Study on flocculant for underwater non-dispersible concrete

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Abstract: A kind of flocculant for underwater non-dispersion concrete was prepared by mixing organic and inorganic components. The proportion of each component was determined by measuring the relevant performance index of mortar. And the verification test was carried out by concrete pouring. The results showed that the admixture meet the requirements of underwater non-dispersion concrete construction, and the main technical indexes meet the requirements of specifications.

1. Introduction
Underwater non-dispersible concrete refers to the construction method of directly pouring concrete in water according to construction requirements and forming structure after hardening. With the extension of concrete buildings to the offshore areas, and the increase of roads and bridges in high water level areas in South China, the problem of underwater non-dispersible concrete has attracted more and more attention. In the process of pouring ordinary concrete mixture into water, it is easy to cause serious separation between aggregate and cement slurry because the mixture was washed by water. The loss of cement seriously affects the strength of the final concrete structure and causes immeasurable water pollution to nearby waters. Practice has proved that concrete anti-dispersant is an indispensable component if underwater concrete pouring is to be carried out conveniently, safely and with high-quality and fresh concrete has good workability.

Concrete anti-dispersant is also known as flocculant. Its special chain molecular structure can enhance the affinity between water molecules and adsorb cement particles into a stable structure to improve the cohesion of concrete mixtures and the adhesion ability of cementitious materials, so that it can resist the effect of washing when pouring in underwater environment. The research of underwater concrete is a new hotspot in the civil engineering industry nowadays, and the research of admixtures, especially flocculants, is the key to its development. Wei [1] et al. studied the influence of Bentonite on rheological properties, anti-dispersion properties and mechanical properties of cement paste. Liu Fang [2] et al. proposed the use of composite polycarboxylic acid water reducer, polycarboxylic acid slump retaining agent, reinforcing agent, retarder and other composite preparation of new underwater non-dispersible concrete admixtures. Zhang Ming [3] et al. studied the suitable range of main parameters of UWB-II flocculant for preparing underwater non-dispersible concrete to obtain good performance. Hydroxypropyl methyl cellulose ether flocculant was studied by Shi Zhan[4]. Tang Elabieta H [5] et al. proposed the preparation of underwater non-dispersible concrete with mineral coagulant, polysaccharide polymer and polycarboxylic acid polymer as main agents.

In this study, organic flocculant and inorganic flocculant were used as the main composite materials. Water reducing agent and water retaining agent were used as auxiliary materials. The
floculant material was selected by testing the underwater dispersion resistance and fluidity of mortar. Concrete was poured into water and its properties were tested.

2. Materials and Methods

2.1. Materials
Cement (P.O 42.5) was produced by Hainan Huashengtianya Cement Co., Ltd. The sand was medium sand with grade matching lattice. The stones were 5-20mm gravel with continuous gradation and gradation matching lattice. Polyacrylamide was produced by Aladdin Reagent Company. High performance polycarboxylic water reducer was used by Shanghai Chenqi Chemical Technology Co., Ltd. Super absorbent resin was used as water retaining component, produced by Shanghai Chenqi Chemical Technology Co., Ltd.

2.2. Methods
Combining with engineering practice, cement, fly ash and mineral powder were selected as cementitious materials of mortar. The basic mix ratio of mortar was shown in Table 1.

| Materials      | Cement (g) | Flyash (g) | Mineral powder (g) | Sand (g) | Water (g) | Water reducing agent (%) |
|----------------|------------|------------|--------------------|----------|-----------|--------------------------|
| Dosage         | 540        | 80         | 80                 | 1350     | 324       | 0.4-1.6                  |

Referring to JGJ/T70-2009 Standard for Testing Methods of Basic Performance of Building Mortar, each group of mortar was stirred slowly for 2 minutes, stopped for 60 seconds and stirred quickly for 2 minutes. After mixing, a little mortar was put into a transparent beaker filled with 400 ml clear water. After 2 minutes, water samples were drawn by suction pipes at 2 cm below the water surface, and turbidity was tested as an index of underwater dispersion resistance of mortar.

The fluidity of mortar was tested by mortar extensibility tester. After mixing, the mortar was slowly poured into the expandability tester. After confirming the filling, the mortar was tampered with a tamping rod for 15 times, then the excess mortar was smoothed with a spatula, and the measuring barrel was raised. After the flow of the mortar was stable, the expandability in both directions was measured with a ruler, and the maximum value was obtained. Mortar was poured into the mould and opened two days later. Its pouring and maintenance conditions were divided into two kinds. First, specimens were poured in air and formed. Mould was removed 2 days later. The specimens were maintained to the test age under the conditions of temperature 20 °C and humidity greater than 95%. Second, specimens were poured into water and formed. Mould was removed 2 days later. The specimens were maintained to the test age under the conditions of temperature 20 °C and humidity greater than 95%.

3. Results and Discussion

3.1. Effect of PAM content on dispersion resistance and fluidity of mortar
Polyacrylamide (PAM) was used as an organic floculant in underwater non-dispersible test of mortar. The test results were shown in Figure 1.
The results showed that the mortar prepared by PAM had non-dispersible effect under water. PAM content was more than 0.9% when used alone. The material was easily soluble in water. Flocculation can be realized by bridge-bond interaction between molecules and surface activation. The aqueous solution had strong surface activity and had good thickening effect on mortar. But it will greatly reduce its fluidity, which is not conducive to the construction of underwater concrete in practical projects. Therefore, in the preparation of flocculant, it is necessary to cooperate with a certain amount of water-reducing and water-retaining components.

