Research on the Impact of Coal Body Structure on Coal and Gas Delayed Outburst

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***Abstract* — Coal and gas delayed outburst is a special type of outburst. At present, it is in the exploratory stage to research on coal and gas delayed outburst, so the research work is of great significance. In this paper, the cause of coal and gas delayed outburst is discussed from the viewpoint of coal body structure characteristics. Some understandings are concluded as follows: the coal and gas outburst may occur when the energy conducive to outburst is greater than the energy not conducive to outburst, which is the mechanics criterion of coal and gas outburst. Among the numerous mining coal seams, some coal seams are consisted of soft-and-broken coal and hard-and-lump coal, and these two coals are may alternately arrayed. For these soft coal and lump coal alternated coal seams, the soft-and-broken coal is with the positive effect of outburst while the hard-and-lump coal is with the negative effect of outburst. At the beginning of unloading, the outburst may not occur when negative effect is greater than positive effect. Along with the time, the deformation of the hard-and-lump coal will increase after unloading, so the negative effect of outburst will decrease gradually. To a certain point of time, the instability and failure of hard-and-lump coal will occur, and this causes the result that the positive effect is greater than the negative effect, which may lead to the outburst of coal and gas. This outburst is a delayed coal and gas outburst, which is the mechanism of coal and gas delayed outburst.**

Keywords - Coal body structure; Coal and gas delayed outburst; Mechanism; Positive effect; Negative effect

I. INTRODUCTION

It is well known that coal and gas outburst is a serious disaster in coal mine production [1,2], and, China is one of the most serious countries in the world about coal and gas outburst [3,4]. At present, China has accumulated more and more substantial progress in theory and in experience including the mechanism of coal and gas outburst, risk evaluation of coal and gas outburst, and, prevention and control measures of coal and gas outburst [5,6].

Among the so many coal and gas outburst cases, coal and gas delayed outbursts have occurred in different degree; the former USSR scholar put forward the phenomenon of delayed outburst in the 1950s, and also, the delayed outbursts were happened not only in China but also in other countries [7,8,9]. The delayed outburst is the phenomenon that the outburst is not happened immediately induced by blasting or other means when coal mining and excavating in outburst prone coal seams, or coal uncovering for outburst prone coal seams in rock cross-cut, but it is actually happened after a period of time. According to statistics, the number of delayed outbursts accounts for only a few percent of total outburst number. Although the proportion is not so large, because of the "delayed", this kind of outbursts often suddenly unexpected happens. The delayed time of delayed outburst is not well defined, it may be a few minutes short, or a dozen hours long, and even a few days later. When the unexpected delayed outburst happen, it is easy to cause significant casualties and property losses. So, usually, the delayed outburst is more harmful than the immediate outburst [10-11].

Although coal and gas outburst is extensively and deeply studied, coal and gas delayed outburst is with particularity, it is still in the exploratory stage at present for the mechanism of delayed outburst. In order to better prevention and control of coal and gas delayed outburst, and to reduce the potential hazard, it is with great significance to research the mechanism of delayed outburst. So, the impact of coal body structure on coal and gas delayed outburst is researched in this paper.

II. THE CHARACTERISTIC OF COAL BODY STRUCTURE

A. The Impact of Coal Body Structure on Coal and Gas Outburst

Coal body structure refers to the deformation and damage degree of coal seam subjected to different kinds of geological processes during geologic evolution history [5]. Under the action of tectonic stress, some coals are fractured and crumpled; these coals are called tectonic coal. And also, under the action of tectonic stress, some coals are not fractured and remain in the original condition; these coals are called protogenesis texture coal. Relatively speaking, the protogenesis texture coal is considerably hard, so we refer it hard-and-lump coal, while tectonic coal is very soft, so we refer it soft-and-broken coal. The outburst risks are significantly different between protogenesis texture coal and tectonic coal, the protogenesis texture coal is with no risk of outburst while tectonic coal is closely related to the coal and gas outburst. And, the tectonic coal including Type

Ⅲ, Type Ⅳ and Type Ⅴ is the key index to predict the risk of coal and gas outburst of coal seams, usually, the more the tectonic coal is, the more the risk of outburst is.

