Effect of Crosslinker Concentration on the Comprehensive Properties of Polyacrylamide-aluminium Citrate/Water Glass Gel

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Abstract. In this paper, the authors discuss the polyacrylamide-aluminum citrate/water glass gel and set the gradient on the cross-linking agent aluminum citrate to study the cross-linking agent content of polyacrylamide-aluminium citrate/water glass gel. The influence of properties, viscosity, strength and resistance characteristics, found that the water retention rate, viscosity and strength resistance of polyacrylamide-aluminium citrate/water glass gel increased first with the increase of aluminum citrate. After the reduction. Among them, when the amount of the cross-linking agent aluminum citrate is 1.2 wt%, the polyacrylamide-aluminium citrate/water glass gel performs excellent in various aspects. The optimal ratio of polyacrylamide-aluminium citrate/water glass gel is finally confirmed, which provides theoretical support for its application in coal mines.

1. Introduction

Coal is one of the most important basic energy sources in the world, and many industries have a large demand for coal. However, the problem of coal spontaneous combustion has always been a stumbling block to the safe production of mines. Once this problem occurs, it will give rise to gas explosion which causes major personal injury and property damage, seriously threatening the safe production of mines and the safety of workers [1-3].

In recent years, gel-based materials have been widely used in coal mines because they are able to rapidly reduce coal body temperature, effectively trap wind, and retain water capacity, and it has achieved good results. The gel developed by Su Jian of Beijing University of Technology is a colloidal material formed by mixing liquid sodium silicate, coagulant NaHCO3 and aggregate bentonite, and polyacrylamide, starch, cellulose, etc. The material has low cost, good fluidity and controllable gelation time. The addition of polyacrylamide improves the poor water retention performance of the traditional inorganic silicone gel to some extent, and is easy to crack and powder after the late solid body loses water, but this effect does not last long under high temperature conditions [4]. Zhao Chunrui from Taiyuan University of Technology prepared a cellulose/aluminium citrate crosslinked gel. The material has good water retention, high temperature resistance and good toughness, but it cannot be accepted by
coal mines because of its high cost [5]. Ren Xiaofeng et al. used the advantages of these two gels to prepare a polyacrylamide-aluminium citrate/water glass gel and verified its excellent performance [6]. However, they did not further study the effect of the concentration of the cross-linking aluminium citrate on the performance of the gel.

Based on this, this study intends to set a concentration gradient by using the cross-linking agent aluminium citrate. The effect of crosslinker concentration on the water retention, strength and resistance characteristics of polyacrylamide-aluminium citrate/water glass gel was studied. The gel ratio of good comprehensive effect was screened out and the mechanism of fire prevention was clarified.

2. Experimental method

2.1. Preparation of polyacrylamide-aluminium citrate/water glass gel

Gel preparation: First, dissolve the polyacrylamide in distilled water and stir until the polyacrylamide is fully dissolved. Then take a certain amount of the cross-linking agent and mix it with the polyacrylamide solution. Then add a certain amount of sodium bicarbonate to the above solution, stir until the sodium bicarbonate powder is completely dissolved. Then slowly add fly ash to the solution and stir until the fly ash is evenly dispersed to obtain the A component. Finally, a certain amount of water glass (component B) is thoroughly mixed with the A component, and stirred until the fly ash particles are no longer settled, and allowed to stand until the system is gelatinized. All the above operations were carried out at room temperature, and the amounts of the components prepared in the gel were as shown in Table 1. The preparation process of cross-linking agent aluminum citrate can be found in the literature [5].

| Number | Polya-crylamide /wt% | Crosslinker (Aluminium citrate) | Sodium silicate /wt% | Sodium Bicarbonate /wt% | Fly Ash /wt% | Distilled water /wt% |
|--------|---------------------|-------------------------------|---------------------|-------------------------|--------------|---------------------|
| G-1    | 0.2                 | ———                           | 17                  | 2                       | 10           | 71                  |
| G-2    | 0.2                 | 0.4                            | 17                  | 2                       | 10           | 71                  |
| G-3    | 0.2                 | 0.8                            | 17                  | 2                       | 10           | 71                  |
| G-4    | 0.2                 | 1.2                            | 17                  | 2                       | 10           | 71                  |
| G-5    | 0.2                 | 1.6                            | 17                  | 2                       | 10           | 71                  |
| G-6    | 0.2                 | 2.0                            | 17                  | 2                       | 10           | 71                  |

