Study on the Influence of HPMC on Rheological Parameters of Cement Paste and Properties of Concrete

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Abstract. The effects of hydroxypropyl methyl cellulose ether (HPMC) with different viscosities on rheological parameters of cement paste and properties of concrete mixed with polycarboxylic superplasticizer (PCE) were studied. The results show that the addition of HPMC with different viscosities can increase the plastic viscosity of the cement paste. High-viscosity HPMC can obtain higher plastic viscosity at a lower dosage, and lower-viscosity HPMC requires a higher dosage to achieve higher plastic viscosity. The mixing of HPMC with different viscosities into concrete can effectively reduce the bleeding rate of concrete, the 3d compressive strength is slightly reduced, and the 28d compressive strength is slightly increased.

1. Introduction
With the scarcity of natural sand and gravel resources, as substitutes, machine-made gravel, recycled aggregates and other types of gravel of varying quality have appeared on the market. The use of these materials usually leads to poor workability of concrete, such as segregation, bleeding and other phenomena. In order to solve these problems, it is generally achieved by adjusting the admixtures mixed into the concrete, such as replacing the less sensitive admixtures, or adding thickening and water-retaining agents [1]. However, there are few admixtures on the market that can significantly improve the bleeding performance of concrete, and the solution is mainly through the addition of thickening and water-retaining agents. The most widely used thickeners in China are cellulose ether and polyacrylic acid thickeners [2]. A small amount of cellulose ether can achieve obvious viscosity increasing effect, especially hydroxypropyl methyl cellulose ether, which has better solubility and thickening water retention than other cellulose ethers, thus obtaining a large amount of usage of. Under normal circumstances, the greater the viscosity of HPMC, the greater the corresponding molecular weight. Therefore, the research of HPMC with different viscosities on the rheological properties of cement and concrete performance is of great significance to guide its practical application.

In this paper, the effects of HPMC with different viscosities on rheological parameters of cement paste and properties of concrete mixed with polycarboxylic superplasticizer (PCE) were studied.

2. Test materials and test methods

2.1. Experimental raw materials
2.1.1. admixture. Admixtures include the following two types:

- HPMC: The specific conditions of HPMC with different viscosities in 5 are shown in Tab 1.

| Code | Solid content/% | Rotor | Speed | Viscosity /mPa*s⁻¹ |
|------|-----------------|-------|-------|-------------------|
| H1   | 1               | 2#    | 5     | 36                |
| H2   | 827.8           |       |       | 1686              |
| H3   | 1686            |       |       | 2022              |
| H4   | 2022            |       |       | 4433              |
| H5   | 4433            |       |       |                   |

- PCE: The details of PCE are shown in Tab 2.

| Code | pH | Solid content/% | State. | source |
|------|----|-----------------|--------|--------|
| PCE  | 6.4| 50              | Colorless transparent liquid. | KZJ New Materials Group Co., Ltd. |

2.1.2. Raw materials for performance testing. Raw materials for performance testing are shown as follows:

- Cement (C): The physical performance of cement is shown in Tab 3.

| Varieties. | Specific surface area / (g/cm³) | Standard consistency water consumption/% | Setting time/min | Flexural strength/MPa | Compressive strength/MPa |
|------------|---------------------------------|----------------------------------------|------------------|-----------------------|--------------------------|
| Reference cement P.I 42.5 | 340 | 25.4 | 193 | 249 | 5.2 | / | 25.2 | / |
| Hongshi P.O 42.5 | 336 | 27.4 | 210 | 300 | 6.4 | 9.1 | 27 | 47.4 |

- Sand (S): Natural sand, fineness modulus is 2.7, mud content is 0.8%.
- Stone(G): Crushed stone G1 with a nominal diameter of 5mm-20 mm, and G2 gravel with a nominal diameter of 16mm-31.5 mm.
- Water.(W): Tap water.

2.2. Viscosity test
Brookfield rotary viscometer was used to test the viscosity of cement paste. The cement paste mixed with PCE is regarded as the reference paste, and different amounts of thickener are added on the basis of the reference paste, and the cement paste obtained is the tested paste. The fluidity of reference paste shall be tested according to GB / T 8077-2012 “Test method for homogeneity of concrete admixtures”. The mixing of paste is shown in Table 4.

| Project | Cement/g | Water/g | PCE/g | HPMC/% |
|---------|----------|---------|-------|--------|
| Reference paste | 500±2 | 145±1 | Adjust according to liquidity | 0 |
The cement paste mixed with PCE has obvious Bingham fluid characteristics, and its rheological properties can be characterized by the rheological equation composed of yield stress and plastic viscosity [3].

\[ \tau = \tau_0 + \eta \gamma \]  \hspace{1cm} (1)

Where \( \tau \) is Bingham fluid shear rate (Pa), \( \tau_0 \) is Yield stress (Pa), \( \eta \) is Plastic viscosity (Pa\cdot s), \( \gamma \) is Bingham fluid shear rate (s\(^{-1}\)). Rotational viscometer gives the shear stress and shear rate. Through linear regression fitting the shear stress and shear rate, the plastic viscosity of the cement paste system can be obtained.

2.3. Concrete test

The concrete mix ratio (kg/m\(^3\)) is m(C): m(S): m(G1): m(G2): m(water) = 360:790:630: 420:177. The compressive strength shall be tested in accordance with GB / T 50081-2016 “Test methods of mechanical properties of ordinary concrete”, slump, expansion and bleeding rate shall be tested in accordance with GB / T 50080-2016 “Test methods for performance of ordinary concrete mixtures”.