B. The Diversity of Coal Body Structure

The past studies have shown that [12,13,14]: the coal body structure may significantly different between different mining areas; the coal seams may be seriously fractured and crumpled for some mining areas while the coal seams may remain the original condition for other mining areas. Also, the coal body structure may significantly different within a same mining area; some coal seams may be seriously fractured and crumpled while some other coal seams may remain the original condition. And furthermore, the sub layers are also not uniform from top to bottom for a specific coal seam, some fractured and crumpled layers may appear in upper part of coal seam, some appear in the low part, while some appear in the middle. Among numerous mining coal seams, some coal seams are consisted of soft-and-broken coal and hard-and-lump coal, these two coals are may alternately arrayed. Usually, the characteristic of coal body structure can be obtained by two ways, one is by field observation of surface outcrop of coal seam, work face of coal mining or tunneling faces [13,14], the other is by identification of coal body structure based on well logging information [15,16].

III. THE IMPACT OF COAL BODY STRUCTURE ON COAL AND GAS DELAYED OUTBURST

Coal and gas delayed outburst is a special type of outburst; it belongs to the research category of coal and gas outburst. In this paper, the research about delayed outburst is from the angle of coal body structure.

A. The Mechanics Criterion of Coal and Gas Outburst

First of all, it is needed to judge whether the coal and gas outburst may occur or not before to judge whether a coal and gas outburst will delay or not. Usually, the energy not conducive to coal and gas outburst, i.e., the hard-and-lump coal is with a certain strength to resist deformation and breakage so as to be with the energy to prevent the outburst, is called negative effect of coal and gas outburst. And, the energy conducive to coal and gas outburst, i.e., the elastic energy of coal, and the gas expansion energy of soft-and-broken coal which promote the outburst, is called positive effect of coal and gas outburst [17]. Essentially, the process of coal and gas outburst is the interaction between negative effect and positive effect, and the coal and gas outburst is likely to happen when the positive effect is greater than the negative effects [18]. The coal and gas outburst is often happened in well developed zone of tectonic coal, and further, the coal and gas outburst is more often happened in the zone of tectonic coal with a certain large thickness, which is due to the strong positive effect including the elastic energy of coal and the gas expansion energy of soft-and-broken coal while the weak negative effect about energy of hard-and-lump coal preventing the outburst.

B. The Impact of Coal Body Structure on Coal and Gas Delayed Outburst

From the angle of the rock mass mechanics, the deformation of rock mass after excavation unloading is with time effect. In a lot of cases of rock mass, the instability and failure is happen after a period of time instead of immediately happen [19]. Similarly, from the angle of gas geology, the mechanical properties are different between protogenesis texture coal, i.e. hard-and-lump coal, and tectonic coal, i.e. soft-and-broken coal, so the time effects are also different between these two coals. After unloading, such as coal mining, coal excavating, coal uncovering in rock cross-cut or tunnel construction, the deformation characteristics of hard-and-lump coal and soft-and-broken coal are different. For the soft-and-broken coal, because this coal is soft and broken, the instability and failure is thus happen after unloading of coal mining or coal uncovering, so, the positive effect including the elastic energy of coal and the gas expansion energy will be released immediately. But for the hard-and-lump coal, because this coal is with protogenesis texture, the instability and failure is not happen immediately after coal uncovering or unloading of coal mining, the deformation increase gradually over time, resulting in instability and failure in a certain time. During this process, the negative effect, i.e., the energy of the coal and rock preventing outburst, is becoming smaller and smaller as time goes. That is to say, for hard-and-lump coal, in the beginning, the positive effect is less than the negative effect, so no outburst will occur, but in the end, the positive effect is more than the negative effect, so the outburst may occur. Comparing to the immediate outburst after coal uncovering or excavation unloading, this kind of outburst is with the characteristic of obvious time delay, which is the mechanism of delayed outburst.

