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Feasibility of using sodium silicate as grouting in loose coal bed sections for methane drainage

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ABSTRACT

Incidents such as borehole collapse, suction drill, and drill pipe drop resulting from borehole instability may occur in the process of drilling in loose coal bed sections for coal mine methane (CMM) drainage before mining. Grouting while drilling (GWD) is a technique used to reduce such incidents. Sodium Silicate used in GWD has the advantages of controllable consolidation-time, non-toxic material, non-pungent odor and relatively inexpensive. Although it will shrink after solidification, this could be used to connect gas channels. This paper presents the feasibility of using Sodium Silicate to make GWD slurry through results of laboratory experiments.

The principal ingredients of the two Sodium Silicate grouting slurry formulae, namely 4% Glycerol Triacetate with 20–40% Sodium Silicate and 4% 1,4-Butyrolactone with 20–40% Sodium Silicate, were selected based on the requirements of GWD. The experimental results from a traditional test device revealed that coal cement stress is still low after 45 min thus limiting its field application. However, after 72 h, multiple cracks appear along the edge of the coal grains suggesting that the formulae can be used to connect gas channels naturally after hardening. If a PH stabilizer is not added, the optimal grouting time occurs within 20 min. In the process of GWD, the grouting slurry will not consolidate until it is injected into the borehole wall, which is enables the drill pipe to remain clean after grouting. Seepage grouting simulation experiments based on a self-developed device indicate that injecting certain slurry into pre-set positions of a drilling hole by circulation wind pressure is feasible to some extent when drilling in fractured, strongly fractured, and pulverized coal beds. In powder coal, however, it will close the gas channels, and thus cannot be applied.

1. Introduction

The application of unbalanced drilling (UBD) with atomization wind as circulating medium has increased in China because of its high efficiency in underground coal bed methane (CBM) drainage drilling. In some soft coal beds, however, this is insufficient. For example, when drilling in loose coal bed sections of the Chinese Panzhuang #3 Coal mine area using UBD technology, only 5% CBM drainage boreholes were successfully completed, and approximately 53% CBM drainage borehole incidents including collapse, suction drill and drill pipe drop resulted from borehole instability (Lu, 2014). In order to overcome such problems, techniques such as drilling-while-casing, drilling with constant pressure, wall protection with screen pipe and wall protection with fluid have been studied and improved (Ji, 2014; Xu et al., 2014; Tao et al., 2011). This paper focuses on GWD, which is a sectional grouting technique to further improve the UBD technology. Slurry is injected into the loose coal bed section to reinforce the borehole wall in the process of UBD. Subsequently, the GWD technique is able to maintain a high efficiency. Wei et al. (2010) and Tao et al. (2011) have researched GWD slurry formulae for CMM drainage in loose coal beds, which have appropriate consolidation time and stress. Tools and techniques still need to be further studied for GWD slurry that could match UBD with atomization wind as a circulating medium.

2. The performance requirement of GWD slurry

The purpose of GWD is to improve viscous resistance and friction resistance in coal grains until it is equal or greater than the radial stress and radial pressure according to the collapse mechanics condition (Guo and Lin, 2010). Consolidation stress is one of the main factors that determine the formula of the slurry because it is the most influencing factor. It is difficult to determine a specific value for consolidation stress because of complicated and changing geological conditions. However, prior researchers have developed methods that help in estimating

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consolidation stress (Yang et al., 2012; Franssona et al., 2007). Another essential factor that could influence the grouting slurry formula is easy-controlled cement time due to limited borehole wall collapse time delay (Qu et al., 2011) and improved drilling efficiency. Mud density, mud rheology, and fluid invasion also influence borehole instability (Gentzis et al., 2009). Gustafson and Stille (1996) stated that "a successful grouting operation means that the grout is thin enough that it also penetrates the fine joints." They studied the relationship between grout penetration and grouting time to derive criteria for grouting (Gustafson and Stille, 2005). Based on previous research and field application requirements at the Sihe Coal mine and Zhaozhuang Coal mine in Shanxi Province, the performance requirements of GWD slurry should be as follows:

(1) The slurry should contain small size grain or solid-free that easily penetrates coal bed fractures.
(2) The slurry should have high fluidity before it is injected into the borehole wall, and increased viscosity afterward for curing. Easy-controlled cement time and stress that guarantees stability of the borehole wall are also required.
(3) Cement should have the ability to break itself to connect gas channels for CBM drainage after completion of borehole drilling.
(4) The slurry formulae should be adaptable to coal mine temperatures.
(5) The remaining slurry in the drill pipe hole should be removed easily.
(6) The slurry must not pollute the environment or be harmful to the operator.
(7) The advantageous consolidation time is approximately 45 min.

