STRESS-STRAIN MODELING IN THE DAMAGE REGIME

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ABSTRACT

The micromechanical damage mechanics developed by Ashby and Sammis allows calculation of the failure surface of a brittle solid containing a known density of initial flaws of known size. However, inclusions of damage mechanics into numerical simulations of underground explosions also requires the effective elastic modulus as a function of damage. If the damage is not changed during a stress increment, then the theoretical results of O'Connell and Budianski (O&B) can be used. However, if the stress increment results in an increase in damage, then the effective elastic modulus will be lower than that given by the O&B theory due to the extra energy associated with crack propagation. Because this is a cumbersome calculation not suitable for implementation in numerical simulation codes, we have adopted the empirical approach of lowering the modulus by an additional factor during crack growth, and have evaluated this factor using stress strain data on Barre granite.

key words: seismic coupling, source modeling, rock mechanics, damage mechanics.

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OBJECTIVE

The objective of this research is to develop a simplified semi-empirical version of the damage mechanics developed by Ashby and Sammis (1990) which is suitable for inclusion in the numerical codes used to simulate underground nuclear explosions. This work is motivated by discrepancies between theoretical and observed seismic waveforms produced by explosions in crystalline rock which have tentatively been ascribed to the extensive fracturing and granulation of the rock in the non-linear source region. It is also possible that such fracturing in an initially anisotropic medium will generate significant S wave energy.

RESEARCH ACCOMPLISHED

The most computationally difficult part of this task has been the evaluation of the effective elastic modulus during damage accumulation. We have decided to handle this problem empirically by fitting stress-strain curves measured in Barre granite in collaboration with Greg Boitnott at New England Research.

In the absence of damage accumulation, Young's modulus decreases with damage according to (O'Connell and Budianski, 1974)

$$E = E_o [1 - 1.25D] \qquad (1)$$

where damage D is defined as

$$D = (4/3)\pi N_V (L + \alpha a)^3 \qquad (2)$$

N_V is the number of cracks of length 2a per unit volume and L is the crack growth as shown in Figure 1.

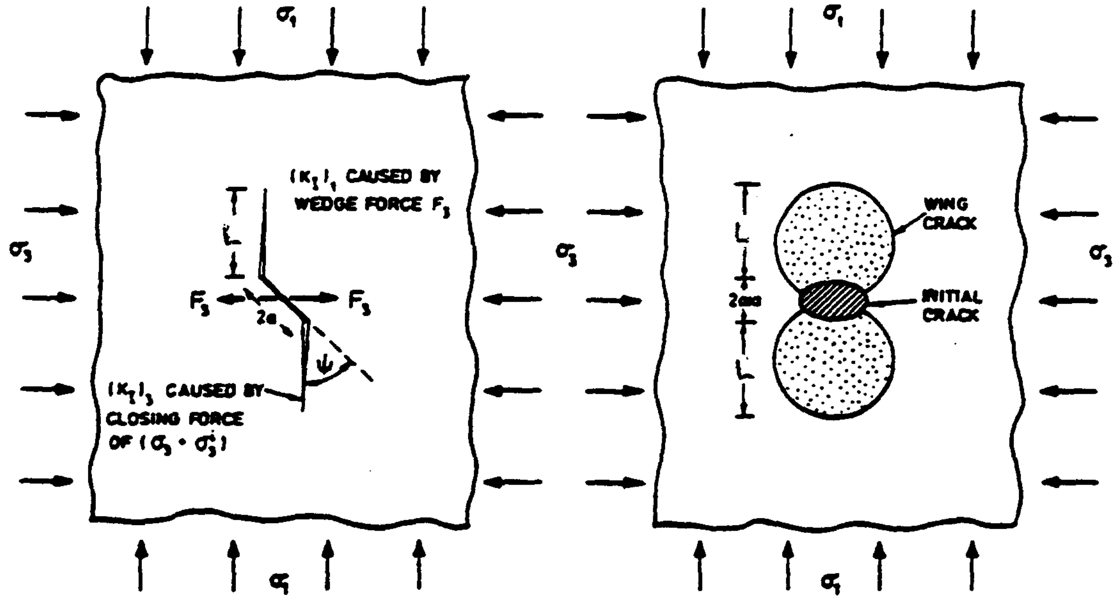

Figure 1 Growth of wing cracks from preexisting inclined cracks in the damage mechanics model developed by Ashby and Sammis (1990).

However, eqn. (1) is only applicable if L does not change during a stress increment. If L increases, then the effective E will be smaller. We represent this effect by introducing an empirical factor ζ into eqn. (1)

$$E = E_0[1 - (1.25 + \zeta)D] \qquad (3)$$

and evaluate ζ by fitting experimental stress-strain curves.

