Original Article

Influence of new hydrophobic agent on the mechanical properties of modified cemented paste backfill

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A R T I C L E  I N F O

Article history:
Received 7 August 2019
Accepted 14 September 2019
Available online 4 October 2019

Keywords:
Cemented paste backfill (CPB)
Cement paste
Hydrophobic agent
Dewatering
Rheological property
Properties of hardened CPB

A B S T R A C T

Cement-based materials is indispensable in the construction process, and the characteristics of cement mortar affect the quality and efficiency of construction obviously. Roof-contacted filling and dehydration in stope are two critical problems in mines in the process of mine filling, which has a very important influence on the strength of filling body. In order to enhance the work performance of cement paste backfill (CPB) and improve the work efficiency in field engineering, the mixed hydrophobic agent was mixed in the CPB slurry to improve the dewatering efficiency. The dewatering test device was designed by authors to test the dewatering efficiency of the CPB mixing different dosage of the hydrophobic agent. The rheological properties of the cement paste mixing with the hydrophobic agent were tested by the rheometer R/S plus to achieve the workability of the CPB. To analyze the influence mechanism of the hydrophobic agent on the dewatering efficiency of CPB, the density, shrinkage, water vapour permeability and capillary water absorption of the CPB specimens were measured. Considering the effect of the hydrophobic agent on the compressive strength of the hardened CPB, it can be concluded that the reasonable addition dosage of hydrophobic agent in CPB is 1% by weight.

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1. Introduction

Portland cement is widely used in construction engineering, mine backfill engineering and engineering, marine concrete engineering and other large-scale projects. The main filling material used in the process of mine backfill is cemented mortar. The dewatering and consolidation efficiency of the CPB needs to be further improved in order to carry on the next mining work. Influenced by the seepage and other factors, the ambient humidity of underground mine is higher. The increase of mining depth leads to high ambient temperature, which will affect the dewatering and consolidation efficiency of CPB backfill. In order to improve the dewatering and consolidation efficiency of CPB, the admixture such as hydrophobic agent or water repellent can be mixed into CPB.

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https://doi.org/10.1016/j.jmrt.2019.09.039
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Many studies have involved the use of hydrophobic agents as admixtures to concrete and cement, and have been widely used in various engineering fields. In order to prevent chloride penetration of marine concrete structures, reduce corrosion of concrete [1] and steel bars [2], improve concrete resistance to chlorine and freeze-thaw resistance [3], hydrophobic agent was mixed in the concrete or concrete surface coated with hydrophobic agent [4,5]. In this study, the hydrophobic agent was applied on the concrete surface to reduce the influence of seawater on concrete. The effect of hydrophobic agent treatment on concrete can be divided into two aspects: surface effect and depth effect. The three important factors for the effective penetration depth of hydrophobic agent in concrete are time, porosity and saturation [6]. Water diffusion coefficient of hydrophobic treated concrete is close to constant. Capillary suction plays an important role in water transport under high humidity [7]. The effect of hydrophobic agent on the capillary porosity of concrete is larger than that of the cementitious porosity, which makes the concrete affected greatly by the hydrophobic agent under high humidity conditions. The feasibility of the application of hydrophobic agent in concrete was obtained by testing the strength characteristics of concrete such as bending strength, compressive strength and moisture absorption rate [8,9]. Hydrophobic agent has been used in concrete and CPB for decades. The addition of hydrophobic agents in crack concrete has a significant effect on the corrosion resistance of reinforcement, especially in the case of high water-cement ratio [10]. After the field core drilling investigation, the effect of hydrophobic agent on the prevention of chloride permeation is obtained based on the long-term data sequence [11,12], and the durability of concrete is improved [13]. The hydrophobic agent in the fresh mortar has a certain effect on the dehydration rate and consolidation time of the mortar system [14,15], and also affects the performance of fresh and hardened mortar and hydration of cementitious material. The hydrophobic agent and water content have a certain influence on the thermal conductivity of CPB, and have a certain influence on the physical properties such as water vapor permeability and capillary rise [16,17]. The rheological experiment of cement paste shows the effect of three additives such as hydrophobic agent on the rheological properties of cement paste and concrete [18]. The application of the hydrophobic agent in the concrete was obtained by experimental study of different types of hydrophobic agent on the penetration depth and capillary water absorption [19]. The compressive strength of CPB is related with its permeability and water absorption [20–22]. The addition dosage of hydrophobic agent in the fresh concrete has a certain influence on the early completion of concrete engineering, the solidification of concrete and the strength after curing 28 days of the site construction. There are two main types of hydrophobic agents used to modify concrete or cement properties. One is silicone [23], the other is wax and its polymers [24,25]. The hydrophobic agents commonly used to modify the properties of concrete or cement are emulsified with paraffin wax, waxes, silicone oils and fatty acids and their condensates [13,26,27].

