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Research on new high-water solidified materials to reinforce coal and eliminate gas outburst

Yinghua Zhang, Peiling Zhou, Zhian Huang*, Yukun Gao, Qiang Luo

State Key Laboratory of High-Efficient Mining and Safety of Metal Mines(University of Science and Technology Beijing), Ministry of Education, Beijing, China, 100083

ABSTRACT

As coal and gas outburst is one of the main mine disasters, it is very important to prevent and eliminate the coal and gas outburst. Grouting setting liquid into coal can strengthen the coal seam, increase rigidity coefficient (f), and reduce expansion energy of gas. According to the related experimental procedures of cement paste, experiments on the performance of complex materials that high-water material added with different admixtures were carried out. Results showed that: as the increase of water-cement ratio (W/C), the mobility and setting time were all increased, but compressive strength and rupture strength were declined, furthermore, high-water material showed early strength, which can reach 80% of 14 days compressive strength when it is 7 days. As a rapid setting and early strength cement, Na_2SiO_3 had the best effects on shortening setting time, when dosage was 3% , the initial setting time and the final setting time were 13min and 21min shorter than blank samples, while the compressive strength increased more than 2 times. As retarder, the initial setting time can extend to 83min when compounding with tartaric acid of dosage of 0.4%. Through the orthogonal experiment the best additive ratio was determined, which was W/C=2, tartaric acid with dosage of 0.2%, Na_2SiO_3 with dosage of 3%, bentonite with dosage of 12%. Reinforcement simulation experiment showed that, grouting radius of new setting liquid was 250mm when grouting pressure was 60KPa, 7d rupture strength and compressive strength were 5.2MPa and 6.4MPa, and were 37% and 88% higher than ordinary high water material, which was effective for reinforcing coal and eliminating gas outburst.

Key words: gas outburst; setting liquid; reinforce coal; high-water solidified materials; rapid setting and early strength cement, retarder

1. INTRODUCTION

Gas outburst is one of the natural disasters that threaten the safety of coal mine (Qin, B.T. et al., 2013). Forming coal sample simulation results showed that, the stress and gas pressure was the power of gas outburst, and the strength of coal was the resistance, thus, gas outburst can be prevented by reinforcing the strength of coal(Yong, Q.L. et al., 2005; Zhu, J.K., 2011; Fu, J.H. et al., 2009).

Reinforcing coal and eliminating gas outburst is that grouting setting liquid into coal, which can infiltrate into the space of the coal and reinforce the coal (Gao, G.F., 2006). The study of grouting setting liquid by domestic and foreign scholars showed that setting liquid has effective effects on prevention of gas outbursts, the lower of its permeability and the greater of its consolidation strength, the better of its effects (Anon et al., 2006; Huang, Z.A. et al., 2010). High water material is a new type of special cement mixed material, whose water cement ratio can be as high as 3:1, and have the characteristics of good liquidity, good permeability, high strength, and adjustable performance parameters (Jiang, X.H. et al., 2010; Lu, L.C., et al., 2005; Yan, Z.P. et al., 2006). Elimination of high water material setting liquid for gas outburst has been demonstrated by experiments and filed experiments by Zhang C.Y. and Xiao P.C. et al., and after handling of setting liquid, f of coal seam was highly increased and ΔP was decreased from 35.5 to 2 (Zhang, Y.H. et al., 2003; Feng, G.M. et al., 2011). Whatever, elimination effects of gas outburst is still not ideal, and high water material has the characteristics of adjustable performance, therefore, a new type of high water material can be researched by compounding with admixtures, which can improve the efficiency of elimination of gas outbursts.

