose reliability is to be estimated, and therefore if the modeling is accurate enough the test determines sufficiently reliable technical strength characteristics. It is evidently premature to speak at this time of material, although a certain indirect estimate of it can be made [1]; it is more logical to speak of the technical strength of a model-structure.

Experiments show that the character of the fracture of a sample depends on the experimental conditions: Cones and prisms near the ends are associated with the appearance of a dangerous concentration of maximum tangential stresses; cracks in the direction of compression are recognized as paradoxical, although normal tensile stresses occur on corresponding areas [2, 3]. The normal tensile stresses produced here may be caused by the nonuniformity of the stressed state due to irreversible deformations in a part of the sample. In the present paper we discuss maximum tangential stresses as another cause of vertical cracks coaxial with the applied pressure.

Let us consider the fracture kinetics of a tubular sample under the conditions of [3]. We assume that fracture occurs after the maximum tangential stress averaged over a rectangular element consisting of two triangles reaches the maximum value $\tau_{max} = \tau_0$. The fractured material loses its previous strength properties: Its elastic modulus jumps down to a value $E_1 = kE_0$, $k < 1$. This leads to a decrease in the total carrying capacity of the whole sample, and consequently to stress relaxation in it for a constant given boundary displacement of the ends $v = \text{const}$, and to a redistribution of the whole stress field. The method of successive approximations is used to calculate the corresponding nonlinear diagram. Then the next displacement of the ends $v_{i+1} = v_i + \Delta v$ is made, the stress field is analyzed, a test is made to see if the strength criterion is satisfied, the fractured region is reconstructed with a change in the material properties, and a refined recalculation is made — a numerical experiment on the deformed and fractured sample.

Figure 1 shows a composite diagram of the fractured region for the following ratios of the dimensions of the sample (H is the height and D is the outside diameter): a) H/D = 1–5 stages of fracture; b) H/D = 2, D = const in comparison with Fig. 1a, 3 stages of fracture; c) H/D = 2, H = const, 4 stages of fracture. The finite-element structure is shown in the upper left-hand corner. The net of 10 × 35 nodes used in all cases may give different accuracy for various sized regions, and the results may have to be corrected, as discussed later. In all the experiments the calculation was performed up to the instant of emergence of the damaged region at both lateral surfaces with the formation of a fracture crack penetrating the whole sample. The assumed model of the behavior of the material (a stepwise transition of the elastic modulus from E_0 to E_1 — an unusual loss of strength) makes it possible to fix the following parts of the $\sigma - \varepsilon$ (average axial stress — average axial strain) diagram: The part of the elastic deformation with the modulus E_0 up to the elastic limit when the fracture condition $\tau_{max} = \tau_0$ is satisfied in the first element; the stepwise part of the flow with drops of the axial stress at the instant of fracture of the next units or group of elements with a subsequent increase with a reduced modulus E_* $(E_1 < E_* < E_0)$, etc., in which the depth of the drop depends on the number of fractured elements and the value of k; the part of the hardening process with the modulus of the fractured material E_0 when all elements of the domain go over into such a state. From what has been said it follows first that fracture in the present paper has been identified with the beginning of plastic flow, and the question is the construction of a zone of flow; second, by this time a difference can be seen in the properties of the material and the sample-structure; third, to obtain in-

Novosibirsk. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 3, pp. 150-153, May-June, 1981. Original article submittted August 12, 1980.