Previous studies showed that hydrophobic agents have been used in CPB and concrete since the last century, but the methods and purposes of use were different. In the process of experiment, the related properties of CPB can be tested and analyzed in order to obtain the performance and reasonable dosage of the hydrophobic agent.

Based on previous research experience, adding the hydrophobic agent to the CPB, the dewatering efficiency of the CPB obtained through experiments to determine the best dewatering effect of CPB corresponding to the hydrophobic agent dosage. To analyze the working mechanism of the hydrophobic agent in CPB, the density, shrinkage, water vapor permeability and capillary water absorption of the hardened CPB were obtained. The compressive strength of hardened CPB was also tested. In order to analyze the fluidity of the cement backfilling tailings mixing with the hydrophobic agent, the effect of hydrophobic agent on the Rheological property of CPB slurry was obtained. The reasonable dosage of hydrophobic agent was obtained by test analysis, which provided guidance for the preparation of cement backfilling tailings in engineering site.

2. Experimental program

2.1. Raw materials

2.1.1. Tailings

CPB preparation at Sanshandao gold mine is mainly used by classified tailings and Portland cement. Grain size parameters and specific surface areas of classified tailings in Samshandao gold mine [28] is shown in Table 1. Particle size distribution curve of classified tailings is shown in Fig. 1.

2.1.2. Cement and water

The cement used in the experiment was 425 cement. The 425 cement is the 32.5 grade cement of ISO international standard, which refers to cement with a 28-day compressive strength of 32.5 MPa.

Ordinary tap water was chosen for preparation of the CPB backfill slurry in this study.

2.1.3. Hydrophobic agent

Water-based hydrophobic agent has hydrophobic and other characteristics (waterproof, self-cleaning, pollution resistance and so on). The mixture of the compound dispersed in water or added in the CPB, can show its hydrophobic properties. The mechanism of the hydrophobicity, water repellency and other properties of the hydrophobic agent is mainly that in the slurry of the CPB, the non-polar groups of the hydrophobic agent components are close to each other and gradually combined together. In the aqueous medium, the nonpolar groups in the hydrophobic agent have obvious mutual attraction. The hydrophobic effect of the hydrophobic agent is not the mutual repulsion between the nonpolar groups and the water. This nonpolar group exhibits a tendency to be combined with each other and be away from the aqueous medium in the water system. The mixed hydrophobic agent was used in this study, which is an aqueous emulsion. It is 1–6% of the total mass to improve the hydrophobicity of the Portland cement (Table 2).
<table>
<thead>
<tr>
<th>Sample</th>
<th>$d_{10}/\mu m$</th>
<th>$d_{50}/\mu m$</th>
<th>$d_{90}/\mu m$</th>
<th>$d_{ave}/\mu m$</th>
<th>Specific surface area/(m$^2$/cm$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classified tailings</td>
<td>11.95</td>
<td>79.68</td>
<td>165.37</td>
<td>81.85</td>
<td>0.306</td>
</tr>
</tbody>
</table>

Table 1 – Grain size parameters and specific surface areas of classified tailings.

![Particle size distribution curve of classified tailings.](image)

Table 2 – Compositions of Ordinary Portland cement (w%).

<table>
<thead>
<tr>
<th>Chemical composition</th>
<th>Typical compound composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO$_2$</td>
<td>C$_3$S</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>C$_2$S</td>
</tr>
<tr>
<td>Fe$_2$O$_3$</td>
<td>C$_4$AF</td>
</tr>
<tr>
<td>MgO</td>
<td>C$_3$A</td>
</tr>
<tr>
<td>CaO</td>
<td></td>
</tr>
<tr>
<td>SO$_3$</td>
<td></td>
</tr>
<tr>
<td>Na$_2$O</td>
<td></td>
</tr>
<tr>
<td>K$_2$O</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>24.5</td>
<td>51.2</td>
</tr>
<tr>
<td>7.6</td>
<td>20.1</td>
</tr>
<tr>
<td>1.9</td>
<td>8.0</td>
</tr>
<tr>
<td>3.6</td>
<td>7.4</td>
</tr>
</tbody>
</table>

Table 3 – Dewatering test scheme for CPB slurry with different dosage of the mixed hydrophobic agent with single layer filter paper.

