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Nanoscale rock mechanical property changes in heterogeneous coal after water adsorption

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ABSTRACT

Rock mechanical properties are of key importance in coal mining exploration, coal bed methane production and CO_2 storage in deep unmineable coal seams; accurate data is required so that geohazards (e.g. layer collapse or methane/CO_2 leakage) can be avoided. In this context it is well established that coal matrix swelling due to water adsorption significantly changes the coal microstructure. However, how water adsorption and the associated with microstructural changes affect the mechanical properties is only poorly understood, despite the fact that micro-scale mechanical properties determine the overall geo-mechanical response as failure initiates at the weakest point. Thus, we measured nanoscale rock mechanical properties via nanoindentation tests and compared the results with traditional acoustic methods on heterogeneous medium rank coal samples in both dry and brine saturated conditions. The microscale heterogeneity of the rock mechanical properties was mapped and compared with the morphology of the sample (measured by SEM and microCT). While the nanoindentation tests measured decreasing indentation moduli after water adsorption (−60% to −66%), the traditional acoustic tests measured an increase (+17%). We concluded that acoustic tests failed to capture the accurate rock mechanical properties changes for the heterogeneous coal during water adsorption. It is thus necessary to measure the coal rock mechanical properties at the microscale to obtain more accurate data and reduce the risk of geohazards.

1. Introduction

Geomechanical response is extremely important in the context of coal mine exploration, (enhanced) coal bed methane (CBM/ECBM), carbon geosequestration and underground coal gasification (UGG) in deep unmineable coal seams [1–6]. Such mechanical characteristics are multi-scale phenomena and range from sedimentation layers, geological structures, to the microstructures of the coal. Thus understanding the microscale mechanical behaviour is vital for large scale geomechanical design [7–10], particularly when predicting the failure behaviour and associated with finite element geomechanical modeling [9,11].

Nowadays these micro-mechanical properties can be measured via nanoindentation tests [12–14]. The nanoindentation test is based on an indenter with known mechanical and geometrical properties which contacts a sample's surface and measures a loading-unloading with force-displacement response curve [12,15,16]. Initially this technique was used for evaluation of homogeneous materials, Constantinides et al. (2006) [17] expanded this technique to heterogeneous materials through grid indentation analysis and thus widely application in the geology and petroleum engineering. In the former studies, the reservoir rocks such as sandstone [18,19], carbonate rocks [20–22], and shale [23,24] have been analysed by such technology. However, there is a serious lack of information in terms of coal nano- and micro-scale mechanical properties (note that coal has a complex composition and is highly heterogeneous e.g. [25–28]).

Furthermore, the coal – reservoir fluid interaction due to physical, chemical and thermal dynamical reactions could change the coal structures were inferred by several researchers in recent years [25,29–31]. The water adsorption in coal matrix and associate with water encroachment, which is a common phenomenon during coal seam exploration and production [32,33], could change the coal microstructures [26]. Such microstructure change leads to the alterations in the coal mechanical properties which play an important role for safety issues, e.g. the gas outburst mostly due to the coal strength changed by structural alteration may from coal matrix swelling affect

