A Criterion for the Ductile Fracture of Mild Steel

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1. Introduction

The current model of ductile fracture is that voids nucleated at non-metallic inclusions, precipitates or grain boundaries link together by either the coalescence or internal necking mechanism[1~2]. The criteria of fracture based on the stress[3], strain[4] or strain energy[5] have been proposed. In actual events, however, such quantities relate to each other. One of the difficulties with the study of ductile fracture is that the successive observation of the local deformation is limited by a large amount of deformation of the specimen. In the present study, ductile fracture of a perforated mild steel sheet was investigated in order to reveal the stages preceding to the fracture and to the localized strain distribution around voids.

2. Experimental

A tensile specimen as shown in Fig.1 was prepared of 0.1% carbon steel in ferrite and pearlite structure. At the central part of the specimen, small holes of 0.3 mm in dia. were drilled. Micrographs of the same area were taken at successive stages of deformation, and the microstructure was used as markers for determining the local strain.

The growth of the holes was found to be enhanced by the triaxial stresses associated with the necking of the specimen in accordance with the prediction by the hole growth theory. Fig.2 shows the change of hole geometries for respective holes. The abscissa is the mean tensile strain of the specimen, and the ordinate is the change of longitudinal, a, and transverse, b, radii. The change of the transverse radius of curvature, ρ, was also measured. Fig.3 shows the plastic strain distribution along a line transverse to the tensile axis, passing the center of the innermost hole. The tensile strain at the distance r from the edge of the hole was to be written as

$$\varepsilon(r) = \frac{\rho/2}{r + \rho/2}\,\varepsilon_a \quad ,$$

where $\varepsilon(r)$ is the tensile strain at r and ε_a is the average elongation of the hole.

Fracture of the specimen was not resulted from the coalescence of the growing holes, but the initiation of a shear crack at the side of a hole marked a critical stage on the occurrence of fracture. The overall deformation of the specimen was limited by this stage. Small voids were observed before fracture on the surface of the specimen at pearlite grains where slip band impinged or at triple points of grain boundaries. However, the linking was hardly observed and the propagation of the shear crack was governed by the

stress states.

3. Analysis

From the above findings, a criterion of the onset of a shear crack was proposed. The criterion was derived from the comparison of the plastic strain energy, W_t, associated with growth of a hole with that, W_s, associated with the initiation of a shear crack, i.e.

$$\frac{\partial W_t}{\partial a} \geq \frac{\partial W_s}{\partial c} \quad ,$$

where a is the hole radius and c is the crack length. By means of the relations obtained in the present experiment, the decrease in ductility by the increase in the volume fraction of voids were calculated. Fig.4 is the result for the case of Edelson and Baldwin[6] with dispersion-hardened copper base alloys assuming uniform distribution of spherical voids. The agreement is quantitatively satisfactory. A model of ductile fracture that the linking of voids was by the formation of a shear crack is proposed.

References

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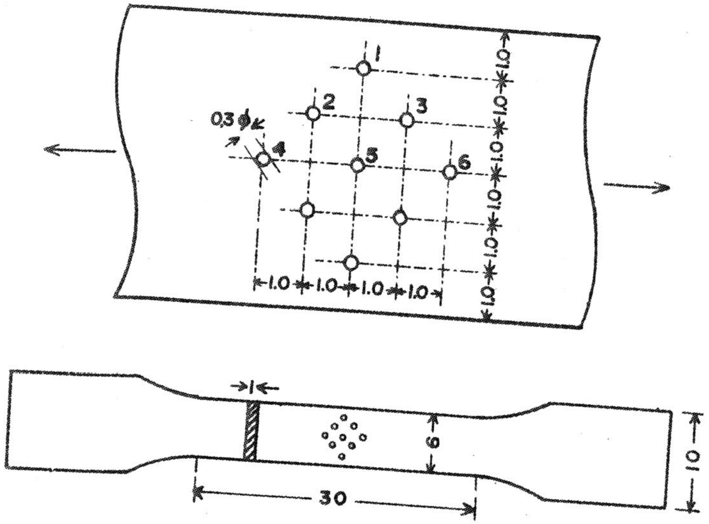

Fig. 1 The Specimen Geometry

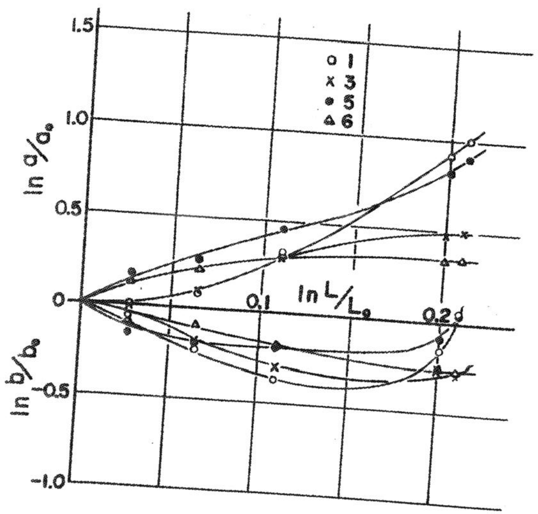

Fig. 2 Change of the Hole Geometries

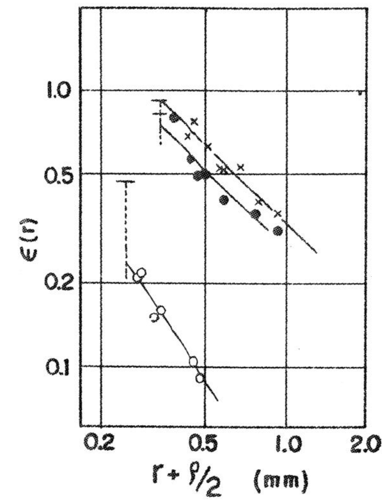

Fig. 3 The Tensile Strain Distribution along the Line Transverse to the Tensile Axis Passing the Center of the Hole 1.

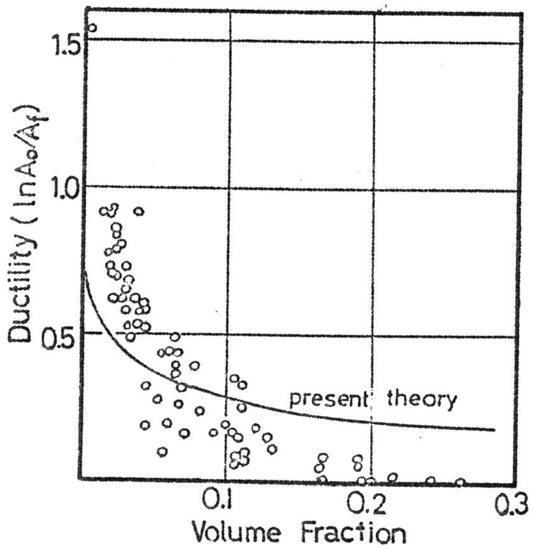

Fig. 4 Decrease in the Ductility by the Increase in the Volume Fraction of Cavities.