<table>
<thead>
<tr>
<th>NO.</th>
<th>Water/g</th>
<th>Cement/g</th>
<th>Tailings/g</th>
<th>Total/g</th>
<th>wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>270</td>
<td>90</td>
<td>540</td>
<td>900</td>
<td>0</td>
</tr>
<tr>
<td>A2</td>
<td>270</td>
<td>90</td>
<td>540</td>
<td>900</td>
<td>0.5</td>
</tr>
<tr>
<td>A3</td>
<td>270</td>
<td>90</td>
<td>540</td>
<td>900</td>
<td>1</td>
</tr>
<tr>
<td>A4</td>
<td>270</td>
<td>90</td>
<td>540</td>
<td>900</td>
<td>2</td>
</tr>
<tr>
<td>A5</td>
<td>270</td>
<td>90</td>
<td>540</td>
<td>900</td>
<td>3</td>
</tr>
<tr>
<td>A6</td>
<td>270</td>
<td>90</td>
<td>540</td>
<td>900</td>
<td>4</td>
</tr>
<tr>
<td>A7</td>
<td>270</td>
<td>90</td>
<td>540</td>
<td>900</td>
<td>6</td>
</tr>
</tbody>
</table>

2.2. CPB specimens

2.2.1. Dewatering test scheme of CPB slurry

The dewatering test scheme of CPB slurry with mixed hydrophobic agent is shown in Table 3, the dosage was 0, 0.5%, 1%, 2%, 3%, 4%, 6% of the total mass, respectively. The slurry was mixed with ordinary tap water, the slurry concentration was 70% and the cement sand ratio was 1:6. The designed experiment included sample repetition.

Test scheme design of cement paste to study the influence of hydrophobic agent on the rheological properties of the filling slurry

In order to study the influence of hydrophobic agent on the rheological properties of the filling slurry, two groups of experiments were designed: cement paste mixed with hydrophobic agent addition dosage of 0, 0.5%, 1%, 2%, 3%, 4%, 6%, respectively, water cement ratio was 3:1; the other group cement paste mixed with the same with hydrophobic agent addition dosage, but the water cement ratio was 3:7.

2.2.2. Test scheme design of test blocks

The amount of hydrophobic agent added was 1%, 2%, 3% and 4% respectively as a result of the use of hydrophobic agent, the recommended amount of hydrophobic agent is 1–4%, the cement sand ratio was 1:6 and 1:10 respectively. However, for
the sake of prudence and comprehensiveness of the study, 0.5% and 6% hydrophobic agent were also selected to compared with the recommended dosage. The concentration of CPB was 70%. According to the experimental design of weighing different components corresponding to the quality, pour into 7.07 cm × 7.07 cm × 7.07 cm standard triple steel-mould after mixing with mixer. The compressive strength of CPB test block was tested after 3 d, 7 d and 14 d respectively.

2.3. Tests of specimens

2.3.1. Test method for yield stress and viscosity of the cement paste

The CPB is non-Newtonian, rheological properties of filling slurry is the shear stress of the filling slurry changed with the change of shear stress rate. The viscosity rheological curve in the slurry is called apparent viscosity.

The slurry test is used according to the test plan, the slurry mixing evenly using a rheometer determination of the rheological properties, the shear rate in the process of increasing with time, record every second of the shear rate, shear stress and apparent viscosity. The experimental results in the process, every ten seconds selects a corresponding data into rheological curve.

The slurry used in the test was prepared according to the test scheme. Its rheological properties were determined by the rheometer shown in Fig. 2. The shearing rate, shear stress and apparent viscosity were recorded during the increase of the shear rate over time. After the experiment, the data was selected every ten seconds to make the corresponding rheological curve.

The test equipment used as shown in Fig. 2, the rheometer produced by Brookfield Engineering Laboratories. The equipment type: RHEOMETER R/S plus was used to offer superior viscosity profiling, yield stress determination through controlled stress measurement.

Bingham fluid rheological equation (Bingham) for:

\[ r = \tau_0 + \eta \gamma \quad (1) \]

When \( \gamma < \tau_0 \), \( \gamma = 0 \), \( \eta = \infty \);

When \( \gamma \geq \tau_0 \), \( r = \tau_0 + \eta \left( \frac{\partial \gamma}{\partial t} \right) \)

Formula: \( r \)—Shear stress (Pa);
\( \tau_0 \)—Yield stress (Pa);
\( \eta \)—Apparent viscosity (Pa·s);
\( \gamma \)—Shear rate (s⁻¹).

