A COMPARISON OF THE STRAIN ENERGY DENSITY AND CRACK TIP OPENING DISPLACEMENT CRITERIA ON DUCTILE FRACTURE

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A comparison is made between the results of crack growth of the Strain Energy Density and CTOD criteria for a variety of specimens with different crack lengths. For the determination of the critical applied stress, the results of an elastic-plastic finite element stress analysis were combined with both the strain energy density and CTOD criteria. Using the above criteria the critical applied stresses for crack initiation were determined for different crack's length, and aluminum alloys with different form of the stress-strain diagram. Also the four-point bend specimen is examined. The more suitable location for measuring the CTOD for the best approach of the two criteria is examined as well.

INTRODUCTION

Conventional failure criteria have been developed to explain failure strength structures made of elastic-plastic materials. The two of the most well known criteria are the Strain Energy Density and the Crack Tip Opening Displacement (CTOD). The strain energy density failure criterion was introduced by Sih (1). In a series of recent publications the strain energy density criterion was used to study the problem of ductile fracture with and without plastic deformation (2,3,4). The CTOD criterion was proposed by Wells (5,6). The application of the CTOD is based on the assumption that δ_c is a material constant independent of the degree of plastic deformation ahead of the crack tip. In the present investigation a comparison is made between the results of initiation of crack growth as it yields by the application of the previously mentioned two criteria. Particular emphasis is given to the best location of measuring the CTOD.

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SPECIMENS GEOMETRY AND MATERIALS PROPERTIES

The specimens considered are orthogonal plates of width 2b=10 cm, height 2h=10 cm and contain a central crack of length 2a=1,2,3,4 and 5 cm (Fig. 1). All the specimens are subjected to a monotonically increasing uniform uniaxial tensile stress and the stress state was approximated as plane strain. In order to study the influence of the mechanical properties of the material, a series of materials with different forms of the stress-strain curves were considered. Two different types of the post yield form of the true stress-true strain of the material in tension Iσ, IIσ, IIIσ and Iε, IIε, IIIε were considered (Fig. 2). All materials have $E=7.2 \times 10^4$ MPa, ν=0.33 and $\sigma_{ys}=2.5 \times 10^2$ MPa. Also a four-bend specimen was included (Fig. 12).

INITIATION OF CRACK GROWTH. COMPARISON OF THE TWO CRITERIA

For the determination of the critical applied stress, the results of an elastic-plastic finite element stress analysis were combined with both the strain energy density (SED) and CTOD criteria. A finite element computer program based on J_2 flow theory of plasticity with twelve-node isoparametric elements and a special crack tip element was used. According to the first criterion the crack starts to grow when material's element at a distance r_0 (radius of core region) ahead of the crack tip absorbs a critical amount of stored strain energy density, equal to the area under the true stress-strain diagram of the material in tension $(dW/dV=(dW/dV)_c)$. According to the second criterion the crack starts to grow under condition, which lead to a particular amount of deformation at the tip of the crack, the crack tip opening displacement $(\delta=\delta_c)$. This is a characteristic of the material at a given temperature, plate thickness, strain rate and environmental conditions.

To demonstrate the procedure of the determination of the critical applied stress for crack growth, a specimen with 2b=2h=10 cm, 2a=3 cm and the material IIε (Fig. 2) with $r_0=0.006$ cm and $(dW/dV)_c=11.48$ MJ/m³ was used.

Figure 3 presents the variation of dW/dV versus distance r measured from crack tip at the direction of crack extension for applied stress σ=30,60,90 and 110 MPa. From this figure, the amount of dW/dV is determined for all the above applied stress steps at a distance $r_0=0.006$ cm. Based on these results, figure 4 is constructed and the critical applied stress σ_i is determined at the point of intersection of the curve dW/dV and the $(dW/dV)_C=11.48$ MJ/m³ line. Figure 5 shows the crack opening displacement (COD). The CTOD (δ_c) is measured at three locations; r_0 (radius of core region), r_p (intersection of the crack edge and elastoplastic boundary) and r_p' (plastic zone at the direction of crack extension) as shown in figures 6 and 7. For comparison the CTOD at each location (r_0, r_p and r_p') was determined so that to result the same critical applied stress σ_i for 2a=3 cm, as figure 8 demonstrate. The results of the comparison are shown in figure 9.

