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岩样单轴压缩塑性变形及断裂能研究

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摘要　首先研究了应变软化阶段岩石试件轴向塑性变形。假设局部化开始于峰值强度而轴向塑性位移根源于局部化的剪切位移。剪切带的相对塑性剪切位移与应力水平及剪切带宽度有关，剪切带宽度由梯度塑性理论确定。剪切带的相对塑性剪切位移在轴向的分量为轴向塑性压缩位移。研究结果表明：剪切带倾角对相对应力－塑性变形曲线斜率有一定的影响；若剪切带倾角存在尺寸效应，不同高宽比试件的相对应力－塑性变形曲线不是一条严格直线，而是一个狭窄的区域，类似“马尾”。但是，剪切带倾角对相对应力－塑性变形曲线斜率的影响是有限的，峰后应力－塑性变形曲线的斜率基本上是常量，这与前人的一些试验现象相符。然后，研究了单轴压缩条件下岩石试件全部断裂能的尺度律。全部断裂能由峰前断裂能及峰后断裂能两部分构成。在峰值强度前，采用Scott模型描述了材料的非线性弹性特征，得到了峰前断裂能的解析解。结果表明：峰前断裂能与试件的高度有关。在峰值强度后，材料的剪切应力－塑性剪切应变的本构关系为线性应变软化，采用梯度塑性理论计算了由于剪切带塑性剪切变形而消耗的断裂能。目前提出的关于全部断裂能尺寸效应的解析解的正确性被前人的试验结果的线性回归结果验证。增加试件高度，全部断裂能增加。增加弹性模量，全部断裂能降低。若不考虑剪切带倾角及抗压强度的尺寸效应，全部断裂能存在尺寸效应的原因是：峰前的均匀塑性变形。

关键词　岩石力学；梯度塑性理论；峰后塑性变形；全部断裂能；尺寸效应；局部化

分类号

ANALYSIS OF PLASTIC DEFORMATION AND FRACTURE ENERGY OF ROCK SPECIMEN IN UNIAXIAL COMPRESSION

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Abstract

Firstly，axial plastic deformation of rock specimen in uniaxial compression subjected to shear failure is investigated. Assumption is made that shear localization in the form of a single shear band is initiated at peak shear stress in shear plane and that axial plastic deformation stems from the plastic shear slip of shear band. Relative shear displacement along shear band depends on shear stress level and shear band thickness described by gradient-dependent plasticity. The relative displacement can be decomposed into axial and lateral parts. The former is equal to axial plastic compressive deformation at rock specimen end. Then，relation between the axial plastic deformation and the flow compressive stress is proposed. It is found that shear band inclination angle influences the slope of the relation curve. If the angle is not dependent on specimen length，then the relation curve is not a strict straight line；but a narrow zone like a horsetail. In fact，the influence of shear band inclination angle can be neglected so that the slope can be approximately regarded as a constant，as is in agreement with some experimental results. Secondly，the effect of specimen length on total fracture energy in uniaxial compression subjected to shear failure is analyzed. Total fracture energy is the sum of pre-peak fracture energy and post-peak fracture energy. In pre-peak stage，Scott model is used to describe the nonlinear elastic stress-strain relation and analytical solution of pre-peak fracture energy is derived. The solution shows that the pre-peak fracture energy is related to specimen length. In strain-softening stage，linear strain-softening constitutive relation between shear stress and plastic shear strain is adopted. Analytical solution of post-peak fracture energy dissipated by localized plastic shear deformation is derived based on gradient-dependent plasticity. The reasonability of present analytical solution of total fracture energy for quasi-brittle materials is verified by linear regression on earlier experimental result. Longer length of specimen leads to higher total fracture energy，and bigger elastic modulus to lower the total fracture energy. If the size effects of compressive strength and inclination angle of shear band are neglected，the reason for size effect of total fracture energy is the uniform plastic compressive deformation in pre-peak stage.

Key words rock mechanics；gradient-dependent plasticity；post-peak plastic deformation；total fracture energy；size effect；localization

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