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DETERMINATION OF DUCTILE FRACTURE(DUCTILITY) AT ANY STRESS STATE BY UNIAXIAL TENSILE TEST

HUNG-KUK OH
Dept. of Mech. Eng. , Ajou University, Suwon,
442-749, South KOREA

INDUSTRIAL SUMMARY

Various ductile fracture criterions are introduced. Brownrigg et al.(1983) showed that the tensile ductility of a steel is linearly increasing with hydrostatic pressure. Atkins also (1980) studied that the elongation decreases linearly with depressive mean stress rise. The proposed new ductile fracture criterion is developed from the theory of fracture toughness under different mean stress from tensile test. The elongation at fracture decreases linearly with increases of depressive mean stress and the decreasing gradient is determined by the line from yield point to ultimate tensile point in the uniaxial tensile test. The material endures elastic and plastic deformation to the time when the mean stress reaches to the maximum sustainable equicohesive bonding stress decreases as the temperature rises, the time elapses, the depressive mean stress rises and the material damages by plastic deformation.

(1) HISTORICAL DUCTILE FRACTURE CRITERIONS

Numerous attempts have been made to relate the fracture stains of metals to macroscopic variables associated with the metal, the process, or both. Such criteria, although perhaps only applicable to one process or class of processes, have obvious advantages in industry. Even if a different criterion was required to determine the workability of a metal in different processes. These relatively simple criteria might be easier to manipulate than a universal ductile-fracture criterion.

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An initial choice for a macroscopic criterion is one based on the total plastic work done up to fracture. This could be stated as "Fracture will occur when the total plastic work per unit volume reaches some characteristic critical value." Assuming that the generalized von Mises stress and criterion can be written as

$$\int_0^{\bar{\varepsilon}_f} \bar{\sigma} d\bar{\varepsilon} = A \tag{1}$$

where $\bar{\varepsilon}_f$ is the effective fracture strain and A is a constant for the metal and a particular process.

Latham(1963) observed that fracture in metal working process tend to occur in the region of largest tensile stress, and he proposed the following of critical tensile plastic work :

$$\int_0^{\bar{\varepsilon}_f} \sigma_T d\bar{\varepsilon} = B \tag{2}$$

where σ_T is the largest tensile stress and B is a constant characteristic of both the material and the process (Ref. 1).

A modification of the Latham criterion was suggested by Brozzo et al. (1972, Ref.2): this modification includes a hydrostatic-pressure term

$$\int_0^{\bar{\varepsilon}_f} \frac{2\sigma_T d\bar{\varepsilon}}{3(\sigma_T - \sigma_m)} = C \tag{3}$$

Where σ_m is the hydrostatic stress and C is dependent on the metal and process as before.

Clift et al. side-pressing experimentation on an aluminum alloy. Also, in parallel with this a finite-element model of the process was run. The finite-element results were used with the above experimentally. It was found that the total plastic-work criterion was the only successful criterion for the prediction of the site of fracture and the amount of plastic deformation.

A valuable semi-empirical criterion has been developed by Osakada et al.(1977,1978,1981,Ref.4, Ref.5,Ref.6).

The criterion has the form

$$\int_0^{\varepsilon_f} < \bar{\varepsilon} + ap - b > d\bar{\varepsilon} = C \qquad (4)$$

Where a , b and c are constants that are derived from experiments, the function<x> is defined by

$$< x >= \begin{cases} x & (x > 0), \\ 0 & (\mathrm{x} < 0). \end{cases}$$

This criterion was derived after a large number of tension, compression and torsion tests on carbon steels. The criterion can also take account of superimposed hydrostatic pressure through the term p and prestrain. The constants a and c appear to be the same for different steels, but it is found that the value of b is affected by microstructural factors such as size, shape and volume fracture of cementite.

Brownrigg et al. (1983) studied the effect of hydrostatic pressure on the tensile ductility of a steel.

They showed

$$\frac{\varepsilon_f(p)}{\varepsilon_f(0)} = 1 + \frac{1.68p}{2\bar{\sigma}} \qquad (5)$$

where $\varepsilon_f(p)$ is the fracture strain under hydrostatic pressure and $\varepsilon_f(0)$ is the fracture strain at atmospheric pressure. Fig.1 shows good agreement between the experiments of Brownrigg et al, and the theory.(Ref.7)