C. How to Judge Whether the Coal and Gas Outburst will Delay or Not

If the entire coal seam is all consisted of protogenesis texture coal, then, based on the basic cognitive of gas geology, the protogenesis texture coal is with no risk of outburst, so this coal seam is with no risk of outburst.

If the entire coal seam are all consisted of tectonic coals, and these tectonic coals are relatively uniform in the breakage degree, then, based on the basic cognitive of gas geology, tectonic coal is closely related to the coal and gas outburst, and, the tectonic coal is the key index to predict the risk of coal and gas outburst, so this coal seam is with the risk of outburst. But, concerning the outburst may delay or not, due to the tectonic coals in this kind of coal seam are relatively uniform in the breakage degree, the deformation and failure characteristics of sub layers of this kind of coal seam are almost the same, so, the delayed outburst usually will not occur.

If the entire coal seam is not only consisted of protogenesis texture coal or hard-and-lump coal, but also consisted of tectonic coal with different breakage degree or soft-and-broken coal, then, based on the basic cognitive of gas geology, this coal seam is probably with the risk of outburst because the tectonic coal is with considerable thickness so as to be with considerable positive effect. And also, the hard-and-lump coal and the soft-and-broken coal are in the same coal seam, their deformation characteristics after excavation unloading are different. For the hard-and-lump coal, the instability and failure is not happen immediately after coal uncovering or unloading of coal mining, the deformation increase gradually over time, resulting in instability and failure in a certain time. During this process, the negative effect, i.e., the energy of the coal and rock preventing outburst, is becoming smaller and smaller as time goes. In the beginning, the positive effect is less than the negative effect, so no outburst will immediate occur, but in the end, the positive effect is more than the negative effect, so the outburst may occur. Comparing to the immediate outburst after coal uncovering or excavation unloading, this kind of outburst is with the characteristic of obvious time delay. So, we can judge whether the outburst will delay or not by the characteristics of coal body structure.

IV. A CASE STUDY

Based on above analysis, an example is given to illustrate the impact of coal body structure on coal and gas delayed outburst.

A. Brief Introduction of a Delayed Outburst

In January 2006, a coal and gas outburst is happened during the shaft excavation at Wangfenggang Coal Mine in Huainan mining area, China [20]. The outburst coal is up to 2831 tons, and the outburst gas is reach to 9.27×10^4 m^3, 12 workers were killed in this accident. When the outburst happened, the excavation depth of this shaft is -928 m, and C13 coal seam is with 6.2 m thickness and 3 m coal seam has been excavated. When the coal and gas outburst is happened, it is 45 hours later after coal uncovering by blasting, so, it is a typical delayed coal and gas outburst.

B. Characteristic of Coal Body Structure at Research Site

Many studies have been done during the past geological exploration and coal mining about C13 coal seam [9,13,21,22], and C13 coal seam is the main mining coal seam in Huainan mining area. Through the field observation [13] (Fig. 1) and well log interpretation [9] (Fig. 2 and Fig. 3), the characteristics of coal body structure are fully understood. In general, C13 coal seam is consisted of soft-and-broken coal and hard-and-lump coal, and these two coals are alternately arrayed within C13 coal seam. And further, hard-and-lump coal is more than soft-and-broken coal in the upper part of C13 coal seam, and most of the coals are protogenesis texture coal and cataclastic coal. On the contrary, soft-and-broken coal is more than hard-and-lump coal in the lower part of C13 coal seam, and, most of the coals are granulated coal, mylonitic coal and cataclastic coal. And, these characteristics of C13 coal seam are stable and obvious at the research site of this shaft and its surrounding.