The previously described procedure was used for a comparison of the SED and CTOD criteria for the materials Iε, IIε, IIIε, and Iσ, IIσ, IIIσ (Fig. 2) and the results are presented in figures 10 and 11 respectively. Also for four-point bend specimen the results are presented in figure 12.

CONCLUSIONS

When the CTOD δ_c is defined so that the two criteria yield to the same critical applied stress σ_i at the same crack length (2a=3 cm), the following conclusions are deduced:

a) The CTOD criterion gives lower values of σ_i for smaler crack lengths for all cases.

b) The CTOD criterion for greater crack lengths gives higher values of σ_i for low strain-hardering materials and lower values for high strain-hardening materials.

c) Generally the measurement of CTOD at the intersection of elastoplastic boundary and the crack edge gives the better results agreement of high strain-hardening materials, whereas the CTOD at r_0 gives better results agreement for low strain-hardening materials.

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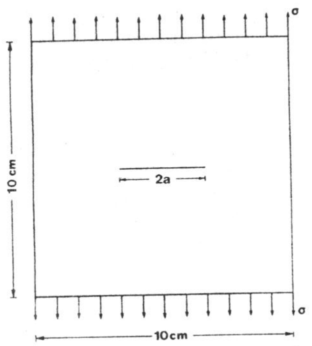

Figure 1 Plate geometry and loading conditions.

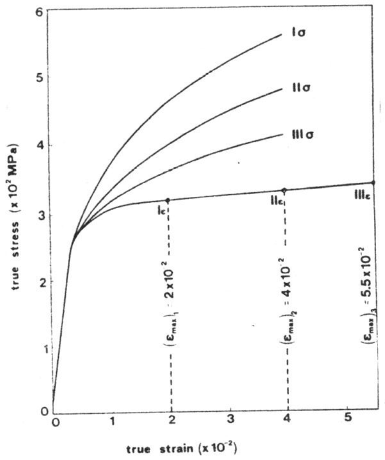

Figure 2 True Stress-true strain diagrams for different all. alloys.

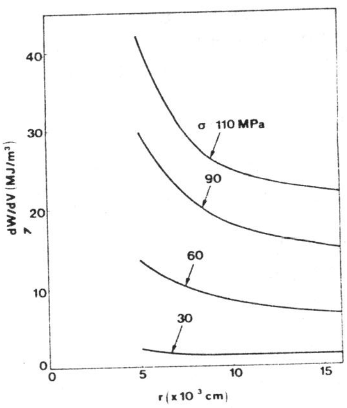

Figure 3 Variation of dW/dV versus distance r from crack tip

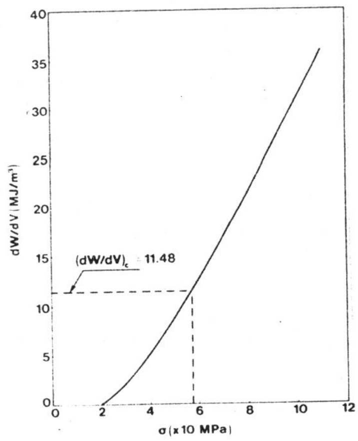

Figure 4 Determination of σ_i from SED criterion (2a=3 cm).

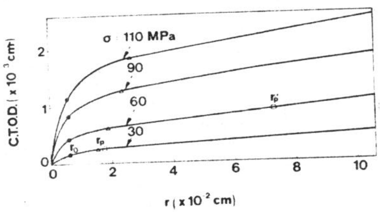

Figure 5 Crack Opening Displacement for 2a=3 cm.

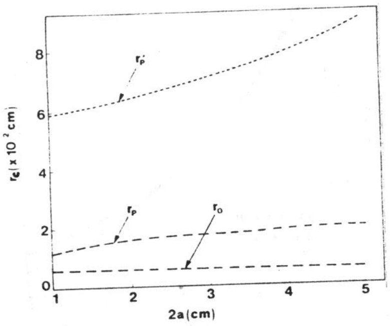

Figure 6 Location of r_c (from crack tip) for measurement of CTOD.

