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The output mechanism of coal powder in CBM production

Reasonable controlling of the coal powder production has become a key factor in CBM well's high and steady yield. However, the forming mechanism and type of coal powder is not systematically studied so far due to the weak of theoretical basis and the lack of information on engineering practice in past. Based on the domestic and foreign literatures, starting from the coal petrography features, by using microcosmic & ultra-microscopic method and combining with engineering practice, the main recognitions are concluded as follow: (1) Through the mechanical model of coal instability failure under the engineering disturbance, the coal transformation is influenced by many factors such as structure, formation, component, coalification degree and gas generation and (and liquid) release. (2) By combining the rock mechanical properties and the on-site CBM wells production, the reason of coal powder production is generally analyzed, the types of coal powder output is classified and its output mechanism is discussed. It is of great practical significance and theoretical reference for the CBM development.

Keywords: *Coal powder, Output mechanism, CBM, Discussion*

1. Introduction

The development and utilization of energy has become a worldwide focus issue [1~6] and the energy shortage and environment pollution has become two huge problems that human beings must face in long-term [3, 4, 6, 7]. The CBM development and utilization in China can not only mitigate the energy supply and demand contradiction and improve the energy structure in some degree, but also can fundamentally guarantee the coal mine safety production and improve global atmospheric environment. The CBM exploration and development at home and abroad shows that the coal seam is different from the sandstone or carbonate reservoir for the CBM development being much more influenced by geological, engineering and production & drainage factors than the gas & oil development, which directly restricts the CBM development efficiency [10, 11, 12]

The low permeability is the biggest factors restricting the CBM development efficiency. [10, 12, 13-16]. In order to improve permeability, the major technologies such as hydraulic fracturing & stimulation, multiple gas displacement and oriented pinnate horizontal drilling [17-23] is adopted at home and abroad. However, due to the complex geological structure [24,25] and high degree of metamorphism characterized with high plastic and weakly cemented [26-28], it is prone to produce coal powder during the engineering process [29,30]. The produced coal powder strands in the duct of cracks and gradually reduce the fracture's conductivity which results the productivity decline in the early period of production [31 ~ 33]. Therefore, the reasonable controlling coal powder output has become a key factor for the CBM wells achieving high and steady production [29], which has great important practical significance and theoretical value.

2. Mechanical characteristic analysis of coal petrography

The close relationship between coal powder and mechanical properties of rock mass structure has been universally accepted [29, 33, 34]. The coal powder production is usually caused by the coal structure damage, and mainly composed of original coal powder in coal seam and secondary coal powder produced by coal framework damaging [33]. The original coal powder in the coal seam is weakly cemented and easily inflows into the wellbore when the fluid moves into the seam. While the secondary coal powder is mainly caused by the shear failure of coal skeleton under the upper & lower pressure difference of seam, which is the main studying point in the paper. The coal body skeleton damage process can be divided into two part, first is the shear failure process and the second is extended failure process [33]. It can be easily got that the rock mechanical study is the prerequisite for the coal powder production recognition.

2.1 Coal ranks

The micro-hardness of coal is determined by the pressing degree of rectangular pyramidal diamond indenter's microscopic compositions under certain pressure & time. Its

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value is signified by the bearing pressure of unit actual contacting area between the pressure coning and coal, which is called Vickers micro-hardness HV (unit N/mm2). Usually a "chair" curve is taken to show the relationship between Vitrinite HV and coal rank (Figure.1). Just as the Figue.1 shows, "under the chair face" is the lignite, "above the chair face" is bituminous, " under the chair face " is anthracite. It can be got from the Fig.1.

