ELECTRON FRACTOGRAPHIC INVESTIGATION OF FRACTURE SURFACES OF ARMCO IRON TESTED TO RUPTURE IN UNIAXIAL TENSION IN AIR AND DURING ELECTROLYTIC HYDROGEN CHARGING

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The geometry of fracture surfaces reflects the process of rupture and can provide valuable information about its mechanism. It is often possible to determine the cause of failure from the appearance of fracture surfaces. Since the mechanism of fracture of metals has not yet been adequately investigated, it is of some interest to carry out comparative studies of fracture surfaces of metals ruptured in air and during hydrogen charging. Investigations of the singularities of the geometry of fracture surfaces of metals ruptured in hydrogen at elevated temperatures and high pressures [1-3] showed that hydrogen charging affects the character of the microscopic fracture of steel which changes from shear of the "pitted" form to a degenerated pitted structure which consists of quasicleavage and intergranular fracture zones.

The aim of this investigation was to carry out an electron fractographic study of fracture surfaces of Armco iron tested to rupture in uniaxial tension in air and during electrolytic hydrogen charging. The tests were carried out on cylindrical specimens 6 mm in diameter, which, after machining, were mechanically polished and annealed for 1.0 h in vacuum at 930°C. Some of these specimens were tested in tension (at a constant strain rate of 0.5%/min) in air, the remainder being tested during hydrogen charging in a 26% H₂SO₄ solution at a current density of 10 A/dm² (the same for all specimens); platinum was used as an anode. The fracture surfaces of broken specimens were not subjected to treatment of any kind; their electron microscope examination was carried out on replicas obtained by a two-stage plastic-carbon method.

Ductile rupture of Armco iron in uniaxial tension produces a fracture surface in the form of a cup whose fibrous bottom is macroscopically oriented normal to the force flux. The conical portion of the cup constitutes a shear surface inclined at approximately 45° to the bottom of the cup. Fractographic investigation showed that the predominant feature of the bottom of the cup in zones away from the shear regions are alternating elongated and equiaxial pits (Fig. 1a) of various magnitude and orientation. The elongated pits cover a much larger proportion of the fracture surface than the equiaxial pits. Inclusions are observed at the bottom of some of the pits. Occasionally evidence of intergranular fracture and quasicleavage is found at the bottom of the cup. The predominant feature of the conical walls of the cup are pits much more elongated than those at the bottom of the cup (Fig. 1b).

A fracture surface of Armco iron ruptured in uniaxial tension during electrolytic hydrogen charging may be described as brittle-ductile: its middle portion represents ductile shear planes oriented at approximately 45° to the direction of the maximum tensile stresses, while its edges have a ribbed structure characteristic of brittle fracture. Fractographic examination of these fracture surfaces showed that the shear planes are covered with elongated pits (Fig. 2a) of the same orientation but varying in size. The peripheral region of the fracture surface, which has a ribbed structure, is covered mainly with intergranular and cleavage fracture facets and shows steps of the, unusual for iron, "river" pattern (Fig. 2b,
Occasionally one observes evidence of quasicleavage (Fig. 2e) and a new kind of fracture (Fig. 2f) with a fibrous surface. Thus, the peripheral part of the fracture surface of Armco iron tested to rupture is characteristic of cleavage and intergranular fracture.

The usual ductile rupture producing the cup-and-cone type of fracture surfaces in tensile specimens has been extensively investigated. Ludwik [4] was one of the first to establish that the rupture of cylindrical specimens of ductile metals under the influence of uniaxial tensile stresses starts in the specimen center, at the smallest cross section of the neck. As the strain increases, the internal crack grows in the radial direction until the conditions become favorable for the rupture path to change its direction from the plane of the transverse cross section to a conical surface inclined at about 45° to the direction of the maximum stress.

A microrelief with uniaxial pits is formed when the maximum principal stress is normal to the crack surface and when the crack propagation rate is relatively slow [5]. Fracture of this kind is usually called the "normal" ductile fracture. However, such conditions are seldom met in practice, so that the area occupied by equiaxial pits at the bottom of a cup-shaped fracture surface is relatively small. It is assumed that equiaxial pits are produced in the initial stages of the nucleation and growth of the crack responsible for the formation of the bottom of the cup, i.e., when the deformation is still quite uniform. Elongated pits, which are characteristic of ductile fracture, are formed when the stress state is such that the formation and coalescence of micropores take place under intense shear conditions. The tips of parabolic boundaries of these pits point to the direction of shear on each fracture surface. In our case elongated pits were observed on the conical portion and at the bottom of the cup (Fig. 1a, b) which is