2. MECHANISM OF REINFORCING COAL AND ELIMINATING OUTBURST

When grouting setting liquid into coal, on the one hand setting liquid infiltrate into the space of the coal, and free gas, partially adsorbed gas is driven out of the grouting coal seam, on the other hand setting liquid and coal is cemented together, which close the passage of gas desorption. At the same times, the

*Corresponding author – email : huang_za@qq.com

water prolapsed by solidification enter small pores, closing gas desorption passage with capillary force, which made the free gas cannot be formed by the adsorption gas, reducing the amount of gas involved and decreasing gas desorption rate (Xiao, P.C., 1994; Wu, Q. et al., 2010; Zhang, C., 2014).

3. NEW HIGH-WATER SOLIDFIED MATERIALS TO ELIMINATE OUTBURST

The key of the method of reinforcing coal and eliminating gas outburst is the development of setting liquid. To conform to the special environment of coal mine and the requirements of grouting, the setting liquid must be low viscosity, good fluidity and can enter tiny pores. High water material is a new type of special cement mixed material, which is constituted of A component and B component, A component is sulphate-aluminate cement clinker and B component consists of gesso and lime. Powder material of A component and B component mixed with water respectively, then rapid setting and solidify through physical and chemical reactions (Cha, J. et al., 2010).

3.1 Experimental materials

Sulphate-aluminate cement clinker, deflocculant; retarder (calcium lignosulfonate and tartaric acid), rapid setting and early strength cement (sodium silicate, triethanolamine, sodium chloride and sodium aluminate), coal powder et al..

3.2 Methods and Instruments

Refer to the cement testing procedures and standards, make experiments on mobility, viscosity, syneresis rate, stability, setting time, compressive strength, tensile strength. Main instruments: NJ-160B cement paste mixer, NDJ-5S digital rotary viscosimeter, setting time standards detector, 40mm×40mm×160mm testing module, digital hydraulic pressure testing machine, HBY-40B standard curing box, et al..

3.3 Results and discussion

1) Effects of water cement ratio（W/C） on the properties of high water material

The W/C of high water material can be as high as 3:1, which has effects on mobility and early strength. High water materials when W/C=1.0, 1.5, 2, 2.5, 3 were prepared respectively, among them the ratio of A component and B component was 1:1, researching on the viscosity and setting time of the setting liquid, the results were shown as Table 1.

It can be seen from Table 1 that: As the increase of W/C of A component and B component, viscosity was decreased, and setting time was increased, final setting time when W/C=3.0 was 4 times of W/C=2.5, the increase of final setting time was larger than the initial setting time. Hence, as the increase of W/C, the mobility was increased, but the increasing of setting time too much was not conducive to grouting. The following study focused on the strength of different W/C.

Table 1: Effects of W/C on viscosity and setting time

W/C	Viscosity		Setting time	
	A component / $mPa \cdot s$	B component / $mPa \cdot s$	Initial setting time / min	Final setting time / min
1.0	817	502	17	24
1.5	60	464	25	50
2	15	316	30	56
2.5	12	86	43	70
3.0	15	50	100	240

Weighed a certain amount of A component and B component, and the ratio was 1:1, mixed with bentonite whose dosage was 10% to improve stability, poured into the blender, then, make testing module for the experiments.

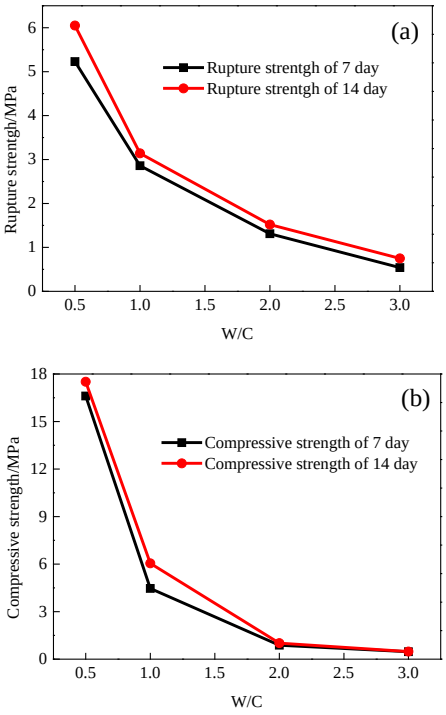

Figure 1: Strength of 7 day and 14 day under different W/C
(a) Rupture strength; (b) Compressive strength