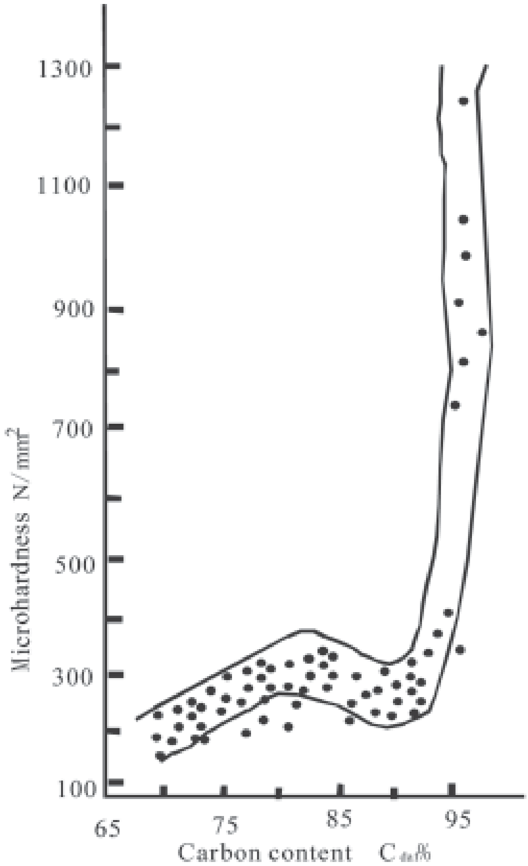

Fig.1 coal microhardness and Carbon content (according to MaJingsheng, 1987)

(1) Microscopic brittleness in low bituminous coal (Cdaf being 80%) have a maximum value; while the micro-hardness in the medium and high bituminous coal (Cdaf is 88%-92%) have a minimum value, indentation is very obvious and more easily to break; To anthracite stage, with the increasing of degree of coalification the micro-hardness increase sharply and vary widely between 294-1961N/mm2.So it also can be considered as auxiliary indexes to classify small kind of anthracite.

(2) Coal micro-hardness depends on size of the aromatic nuclear, the order of arrangement between the molecules, oxygen content and crosslinking degree, and the amount of the high plastic substance in the coal unit structure. For example, because the lignite is rich with high plasticity humic acid, so the micro-hardness is low, however with the increasing of coalification degree, the introduction of oxygen atom and oxygen key generation make the molecular interaction increasing, and the micro-hardness is also gradually increase. While in the high coalification degree of bituminous coal, due to crosslinking being relative weak, so micro-hardness value is minimum, for anthracite carrying with highly aromatic nuclear structure, the micro-hardness increase accordingly with the coalification degree (Fig.2).

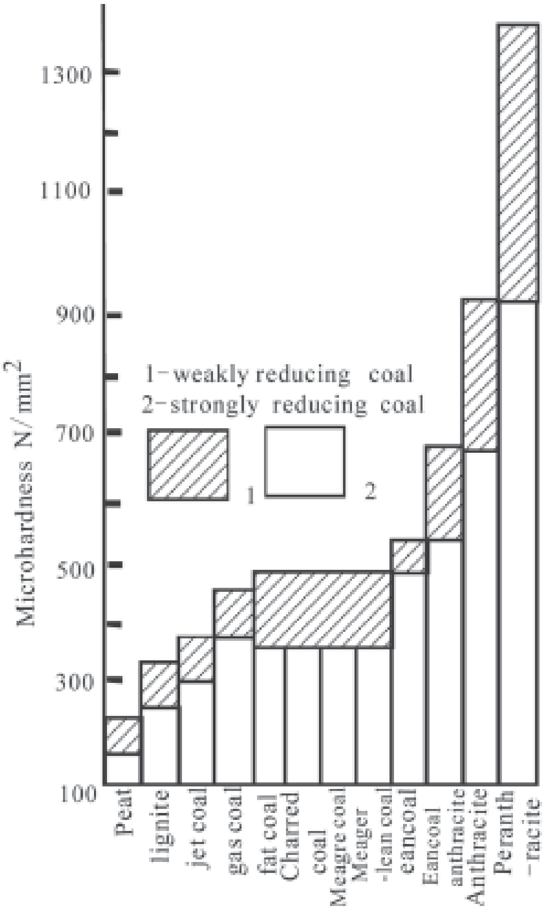

Fig.2 The relationship between Microscopic dawolong and degree of coalificationÿaccording to N.N. Ammocob, 1963.