0021-8944/81/2203-0422$07.50

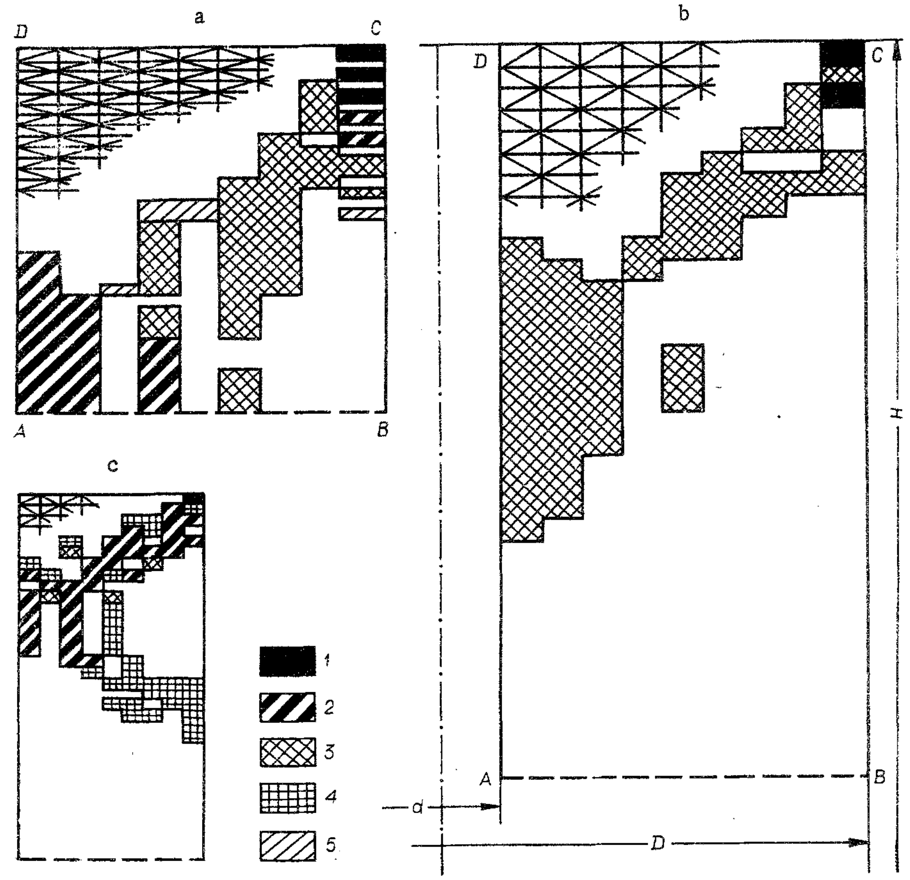

Fig. 1

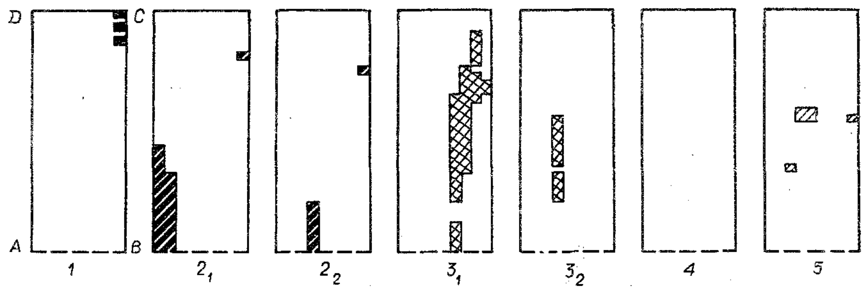

Fig. 2

tegral characteristics of the diagram (breaking point, softening portion) it is necessary to assume further hypotheses of the local behavior of the medium.

A change of the ratio of the properties of the initial and fractured material (the coefficient k), the geometry, and the character of the boundary effect (u, v) enable one to see a whole gamut of different courses of the fracture process. Frequently the fractured region penetrates the whole sample from the upper (the symmetric half of the diagram is considered) outside corner region down to the inner radius near the plane of symmetry AB in the central part, resembling the experimental fracture cones. It is possible for the fractured region to begin and move in the opposite direction from the inner radius and inner localized cavities. The appearance of vertical domains inside the sample, and fractures from the inside radius from the plane of symmetry in the central portion, is very interesting. Sometimes an oblique slip plane has a "lamellar" structure consisting of a number of successive vertically oriented cracks.