Note: when the shear stress \( r \) is greater than the yield stress \( \tau_0 \), the slurry can flow, which has the properties of plastic liquid. When the shear stress \( r \) is less than the yield stress \( \tau_0 \), the slurry has no mobility.

The rheological properties of mine filling slurry are influenced by mixture degeneration mixing the mixture and mixture composition, its rheological property is Bingham fluid, the yield stress produced by adhesion and friction between particles in slurry, shear stress in slurry test is greater than \( \tau_0 \), and then the slurry began to flow. The apparent viscosity is caused by the internal structure of the slurry, which is the different characteristics of not conducive to slurry flow, and reacted the deformation rate of reaction slurry. When the shear stress is larger than the yield stress, the slurry begins to flow, and the apparent viscosity of the slurry represents the flow resistance of the slurry. The shear stress and apparent viscosity of the slurry rheological properties are mainly affected by the composition of the slurry and the characteristics of different particles in the slurry.

2.3.2. Density and shrinkage

Density and shrinkage are measured using a compressive strength CPB test block. The density of the CPB blocks is measured according to the national standard GB/T 17671-1999" [29]. The shrinkage of CPB is measured based on the national standard JC/T 603-2004 CPB dry shrinkage test method" [30]. The shrinkage rate St (%) of CPB at various ages is calculated according to the formula [51]:

\[ S_t = \frac{L_0 - L_t}{L} \quad (2) \]

Formula: \( S_t \) — Shrinkage rate at t age, %; 
\( L_0 \) — Initial measurement, mm; 
\( L_t \) — Measurement at t age, mm; 
\( L \) — Effective length of specimen, mm;

When the \( S_t \) is "+", it means contraction; and the \( S_t \) is "−", it means negative contraction, expansion.

2.4. Experimental apparatus

2.4.1. Design of dewatering test device

The test device shown in Fig. 3 was designed to test the dewatering efficiency of CPB slurry with mixed hydrophobic agent.

The dewatering efficiency test of CPB slurry with different dosage of mixed hydrophobic agent was carried out using the device. In the test process, recorded the data once every five minutes within 100 min, the final data was obtained after 12 h.

2.4.2. Water vapour permeability

It is well known that the water vapour permeability is vapour transport rate of the unit water per unit vapour pressure under certain conditions [32]. It represents transport ability and permeability of the material.

The water vapour permeability coefficient is determined with reference to international standard ISO12572 [33]. Fig. 4
has been kept running to ensure that the dryer internal air movement. The specimen and its sealed glass container were weighed once every 3 to 4 days and the thickness of the air layer was measured. After the end of the weighing process, remove the specimen out from the mouth of the glass container, broke quickly and measure the moisture content of the central part of the specimen by the drying method.

2.4.3. Capillary water absorption
The capillary water absorption of the CPB was measured according to the method of ISO 15148:2002 [34,35].

Fig. 5 was the water vapour permeability measurement apparatus. In the test, epoxy resin was used to seal the four sides of the test specimen but the upper and lower sides. After drying, they are soaked in water respectively, and the capillary water absorption of the test specimens were measured by comparing the weight before and after the process.

3. Results and discussion

3.1. Effect of hydrophobic agent on rheological properties and dewatering property of CPB slurry
In order to study the effect of the addition of hydrophobic agents on the rheological properties of the slurry, the rheological and plastic viscosities corresponding to the different shear rates of the filling slurry were determined by the content of different hydrophobic agents (0, 0.5%, 1%, 2%, 3%, 4%, 6%, respectively) and different cement sand ratios (1:6, 1:10).

It can be seen from Fig. 6 that the rheological curve of cement paste slurry with hydrophobic agent is similar to that of straight line, especially hydrophobic agent addition is smaller, which is more in line with the Bingham model. When
the hydrophobic agent addition was more than 4%, the stress of cement slurry at the initial stage was larger, the viscosity value was infinite. At this time, the slurry is viscous and the force fails to destroy the structure of the slurry. When the shear rate reaches 50/s, the maximum stress of failure of the inner body structure is reached, the network structure begins to become smaller aggregates, then the slurry flow is stable. When the addition amount of hydrophobic agent is less than 3%, the slurry has better fluidity at low speed and high speed of shear rate.