2.2 MICROSCOPIC COMPONENTS OF COAL

The microscopic components of coal have a great influence on the microscopic brittleness of coal [35, 36]. Vitrinite is the microscopic component with high brittleness and easily broken under pressure; semi vitrinite's takes second place; semifeminist and finite's is decreased in turn; axinite's is minimum and the toughness is the largest. And according to amoxicillin [37] with certain pressure experiment, the creasing value which appears cracks in each 100-creasing designated brittleness. The higher the creasing value is, the greater the brittleness is (Fig.3). The figure shows that the degree of coalification is also an important effected factor on brittleness, the higher the degree of the coalification is, the smaller the brittleness is.

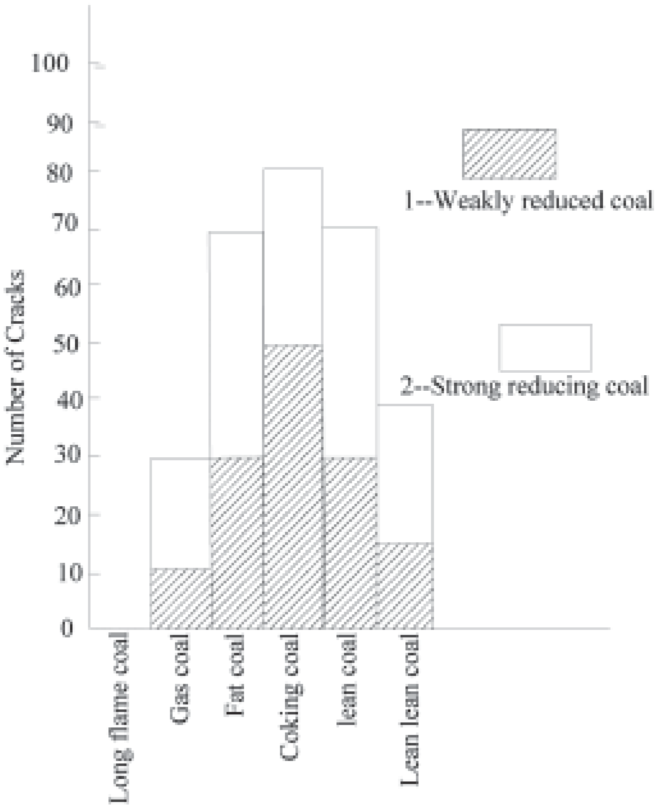

Fig.3 The relationship between the degree of hardness and degree of coalification ÿaccording to N.N. Ammocob, 1963

2.3 Controlling factors of influence coal petrography anti-friction hardness

The microscopic component of coal influences the coal's anti-friction hardness: inertinite's anti-friction being higher than the vitrinite, while the exinite being between them. Next, the degree of coalification also has great important influence [38].

2.4 Coal structure

The understanding of the coal structure has already experienced a long history. Amomsov and Zhemchuzhnikov of Soviet Union started studies on the fracture, while the systematic study began in the 1960s. The contemporaries such as Macrae et al, Van Krevlen and Stach et al in their respective works have also reported the fissures in coal [39-41], which may be defined as early researches of coal structure. In recent years, HuShaoXiang etc. [42] (2000) used coal petrography as an example to analyze the correlation of structure plane of different size rock mass. Kanglijun [43] (2000) discovered the spatial distribution and mutual cutting relation of the areal structure plane by doing the mechanical analysis of sishimen 15 layers' structure, wronging, xingshan mine. Especially, Hancongfa [44] (2003) classifies the common structure plane in coal mine production and gives the mechanics appraisal method.

