Study on the Effect of Cellulose Ether on the Performance of Concrete

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ABSTRACT: In this paper, the influence of HPMC, which serves as an admixture, on workability, air content, slump loss and compressive strength of concrete is studied in detail based on a blending method. The test results show that the workability of concrete with a 2% admixture containing 0.04% HPMC can meet the construction requirements under the same conditions. Besides, its air content is 2.1% and the compressive strength of it is the highest. However, when the content of HPMC exceeds 0.04% or more, the air content of concrete will be higher and the compressive strength of it will get lower.

1. Introduction

With the increasing development of national infrastructure, the need of concrete has been incredibly increasing. On the one hand, mixing plants always use some extreme proportions of concrete mix to control the production cost, which usually refers to the low glue material consumption, low cement content and low water usage, namely “the three-low mix ratio”. On the other hand, the deterioration of raw materials leads to the increase of uncontrollable factors in the process of concrete production. Therefore, concrete admixture manufacturers have been facing gradually fiercer and fiercer challenge of the advancement of technologies to satisfy the needs of customers.

In order to solve the problem of concrete workability, various thickeners, water-retaining agents and air-entraining agents have been widely used. Among them, hydroxypropyl methyl cellulose ether (HPMC) is a combination of an air-entraining agent and a thickener. As for the using of HPMC, it has obvious advantages and disadvantages. The advantages are that it can serve as both an air-entraining agent and a thickener, which can greatly improve the coagulant pumping performance. However, the disadvantages refer to the poor performance of water solubility, colloidal precipitation caused by relatively low temperature and uneven stirring, and the overdose leading to the poor performance and low concrete strength of concrete.

At present, it is found that the addition of cellulose ether can reduce the fluidity of concrete to some extent, but it can improve its uniformity and strength, to a greater or lesser degree [1]. Cellulose ether with different viscosity can increase the early concrete compressive strength at a lower content. It means cellulose ether with lower viscosity can enhance the later compressive strength of concrete while cellulose ether with higher viscosity will lower it [2]. Cellulose ether at a low content is beneficial to the decrease the viscosity of slurry while cellulose ether at a high content can improve the...
mechanical properties of cellular concrete \cite{3}. Appropriate amount of cellulose ether can greatly improve the working performance of full lightweight aggregate concrete, such as reduce floating and increasing strength \cite{4}. Compressive strength of the hardened cellular concrete sample with HPMC is significantly decreased, and its compressive strength in 28 days is almost the same as about 80% of that of the HPMC sample. \cite{5}

2. Raw Materials of the Tests

2.1. Raw Materials and Laboratory Equipment

Details of the raw materials used in the tests are shown in Table 1 below:

| Compound Raw Materials | Raw Materials             | Specifications | Manufacturers                                      |
|------------------------|---------------------------|----------------|---------------------------------------------------|
|                        | Water Reducer Mother Liquor (S08) | 50% solid       | KZJ New Materials Group Guizhou Co. Ltd.          |
|                        | Slump Retention Mother Liquor (S10G) | 50% solid       | KZJ New Materials Group Guizhou Co. Ltd.          |
|                        | HPMC (B19)                | Viscosity 40,000 | Guiyang Nanning Hongfeng Chemical Co., Ltd.       |
|                        | White Sugar (H1)          | Edible Grade    | Shanghai Yaoxin Sugar Co., Ltd.                   |
|                        | Sodium Gluconate (H2)     | Edible Grade    | Shandong Kaixiang Biotechnology Co., Ltd.         |
|                        | Defoamer (X1)             | Industrial Grade | Takamoto Grease (Suzhou) Co., Ltd.                |

| Concrete Performance Testing | Raw Materials         | Specifications | Manufacturers                                      |
|-----------------------------|-----------------------|----------------|---------------------------------------------------|
|                            | Cement (C)            | P.O 42.5       | Guizhou Longli Hongshi Cement Co., Ltd.           |
|                            | Powder Ash (F)        | Class II       | Guizhou Power Plant                                |
|                            | Machine-made Sand (S) | MB:1.0, MX:3.0 | Guizhou Lianjiangyuan Building Materials Co., Ltd. |
|                            | Crushed Stone (G)     | Particle Size: 5-31.5 mm | Guizhou Lianjiangyuan Building Materials Co., Ltd. |
|                            | Water (W)             | Tap Water       | Self-made                                         |