2.2. Testing method

The measurement of the constant temperature and heat retention rate can be found in the literature [7]. Viscosity test: digital rotational viscometer (LVDV-2); gel consolidation strength test with the same literature [7]. Determination of the inhibition rate during temperature programming can be found in the literature [6].
3. Experimental results and analysis

3.1. Effect of crosslinker concentration on thermal and water retention of gel

![Figure 1](image1.png)

**Figure 1.** The water retention rate of the gel changes with the amount of crosslinker

Figure 1 shows that the water retention of polyacrylamide-aluminium citrate/water glass gel increases first and then decreases as the amount of aluminium citrate increases. This is because within a certain range, the increase of aluminium citrate dosage causes multiple linear molecules to crosslink into a denser network structure, water molecules are encapsulated therein, and it is not easy to be lost, so its water retention performance is better. When it exceeds a certain range, the amount of metal ions exceeds the number of carboxyl groups in the polymer, and the excess metal ions collide with each other to make the system difficult to store water, resulting in a decrease in the water retention rate of the polyacrylamide-aluminium citrate/water glass gel.

3.2. Effect of crosslinker concentration on gel viscosity and strength

![Figure 2](image2.png)

**Figure 2.** Effect of Crosslinker content on gel adhesion and strength
Figure 2 shows that the viscosity and strength of polyacrylamide-aluminium citrate/water glass gel increase first and then decrease as the amount of aluminium citrate increases. This is because the cross-linking reaction between polyacrylamide and aluminium citrate is a significant cage effect. Due to the large size of the polymer molecules, the diffusion rate is reduced. Therefore, when polyacrylamide undergoes a certain degree of hydrolysis, the possibility that the cross-linkable groups in polyacrylamide and Aluminium citrate molecules are located in the same "cage" mainly depends on the diffusion of Aluminium citrate molecules, i.e. the concentration of Aluminium citrate. The aluminium citrate content increases within a certain range, and the cross-linking between polyacrylamide and aluminium citrate is gradually enhanced. And the resulting crosslinked network has a dense structure, resulting in enhanced viscosity and strength of the polyacrylamide-aluminium citrate/water glass gel. When the amount of aluminium citrate increases beyond this range, as the amount of metal ions exceeds the number of carboxyl groups in the polymer, a gel sheet in the form of solid particles is formed instead of the entire gel, which directly results in polyacrylamide-aluminium citrate /Water glass gel viscosity and strength are significantly reduced.

3.3. Analysis of self-ignition resistance of coal based on temperature programmed

![Figure 3](image)

**Figure 3.** Coal self-ignition resistance effect (average inhibition rate of each gel during temperature programmed)

The gel material in Figure 3 has different degrees of inhibition on the oxidation of coal. This is because the gel can form a dense colloid structure on the coal surface, effectively inhibit the contact between coal and oxygen, and at the same time, the colloid contains a certain amount of moisture. When water evaporates, it can effectively reduce the coal temperature, thereby reducing the oxidation rate of coal. Figure 3 shows that the inhibition rate of polyacrylamide-aluminium citrate/water glass gel increases first and then decreases as the amount of aluminium citrate increases. This is because with the increase of the content of crosslinking agent aluminium citrate, the degree of crosslinking of the two kinds of gel structure is greater, the interpenetrating network structure formed is denser, the intermolecular interaction force is stronger, and the dense colloidal structure in the heating process can be effectively covered on the coal surface after being fully mixed with the coal, and has a good blocking effect. However, when the aluminium citrate content is too high, the excess aluminium citrate can not only be effectively utilized. When the gel loses too much water under high temperature conditions, aluminium citrate will become a catalyst for coal oxidation [8], causing its resistance to deterioration.
4. Conclusion
In this paper, we study the effect of crosslinker content on the water retention, viscosity, and strength and resistance characteristics of polyacrylamide-aluminum citrate/water glass gel. It is concluded that the water retention rate, viscosity and strength resistance of acrylamide-aluminum citrate/water glass gel increase first and then decrease with the increase of aluminum citrate. Among them, the optimum cross-linking agent aluminum citrate is 1.2 wt%, in which case the polyacrylamide-aluminum citrate/water glass gel has the best performance in all aspects. This provides theoretical support for its application in coal mines.

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