3. Results and discussion

3.1. Effect of HPMC on rheological properties of cement paste

HPMC with different viscosity were prepared into 1 wt.% solution. PCE is used as the reference paste additive. The fluidity of reference paste is 240 mm ~ 260 mm by adjusting the amount of PCE, that is to say, the amount of PCE is determined, and then HPMC with different viscosity is added. The rheological properties of cement paste were tested when the contents of H1, H2, H3, H4 and H5 were 0wt.%, 5wt.%, 10wt.%, 15wt.%, 20wt.%, 25wt.%, 30wt.% respectively. Taking shear stress as ordinate and shear rate as abscissa, linear regression analysis was carried out, and the slope was plastic viscosity. The plastic viscosity ratio is calculated according to formula (2), and the calculation result is accurate to 0.01.

\[ \eta = \frac{\eta_2}{\eta_1} \times 100\% \]  \hspace{1cm} (2)

Where \( \eta \) is plastic viscosity ratio of tested paste, \( \eta_1 \) is plastic viscosity of reference paste (MPa\cdot s), \( \eta_2 \) is plastic viscosity of tested paste (MPa\cdot s).

The results show that the cement paste conforms to Bingham fluid equation, and the correlation coefficient \( R^2 \) is between 0.9709 and 0.99. The plastic viscosity ratios of H1, H2, H3, H4 and H5 cement pastes with different contents are shown in Tab 5 and Fig 1.
Fig 1. Plastic viscosity ratio of HPMC cement paste with different viscosity

It can be seen from Tab 5 and Fig 1, the addition of HPMC with different viscosities can increase the plastic viscosity ratio of the cement paste. Therefore, HPMC with different viscosity can increase the viscosity of cement paste. Among them, when the dosage of H1 reaches 15wt.%, the viscosity can be increased, and with the increase of H1 dosage, the effect of viscosity increase is not obvious. When the dosage of H2, H3 and H4 reaches 10wt.%, the viscosity increases, with the increase of the dosage, the viscosity increasing effect is improved. When the dosage of H5 is 5wt.%, the viscosity increases, and with the increase of the dosage, the viscosity increasing effect is improved.

The experimental results show that the higher the molecular weight of HPMC is, the greater the plastic viscosity ratio of the paste is, which means that the viscosity of cement paste is more obvious. This may be due to the fact that the structure of HPMC contains hydroxyl and ether bonds. The higher the molecular weight, the more concentrated the distribution of these hydroxyl and ether bonds. Oxygen atoms on these groups combine with water molecules to form hydrogen bonds, which makes free water molecules become Combined water. The higher the molecular weight of HPMC is, the more obvious the effect is. when the dosage of HPMC increases to 20wt.%, the viscosity increasing effect is equivalent, which may be because there are enough hydroxyl groups and ether bonds in the cement paste to make the free water molecules become bound water.

3.2. Effect of HPMC on concrete properties
Adjust the content of PCE to make the expansion of reference concrete be (540 ± 10) mm. When the dosage of H1, H2, H3, H4, H5 is 15 wt.% of PCE, the influence of HPMC on the dispersion, bleeding rate, air content and compressive strength of concrete is investigated. Among them, the reference concrete is the concrete with PCE alone, and the test results are shown in Tab 6.

| Code | Slump/mm | Expansion/mm | bleeding rate/% | air content/% | Compressive strength ratio |
|------|----------|--------------|----------------|--------------|---------------------------|
|      |          |              |                |              | 3d  | 7d  | 28d  |
| Reference | 195  | 535          | 1              | 1.7          | 1.00 | 1.00 | 1.00 |
| H1    | 200      | 530          | 59.77          | 1.9          | 0.99 | 1.00 | 1.03 |
| H2    | 205      | 525          | 32.11          | 2.1          | 0.98 | 0.99 | 1.02 |
| H3    | 200      | 520          | 26.59          | 2.2          | 0.98 | 0.99 | 1.03 |
| H4    | 195      | 510          | 13.17          | 2.4          | 0.97 | 0.98 | 1.02 |
| H5    | 200      | 500          | 0              | 2.6          | 0.95 | 0.97 | 1.02 |

The results show that with the increase of HPMC viscosity, the expansion degree of concrete decreases. With the increase of HPMC viscosity, the bleeding ratio decreases gradually, and the water
locking effect of concrete becomes better with the increase of HPMC viscosity. With the increase of HPMC viscosity, the air content of concrete gradually increases. With the increase of HPMC viscosity, the compressive strength ratio decreases, the 3d and 7d early strength of concrete is lower than that of the reference, and the 28d strength is close to the reference, which indicates that HPMC has great influence on the early strength of concrete. The study of M [4] shows that cellulose ether not only has the effect of increasing viscosity, but also has the effect of air entraining and retarding setting when the content is large, which leads to the low early strength of concrete. The research by Ou Zhihua [5] et al. Shows that cellulose ether has strong surface activity and is easy to form bubbles, and it will be directionally adsorbed to the bubble liquid interface to stabilize bubbles. Moreover, its ability to stabilize bubbles will increase with the increase of molecular chain of cellulose ether, and the increase of air content will affect the strength of concrete.

4. Conclusion
Through the study of this paper, the following conclusions are obtained.

- HPMC with different viscosity can increase the viscosity of cement paste, and the plastic viscosity ratio of cement paste system increases with the increase of the content of HPMC. When the dosage of HPMC is small, the higher the viscosity of HPMC is, the more obvious the effect of increasing the viscosity of cement paste is. with the increase of HPMC content to 20wt.%, the viscosity increasing effect is equivalent.

- When the dosage of HPMC is 15wt.% of PCE, with the increase of HPMC viscosity, the expansion degree of concrete decreases, the bleeding ratio decreases, the air content increases, and the compressive strength ratio decreases. The 3d and 7d early strength of HPMC concrete is lower than the reference, and the 28d strength is close to the reference.

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