Details of the main instruments used in the tests are shown in Table 2:

| Experimental Apparatus                  | Model    | Main Technical Parameters                                      |
|----------------------------------------|----------|---------------------------------------------------------------|
| Forced Single Horizontal Shaft Mixer    | SJD-60   | Amount of Mixing: 60L                                         |
| Numerical Control Standard Curing Chamber | SHBY-40B | Temperature: 20 ±1°C, Humidity: ≥95%                          |
| Constant Loading Pressure Testing Machine | TSY-2000 | Maximum Load: 2000 KN                                        |
| Concrete Air Content Tester            | AHC-7L   | Volume: 7L, Measuring Range: 1%-10%                           |

2.2. Compounding of the Polycarboxylate Water Reducing Agent

In order to ensure the representativeness of the test data, the same polycarboxylate water reducing agent will be used in the test, and all the mother liquor is produced by KZJ New Materials Group Guizhou Co. Ltd. The compound formula of the mother liquor is shown in Table 3:

| Compound Raw Materials | Raw Materials             | Specifications | Manufacturers                                      |
|------------------------|---------------------------|----------------|---------------------------------------------------|
|                        | Water Reducer Mother Liquor (S08) | 50% solid       | KZJ New Materials Group Guizhou Co. Ltd.          |
|                        | Slump Retention Mother Liquor (S10G) | 50% solid       | KZJ New Materials Group Guizhou Co. Ltd.          |
|                        | HPMC (B19)                | Viscosity 40,000 | Guiyang Nanning Hongfeng Chemical Co., Ltd.       |
|                        | White Sugar (H1)          | Edible Grade    | Shanghai Yaoxin Sugar Co., Ltd.                   |
|                        | Sodium Gluconate (H2)     | Edible Grade    | Shandong Kaixiang Biotechnology Co., Ltd.         |
|                        | Defoamer (X1)             | Industrial Grade | Takamoto Grease (Suzhou) Co., Ltd.                |

| Concrete Performance Testing | Raw Materials         | Specifications | Manufacturers                                      |
|-----------------------------|-----------------------|----------------|---------------------------------------------------|
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|                            | Powder Ash (F)        | Class II       | Guizhou Power Plant                                |
|                            | Machine-made Sand (S) | MB:1.0, MX:3.0 | Guizhou Lianjiangyuan Building Materials Co., Ltd. |
|                            | Crushed Stone (G)     | Particle Size: 5-31.5 mm | Guizhou Lianjiangyuan Building Materials Co., Ltd. |
|                            | Water (W)             | Tap Water       | Self-made                                         |

| Experimental Apparatus                  | Model    | Main Technical Parameters                                      |
|----------------------------------------|----------|---------------------------------------------------------------|
| Forced Single Horizontal Shaft Mixer    | SJD-60   | Amount of Mixing: 60L                                         |
| Numerical Control Standard Curing Chamber | SHBY-40B | Temperature: 20 ±1°C, Humidity: ≥95%                          |
| Constant Loading Pressure Testing Machine | TSY-2000 | Maximum Load: 2000 KN                                        |
| Concrete Air Content Tester            | AHC-7L   | Volume: 7L, Measuring Range: 1%-10%                           |
2.3. Test Methods of Concrete

The methods of the measurement of concrete properties will be conducted based on GB/T 50080—2016 “Test Methods for Performance of Ordinary Concrete Mixtures” and GB/T 50081—2016 “Test Methods for Mechanical Properties of Ordinary Concrete” while the measurement of concrete compressive strength will be carried out according to GB 50107-2010 “Evaluation Standard for Concrete Compressive Strength”. C30 concrete mix ratio will be used in the tests on concrete performance to measure the effect of different mixing amounts of B19 on the workability, slump loss, air content and compressive strength of concrete. The detailed mix ratio can be shown as Table 4:

|   | C   | F   | S   | G   | W   |
|---|-----|-----|-----|-----|-----|
|   | 260 | 80  | 1040| 850 | 170 |

3. Test Results and Analysis

3.1. Study on the Water Solubility of Carboxymethyl Cellulose Ether

In order to systematically study the water solubility of B19, the above-mentioned B19 at different mixing amounts is added into polycarboxylate water reducing agents to test the solubility, and the mixing amounts will be 0.1% ~ 0.5%. The specific data are shown as Table 5:

| Mixing Amount | 0.1% | 0.2% | 0.3% | 0.4% | 0.5% |
|---------------|------|------|------|------|------|
| Solubility    | Dissolves rapidly | Dissolves | Small is insoluble | Partial insolubility | Amount is insoluble |

According to the test data in Table 5 above, the solubility of B19 decreases with the increase of its mixing amount. When its mixing amount is less than 0.1%, it can dissolve rapidly, which can help save quite a lot compounding and mixing time and improve the production efficiency. When its mixing amount is more than 0.3%, it will be hard for B19 to dissolve. Moreover, when the mixing amount of B19 is increasing, part of it won’t dissolve, which will cause precipitation, pipeline blockage and other problems in actual projects. It shows the mixing amount of B19 can’t exceed 0.1% in actual projects.

