MICROSCOPIC AND MACROSCOPIC PLASTIC DEFORMATION AS A CRITERION
OF THE LIMITING STATE OF A MATERIAL DURING FRACTURE

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In tests of a material for static fracture toughness (K IC), the stress state of the material at the moment of fracture is of fundamental importance. Correct determination of K IC is related to the formation of a minimal plastic-strain zone at the crack tip [1]. However, due to the complexity of monitoring the plastic zones during crack propagation, K IC is generally evaluated with either theoretical values of plastic zone size or other, not-always-substantiated criteria realized in specimens under plane-strain conditions [1-3]. It was suggested in [4] that in tests of a material in the ductile-brittle transition range, the change in the character of fracture is connected with a shift in the stress state of the material at the moment of fracture.

This article examines the possibility of using microscopic and macroscopic plastic-strain zones [5] under the fracture surfaces of materials with a bcc lattice as criteria of the limiting state of the material during fracture in the range of the ductile-brittle transition.

Test Method. The mechanical tests included: 1) static tests, in off-center tension, of specimens of steel 15Kh2MFA 2·10⁻² m thick containing an induced fatigue crack, with a test-temperature range of −196 to +20°C*; 2) impact tests of prismatic specimens of steel 45 measuring (1.5 × 1.5)·10⁻² m in cross section, with the specimens containing a V-shaped stress raiser and being tested in the temperature range −196 to +180°C. The steel 45 specimens were annealed at 900°C before testing.

The fracture surface of the specimens was subjected to microscopic fractographic analysis with an optical microscope and a comparator, while a microscopic fractographic analysis was made on a JSM-U3 scanning electron microscope.

Structural changes in the material near the fracture surfaces were studied by x-ray diffraction. Here, we photographed the central part of the fracture surfaces on a DRON-1.5 diffractometer in Co Kα radiation. The depth of the plastic zones was determined by the method of layer-by-layer etching of the fracture surface and its subsequent photographing on the diffractometer [6]. Here, the thickness of the etched layer of material from the fracture surface was evaluated by the method in [7]. The presence of plastic strain was judged from the width of the (220)Kα₁ diffraction line. The depth of the microscopic and macroscopic plastic-strain zones under the fracture surfaces was determined from the thickness of the etched layer corresponding to the beginning of the horizontal section of the curve describing the relationship between the width of the line and the thickness of the etched layer [6]. The relative error of the determination of the width of the (220)Kα₁ diffraction line did not exceed 10%. The maximum scatter of the line-width values was related to the roughness of the test surface and amounted to (0.2-0.3)·10⁻³ rad for the brittle frac-

*Mechanical tests of steel 15Kh2MFA were conducted by colleagues at the Moscow Physical-Engineering Institute V. M. Markochev and A. P. Bobrinskii.


0039-2316/84/1604-0473$8.50 © 1984 Plenum Publishing Corporation
Tests Results and Discussion. The fractographic analysis showed that in the range of the ductile–brittle transition, static fracture of steel 15Kh2MFA specimens is accompanied by the formation of a concentrated ductile zone $l_c$ on the fracture surface. The length of this zone changes in the shape of an S (Fig. 1) from a minimum value ($l_c = \theta$, where $\theta$ is the shear zone [3]) at $-50$ to $-60^\circ$C to a maximum value ($l_c = W$, where $W$ is the length of the fracture surface, $W = 2 \cdot 10^{-3}$ m) at $20^\circ$C.

tures and $(0.5-0.7) \cdot 10^{-3}$ rad for the ductile fractures. This made it possible to determine the depth of the strongly deformed microzones with an accuracy of $10^{-5}$ m and the depth of the weakly deformed macrozones to within $10^{-4}$ m.