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The effect of natural fractures on hydraulic fracturing propagation in coal seams

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A R T I C L E I N F O

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A B S T R A C T

The purpose of hydraulic fracturing is to improve the gas permeability of a coal seam by the high-pressure injection of fracturing fluid into cracks. Some promising results of hydraulic fracturing in a coal seam using isotropic and intact model have been published in our previous study (Wang et al., 2014), based on which further research is necessary for the reason that natural coal is anisotropic, inhomogeneous, inelastic, and characterized by multiple discontinuities, which can be one of the most important factors governing the deformability, strength and permeability. It is difficult to accurately identify and predict the manner in which hydraulic fractures initiate and propagate because of the pre-existing natural fractures. In this paper, five typical coal models—intact coal, layered jointed coal, vertical jointed coal, orthogonal jointed coal, and synthetic jointed coal—are established to simulate hydraulic fracturing in coal seam based on two-dimensional particle flow code (PFC2D). The effect of natural existing fractures on fluid-driven hydraulic fracture is investigated by analyzing the variation of fracture radius, cumulative crack number, and growth rate of porosity versus injection time. It is shown that the existence of natural fractures, which has a significant induced effect on the initiation and propagation of hydraulic fracture, contributes greatly to the increase of crack number and growth rate of porosity. The fracture network is greatly influenced by the interaction between hydraulic fracture and natural fractures. Natural fractures with different structural properties may result in different propagation types of hydraulic fracture, which can be categorized as capturing type, crossing type, and compound type.

1. Introduction

Today, Hydraulic fracturing (HF) is used extensively in the petroleum industry to stimulate oil and gas wells to increase their productivity (Adachi et al., 2007). Cipolla and Wright (2000) detailed the state of the art in applying both conventional and advanced technologies to better understand HF and to improve treatment designs. The permeability of coal-bed methane reservoirs in China is so low that it must be stimulated before the gas can be produced (Wright et al., 1995; Shan et al., 2005; Li et al., 2010). Research efforts in recent year have proved that the hydraulic fracturing technology, adopted as an efficient stimulation approach, can significantly enhance the coal seam permeability , thus improving the productivity of coal-bed methane (Yuan et al., 2012; Hou et al., 2013; Li et al., 2014). Coal seams are dual porosity reservoirs that consist of porous matrix and cleat (fracture) network. During the process of hydraulic fracturing, high-pressure fluid penetrates into both the matrix and the cleats along many artificially induced cracks, which not only extrude and release gas, but also provide transportable passage for gas. However , it is difficult to control or predict the effects of hydraulic fracturing because of geologic complexity and mechanism uncertainties. Wu et al. (2006) have found hydraulic fractures mainly have three kinds of mode in coal seams in China: predominantly horizontal fracture system; priority with vertical fracture system and complex fracture system, but the forming mechanism of different hydraulic fracture modes has not been well understood.

During the past six decades, considerable effort has been applied to understand the mechanics of hydraulic fractures (Chang, 2004). The Finite Element Method (FEM) and the Boundary Element Method (BEM) have been used to simulate HF in complex structures (Papanastasiou, 1997; Vychytil and Horii, 1998). Wang et al. (2010) have proposed a coupled algorithm combining FEM and a meshless