In addition, Fuxuehai and others [45] has verified that the coal reservoir openings, adsorption or free gas, water medium in the crack contribute to the deformation development and reduce the coal hardness and elastic modulus by carrying out the coal petrography mechanics experimental study of multiphase medium.

3. Observation analyses at coal powder output stage

On the basis of the production influence (observation of YH01 and YH25), the coal powder production can be divided into four stages and the regularity is as follows:

(1) Before gas produced, it is mainly medium or coarse particles. The coarse particles deposit into the rathole while the medium particles will easily cause stuck pump after reaching a certain concentration.

Table 1 The types of coal powder

Geologic origin	inherent coal powder (original coal powder)	Inorganic mineral Tectogenesis coal powder
Engineering incentive Secondary coal powder	Generated by mechanical damage	generated in Drilling process generated in Fracturing process
	Produced in Mining stage	Fluid flow function Gas-liquid-solid three-phase flow function Produced in Desorption stage

(2) In the early stage of gas production, the medium and fine particles get the priority. The fine particles are expelled from wellbore in suspending fluid condition, while the medium particles often lead to stuck pump or bury pump because of the water production decrease. For example, the well YH25 located in the southern Qinshui basin has showed strong production growth in early stage, simultaneously with the continuous increase of casing pressure, water yield and gas production. However, the well has encountered very serious interference of coal powder which result constantly interruption to the gas production growth.

(3) In the middle stage of gas production, fine particles take the main position. Some of the fine particles are discharged in the suspending fluid form, while the others deposit into the rathole.

(4) In the later gas production period, basically there is no water production and the micro-sized fine particles take the priority which can be ejected with the gas production in the dust form. The well YH01 is under such condition after two and a half years' production and drainage, High-speed gas carried with micro-sized fine particles can dredge and polish micro-pore, fractures & channels existing in the dry seam, which has obviously improved the gas permeability around the horizontal well bore and been in favor of releasing CBM productivity.

4. The output mechanism of coal powder

Based on the Coal mechanical properties analysis, Coal powder production observation and previous research results summarization[10,12,29-31],it is thought that the coal's own properties is the basic reason for the powder production while the engineering disturbance is only the incentive. It can be classified into 7 subclass factors after comprehensively considering the powder formation mechanism, the output source and the influence of production (Table.1).

4.1 Inherent coal powder in coal seam

The coal's low Young modulus and high Poisson ratio make it achieve strong deformation degree under relatively low temperature and weak tectonic stress action [46]. According to YangQi [47], it is a kind of extremely universal phenomenon that tectonic events can cause coal seems shape and thickness changes. Because the coal seam is very soft, it is easily happening plastic flow under the influence of tectonic stress. There are mainly three kinds of tectonic pattern which can cause coal seems thickness and form changing: changes mainly caused by drape; changes mainly resulted by fault and complex changes mainly caused by fault and drape. These three changes can form the first kind of coal powder in varying degrees, Therefore, the research in geology field is mainly focus on the controlling factors of the inherent coal powder formation.

By summarizing the previous research results [10, 12, 29-31], the inherent coal powder can be divided into two types. One source is mineral composition controlled by sedimentary environment, which is named clay mineral, another source is tectonic structure caused by geologic stress.

(1) Clay mineral

From the output source point view, clay mineral is an important source of coal powder. According to the coal composition testing, clay mineral are mainly kaolinite, illite, chlorite and Iraq/palm layer minerals, among them kaolinite and illite taking priority. [48].

(2) Structure

According to the same coal rank (high, medium and low) lateral comparison, it is found that powdery Mylonitic coal in macroscopic view and graininess in microscopic view is easy to form coal powder. Primary Texture coal produces relatively few coal powders [29] (Fig.4).