Figure 2 shows the fit for two cases for which ζ was found to be $\zeta = 0.55$ and $\zeta = 0.50$ respectively. The positive curvature of the data at low stresses is due to crack closure and was not modeled. The curvature at high stresses is well described by eqn. (3). We are still working to analyze the hysteresis loops.

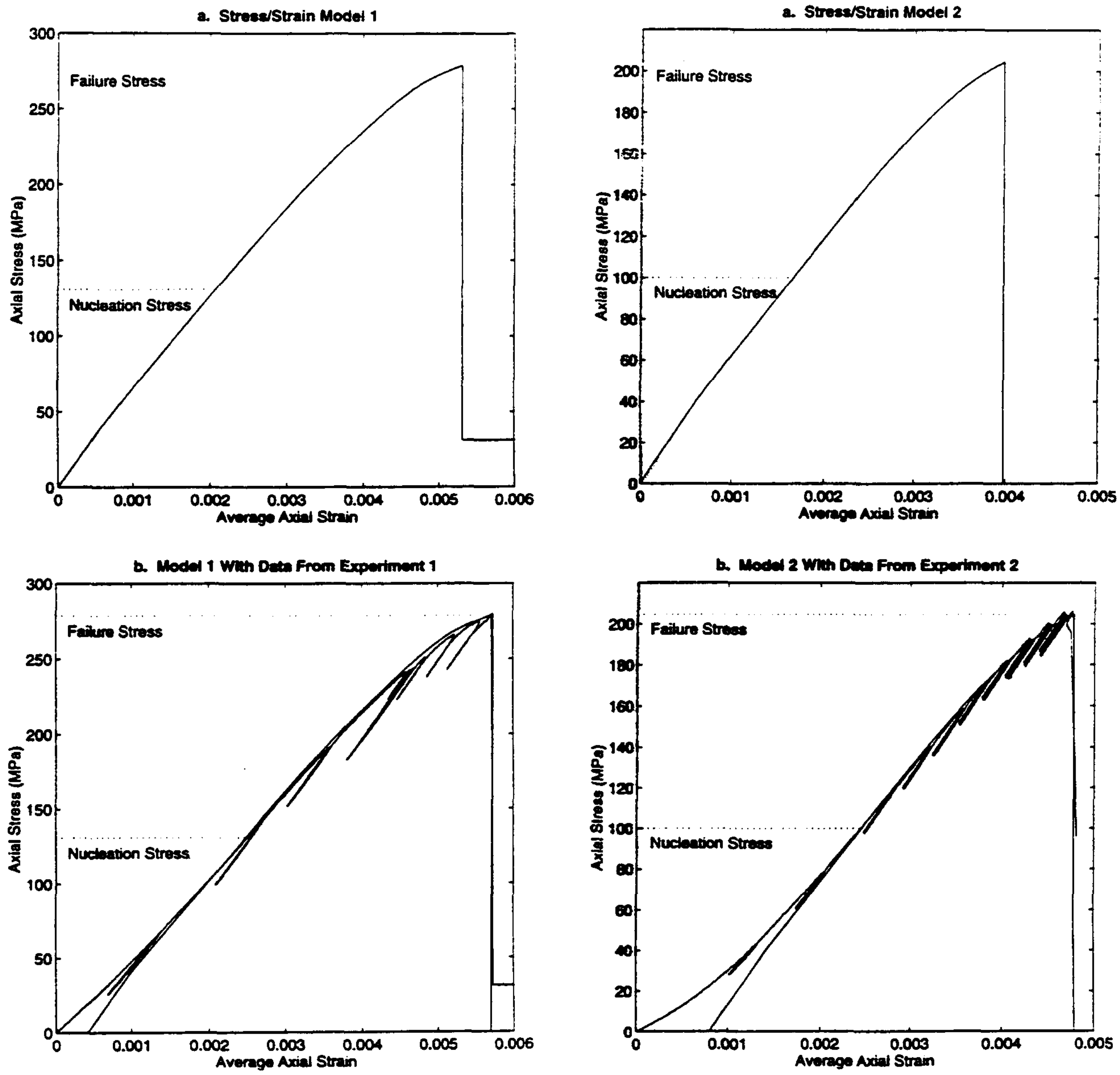

Figure 2 Stress-strain curves fit to two experiments in Barre granite in order to find the empirical factor ζ. For experiment 1 on the left, ζ=0.55. For experiment 2 on the right, ζ=0.50

CONCLUSIONS AND RECOMMENDATIONS

The empirical approach reproduces stress-strain curves measured in the laboratory and have established the approximate value of the empirical parameter ζ. The next step is implementation in a source code.

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