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Anisotropic characteristics of low-rank coal fractures in the Fukang mining area, China

Zhenzhi Wang[a,b], Jienan Pan[a,b,*], Quanlin Hou[c], Bensheng Yu[d], Meng Li[a,b], Qinghe Niu[a]

[a] School of Resources & Environment, Henan Polytechnic University, Jiaozuo 454000, China
[b] Collaborative Innovation Center of Coalbed Methane and Shale Gas for Central Plains Economic Region, Henan Province, China
[c] Key Lab of Computational Geodynamics, College of Earth Sciences, University of Chinese Academy of Sciences, Beijing 100049, China
[d] School of Physics & Electronic Information Engineering, Henan Polytechnic University, Jiaozuo 454000, China

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ABSTRACT

Fractures are the main migration pathways for Coalbed Methane (CBM) in coals, which dominate the permeability of coal reservoirs. One significant anisotropic characteristic of coal is the permeability difference in the parallel and vertical bedding plane directions. Investigating the fracture characteristics in different orientations is an interesting and meaningful issue to understand the genetic mechanism of permeability contrast. This work quantitatively studied the fracture structure characteristics in different directions through the given parameters of Fukang mining area, China. The aperture, porosity, density and connectivity of coal fractures ratio in parallel bedding plane direction are 1.31, 1.12, 1.61 and 1.26 times of that in vertical direction. The main findings through the fractal calculation of fracture on end plane were draw as followings: the roughness in parallel bedding plane direction is less than that in vertical direction; the roughness of the exogenetic fracture is greater than that of cleat; there is a positive correlation between the cleat roughness and aperture; the roughness of shear fracture exceeds the roughness of tensile fracture. Additionally, the causes of fracture development discrepancies in different bedding plane directions were investigated from the perspective of the tectonic evolution history in Fukang mining area. The ratio of the fracture aperture in different bedding plane directions increases linearly with the increasing of the reservoir pressure by comparative analysis. The coal reservoir permeability in parallel bedding plane direction is 1.33–12.91 larger than that in vertical direction according to Darcy's law and the plate law. This research gives clearer insight for the heterogeneous fracture and anisotropic seepage, and provides potential theoretical guidance of CBM numerical simulation in Fukang mining area, China.

1. Introduction

Coalbed methane (CBM) is a kind of clean and efficient unconventional gas, and it is also known as mash gas in the coal mining industry. CBM is mainly adsorbed in the micropores of coal seams [1–3], and the rest is stored as free gas in fractures or macropores. The open-ended nature of fractures allows for diverse CBM migration pathways [4], and the CBM can be driven into well bores through fractures and then pumped up to the ground simultaneously. Diffusion and seepage are the two main migration processes of CBM in coal seams. Diffusion occurs among micropores in the coal matrix and is a relatively slow process, conversely, seepage occurs in the interconnected fracture network and possesses a faster speed [5–7]. The adsorbed gas in micropores is firstly desorbed and then it permeates into coal mining faces from fractures once the stress condition is changed [4]. Therefore, the permeability in a coal reservoir is one of the most important parameters to assess CBM productivity [8–10].

Coal possesses strong heterogeneity after a long sedimentation process, and the permeability varies extensively between different orientations, especially in the vertical and parallel directions of coal bedding [4,11]. Koening and Stubbs [12] found that the permeability ratio in different directions of coal bedding could reach a maximum of 17:1 according to the permeability results from the Warrior Basin. Wang et al. [13] and Li et al. [14] also drew the same conclusion from their research results. However, few literatures provided comprehensive comparisons about the fracture characteristics, and the causes of the varied permeability in different orientations are also scarcely understood.

The natural fractures in coal can be divided into two categories according to the formation cause: endogenic fractures (cleats) and exogenous fractures [5]. The uniform shrinkage of the coal matrix leads to the generation of mutually orthogonal endogenic fractures during the

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[*] Corresponding author at: School of Resources & Environment, Henan Polytechnic University, Jiaozuo 454000, China.
E-mail address: panjienan@163.com (J. Pan).