Location: Xie-er

Coal body	Thickness (cm)
Ⅰ - Ⅱ	33
Ⅲ	176
Ⅰ - Ⅱ	50
Ⅲ	25
Ⅳ - Ⅴ	20
Ⅲ	42
Ⅰ - Ⅱ	23
Ⅳ - Ⅴ	21
Ⅳ - Ⅴ	15
Ⅳ - Ⅴ	22
Ⅲ	33
Total	460

Fig.1 Coal Body Structure by Field Observation

Location: Jia Ⅻ-3

Coal body	Thickness (cm)
Ⅰ - Ⅱ	91
Ⅳ - Ⅴ	42
Ⅰ - Ⅱ	55
Ⅳ - Ⅴ	44
Ⅰ - Ⅱ	25
Ⅲ	27
Ⅳ - Ⅴ	70
Ⅲ	21
Total	375

Location: Jing-7

Coal body	Thickness (cm)
Ⅰ - Ⅱ	45
Ⅳ - Ⅴ	59
Ⅰ - Ⅱ	62
Ⅲ	84
Ⅰ - Ⅱ	23
Ⅲ	24
Ⅰ - Ⅱ	65
Ⅲ	32
Ⅰ - Ⅱ	102
Ⅳ - Ⅴ	96
Ⅲ	110
Total	702

Location: Jiandong-1

Coal body	Thickness (cm)
Ⅰ - Ⅱ	72
Ⅲ	63
Ⅰ - Ⅱ	69
Ⅳ - Ⅴ	87
Ⅰ - Ⅱ	152
Ⅲ	51
Ⅰ - Ⅱ	84
Ⅳ - Ⅴ	67
Ⅲ	43
Ⅳ - Ⅴ	56
Ⅲ	129
Total	873

Location: Xin-fujian

Coal body	Thickness (cm)
Ⅰ - Ⅱ	157
Ⅲ	110
Ⅳ - Ⅴ	67
Ⅲ	51
Ⅰ - Ⅱ	56
Ⅳ - Ⅴ	82
Ⅲ	69
Total	592

Fig.2 Coal Body Structure by Well Log Interpretation

Location: Ⅷ3-5

Coal body	Thickness (cm)
Ⅰ-Ⅱ	34
Ⅲ	33
Ⅰ-Ⅱ	113
Ⅳ-Ⅴ	57
Ⅰ-Ⅱ	23
Ⅳ-Ⅴ	75
Ⅲ	60
Total	395

Location: Ⅴ07-1

Coal body	Thickness (cm)
Ⅰ-Ⅱ	117
Ⅰ-Ⅱ	77
Ⅲ	59
Ⅰ-Ⅱ	134
Ⅳ-Ⅴ	129
Ⅲ	42
Total	558

Location: Ⅳ-07-1

Coal body	Thickness (cm)
Ⅰ-Ⅱ	37
Ⅲ	31
Ⅰ-Ⅱ	50
Ⅳ-Ⅴ	33
Ⅰ-Ⅱ	33
Ⅲ	30
Ⅰ-Ⅱ	41
Ⅳ-Ⅴ	45
Ⅲ	66
Ⅳ-Ⅴ	41
Ⅲ	38
Total	445

Location: Ⅸ-Ⅰ-6

Coal body	Thickness (cm)
Ⅰ-Ⅱ	56
Ⅲ	48
Ⅰ-Ⅱ	43
Ⅲ	21
Ⅰ-Ⅱ	31
Ⅳ-Ⅴ	32
Ⅰ-Ⅱ	41
Ⅳ-Ⅴ	67
Ⅲ	52
Total	391

Fig.3 Coal Body Structure by Well Log Interpretation

C. The Impact of Coal Body Structure on Coal and Gas Outburst

The thickness of C13 coal seam is about 6.2 m, the coal body structure is fractured and crumpled, and the tectonic coal is well developed, the total of tectonic coals accounts for half of the coal seam thickness or more. Based on the data from the Report of Inspection Hole of Main Shaft, the comprehensive coal and gas outburst risk evaluation index (K) is up to 50, is far more than the critical value 15, and this critical value is from "Standard of Prevention and Control of Coal and Gas Outburst Rules" [23], so C13 coal seam is with serious risk of coal and gas outburst. Moreover, coal mine production also confirms this serious outburst risks, dozens of coal and gas outburst have been happened in this coal seam during the history of coal mine production. Usually, for C13 coal seam, it is necessary to take measures to prevent and control the outburst.

