International Journal of Rock Mechanics & Mining Sciences 59 (2013) 179–190

Contents lists available at SciVerse ScienceDirect

International Journal of Rock Mechanics & Mining Sciences

journal homepage: www.elsevier.com/locate/ijrmms

# Numerical modeling on destress blasting in coal seam for enhancing gas drainage

W.C. Zhu*, C.H. Wei, S. Li, J. Wei, M.S. Zhang

*Key Laboratory of Ministry of Education on Safe Mining of Deep Metal Mines, Northeastern University, Shenyang 110819, China*

A R T I C L E  I N F O

*Article history:*
Received 6 August 2011
Received in revised form
30 July 2012
Accepted 3 November 2012
Available online 28 February 2013

*Keywords:*
Coal seam
Destress blasting
Gas drainage
Blasting stress wave
Blasting damage
Numerical simulation

A B S T R A C T

Controlled blasting for loosening coal seams is one of the most important measures to enhance gas drainage and thus prevent coal and gas outbursts. The formation and development of blasting-induced damage zone, as well as the gas flow in damaged coal seams, can be considered as a coupled process among gas flow, solid deformation and damage. In this work, a coupled multiphysical model for the interaction between blasting damage of coal seam and gas flow is proposed, based on which, the effect of destress blasting on draining gas in coal seam is numerically simulated and the associated mechanisms for enhanced gas drainage induced by blasting damage are clarified. The loosening of coal seam induced by blasting is considered as a damage process that is dominated by the combined contribution of blasting stress wave and blasting-induced gas pressure, in this respect, the blasting damage of rock and coal seam is numerically simulated and compared with the existing experimental observations. Then, by considering the effect of coal seam damage on the gas permeability, the gas drainage enhanced by blasting damage is quantified based on the numerical simulations. It is demonstrated that the blasting damage around the borehole can not only alleviate the stress concentration at the perimeter of the borehole but also enhance the gas drainage due to the increase of the gas permeability in the damaged coal seam.



## 1. Introduction

Coal and gas outbursts have created serious difficulties for the coal mining industry around the world, leading to high intensity research efforts, large expenditures, and determined attempts to improve the various ventilation and gas drainage technique [1]. In this regard, improved solutions, such as the optimization of drainage systems and measures for the control of gas emissions during mining operations, are still needed to be found in order to predict and prevent the coal and gas outbursts [2]. High gas content is one of the most important factors that controls the coalbed methane productivity, however, it does not necessarily guarantee high production rate when permeability is too low, which is the case that is usually encountered in many coal fields of China [3]. The most commonly applied methane control solution, especially in high in-place gas content coalbed, is drilling methane drainage boreholes into the panel area prior to longwall mining to reduce the methane content of the coalbed [4]. The coal seam is generally affected by the complex geological conditions, such as low permeability and low saturation, the hydraulic fracturing, waterjet and controlling blasting are usually implemented in order to increase the permeability of coal seam and enhance the gas drainage. During the hydraulic fracturing the creation of the fractures is generally affected by the in-situ geostress conditions [5]. High-pressure waterjets are utilized to create artificial factures in specific directions within the existing gas drainage borehole and form fractural networks in a panel [3]. When high-pressure pulsed waterjet impacts the coal seam with high speed, the stress wave will be triggered, which may also enhance the coal permeability [6].

In addition, the controlling blasting, for example, pre-splitting blasting, or destress blasting is usually utilized to induce the damage in the coal seam. Destress blasting in one of the tools to improve mine safety and it is one of the most valuable techniques to control the damaging effects of rockbursts. [7]. Konicek et al. [8] presented a state-of-the-art review of destress blasting in coal mining, and discussed the effectiveness of destress blasting as a measure to overcome the challenges of high mining-induced stresses causing coal bumps and rockbursts. Andrieuxa and Hadjigeorgiou [9] focused on destress blasting as a technique for reducing ground stresses in underground mines in order to alleviate or mitigate the effects of rockbursts, which provided a series of easily implemented steps that result in a rational assessment of the likelihood of success of a given destress blast design in a given situation of rock mass conditions and stress regime. The pre-splitting blasting was thought to be an effective

* Corresponding author. Tel.: +86 24 83687705; fax: +86 24 83681186.
*E-mail address:* zhuwancheng@mail.neu.edu.cn (W.C. Zhu).

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http://dx.doi.org/10.1016/j.ijrmms.2012.11.004

measure to enhance the pre-drainage rate of gas in low permeability coal seam [10]. Hydraulic fracturing after water-pressure controlled blasting was also adopted to increase the number and range of hydraulic cracks and improve the permeability of coal seams [11].

During the destress blasting, the detonating of explosive results in two types of loadings applied on the borehole wall, namely a stress wave pulse and a explosion gas pressure with longer duration. The stress wave is responsible for initiation of the crushing zone and the surrounding radial fractures, while the explosion gas pressure further extends the fractures [12,13]. In the blasting practice, the waveform should be regulated in order to control the fractures around the cavity.