3.2. Measurement of Concrete Properties

(1) Tests on the Workability and Slump Loss of Concrete

Concrete workability is measured by the emptying time of concrete. B19 serves as an additive and its mixing amount is from 0% to 0.3%. The initial slump loss (T0), expansion (K0), slump loss after one hour (T1) and expansion (K1) will be compared respectively. The detailed data will be shown as Table 6:

| Concrete Number | A(%) | B19(%) | T0(mm) | T0(mm) | Emptying time(s) | T1(mm) | T1(mm) |
|-----------------|------|--------|--------|--------|------------------|--------|--------|
| C0              | 2.0  | 0      | 200    | 560    | 7.56             | 210    | 480    |
| C1              | 2.0  | 0.02   | 220    | 570    | 5.32             | 210    | 490    |
| C2              | 2.0  | 0.04   | 230    | 580    | 2.35             | 210    | 510    |
| C3              | 2.0  | 0.06   | 230    | 580    | 2.76             | 210    | 510    |
| C4              | 2.0  | 0.08   | 230    | 570    | 2.86             | 210    | 490    |
| C4              | 2.0  | 0.1    | 230    | 550    | 3.05             | 200    | 480    |
| C6              | 2.0  | 0.2    | 220    | 540    | 3.17             | 200    | 460    |
| C7              | 2.0  | 0.3    | 220    | 520    | 3.25             | 200    | 450    |

According to Table 6, when adding the same amount of the additive, the workability of concrete without B19 is poor and its emptying time is the longest, up to 7.56s. With the increasing amount of...
B19, the emptying time of concrete will be shortened. When the amount of B19 is up to 0.04%, the emptying time of concrete is the shortest. When the amount of B19 exceeds 0.04%, the emptying time won’t be shortened anymore and is basically the same. When the amount of B19 is 0.04%, concrete expansion can reach its maximum, 580mm. When the amount of B19 exceeds 0.08%, the initial concrete expansion will gradually decrease. It means when the mixing amount of B19 exceeds 0.08%, the addition of B19 will introduce plenty of air bubbles into concrete, which will cause the increase of the consistency of concrete slurry and turn the free water in concrete into small air bubbles, leading to the decrease of concrete expansion.

After 1-h loss, the expansion of concrete increases from 480mm to 510mm when the mixing amount of B19 is from 0% to 0.06%, which shows that the better the workability of concrete is, the better performance of slump retention of polycarboxylate water reducing agent will be. When the mixing amount of B19 exceeds 0.08%, concrete expansion will gradually decrease, which is consistent with the initial law of change.

The test results show that proper mixing amount of B19 can improve the workability of concrete. When the mixing amount of B19 is from 0.04% to 0.08%, the workability of concrete is good and it won’t affect the expansion of concrete. When its amount is less than 0.04%, the workability of concrete is poor and it can’t meet the requirements of construction projects; When its amount is more than 0.04%, the concrete expansion will gradually decrease, and polycarboxylate water reducing agent will show poor performance. Therefore, the most proper mixing amount of B19 should be decided by concrete strength.

(2) The Initial State of Concrete

Under the same condition that the mixing amount of the additive is 2%, the initial state of concrete is shown in Figure 1:

![Initial State of Concrete](image)

As can be seen from Fig. 1, different initial states of concrete with different mixing amount of B19 are shown from C0 to C7. Combined with the experimental data in Table 6, there are more exposed stones shown as C0 where there’s no B19 added, and the concrete workability is poor as well as the longest emptying time, 7.56s. When B19 is added, the workability of concrete is getting better and better, and there are less and less exposed stones. When the mixing amount of B19 reaches 0.04%, as is shown in C2, there are less exposed stones and the emptying time of concrete is the shortest, 2.35s. When the mixing amount of B19 exceeds 0.2%, as is shown as C6, there’s basically no exposed stone, and the concrete surface is covered with a layer of floating grout. When it’s used in real projects, the solid structure of concrete is prone to delamination after vibration, which will do harm to the quality of projects. Therefore, the best mixing amount of B19 should be determined by the compressive strength of concrete at later stage.