As shown in Figure 1, compressive strength and rupture strength declined as W/C increased, 14 day compressive strength was 17.51MPa and 14 day rupture strength was 6.05Mpa when W/C=0.5, but 14 day compressive strength and 14 day rupture strength

was less than 1MPa. 14 day compressive strength and rupture strength were almost close to 7 day compressive strength and rupture strength, indicating that high water material had the character of early strength, the strength of 7 day had reach 80% of 14 day, this performance is very good for dealing with urgent situations.

2) Influence of rapid setting and early strength cement on the high water material

High water material with adjustable performance, therefore, the better performance setting liquid can be obtained by compounding with admixture. When W/C=2.5, bentonite dosage is 12%, adding rapid setting and early strength cement to the high water material, then, studied on the properties of setting liquid. The species and dosage of rapid setting and early strength cement was shown in Figure 2.

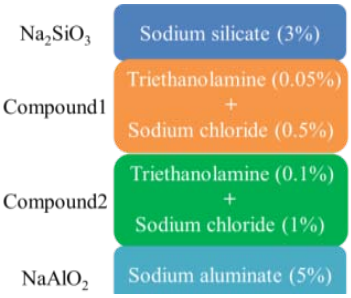

Figure 2: Species and dosage of rapid setting and early strength cement

It can be seen from Figure 3 that setting time was decreased obviously when there was rapid setting and early strength cement. Among the rapid setting and early strength cements, Na_2SiO_3 that dosage was 3% had the biggest influence on initial setting time, initial setting time of the setting liquid with Na_2SiO_3 was 17min, which was 13min shorter than the blank sample. The greatest impact on the final setting time was that liquid with $NaAlO_2$, which was 24min shorter than the blank sample. As the increase dosage of compound, setting time was declined but changed a little.Not only the setting time changed but also the solidification strength, when adding rapid setting and early strength cement. Compressive strength and rupture strength were used to represent the mechanical strength of grout stone, as shown in Figure 4, the strength were all increased when added rapid setting and early strength cement.

(1) From the aspect of rupture strength, the strength of setting liquid with Na_2SiO_3 was biggest each period, rupture strength of 14 day was 0.68MPa higher than blank sample. For the same sample, 7 day rupture strength was the biggest, because of the evaporation of water, 14 day rupture strength was decreased, among them, liquid with compound reduced the maximum and liquid with Na_2SiO_3 reduced minimum. Therefore, the setting liquid with Na_2SiO_3 has big early strength and changed little over time.

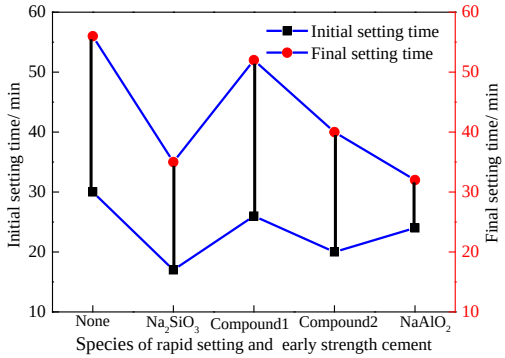

Figure 3: The effects of rapid setting and early strength cement on setting time

(2) From the aspect of compressive strength, it was increased as time increased. Compressive strength was increased after adding rapid setting and early strength cement, the most obviously was Na_2SiO_3, whose 1 day strength was 1.58MPa and was 2.4 times of blank sample (0.65MPa), 7 day and 14 day strength was the biggest too. The 14 day compressive strength of setting liquid with $NaAlO_2$ was 1.64MPa, which was small than that with Na_2SiO_3.