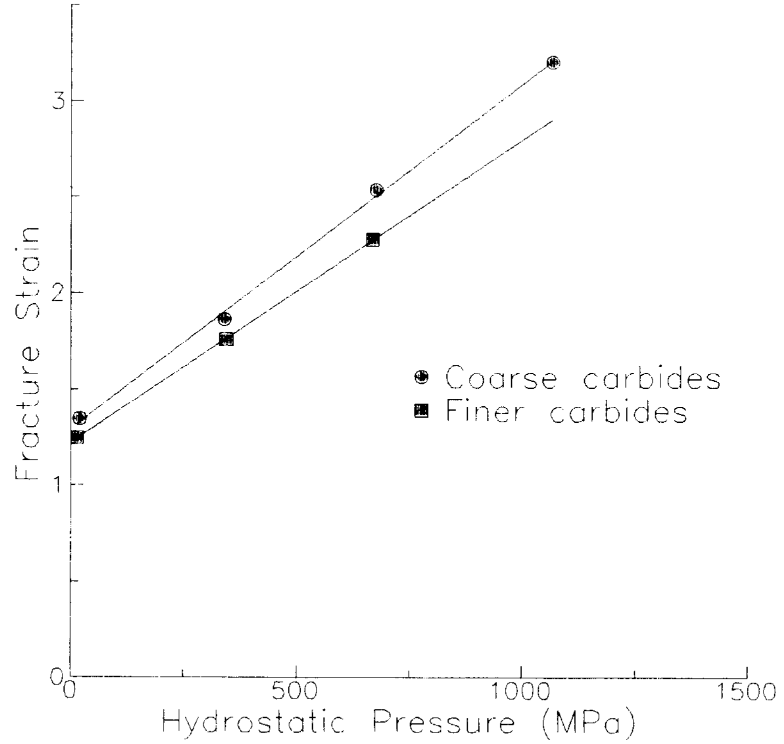

Fig.1 Fracture strain versus hydrostatic pressure for both coarse and fine carbides. (After A.Brownrigg et al., Acta Metall.31,1141-1150(1983).)

(2) PROPOSED NEW DUCTILE FRACTURE CRITERION

Ref.8 shows about the fracture toughness under different mean stress from tensile test that if plastic deformation occurs under different mean stress from tensile test, the elongation, the surface energy per unit area and the fracture toughness are changed because the atomic bonding force reduces or increase with the variation of mean stress.

Because the mean stress in uniaxial tensile test is one third of the axial stress, variation of mean stress is equivalent to three times effect in uniaxial stress.

The elongation change caused by mean stress variation is $(-\Delta\sigma_m/\tan\theta)$ in Fig.2.

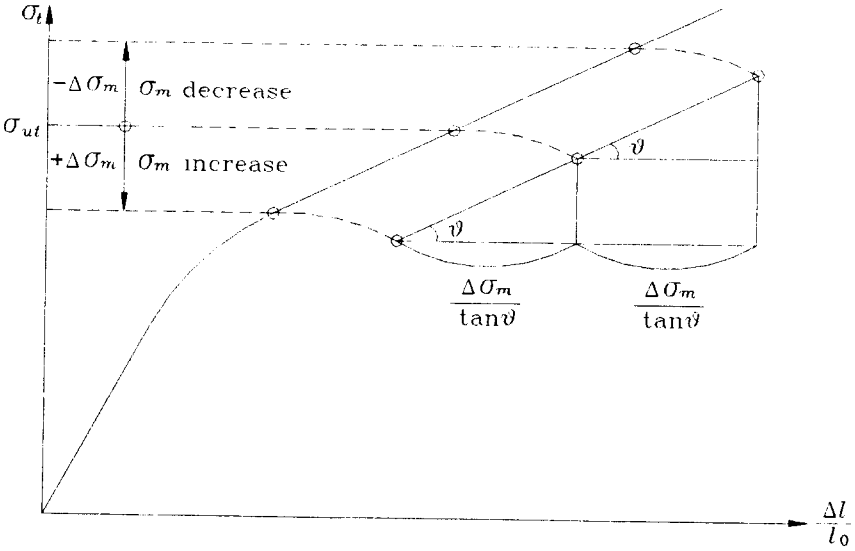

Fig.2 True stress-elongation curve in uniaxial tensile test with varying mean stress

The changed surface energy per unit area is as follows

$$\gamma_p = \gamma_s \frac{\left\{\left(\frac{\Delta\ell}{\ell}\right)_f - \frac{\Delta\sigma_m}{\tan\theta}\right\}}{\left(\sigma_u - \Delta\sigma_m\right)/E} \tag{6}$$

where γ_p is total surface energy per unit area, γ_s is brittle elastic surface energy per unit area, $\Delta\sigma_m$ mean stress variation, E is Young' s modulus of elasticity and σ_u is the ultimate tensile strength.

The proposed new ductile fracture criterion then is as above

$$\left(\frac{\Delta\ell}{\ell_0}\right)_{f\,\mathrm{at}\,\Delta\sigma_m} = \left(\frac{\Delta\ell}{\ell_0}\right)_f + \left(\frac{-1}{\tan\theta}\right)\Delta\sigma_m \tag{7}$$

This means that the material endures elastic and plastic deformation to the time when the mean stress reaches to the maximum equicohesive bonding stress.

(3) EXPERIMENTAL EVIDENCES

Atkins(1980, Ref.9) showed various fracture points for sheet metal testing as in Fig.3. They are simple tension, plane strain and biaxial tension states for aluminum alloys.

It represents that the elongation decreases linearly with depressive mean stress $(\Delta\sigma_m)$.