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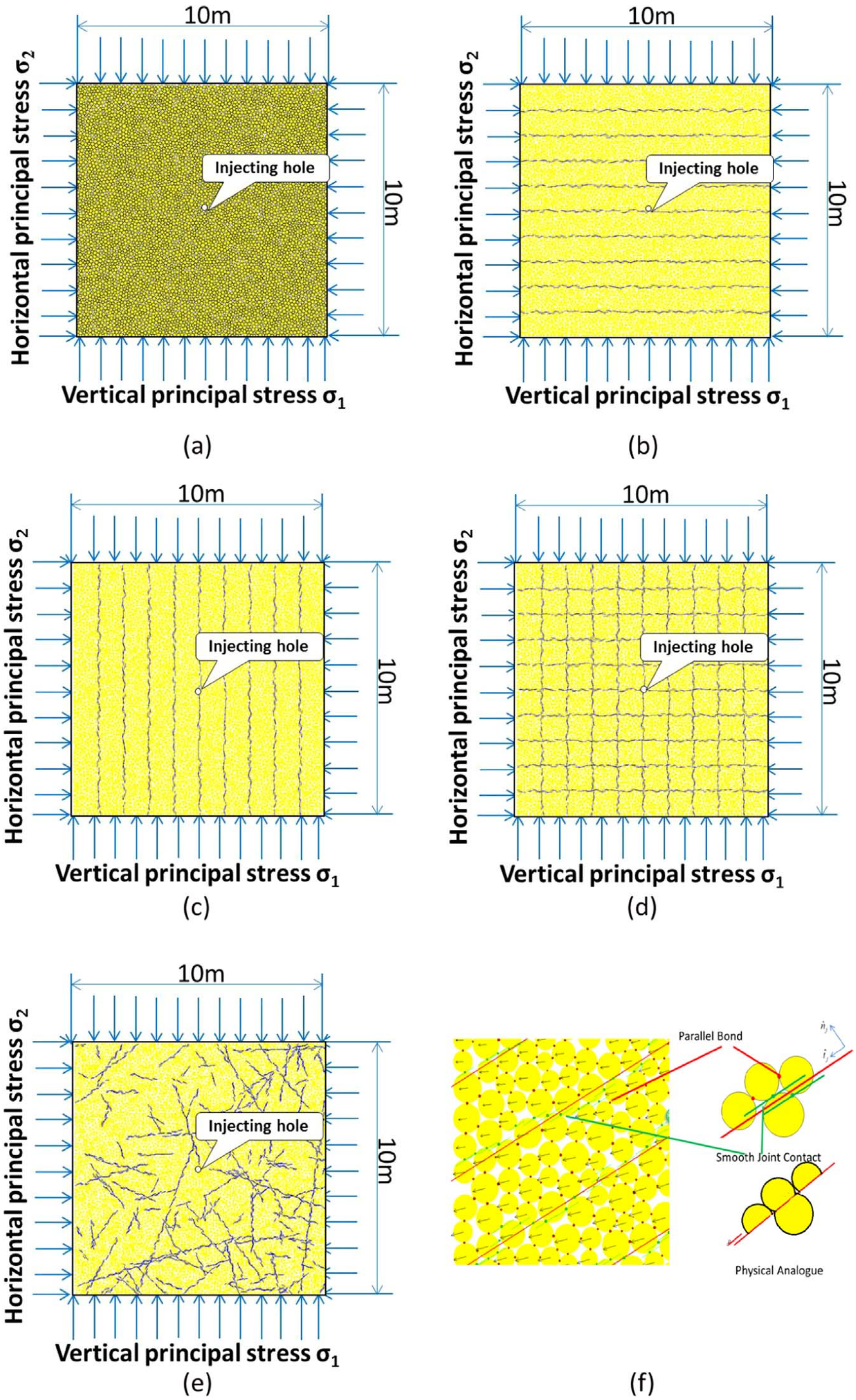

Fig. 1. HF calculation models of different types of coal rock mass: (a) intact coal model; (b) layered jointed coal model with a series of horizontal joints; (c) vertical coal model with a series of vertical joints; (d) fractured coal with a series of orthogonal joints and rock blocks; (e) synthetic jointed coal model in which a discrete fracture network is generated; (f) Concept of smooth joint contact model.

method for the simulation of the propagation of fracturing under either external forces or hydraulic pressure. In attempts to validate the models, microseismic monitoring has been used to image the extent and nature of hydraulic fractures. One of the major findings of these studies is that the nature of the hydraulic fractures determined by observing the recorded seismicity does not generally agree with that predicted by conventional analytical and numerical models (Al-Busaidi et al., 2005). For this reason discontinuum-based discrete element methods (DEM) have been applied to the simulation of HF. With these techniques, the continuum is divided into distinct blocks or particles between which fluid can flow. This allows for a better understanding of hydraulic fracture growth in the coal rock mass, which may contain multiple pre-existing cracks, joints or flaws. The particle flow DEM has become an effective tool for modeling crack propagation (Potyondy and Cundall, 2004; Li et al., 2016). Al-Busaidi et al. (2005) simulated HF in granite using DEM with the results compared to acoustic emission data from experiments. The propagation of HF in coal seams under high-pressure water has been simulated using RFPA based on the maximum tensile strain criterion (Du, 2008; Huang, 2009). Shimizu (2010) and Shimizu et al. (2011) performed a series of HF simulations in competent rock using a coupled flow-deformation DEM code to investigate the influence of fluid viscosity and particle size distribution.