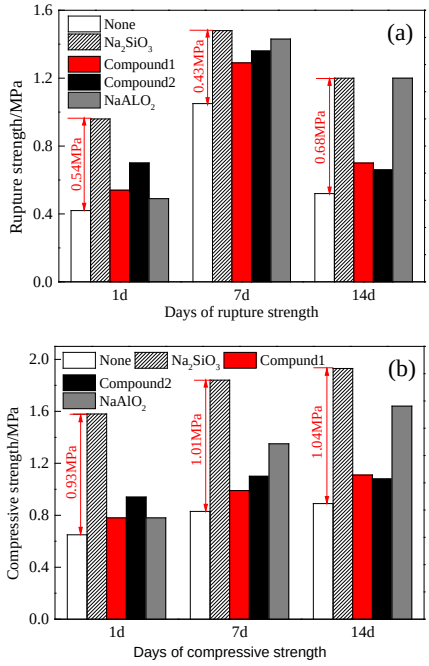

Figure 4: The effects of rapid setting and early strength cement on compressive strength and rupture strength
(a) Rupture strength; (b) Compressive strength

3) Influence of retarder on the high water materia

The early strength of high water material as increased after compounding with rapid setting and early strength cement, nevertheless, the mobility of the liquid was declined, and setting time decreased too much, which was not conducive to the penetration in coal. On the other hand, mobility and setting time can be adjusted through mixing with retarder.

In this work, calcium lignosulfonate and tartaric acid was used as retarder, Table 2 depicted that setting time increased as the increase of dosage of retarder. The effects of tartaric acid on the setting time was relatively large, the initial setting time of calcium lignosulfonate when dosage was 0.2% was close to that tartaric acid that dosage was 0.2%. When the dosage of tartaric acid was 0.2%, the initial setting time was 118min and final setting time was 167min, which were 83min and 108min longer than that of blank sample respectively.

Table 2: Influence of retarder on the high water material

Retarder		Initial setting time/ min	Final setting time/min
Name	Dosage（%）		
Calcium lignosulfonate	0.25	35	59
Calcium lignosulfonate	0.35	41	62
Calcium lignosulfonate	0.45	58	135
Tartaric acid	0.2	43	78
Tartaric acid	0.3	67	105
Tartaric acid	0.4	119	167

In addition, compounding with retarder influenced the mobility of the liquid. As shown in Figure 5, mobility was increased obviously, the increasing effects of tartaric acid was bigger than calcium lignosulfonate. As the increase of the dosage of retarder the mobility increased. The mobility can be 410mm when the dosage of tartaric acid was 0.4%, which was 1.4 times of blank sample, when the dosage of calcium lignosulfonate was 0.45%, the mobility of the liquid was 1.2 times of blank sample.

Because of high water material is in the range of easy setting, thus, if mobility is the reference standard, then, tartaric acid will be the best retarder.

Above all, W/C, rapid setting and early strength cement and retarder were the factor influence the performance of setting liquid. Ultimately, the best composition was determined by multi factor orthogonal experiment, which was W/C=2:1, retarder was tartaric acid whose dosage was 0.2%, rapid setting and early strength cement was Na_2SiO_3 whose dosage was 3%, bentonite dosage was 12%.

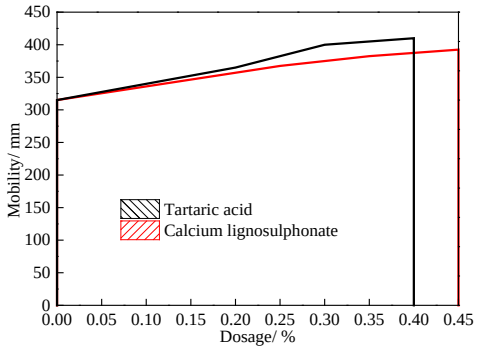

Figure 5: Effects of retarder on mobility of high water material

4. COAL REINFORCEMENT EXPERIMENT

In order to study the effects of grouting setting liquid, grouting process was simulated in the lab, the experiment model as Figure 6. Firstly, particle size of coal particles was selected, which were more than 2mm and less than 5mm, secondly, grouting new setting liquid on the coal. The grouting effect were showed in Figure 7.