Fig. 7, the apparent viscosity curves of the filling slurry are shown as the amount of different hydrophobic agent added, from the Fig. 7 we can clearly see that the apparent viscosity of the filling slurry with different hydrophobicity is decreased with the increase of shear rate. There is a large difference in the apparent viscosity of the slurry with different hydrophobicity in the low stage. The slurry of different hydrophobic agent additions had different plastic viscosities at the same shear rate. The apparent viscosity of the slurry of different hydrophobic agent content at low speed is increasing in the overall trend. The apparent viscosity of slurry with different hydrophobic agent is similar in the high-speed stage of shear rate greater than 80/s.

The dewatering test results of CPB slurry with hydrophobic agent are shown in Fig. 8, each group of data was the mean of the three tests.

It can be concluded from Fig. 8 that the dewatering efficiency is related with the dosage of hydrophobic agent. Before 40 min, the dewatering content of CPB slurry without hydrophobic agent increased fast. But after 40 min, the dewatering efficiency of CPB slurry was higher with the mixed hydrophobic agent dosage 1% than that without hydrophobic agent. When the hydrophobic agent dosage in the slurry increased at more than 1%, the dewatering efficiency and
dewatering content were decreased obviously. Because it showed fluffy effect for CPB as the hydrophobic agent dosage increased.

After 90 min, the dewatering content of the slurry remained basically the same. The final dewatering content of the slurry with 1% hydrophobic agent reached to 70 ml, 5 ml more than that without the hydrophobic agent. But when the hydrophobic agent was more 1% of the total slurry mass, it increased water absorption and prolonged the dewatering time. Therefore, the dosage of hydrophobic agent should not larger than 1%, and it also accord with the requirements of controlling backfilling cost.

In order to analysis the effect mechanism of the hydrophobic agent on the CPB, the density, shrinkage, water vapour
permeability, capillary water absorption of the hardened CPB was also tested separately. The effect of hydrophobic agent on the compressive strength of the hardened CPB and the rheological properties of the cement paste were tested, considering about the backfilling slurry transport and the strength of the backfill body.

3.2. Effect of hydrophobic agent on properties of hardened CPB

The experimental results of density and shrinkage of CPB are shown in Fig. 9.

As shown in Fig. 9, the density of CPB decreases with the increase of the amount of hydrophobic agent, but this change is not significant. However, the density would change more obviously when the amount of hydrophobic additive is increased. As the hydrophobic agent has some air entraining effect, not only increased the new mortar gas content, but also leads to the porosity of hardened mortar increases, and the volume density of hardened mortar decreased eventually. Therefore, in order to reduce the influence of hydrophobic agent on the strength of CPB, the amount of hydrophobic agent should not more than 1%.

Due to the addition of different amount of hydrophobic agent, the shrinkage of CPB shows a tendency to increase and then decrease with the increase of the amount of hydrophobic agent, but this difference is very small. However, pores and capillary penetration would appear more in the CPB with the increase of the amount of hydrophobic agent. When the CPB micro-expansion, its performance can achieve anti-cracking effect. But the effect of the expansion of the CPB is very obvious as the amount of the hydrophobic agent was added, which has a certain adverse effect on the strength of CPB.

The shrinkage of the CPB with the hydrophobic agent is larger than that of the CPB without the hydrophobic agent. The difference of shrinkage between CPBs with the hydrophobic agent of 1% and without hydrophobic agent is the largest. Because the increase of the amount of hydrophobic agent will lead to an increase of water used in the mortar, and part of the increased water is absorbed and retained with storage. With the hydration reaction of cement, the humidity of the mortar system is decreasing, the absorbed water would release slowly and continue to provide water for the hydration of cement and the formation of ettringite. The other part of the additional water is directly involved in the hydration process of cement.

3.2.1. Water vapour permeability

It is well known that the water vapour permeability is vapour transport rate of the unit water per unit vapour pressure under certain conditions [32]. It represents transport ability and permeability of the material.

The permeability coefficient indicates the difficulty encountered by the water molecules when passing through the CPB, so the lower the coefficient, the higher the permeability. Water vapour permeability measurement (Fig. 10) indicated that the hydrophobic agent has a certain effect on the transpiration of water vapour permeability, improve the water and transport capacity of CPB. For CPB with more hydrophobic agent, the increase of water vapour permeability is more obvious. When compared these results with water absorption, we must observe that the water vapour molecules are much smaller than water, so some micro-pores are sufficient to allow water vapour to pass through.

3.2.2. Capillary water absorption

The capillary water absorption of the CPB was measured according to the method of ISO 15148:2002 [36,37].