3.2. Effect of bentonite content on dispersion resistance and fluidity of mortar
Compound inorganic flocculant with polyacrylamide can replace part of organic flocculant to participate in flocculation and reduce material cost. Using bentonite and PAM, the underwater dispersion resistance of mortar was observed. The experimental results were shown in Figure 2.

The results showed that the mixture of bentonite and polyacrylamide can realize the underwater dispersion resistance of mortar. But compared with the test results of No. 6 and No. 7, although No. 7 had lower turbidity than No. 6, No. 6 had greater liquidity and lower cost. Therefore, 8% bentonite was chosen as the inorganic flocculant component of the anti-dispersant. This material was easy to purchase in the market and had low price. It can play a role in increasing viscosity of cementitious materials and has good adaptability.

3.3. Effect of water retaining agent on dispersion resistance and fluidity of mortar
Superabsorbent resin was chosen as water retaining agent. It is a polyacrylic acid compound with hydrophilic group and cross-linking structure. It can absorb a large amount of water swelling and keep water from flowing out. The flocculation component can produce better underwater anti-dispersion effect on mortar. This component also has some influence on the fluidity of mortar. Mortar was prepared with 8% bentonite, 0.9% PAM and superabsorbent resins. The underwater anti-dispersion and fluidity of the mortar were tested. The experimental results were shown in Figure 3.
The results showed that the mortar mixed with water retaining agent can achieve good fluidity while ensuring the anti dispersion performance under water. When the content of water retaining agent was 0.2%–0.6%, the underwater dispersion resistance of mortar can be increased without affecting its fluidity. When the content of water retaining agent was more than 0.8%, the proportion of water involved in hydration reaction in the early stage will be too small, which was not conducive to the formation of early strength. Comparing the results of anti-dispersion and fluidity test, 0.4% of water retaining agent was selected as the anti-dispersant for underwater concrete.

![Figure 3 Effect of water retaining agent on dispersion resistance and fluidity of mortar](image)

3.4. Effect of water reducing agent on dispersion resistance and fluidity of mortar

The mortar was prepared with polycarboxylic acid superplasticizer, 8.0% bentonite, 0.9% PAM and 0.4% water retaining agent. The underwater dispersion resistance and fluidity of the mortar were tested. The test results were shown in Figure 4.

By comparing the results of anti-dispersibility and fluidity test of mortar, 0.25% of water reducing agent was selected. The anti-dispersibility of underwater pouring mortar was good, and the fluidity was not less than 200 mm.

![Figure 4 Effect of water reducing agent on dispersion resistance and fluidity of mortar](image)

3.5. Verification test of underwater concrete

The anti-dispersant agent was used to prepare concrete and poured it into water. The mix ratio was shown in Table 2.

| Materials | Cement (kg) | Water (L) | Sand (kg) | Stone (kg) | Water reducing agent | Flocculant (%) | Bentonite (%) | Water retaining agent (%) |
|-----------|-------------|-----------|-----------|------------|----------------------|----------------|---------------|--------------------------|
| Dosage    | 600         | 270       | 1040      | 1540       | 0.25%                | 0.9%           | 8.0%          | 0.4%                     |

When concrete was poured into the mould and opened two days later, the pouring and curing conditions were divided into two kinds. First, specimens were poured in air and formed. After demoulding, the specimens were maintained to the test age in water at 20 °C. Second, specimens were
poured in water and formed. After demoulding, the specimens were maintained to the test age in water at 20 °C.

Before pouring into moulds, the slump and expansion of concrete were measured. The compressive strength of concrete was measured at test age. The results were shown in Table 3.

| Pouring condition | Slump   | Expansion | pH  | Compressive strength | 28-day water-land strength ratio |
|-------------------|---------|-----------|-----|-----------------------|---------------------------------|
| Under water       | 243mm   | 455x460mm | 8.94| 24.3MPa               | 90.0%                           |
| air               | 235mm   | 470x480mm | /   | 27.8MPa               | 44.2MPa                          |

According to Underwater Non-dispersible Concrete Test Rules, underwater non-dispersible concrete requires slump of (230±20) mm; expansion of (450±20) mm after five minutes; suspension pH value < 12; water-land strength ratio not less than 60.0% after 7 days; water-land strength ratio not less than 70.0% after 28 days.

The test results showed that the 28-day water-land strength ratio reached 90%, the suspension pH value was 8-9, which had good anti-dispersion ability. The concrete slump was not less than 230 mm, and the expansion was not less than 450 mm which had good fluidity.

4. Conclusions
Material composition and dosage for underwater non-dispersible concrete were optimized through mortar test. Material composition was as follows: polyacrylamide 0.9%, bentonite 8.0%, water retaining agent 0.4% and water reducing agent 0.25%.

The underwater concrete had good fluidity and anti-dispersibility. It could meet the requirements of underwater concrete pouring. Its water-land strength ratio meets the requirements of national standards. The cost of the flocculant was lower than the average market price, so it had potential of engineering application.

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