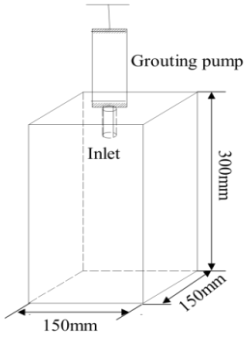

Figure 6: Grouting simulation experiment model

From the simulation experiment can be drawn that, dispersed particles were bonded together effectively by new setting liquid, and the strength was great. The grouting radius was 250mm when grouting pressure was 60KPa, which indicated that the new setting liquid had good adhesion and permeability.

Testing the strength of solidified body, rupture strength and compressive strength were showed as Figure 8. From Figure 8 we can see that the 1d, 7d, 14d strength of new setting liquid all have increased, 7d rupture strength and compressive strength were

5.2MPa and 6.4MPa respectively, and were respectively 37% and 88% higher than ordinary high water material.

Figure 7: Grouting effect picture

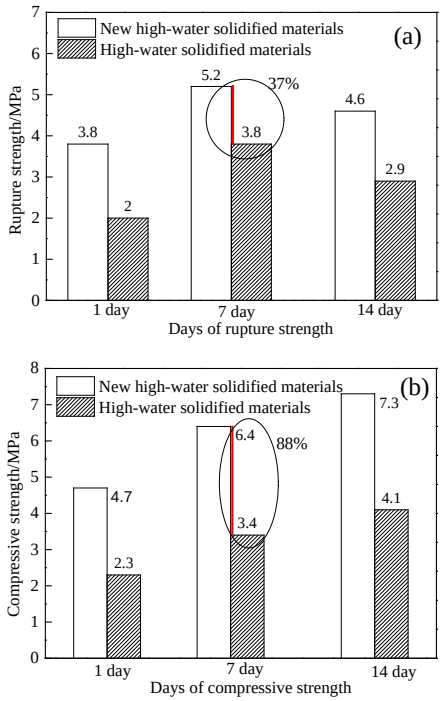

Figure8: Strength of coal dealing with new setting liquid
(a) Rupture strength; (b) Compressive strength

5. CONCLUSIONS

(1) As W/C of high water materials increased, setting time increased, viscosity declined and strength declined too. When W/C=0.5, 14d compressive strength was 17.51MPa, rupture strength was 6.06MPa, nevertheless, 14d compressive strength and rupture strength were less than 1MPa when W/C=3.0.

(2) While high water material mixed with different rapid setting and early strength cement, which has the most obviously changing effects was Na_2SiO_3. When setting liquid compound with Na_2SiO_3 of dosage of 3%, initial setting time can be shortened by 13min, 14d rupture strength and compressive strength were increased by 0.68MPa and1.04MPa.

(3) Setting time and mobility can be adjusted by retarder, as a retarder tartaric acid had significant influence on the setting liquid. The initial setting time of tartaric acid that dosage was 0.2% was equal to that calcium lignosulfonate that dosage was 0.35%, the initial setting time and final setting time were extended 83min and 108min. When the dosage of tartaric acid was 4%, the mobility of setting liquid was 410mm, which was increased by 31%.

(4) Finally, the best ratio was: W/C=2, tartaric acid with dosage of 0.2%, Na_2SiO_3 with dosage of 3%, bentonite with dosage of 12%.

(5) Reinforcement simulation experiment of the new setting liquid showed that, grouting radius was 250mm when grouting pressure was 60KPa, 7d rupture strength and compressive strength were 5.2MPa and 6.4MPa respectively. The new high-water solidified materials with high strength and high fluidity was effective for the reinforce coal and eliminate gas outburst.

6. ACKNOWLEDGEMENT

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