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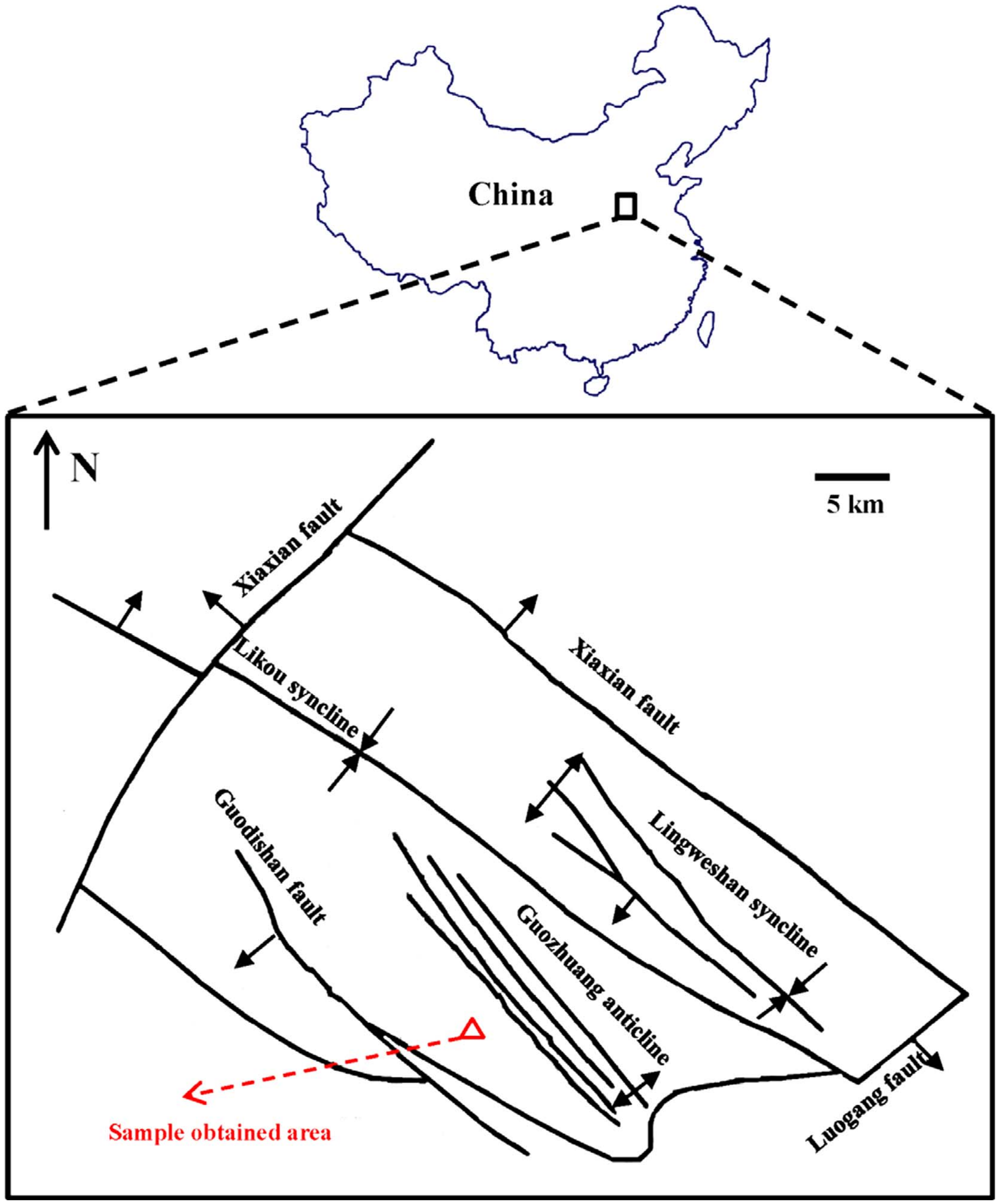

Fig. 1. The geological map of the Pingdingshan coal mine, China.

[34]. However, how such swelling stress changes the microstructures and then change the rock mechanical properties are still poorly understood.

Thus in this study, we conducted the nanoindentation tests on heterogeneous sub-bituminous coal at both dry and wet (by brine saturated) conditions and compared obtained the micromechanical results with core scale results – by acoustic measurements; and we discussed how the coal morphology (measured by SEM and microCT) is related to the geo-mechanical properties and how such geo-mechanical properties changed due to water adsorption.

2. Methodology

2.1. Materials

A medium rank sub-bituminous coal block (carbon content ~55–60 wt% measured by Chinese standard GB/T 212-2008) obtained from Pingdinghsan coal mine located in Henan province, China (Fig. 1), was selected for this study. The coal was deposited at the Permian layer with around ~15 m thickness, where the stratigraphic column is presented in Fig. 2. The physical properties of this coal were tabled in Table 1 [27]. A cuboid coal sample (8 mm × 5 mm × 2 mm) was cut and polished (by a 3 μm diamond abrasive paste) for the nanoindentation tests (using an IBIS nanoindentation system; Fisher-Crips Laboratories) and SEM (using a Phenom XL Scanning Electron Microscope). Furthermore, a large cylindrical core plug (37.5 mm diameter, 34 mm length) was also drilled for the classic ultrasonic test. The highly heterogeneous coal microstructure is obtained in both SEM and microCT images (using an Xradia Versa-XRM instrument, see [35,36]), see Fig. 3.

2.2. Nanoindentation test

The dry cuboid coal sample (8 mm × 5 mm × 2 mm) was fixed on