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Rock Failure Analysis under Dynamic Loading Based on a Micromechanical Damage Model

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Abstract

A micromechanical constitutive damage model accounting for micro-crack interactions was developed for brittle failure of rock materials under compressive dynamic loading. The proposed model incorporates pre-existing flaws and micro-cracks that have same size with specific orientation. Frictional sliding on micro-cracks leading to inelastic deformation is very influential mechanism resulting in damage occurrence due to nucleation of wing-crack from both sides of pre-existing micro-cracks. Several homogenization schemes including dilute, Mori-Tanaka, self-consistence, Ponte-Castandea & Willis are usually implemented for up-scaling of micro-cracks interactions. In this study the Self-Consistent homogenization Scheme (SCS) was used in the developed damage model in which each micro-crack inside the elliptical inclusion surrounded by homogenized matrix experiences a stress field different from that acts on isolated cracks. Therefore, the difference between global stresses acting on rock material and local stresses experienced by micro-crack inside inclusion yields stress intensity factor (SIF) at the cracks tips which are utilized in the formulation of the dynamic crack growth criterion. Also the damage parameter was defined in term of crack density parameter. The developed model was programmed and used as a separate and new constitutive model in the commercial finite difference software (FLAC). The dynamic uniaxial compressive strength test of a brittle rock was simulated numerically and the simulated stress-strain curves under different imposed strain rates were compared each other. The analysis results show a very good strain rate dependency especially in peak and post-elastic region. The proposed model predicts a macroscopic stress-strain relation and a peak stress (compressive strength) with an associated transition strain rate beyond which the compressive strength of the material becomes highly strain rate sensitive. Also the damage growth process was studied by using the proposed micromechanical damage model and scale law was plotted to distinguish the dynamic and quasi-dynamic loading boundary. Results also show that as the applied strain rate increases, the simulated peak strength increases and the damage evolution becomes slower with strain increment.

Keywords: Damage; Micromechanical Model; Strain Rate; Micro-Cracks; Stress Intensity Factor.

1. Introduction

Brittle materials such as rocks show highly non-linear and complex response to external dynamic loads especially in peak and post-peak region. The comprehension and interpretation of the rock failure mechanism under dynamic loading is important for engineering practices. The measures to promote the failure of rocks in open pit mines and underground spaces rely on the fundamental understanding of the failure mechanisms in rock materials. The degree of issue greatly increases when the rock material is under dynamical loading. The rock materials have intrinsic defects in micro-scale such as in-homogeneities, micro-pores, micro-cracks and grain boundaries mismatches that cause stress concentration and decrease the overall rock strengths [1]. These intrinsic defects could be categorized into different families in term of size and orientation. According to the weakest link theory under quasi-static loading condition some of the large flaws

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