In this sense a step-by-step analysis of the fracture process corresponding, for example, to the case shown in Fig. 1a (H/D = 1) is of interest. Figure 2 shows the fracture steps denoted by the numbers 1-5, where the subscripts define more precisely the successive

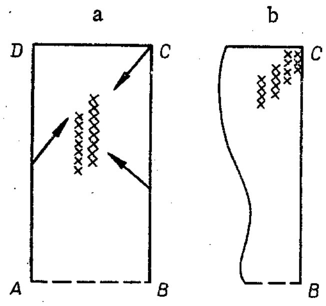

Fig. 3

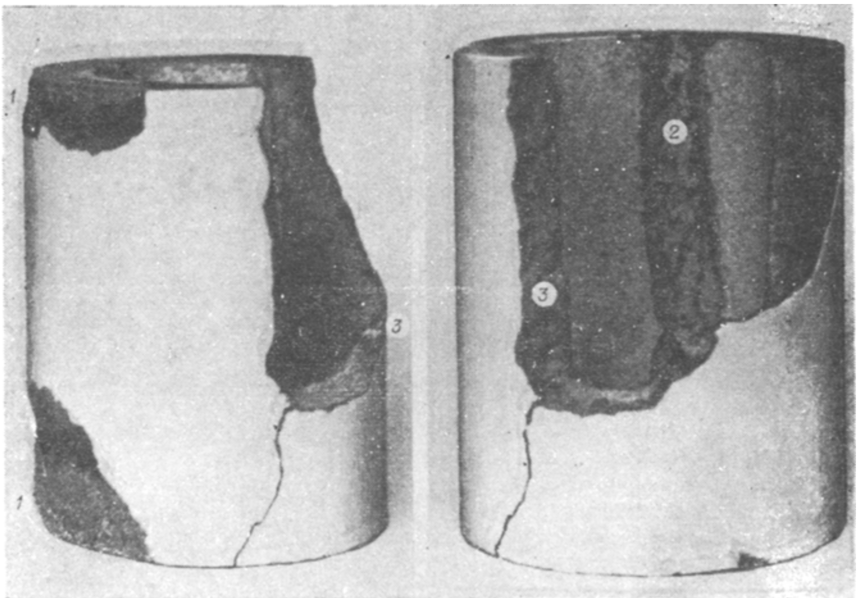

Fig. 4

approximations of the calculation which are also substages of the process. An element-by-element analysis with respect to the relative level of average stresses indicates the direction of development of the process.

First three rectangular elements on the outside radius at the loaded end are fractured (stage 1, Fig. 2); then an extended region at the inside radius near the plane of symmetry (2_1) turns out to be dangerous, then the elements along the vertical lines $(2_2, 3_1, 3_2)$ and an extensive zone in the corner region (3_1). At stage 4 the fracture process stops; at stage 5 additional separate elements and groups of elements are fractured, and the fractured domains on the inside and outside radii are joined into one through crack which penetrates the whole sample and possibly separates the outside region and the cone.

With an increase in height or a decrease in diameter of the sample the H/D ratio is increased and additional fracture zones are noted from the outside radius of the central portion (Fig. 1c). Figures 3a and b respectively show the kinetics of propagation of fracture zones and the "lamellar" structure of oblique slip surfaces obtained in a number of calculations. Particular attention should be paid to the possibility of the formation of such vertical cracks (Figs. 3a, b) coaxial with the compression, which also occur in the central portion of the sample, and, depending on the degree of constraint of the boundaries and the geometry, occasionally turn out to be dangerous [2, 3]. These cracks are not due to normal tensile stresses, but to the limiting values of the maximum tangential stresses.

Let us compare the results of numerical and full-scale experiments. Figure 4 shows one such example obtained in the Yu. A. Veksler laboratory (Karaganda). A tubular concrete sample was fractured under axial compression. Splitting of the corners is visible (1) (most likely this is fracture of the first stage); splitting is possible along a vertical crack with exit on the outside lateral surface — the separation of layers; fracture 2 in the neighborhood of the inside radius near the plane of symmetry, and also 3 at the outside radius in the central part of the sample with passage to the inside, and general chipping off.

The authors thank E. I. Shemyakin for his attention to the work and a discussion of the results.

LITERATURE CITED

1. G. N. Kuznetsov, Mechanical Properties of Rocks [in Russian], Ugletekhizdat, Moscow (1947).
2. R. B. Beisetaev and V. S. Nikiforovskii, "Strength of solids in uniaxial compression," Fiz.-Tekh. Probl. Razrab. Polezn. Iskop., No. 3 (1976).
3. M. M. Muzdakbaev and V. S. Nikiforovskii, "Compressive strength of materials," Zh. Prikl. Mekh. Tekh. Fiz., No. 2 (1978).