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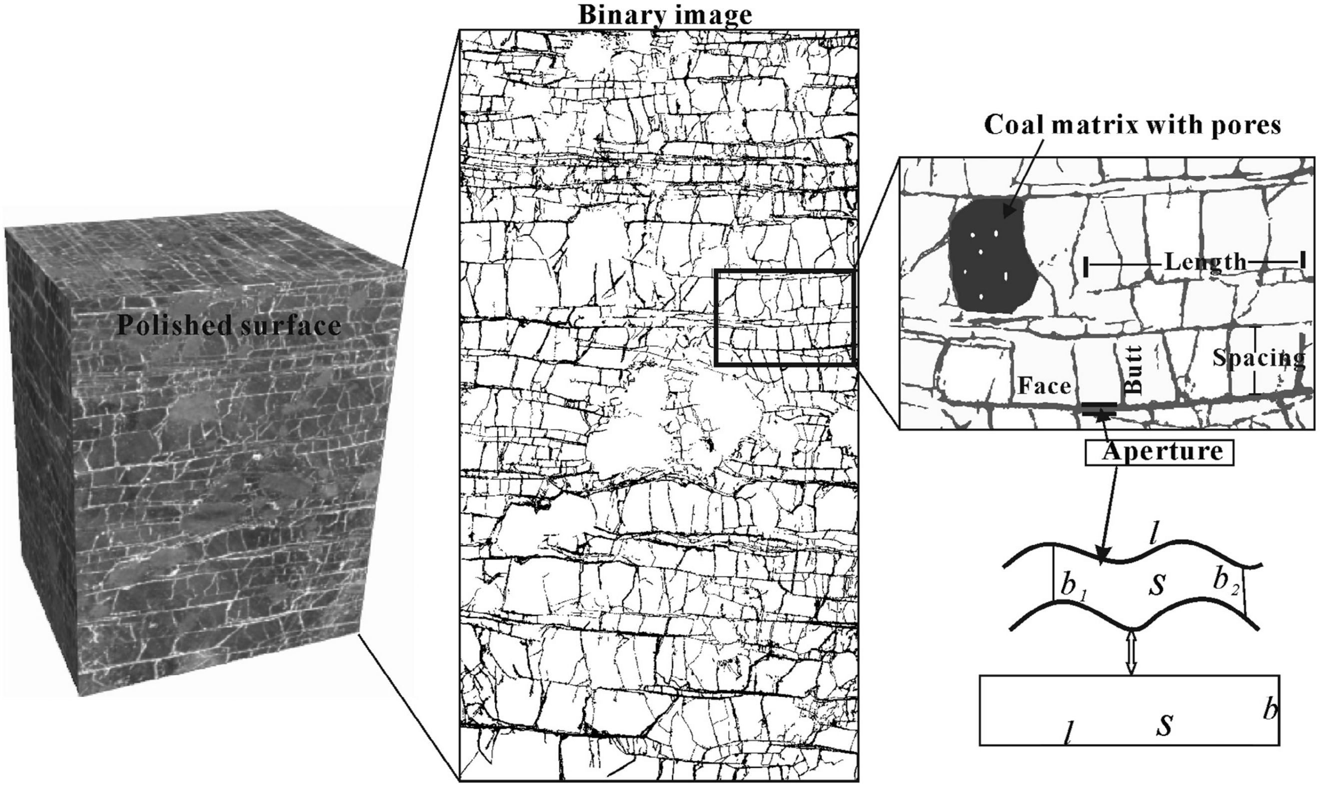

Fig. 1. Characteristics of the coal fractures. Coal blocks were marked according to the bedding plane direction and surface topography images were photographed by stereomicroscope. Image–Pro Plus software was used to calculate the area, aperture and length of each fracture from the binary images processed by binarization technique.

coalification process [15]. The longer one is called face cleat, and the other one is named butt cleat, and the latter terminates in the former generally (see Fig. 1). The cleats contain open fractures and have no shear characteristics [4,16]. Developmental characteristics of fractures greatly relate with in-situ stress [4] and reservoir pressure [4,14,16]. Face cleats are perpendicular to the direction of minimum principal stress, correspondingly, butt cleats are perpendicular to the direction of maximum principal stress [4,17]. Cleats in coal are formed by the internal driving force which mainly composed by reservoir pressure [18], and during the burial process of coal, the fractures are expanded or closed due to reservoir pressure changes. For the cleat aperture, face cleat shows 5-fold greater than butt cleat [19]. There exists a linear relationship between cleat width and height [20]. The fracture cross characteristics and their connectivity were thoroughly expounded in previous studies [21,22]. In addition, some other quantitative parameters (e.g. fractal dimension and roughness) have been applied to the investigation of coal fractures. In 1977, Barton and Choubey [23] defined 10 typical joint roughness coefficient (JRC) curves, which represent different characteristics. The JRC curve can be quantitatively expressed by the fractal dimension of the fracture wall [24–27]. The geometry of the fracture surface and contact condition cause changes in the permeability when the fluid flows through a fracture, and the definition of roughness was put forward [28–30]. Despite these quite independent researches, comprehensive study about fractures in coal is needed.

The methods to investigate fractures in coal mainly include field measurements and laboratory measurements. Field measurements can give a macroscopic description, and the tectonic effect can also be taken into account, whereas laboratory measurements can observe the micro morphology of fractures with a higher accuracy. In the laboratory, polarizing microscopy [19], computed tomography (CT) [19,31–33] and scanning electron microscope (SEM) [15,34] are effective tools for observing the fractures in coals. For micrometre sized fractures, stereomicroscope is suitable for measuring the distribution characteristics; besides, it is low-cost and can be used to test more samples and provide more information with limited funds by comparing with SEM and CT imaging technique.

This study aims to extract information concerning the fracture aperture, fracture porosity, surface density, spacing, surface roughness, and connectivity rate from images photographed by a stereomicroscope and compare the differences among fractures in different orientations. Furthermore, we will discuss the seepage variances according to fracture characteristics and give insight into the anisotropic permeability of coal seam in different burial locations.

2. Geological background and sample preparation

2.1. Geological setting

The Fukang mining area is located in Fukang City, Xinjiang, China. The mining area chosen for this study lies in the southern part of the Junggar Basin, north of Peak Bogda in the East Tianshan Mountains. This mine area covers 2000 km^2 of land which has great value of CBM exploration and development with great resource abundance (1.45×10^8 m^3/km^2) and high gas content (avg. 5.5 m^3/t) [35] (see Fig. 2). The upper wall of the Fukang fault is in the Bogda Mountain thrust nappe, and the lower wall is in the Junggar Basin subduction crust. Intense fold-and-thrust tectonic deformations are common inside of the thrust nappe. In the Early-Middle Jurassic, the coal-bearing strata are sedimented in fan delta, braid river delta and lake [36]. After Jurassic, the Yanshan tectonic movement led to the uplift of the Fukang fault zone, and the Middle Upper Jurassic stratum was severely eroded. The tensile faults converted into reverse faults (Ganhezi fault and Wuliangshan fault) with the steering of extrusion stress. The Fukang fault belt was preliminarily formed in this period. In the Early Middle Cretaceous, the pre Bogda mountain depression engendered an inverse-folding effect under the tectonic movement of Yanshan tectonic phase III. During the inverse process, the NS trending extrusion stress was