To achieve these, a series of laboratory tests were conducted to select the optimal slurry formulae. Subsequently, two Sodium silicate slurry formulae that could be used in GWD were introduced. Sodium silicate is environmentally-friendly and not harmful. Shrinkage after consolidation is helpful in connecting gas channels. According the Danielle et al. (2013), the consolidation time of Sodium silicate slurry can be controlled by controlling the time for its PH value to reach 8–9.

3. Experiments for sodium silicate slurry fomulae

A Cup-down method was used to identify whether the slurry had lost fluidity and to observe the consolidation time. A disposable plastic cup filled with slurry was placed on its side, to observe and identify loss of fluidity when the slurry stopped flowing. Consolidation time is defined as a time length from the completion of raw material mixture to the loss of fluidity. The dosage of sodium silicate and water was measured using a 200 mL cylinder, while a dropper controlled the dosage of other raw materials. According to a provision from the China Coal Mine Safety Regulation, workplace temperatures in underground coal mines should not exceed 28 °C. Field experiments were conducted at the Zhaozhuang Coal mine in Shanxi Province, China. Underground temperatures were between 16 °C and 18 °C as measured by an in-situ gas detector developed in-house. The experimental temperature was approximately 20 °C, meeting the provision and mirroring the field environment.

3.1. Sodium silicate mixed with 1,4-Butyrolactone

In order to determine a formula with reasonable consolidation time, a dosage of 1,4-Butyrolactone was controlled between 1% and 4%, and the Sodium Silicate dosage was controlled between 5% and 80%. The experimental results are shown in Figs. 1 and 2.

As shown in Fig. 1, the consolidation time initially declined sharply, then changed slowly with an increase of sodium silicate, and exhibited a consolidation time of approximate 45 min when the Sodium Silicate dosage ranged between 20% and 40%. The span of 45 min met the requirements of a GWD project and the wide dosage range confirms that it is straightforward to prepare the slurry and beneficial for field applications. Pierce depth was used to analyze consolidation stress. Consolidation stresses were higher and more stable when Sodium Silicate dosage ranged from 20% to 40%, and reached its maximum between 35% and 40% as illustrated in Fig. 2. Subsequently, the effect of the amount of 1,4-Butyrolactone on consolidation time was studied under the condition of adding 40% Sodium Silicate. The amount of raw materials and the experimental results are shown in Table 1 and Fig. 3.

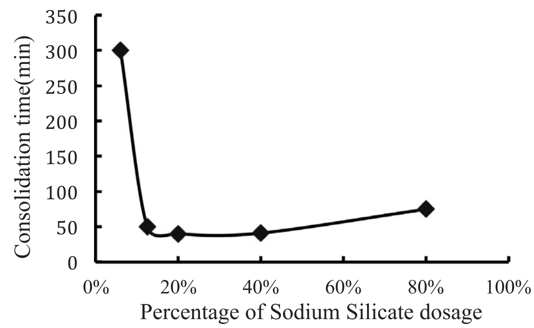

Fig. 1. Percentage of sodium silicate dosage vs. consolidation time.

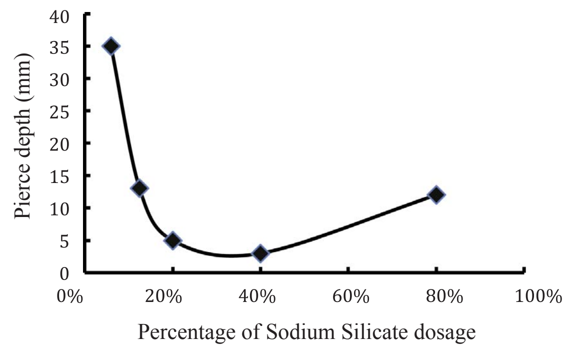

Fig. 2. Percentage of sodium silicate vs. pierce depth.

Fig. 4 illustrates how consolidation time declined with an increase in 1,4-Butyrolactone dosage, and was approximately 45 min when 1,4-Butyrolactonedosage reached 4%.

Experiments were also designed as adding more than 40% Sodium Silicate and greater than 5% 1,4-Butyrolactone as presented in Table 2. The results indicate that the consolidation time is too short (≪45 min) for GWD project.

3.2. Sodium silicate mixed with glycerol triacetate

Glycerol Triacetate dosage was regulated between 2% and 4%, and Sodium Silicate dosage was regulated between 16% and 40%. Table 3 presents the experimental combinations with the results illustrated in Figs. 4–6.

Table 1
The effect of 1,4-Butyrolactone dosage on consolidation time when adding 40% Sodium Silicate.

Expt. no.	1,4-Butyrolactone (ml)	Sodium silicate (ml)	Water (ml)	Consolidation time (min)
1	20	0.5	50	> 150
2	20	0.9	50	> 150
3	20	1.2	50	135
4	20	1.4	50	85
5	20	1.6	50	80
6	20	1.8	50	74
7	20	2	50	40
8	20	2.2	50	42
9	20	2.4	50	27

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