In this respect, in order to examine the gas extraction in damaged coal seam induced by destress blasting, the formation of blasting damaged zone, together with the subsequent gas migration in coal seam should be considered as a fully coupled process among gas flow, deformation and damage of coal seam. In the past several decades, many attempts have been made in the numerical simulations of blasting-induced damage and gas drainage in coal seam, respectively [2,12–21]. Karacan et al. [21] investigated the different horizontal methane drainage borehole patterns, borehole lengths, and degasification times prior to and during the panel extraction to evaluate their effectiveness in reducing methane emission using a 3D reservoir modeling of a longwall panel. The Lunagas 'Floorgas' and 'Roofgas' are PC based computer programs that developed based on boundary element method for the simulations of strata relaxation and gas release phenomena associated with underground mining activities [1], which offer an effective tool for improving the accuracy and quality of gas control, gas capture technologies and ventilation system design. However, up to now, what is not understood is that the associated mechanism during the gas drainage in the coal seam that is damaged and distressed by blasting, when it is examined as a whole process that is combined with the damage of coal seam and gas flow in the damaged coal seam.

To this end, in this work, a coupled coal-gas model for the interaction between blasting damage of coal seam and gas flow is proposed, based on which, the evolution of damaged zone and coal seam stress near the working face before and after destress blasting is examined by means of numerical simulation. Finally, the effect of destress blasting on draining gas in coalbed is detailed.

## 2. Assignment of material properties

In order to characterize the heterogeneity of geo-materials such as rock, concrete and coal, in this study, the geo-material is assumed to be composed of many mesoscopic elements, and the mechanical properties of these elements are assumed to conform to a given Weibull distribution as defined in the following probability density function [22]

$$f(u)=\frac{m}{u_0}(u/u_0)^{m-1}\exp\left[-(u/u_0)^m\right] \tag{1}$$

where $u$ is the mechanical parameter of the element (such as strength or elastic modulus); the scale parameter $u_0$ is related to the average of the element parameters and the parameter $m$ defines the shape of the distribution function. From the properties of the Weibull distribution, a larger value of $m$ implies a more homogeneous material and vice versa. Therefore, the parameter $m$ is called the homogeneity index. For higher values of the homogeneity index, the strengths of more elements are concentrated closer to $u_0$. An increase in homogeneity index leads to more homogeneous numerical specimen. Using Eq. (1) in a computer simulation of a medium composed of many mesoscopic elements, one can produce numerically a heterogeneous geo-material specimen. The computationally produced heterogeneous specimen is analogous to a real specimen tested in the laboratory, so in this investigation it is referred to as a numerical specimen. In this respect, the influence of heterogeneity of material properties on coupled process can be examined based on the numerical simulations.

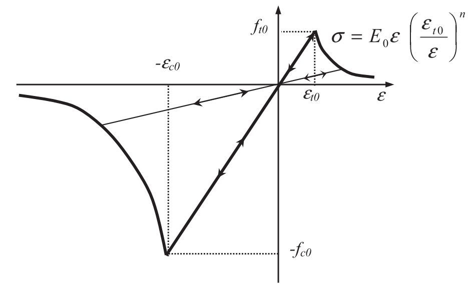

**Fig. 1.** The elastic damage-based constitutive law under uniaxial stress condition.

## 3. Governing equations

The present study will involve two coupled processes that are blasting damage of coal seam and gas flow in damaged coal seam, where one physical process affects the initiation and progress of the other. In this study, conservation equations for mass and momentum are derived on the macroscopic scale (all variables are averaged over the REV of the medium) for a saturated, porous elastic medium (coal seam).

### 3.1. Mechanical equilibrium and damage evolution equation

Initially the porous medium is assumed elastic, with constitutive relationship defined by a generalized Hooke's law. In this regard, a modified Navier's equation, in terms of displacement under a combination of changes of applied stresses (positive for tension) and gas pressures $p$ (negative for suction) is expressed as

$$Gu_{i,jj}+\frac{G}{1-2\nu}u_{j,ji}-\alpha p_{,i}+F_i=\rho_s\frac{\partial^2 u_i}{\partial t^2}, \tag{2}$$

where $u_i$ ($i$=$x$, $y$, $z$) is displacement (m), $t$ is time (s), $\rho_s$ is rock density (kg/m$^3$), $G$ is shear modulus (Pa), $\nu$ is the Poisson's ratio, $F_i$ is the component of the net body force in the $i$-direction (N/m$^3$), and the parameter $\alpha$ ($\leq 1$) is Biot's coefficient. This equation expresses the mechanical equilibrium in porous media subjected to dynamic loading where the effect of fluid pressure is taken into account according to effective stress law.

As illustrated in Fig. 1, the damage of medium in tension or shear is initiated when its state of stress satisfies the maximum tensile stress criterion or the Mohr–Coulomb criterion, respectively, as expressed by [22]

$$F_1 \equiv \sigma_1 - f_{t0} = 0 \text{ or } F_2 \equiv -\sigma_3+\sigma_1[(1+\sin\theta)/(1-\sin\phi)]-f_{c0}=0 \tag{3}$$

where $f_{t0}$ and $f_{c0}$ are uniaxial tensile and compressive strengths (Pa), respectively, $\theta$ is internal frictional angle, and $F_1$ and $F_2$ are two damage threshold functions.

According to the elastic damage theory, the elastic modulus of an element degrades monotonically as damage evolves, and the elastic modulus of damaged material is expressed as follows:

$$E=(1-D)E_0 \tag{4}$$