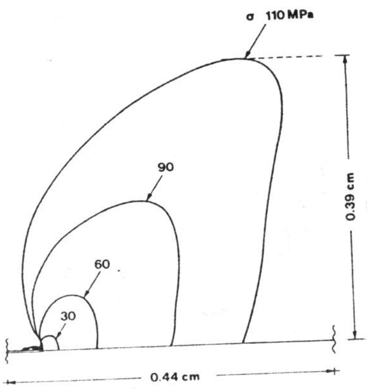

Figure 7 Elastic-Plastic boundaries for 2a=3 cm.

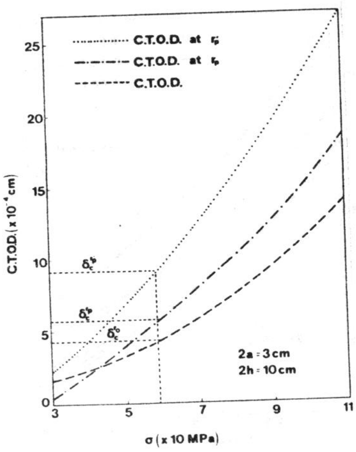

Figure 8 Definition of critical values δ_c of CTOD for 2a=3 cm.

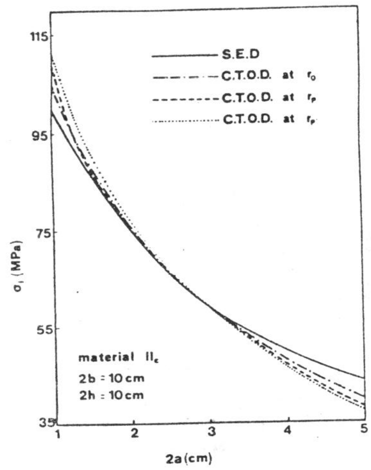

Figure 9 Critical applied stress σ_i versus crack length.

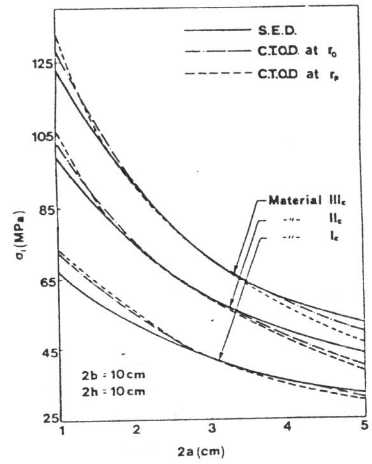

Figure 10 Variation of σ_i for materials Iε, IIε and IIIε.

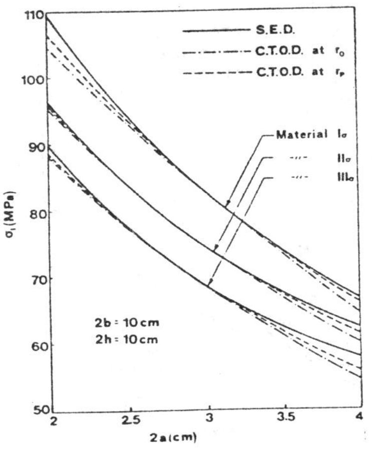

Figure 11 Variation of σ_i for materials Iσ, IIσ and IIIσ.

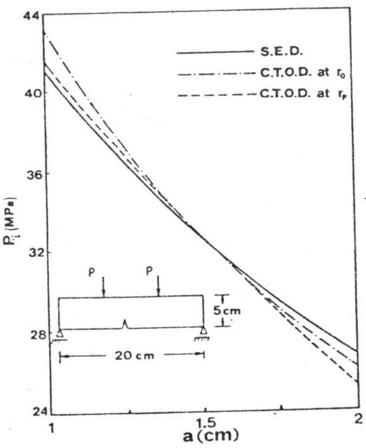

Figure 12 Variation of P_i for four point bend specimen.