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Stochastic Elasto-plastic Fracture Analysis of Aluminum Foam Using Cohesive zone Model

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ABSTRACT

1. Introduction

The recent development in foaming technology has made metallic foams become available for a wide range of potential applications, such as automotive, transport, ships and military field. Components made with metallic foams may have defects such as cracks, notches or circular holes due to manufacturing processes or damage while in service. The cohesive crack model describes the material behavior in the process zone in front of the crack tip. J.-S. Blazy [1] proposed a statistical model to predict the mechanical response under complex loading conditions. C.Chen [2] used a Dugdale-type cohesive zone model to predict the mode I crack growth resistance of metallic foams. However, the most published literatures have not considered the effect of microscopic heterogeneity upon nonlinear fracture behavior of Aluminum foam. The present paper focuses the attention on the effects of plastic compressibility and probability distribution of the peak bridging stress induced by microscopic heterogeneity of aluminum foams upon Mode I elasto-plastic fracture behavior.

2. Constitutive model and Cohesive zone model with Weibull statistical analysis

The metallic foams are a class of material of plastic compressibility. The effect of the mean stress σ_m should be taken into account in the plastic constitutive relation. The elasto-plastic constitutive equation based on the yield/loading surface is expressed by

$$\dot{\varepsilon}_{ij} = \dot{\varepsilon}_{ij}^{e} + \dot{\varepsilon}_{ij}^{p} = \frac{1+\nu}{E}\dot{\sigma}_{ij} - \frac{\nu}{E}\dot{\sigma}_{kk}\delta_{ij} + \frac{\dot{\hat{\sigma}}}{H(\hat{\sigma})}\frac{\partial \Phi}{\partial \sigma_{ij}} \tag{1}$$

where the equivalent stress $\hat{\sigma}$ is given by

$$\hat{\sigma} = \sigma_e + 0.03\frac{\rho^*}{\rho_s}\sigma_m \tag{2}$$

Here, σ_e and σ_m denote the von Mises effective stress and the mean stress, respectively.

Because of the presence of microscopic heterogeneity of foams, the local cohesive parameters possess of scattered characteristic. Assume that peak bridging stress σ_c obeys Weibull distribution:

$$f(\sigma_c) = \frac{m}{\eta} \cdot (\frac{\sigma_c}{\eta})^{m-1} \cdot \exp[-(\frac{\sigma_c}{\eta})^m] \quad (3)$$

in which η is the scale factor and m is shape factor.

3. Numerical examples and conclusions

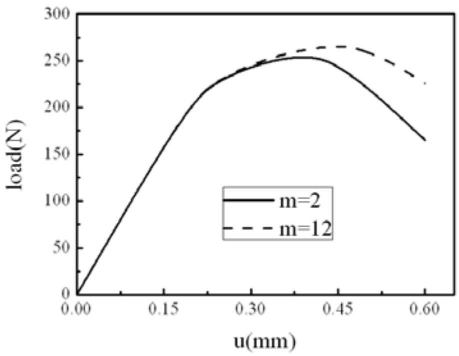

Fig. 1. The influence of Weibull parameters on load/displacement curves

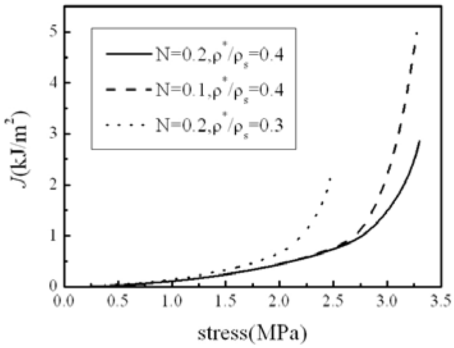

Fig.2. The influence of hardening index N and relative density ρ^*/ρ_s on J-integral

Assume that a rectangle foams plate with a span centre crack under uniform tensile stress along two short sides of the plate. Fig.1. shows that: (1) the curves depict 3 regions in evidence, such as elastic region, plastic hardening region and failure (strain softening) region after reaching at peak load; (2) the value of peak load drops with decreasing m, which implies more heterogeneous foam (a smaller m) is relatively weaker and less tougher than a more homogeneous foam.

Fig.2. indicates:(1) the variation of J-integral value with external loading is rather flat under lower stress stage, however, with external load increasing and the crack tip entering into plastic state, the variation of J-integral value is increasing rapidly, especially for N=0.1. (2) With external load increasing, J-integral increases until a peak value is attained. As expected, the values increase in magnitude with $\bar{\rho}$ increasing.

A stochastic study has been carried out to analyze the nonlinear fracture behavior of aluminum foam with a cohesive zone model. The conclusions can be drawn as:

(1) The variation of J-integral with the probability parameters is not evident before the foam failure, whereas the effect on process of crack growing is more significant.

(2) The hardening index and relative density of the foam clearly influence the value of J-integral and the load/displacement curves.

(3) Outcomes of the research be useful to get a better understanding of effect of microscopic heterogeneity upon the nonlinear fracture behavior of metallic foams.

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