The test results are shown in Fig. 10. With the decrease of cement sand ratio, the total porosity of CPB gradually increased, while the capillary porosity gradually reduced. The large pores have little effect on the capillary water absorption, and the continuity of the capillary pores were broken and the degree of bending of the capillary suction path is increased. With the increase of hydrophobic agent, the continuity of capillary pores was improved and the capillary porosity was increased obviously. Therefore, the more hydrophobic agent, the greater capillary porosity, the greater capillary action coefficient. The hydrophobic agent plays a certain role in improving the adhesion of CPB and improving the dewatering effect.

3.2.3. Effect analysis of hydrophobic agent on compressive strength of hardened CPB

The hardened CPB blocks are prepared mixing different hydrophobic agent dosages, and there are 12 groups of specimens: CPB with the cement sand ratio of 1:6 or 1:10, the curing time are 3 days, 7 days and 14 days, and different hydrophobic agent dosages of 0, 1%, 2%, 3%, 4%.

From Fig. 11, the compressive strength of CPB blocks with the cement sand ratio of 1:10 mixed with the hydrophobic agent dosage of 1% in mass, which is double compared with that without hydrophobic agent. But the compressive strength of CPB block did not increase with the hydrophobic agent dosage. When the hydrophobic agent dosage of the specimens is more than 2%, the compressive strength of specimens decreased to less than that of specimens without hydrophobic agent. So, the hydrophobic agent dosage in mass of the CPB should less than 2%.

Fig. 12 shows the various trend of the compressive strength of the CPB blocks mixed with different hydrophobic agent dosage in mass. The compressive strength of the specimens mixing with hydrophobic agent dosage of 1% in mass after curing 3 days was higher than that without hydrophobic agent, but the compressive strength decreased as the addition dosage of the hydrophobic agent of the specimens was more than 1% in mass. However, the compressive strength of the specimens mixed with hydrophobic agent dosage less than 2%, it was higher than that without hydrophobic agent, even though the compressive strength decreased with the hydrophobic agent dosage increased. Thus, the addition dosage of the hydrophobic agent in CPB should be less than 2% in mass.

Based on the analysis before, the addition dosage of the hydrophobic agent in CPB had certain effect on the water absorption and the hydration reaction. The hydrophobic agent improved the dewatering efficiency, promoted the hardened time shorten of the specimens. But the specimens became fluffy and the density of the specimens decreased as the hydrophobic agent dosage increased. The results showed that
the dewatering effect was the best when the amount of hydrophobic agent in CPB was 1%.

4. Conclusion

After a comprehensive analysis of the research of internationally relevant scholars in the field, the mixed hydrophobic agent with strong hydrophobic characteristics was screened through the analysis of the composition of the hydrophobic agent. The effect of hydrophobic agent on the dewatering efficiency of CPB was studied. The results showed that the dewatering effect was the best when the amount of hydrophobic agent in CPB was 1%.

1) The rheological properties, density, shrinkage, water vapour permeability, capillary water absorption, compressive strength of the hardened CPB was tested. The shear stress of the slurry at high and low speed is quite different, the shear stress at the beginning of the rheological test is greater than the high-speed stage for the addition of different hydrophobic slurry. In the high-speed and low-speed stages of the rheological test, the shear stress shows an increasing trend. The apparent viscosity of the filling slurry...
with different amount of hydrophobic agent decreases with the increase of shear rate. In the high-speed stage where the shear rate is greater than 80/s, the apparent viscosity of the slurry with different hydrophobicity is converged.

2) The addition of hydrophobic agent has little effect on the density and shrinkage of CPB, but it has obvious effect on the water vapour permeability and capillary water absorption. It also confirms the role of hydrophobic agent in improving the dewatering and gelation efficiency in CPB.

3) The compressive strength of CPB increases first and then decreases with the increase of hydrophobic agent. The compressive strength of the CPB is increased obviously when the amount of hydrophobic agent is 1%, compared with that without hydrophobic agent, when the cement sand ratio of CPB was 1:6 or 1:10. In addition, the compressive strength of the CPB block in different curing age with the addition of 1% of the hydrophobic agent is better than that without adding hydrophobic agent.

**Conflict of interest**

The authors declare no conflicts of interest.

**Acknowledgments**

This work was financially by National Natural Science Foundation of China (Grant No. 51774022), the State Key Research
Development Program of China (Grant No. 2017YFC0804101), and the China Scholarship Council Program for my study at the University of British Columbia (CSC NO. 201706460058).

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