(3) Tests on the Air Content of Concrete

The air content of concrete with different mixing amount of B19 is measured by the national standard 7L concrete air content tester respectively. The detailed test data will be shown in Table 7 below:
Table 7 Data of Concrete Air Content

| Concrete Number | C0   | C1   | C2   | C3   | C4   | C5   | C6   | C7   |
|-----------------|------|------|------|------|------|------|------|------|
| B19 (%)         | 0    | 0.02 | 0.04 | 0.06 | 0.08 | 0.1  | 0.2  | 0.3  |
| Air Content (%) | 1.2  | 1.6  | 2.1  | 2.8  | 3.5  | 4.8  | 5.9  | 7.1  |

According to the above Table 7, without B19, the air content brought by polycarboxylate water reducing agent is 1.2%. When the mixing amount of B19 is from 0.04% to 0.08%, the air content of concrete varies from 2% to 4%. When the mixing amount of B19 is increasing, the air content of concrete is too high, which will affect the compressive strength of concrete. Therefore, the best mixing amount of B19 should be determined by the compressive strength of concrete.

4. Tests on Concrete Strength

The compressive strength of concrete is tested in the numerical control standard concrete curing chamber where the temperature is 20±2°C and humidity is 95% or above in three days, seven days and twenty-eight days. The forming test model is 150×150×150mm. The detailed experimental data will be shown as follows:

![Fig. 2 Compressive Strength Tested in Standard Curing Chamber](image)

As can be seen from Fig. 2, for 3-day compressive strength, the intensity of pressure of C0 is 25.2 MPa. When the mixing amount of B19 is from 0 to 0.04%, 3-day compressive strength of concrete will gradually increase. When the mixing amount of B19 is 0.04%, the compressive strength of concrete in C2 reaches the maximum, 28.4MPa. With the increasing mixing amount of B19, 3-day compressive strength of concrete will gradually decrease. When the mixing amount of B19 is 0.3%, the compressive strength of concrete in C7 reaches the minimum, merely 20.9MPa, which is 4.3MPa less than that of concrete in C0. As for 7-day compressive strength, the intensity of pressure of C0 is 33.2MPa. And its growth trend is the same as that of 3-day compressive strength, when the mixing amount of B19 is from 0 to 0.04%. And the compressive strength of concrete in C2 reaches the maximum, 35.6MPa, when the mixing amount of B19 is 0.04%. When the mixing amount of B19 is 0.3%, the compressive strength of concrete in C7 reaches the minimum, merely 25.7MPa, which is 130% of the design compressive strength. As for 28-day compressive strength, the intensity of pressure of C0 is 36.1MPa, which is 120% of the design compressive strength. And when the mixing amount of B19 is 0.04%, the compressive strength of concrete in C2 reaches the maximum, 39.1MPa, which is 130% of the design compressive strength. When the mixing amount of B19 is from 0.06% to 0.3%, the compressive strength will gradually decrease. And when the mixing amount of B19 is 0.3%, the compressive strength of concrete in C7 reaches the minimum, merely 29.7MPa, which is 99% of the design compressive strength.

The test results show that the 3-day, 7-day, and 28-day compressive strength of concrete will
increase in the beginning and then decrease later when adding polycarboxylate water reducing agent with the increasing mixing amount of B19. And when the mixing amount of B19 is 0.04%, the compressive strength reaches the maximum. Among them, 28-day compressive strength of concrete can reach 130% of the design compressive strength and is 3MPa higher than the blank sample. It means the proper mixing amount of B19 can enhance concrete workability and compressive strength in days. When the mixing amount of B19 exceeds the optimum value, the compressive strength will decrease. When the mixing amount is 0.3%, its value will be merely 29.7MPa. Combined with the tests on water solubility, workability and air content tests, it’s known that the larger mixing amount of B19 is, the lower the solubility will be. Therefore, it will need more energy to make it dissolve in the production process. Meanwhile, the higher the air content is, the lower the compressive strength of concrete will be, leading to the quality problems during the production.

4. Conclusion
(1) In this paper, the application of HPMC as a thickener in the polycarboxylate water reducing agent is studied in detail. The solubility test results show that when the mixture of HPMC is not more than 0.1%, it can be dissolved rapidly and the mixing process can be shortened. And its solubility decreases gradually with the increase of the mixing amount. When the amount of it exceeds 0.3%, part of it can’t dissolve.

(2) The concrete tests show that the proper mixing amount of HPMC can improve the workability of concrete. When its mixing amount varies from 0.04% to 0.08%, the workability of concrete is basically the same, but the air content increases gradually. With the increasing mixing amount of HPMC, the water-reducing rate of the polycarboxylate water reducing agent will decrease, which will affect the workability of concrete.

(3) Within a certain range of mixing amount, HPMC can increase the 3-day, 7-day, and 28-day compressive strength of concrete. When the mixing amount of HPMC is less than 0.06%, it shows no side effect on the compressive strength of concrete. Besides, when the mixing amount is 0.04%, the compressive strength of concrete reaches 130% of the design strength. When the mixing amount is more than 0.06%, the more the mixing amount is, the more the compressive strength of concrete will decrease.

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