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The Three-Stage Model Based on Strain Strength Distribution for the Tensile Failure Process of Rock and Concrete Materials**

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ABSTRACT A three-stage model is introduced to describe the tensile failure process of rock and concrete materials. Failure of the material is defined to contain three stages in the model, which include elastic deformation stage, body damage stage and localization damage stage. The failure mode change from uniform body damage to localization damage is expressed. The heterogeneity of material is described with strain strength distribution. The fracture factor and intact factor, defined as the distribution function of strain strength, are used to express the fracture state in the failure process. And the distributive parameters can be determined through the experimental stress-strain curve.

KEY WORDS three-stage constitutive model, tensile failure, distribution of strain strength, fracture factor, rock and concrete

I. Introduction

Rock and concrete materials are usually discontinuous with joints and pre-existing cracks on the micro scales[1]. The internal micro cracks and micro defects will occur and grow in the failure process of the brittle material[2]. It is difficult to describe the failure behavior of rock and concrete materials because of its discontinuity and heterogeneity. Tensile failure is one of the most common failure modes of rock and concrete materials. Commonly, the tensile strength is much lower than the compressive strength and shear strength of these materials. Although rock and concrete would hardly be in the simple state of pure tension or direct tension, the splitting failure in compression and the bending failure of rock and concrete beams are both caused by the tensile stress in local domain. So it is of great significance to understand and describe the constitutive relationship, the bearing capacity, the mechanism of deformation and the failure during tensile failure process[3].

The constitutive relationship of materials is usually expressed by the relationship between stress and strain, which could be described intuitively with the complete stress-strain curves. The complete stress-strain curve of uniaxial tension test is usually divided into two parts by means of simple analysis of the experimental curve, e.g. the rising part before the peak stress is reached and the strain softening part after[4]. The fitting methods of simple linear type, polynomial type, fractional type and mixed type have been used to fit the complete stress-strain curves[5–7]. However, most of these methods are usually phenomenological without considering the mechanism of mesoscopic damage and fracture.

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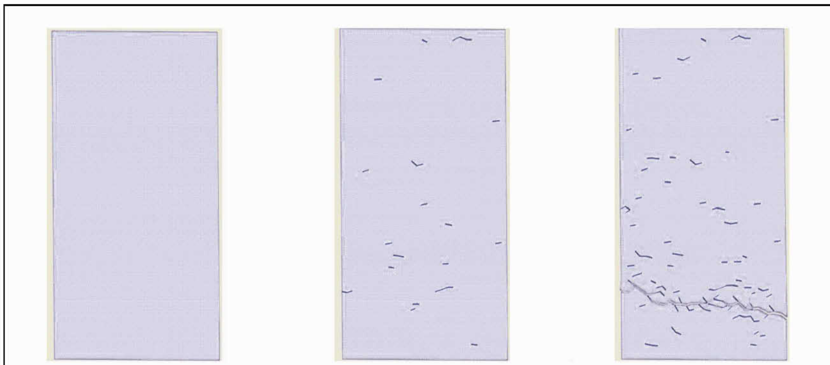
The damage and fracture will occur before the peak stress is reached in the tensile failure process, which is the internal reason for the nonlinear phenomenon on the macroscopic stress-strain curves. The research results in mesoscopic scale can explain the damage mechanism for tensile failure process of rock. And some damage constitutive models considering mesoscopic mechanical properties have been proposed[8,9]. However, these models are homogeneous models without considering the phenomena of failure localization in the strain softening stage. And most of the mesoscopic models are too complex to be used in the analysis of practical problems directly. The macroscopic constitutive relationship which is capable of describing the mesoscopic damage mechanism and considering the convenience of application needs to be established[10].

The constitutive model based on strain strength distribution[11–13] was proposed in order to establish the relationship between mesoscopic damage and macroscopic property. Strain is the strength measuring index and the material properties are described by the distribution density function. Fracture state is expressed by the fracture factor. Considering the internal heterogeneity of strain strength and the friction on fractured micro planes, the macroscopic mechanical behavior of nonlinearity and strain softening can be obtained naturally.

The objective of this paper is to introduce a statistic damage model to describe the constitutive relationship for the tensile failure process of rock and concrete materials. It is a three-stage model for the representative volume element (RVE) based on strain strength distribution. Considering the mesoscopic damage and fracture mechanism in the process of tensile failure, the relationship between mesoscopic damage and macroscopic property is established by using the strain strength distribution model and experimental stress-strain curves. In this model, the complete stress-strain curve is divided into three parts, including the linear part, the nonlinear part and the strain softening part. A modified plan of softening strain for the stress-strain curve is introduced in this paper based on the traditional modified plan[14,15] so that the strain softening property can be described in a unified form. The parameters of distribution density function of tensile strain strength can be obtained by means of curve fitting and then the whole failure process can be described quantitatively.

II. Statement of the Problem

The occurrence and development of damage and fracture in the test specimen can be observed in both laboratory experiments and numerical simulations. New cracks do not initiate in the early stage of the loading process. Damage occurs and grows when the load exceeds the linear elastic limit. And then the micro cracks grow randomly all over the specimen. The principal crack forms in the localization band as the load continues to increase. In this process, the damage mode changes from the uniform body damage to the localization damage. The peak stress is the feature point of the change and the indication of the occurrence of failure. Generally, the failure process mentioned above can be divided into three stages, as shown in Fig.1.



(a) Elastic deformation (b) Uniformly body damage (c) The deformation localization

Fig. 1. The fracture state during failure process. (a) No damage takes place in the elastic deformation stage, (b) Damage occurs and micro cracks grow randomly all over the specimen in the uniform damage stage, (c) A principal crack forms in a finite narrow region because of the damage localization.