D. The Impact of Coal Body Structure on Coal and Gas Delayed Outburst

The above has shown that: C13 coal seam is consisted of soft-and-broken coal and hard-and-lump coal, and most of the coals are hard-and-lump coal in the upper part of C13 coal seam, while most of the coals are soft-and-broken coal in the lower part of C13 coal seam. The samples are collected and tested respectively, and the parameters are shown in Table I. The hard-and-lump coal sample in the upper part of C13 coal seam reveals no risk of outburst while the soft-and-broken coal sample in the lower part of C13 coal seam reveals risk of outburst.

TABLE I. RISK PARAMETERS OF COAL AND GAS OUTBURST

sample	consistence coefficient of coal (f)	initial velocity of gas emission (Δp)	comprehensive index (K)	risk of coal and gas outburst
C13-upper part	0.65	6	9.23	No risk
C13-lower part	0.26	8	30.77	With risk

In the process of coal uncovering the upper part of C13 coal seam, the hard-and-lump coal is more in upper part of the coal seam, and this kind of coal not only is not conducive to coal and gas outburst, but also is with the considerable ability to resist deformation so as to play the role to prevent the risk of coal and gas outburst. In addition, some measures are taken for prevention and control of coal and gas outburst, so, no coal and gas outburst is happened during the process of coal uncovering in the upper part of C13 coal seam.

The process of uncovering coal is gradually decreased process of hard-and-lump coal's thickness, and also gradually decreased process of hard-and-lump coal's ability to prevent coal and gas outburst. In the process of coal uncovering the middle part or lower part of C13 coal seam, the ability to prevent the risk of coal and gas outburst is decreased due to the thickness reduction of hard-and-lump coal. Soft-and-broken coal is more in the lower part of C13 coal seam, and, this kind of coal is prone to coal and gas outburst. The thickness of soft-and-broken coal is considerable large so as to be with the considerable energy of coal and gas outburst. So, the coal and gas outburst may happen after the time when 3 meters of C13 coal seam has been uncovered instead of just the time of coal uncovering of C13 coal seam.

It has already been described above, most of the coals are soft-and-broken coal in the lower part of C13 coal seam instead of hard-and-lump coal in the upper part. The soft-and-broken coal is with the positive effect of outburst while the hard-and-lump coal is with the negative effect of outburst. At the beginning of unloading, the outburst may not occur when negative effect is greater than positive

effect. Along with the time, thickness of hard-and-lump coal is decreased, and, the deformation of the hard-and-lump coal will increase after unloading, so the negative effect of outburst will decrease gradually. To a certain point of time, the instability and failure of hard-and-lump coal will occur, and this causes the result that the positive effect is greater than the negative effect, which may lead to the outburst of coal and gas. This outburst is a delayed coal and gas outburst, which is the cause of coal and gas delayed outburst.

V. CONCLUSION

Based on the above research, some conclusions are drawn as follows:

1. Coal and gas delayed outburst is a special type of outburst. At present, it is in the exploratory stage to research on coal and gas delayed outburst, so the research work is of great significance.

2. The coal body structure is the key factor effecting the coal and gas outburst. And, the coal and gas outburst may occur when the energy conducive to outburst is greater than the energy not conducive to outburst, which is the mechanics criterion of coal and gas outburst.

3. The coal body structure is also the key factor controlling the coal and gas outburst will be delayed or not. For some soft-and-broken coal and hard-and-lump coal alternately arrayed coal seams, the soft-and-broken coal is with the positive effect of outburst while the hard-and-lump coal is with the negative effect of outburst. And, the deformation of the hard-and-lump coal will increase after unloading, so the negative effect of outburst will decrease gradually. For some of coal seams, this kind of phenomenon may occur, i.e., from the time of coal uncovering to the happening time of coal and gas outburst, also, positive effect is from greater than to less than negative effect, it is exactly a process and has a time delay, which is the mechanics criterion of coal and gas delayed outburst.

CONFLICT OF INTEREST

The author confirms that this article content has no conflicts of interest.

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