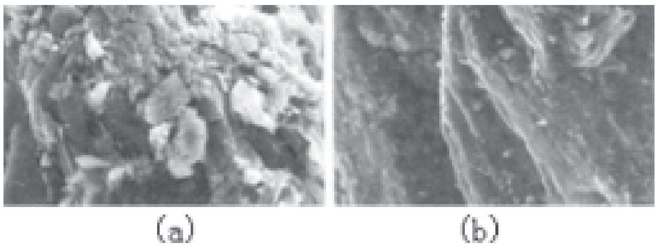

Fig.4 Differences and similarities of structural coal in different particle size under microscope

4.2 Mechanical generation coal powder

(1) The mutability mechanical causes

Drilling tool grinding and fracturing proppant polishing are significant cause of coal powder production [29]. In the drilling process, drilling tool polishes the coal bed to generate coarse powder particle, which can be produced out of the well bore in the early production stage. (Chart 6). In the fracturing process, it can also produce coal powder in the crack surface because of the fracturing fluid high-speed breakthrough under high pressure and the strike to the fracture in the proppant injecting process (speed sensitive and water sensitive effect). [49, 50]

(2) Gradient mechanical generated coal powder

The gradient mechanical generated coal powder is mainly caused by Solid and liquid two phase flow function, closing of fracture, or dynamic equilibrium disturbance resulted by water drainage and pressure decreasing. This kind of coal powder is relatively small but very harmful and can be easily detained in the cleat or fracture which cause permeability decreasing [51-53].

The gradient mechanical generated coal powder is produced in the production & drainage stage due to coal framework deformation caused by water drainage and pressure decreasing. The output mechanism of gradient mechanical generated coal powder will be elaborated in the following. [54, 55]

The influence of Coal skeleton deformation on the fluid flow and seepage

Coal is transformed under the effective stress. Its internal pore, fracture and fissure are changed, developed, fractured and even interconnected in the deformation process. Simultaneously, the opening and closure degree of fissure and pore are also changed, which changed the coal's permeability, influenced the fluid flow and seepage condition, then CBM flow pattern and finally affected the coal powder generation & production.

The influence of fluid flow and seepage on coal skeleton transformation

Fluid flow and seepage has great effect on coal framework. Fluid not only has pore pressure mechanical functions on Coal, but also make stress-strain relationship of coal changed [45], which lead the elastic modulus and compression strength of coal changing.

The equation expressed the relationship between fluid flow seepage and coal framework elastic modulus is as follows:

$$E = a_0 \exp(-b_0 P) \quad \text{... 1}$$

In the equation:

E - elastic modulus,

P - pore pressure of the fluid,

a_0, b_0 - constant

The relationship between compressive strength and pore pressure is expressed in the following equation:

$$\sigma_c = a_1 \exp(-b_1 P) \quad ...\ 2$$

In the equation:

σ_C— compression strength of coal

a_1, b_1—constant

In line with CBM drainage and production,the row mining strength controls the reservoir pressure drop,and then elastic modulus of coal skeleton changes[56]. The shear failure occurred because of breaking the original stress and strain equilibrium relationship, which of course cause coal powder production.

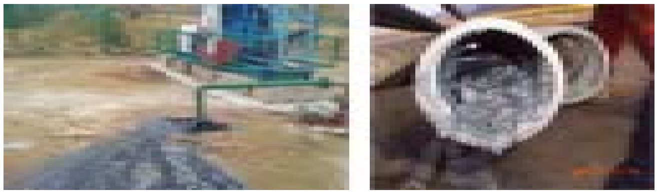

Fig.5 the coal powder in physical disturbance

5. Conclusions

Taking reference from domestic and foreign research results, starting from coal characteristics, by adopting microcosmic & superfine method and combining with mechanical model under the engineering disturbance, the recognitions in this paper can be summarized as follows:

1. By means of the mechanical model of coal instability failure under the engineering disturbance, it is got that the structure, formation, composition, coalification degree and gas generation & (liquid) release of coal have great influence on the coal transformation.
2. By combining the mechanical properties of coal and the CBM well' s actual production, it is analyzed the cause of coal powder production, classified the generation type of coal powder and thoroughly discussed the coal powder output mechanism in the paper.

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