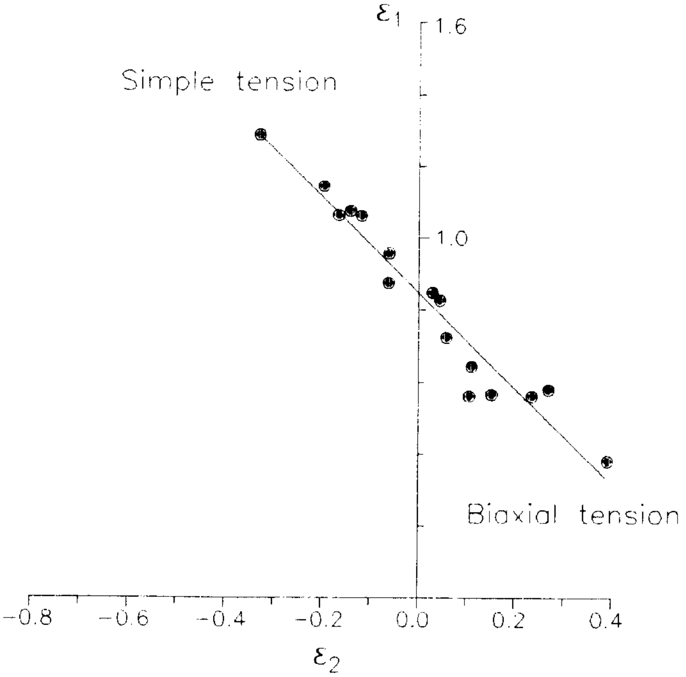

Fig.3 Fracture points for sheet testing

(Based on a diagram taken from A.G.Atkins, The Mechanics of Ductile Fracture in Metal Forming. ICFG, 1980)

Brownrigg et al.(1983) studied the effect of hydrostatic pressure on the tensile ductility of a steel. They showed as in equation(5) and Fig.1 good agreement between the experiments and the theory.

Author plotted theoretical and experimental points in Fig.4 according to the proposed new ductile fracture criterion, equation(7).

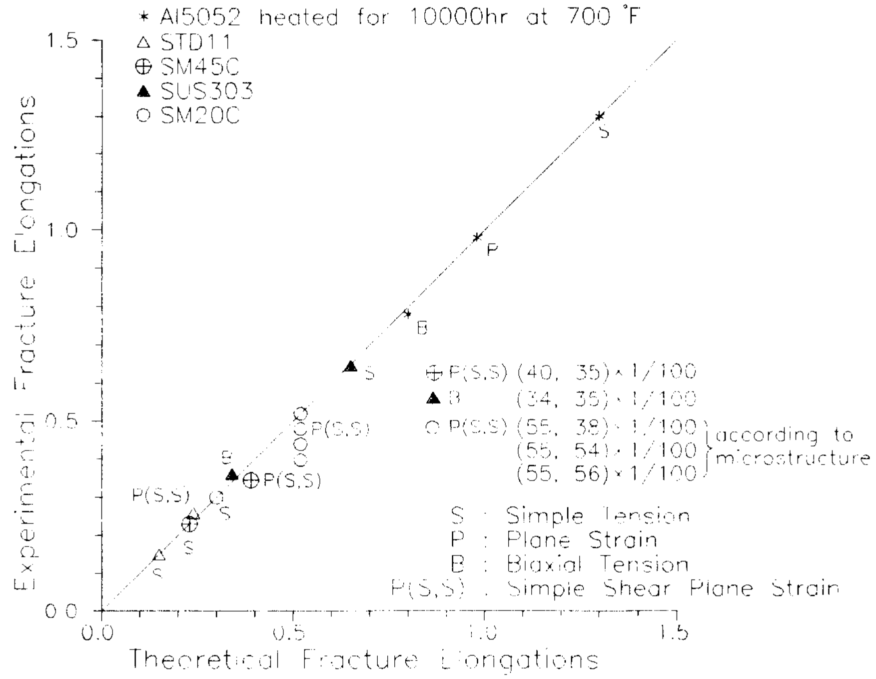

Fig.4 Comparison of theoretical with experimental elongations under various mean pressure variations

(4) MEANING OF NEW CRITERION, ITS INDUSTRIAL APPLICATION AND CONCLUSION

The new criterion means that the material endures elastic and plastic deformation to the time when the mean stress reaches to the maximum sustainable equicohesive bonding stress. As the temperature rises the thermal vibration energy makes the equicohesive stress decrease. And also at a certain temperature and stress state the cohesive force decrease as the time elapses. Therefore temperature rise, time elapse and depressive mean stress' es increase reduce the equicohesive bonding stress in the material.

The material fractures at the time when the equicohesive bonding stress can not sustain external mean stress. The plastic deformation also reduces the equicohesive bonding stress by damaging its microstructure.

The mechanics and mechanisms of ductile fracture in metals are of significance for both engineers and metallurgists in designing against plastic collapse and fracture of structures and workpieces. The avoidance of ductile fracture is of importance in metal forming processes, such as design of the process and die in forging, extrusion and drawing.

The following conclusions are about new by proposed criterion.

(1) The ductile fracture limit can be determined by equation.(7)

(2) The material endures elastic and plastic deformation to the time when the mean stress reaches to the maximum sustainable equicohesive bonding stress.

(3) The maximum sustainable equicohesive bonding stress decreases as the temperature rises, the time elapses, the depressive mean stress rises and the material damages by plastic deformation.

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