Improvement study on the rapid hardening epoxy mortar

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Abstract. Mechanical properties of epoxy resin mortar with different proportions were tested based on orthogonal method. The influences of each factor on the compressive strength, flexural strength and bond strength of epoxy resin mortar after 1 day were analyzed by extremum difference analysis. The results indicated that the diluents occurred the highest influence on the mechanical properties of the epoxy mortar; the mass ratio of cement to sand (C/S) mainly affected the bond strength of the epoxy mortar; the increasing curing agent content would reduce the toughness of mortar. Based on the orthogonal analysis, the optimum proportion of the epoxy mortar was determined, which included a ratio of filler to liquids (F/L) of 2:1, a curing agent dose of 100% (referenced by the mass of epoxy resin), a C/S of 2:1 and a diluent dose of 10%.

1. Introduction
The ordinary mortar and asphalt mortar are the common-used bond materials for the underwater prefabricated hydraulic structures. However, these 2 materials have long hardening periods and poor bond strengths, which might induce the seepage of the adhesive joint, harming the long-term stability of the structures. Additionally, the asphalt mortar is somewhat toxic, threatening the health of the constructors.

Recently, some studies[1,2] have discussed the feasibility of using composite epoxy mortar as the bonding material for underwater prefabricated hydraulic structures. The composite epoxy mortar prepared by replacing part of cement with epoxy resin in the mortar has the advantages of low elastic modulus, high toughness, high impermeability and low volume shrinkage[3,4]. The composition of composite epoxy mortar is complex, the strength, toughness and bonding performance of mortar are mainly affected by the mixing amount of filler and epoxy resin, the ratio of filler to liquid (F/L), the mass ratio of cement to sand (C/S). Meanwhile, does of curing agent, diluent, emulsifier and defoaming agent also affects the mechanical properties of epoxy mortar[5,6]. The relevant studies[7-9] have clarified the influence of different doses of epoxy resin, cement and other auxiliary components on the mechanical properties of composite epoxy mortar. However, there are few studies on the influence of the interaction between the main factors and various auxiliary components on the mechanical properties.
of composite epoxy mortar, thus, there are few applications of composite epoxy mortar in the construction process of underwater prefabricated hydraulic structures.

In view of the above background, this paper focuses on the effect of four factors on the mechanical properties of epoxy resin mortar, including the content of curing agent, the F/L, the content of diluent, and the C/S.

2. Materials and Methodology

2.1. Materials and mix proportion

The materials were mixed with distilled water. The epoxy mortar was prepared with bisphenol A epoxy resin (epoxy equivalent is 222.4 g/mol and density is 1.16 g/cm³), diluent (main component is C12-14 alkyl glycidyl ether) and polyamide curing agent as liquid material, and P·O 42.5 cement, standard sand as fillers. The chemical composition, specific surface area and density of cement are shown in Table 1. The molded specimens were cured for 1 d under standard laboratory conditions. The specimen before demoulding is shown in Figure 1.

Table 1. Mass fraction, specific surface area and density of the cement.

|   | SiO₂ (%) | Al₂O₃ (%) | Fe₂O₃ (%) | CaO (%) | MgO (%) | SO₃ (%) | K₂O (%) | TiO₂ (%) | Specific surface area (m²/kg) | Density (g/cm³) |
|---|----------|-----------|-----------|---------|---------|---------|---------|---------|-------------------------------|----------------|
|   | 21.92    | 7.50      | 3.44      | 58.46   | 1.31    | 1.72    | 0.65    | 0.33    | 335                           | 3.03            |

Figure 1. Rapid hardening epoxy mortar samples.

The orthogonal test with 4 factors and 3 levels (L₉(3⁴)) was designed by selecting F/L, C/S, content of curing agent and content of diluent as variables. Factors and levels of the orthogonal test is shown in Table 2.
Table 2. Factors and levels of the orthogonal test.

|     | F/L    | Curing agent | C/S   | Diluent |
|-----|--------|--------------|-------|---------|
| H1  | 1 (2:1)| 1 (90%)      | 1 (1:2)| 1 (10%) |
| H2  | 1 (2:1)| 2 (100%)     | 2 (1:1.5)| 2 (15%) |
| H3  | 1 (2:1)| 3 (110%)     | 3 (1:1)| 3 (20%) |
| H4  | 2 (2.5:1)| 1 (90%)   | 2 (1:1.5)| 3 (20%) |
| H5  | 2 (2.5:1)| 2 (100%)   | 3 (1:1)| 1 (10%) |
| H6  | 2 (2.5:1)| 3 (110%)   | 1 (1:2)| 2 (15%) |
| H7  | 3 (3:1)| 1 (90%)      | 3 (1:1)| 2 (15%) |
| H8  | 3 (3:1)| 2 (100%)     | 1 (1:2)| 3 (20%) |
| H9  | 3 (3:1)| 3 (110%)     | 2 (1:1.5)| 1 (10%) |

2.2. Mechanical properties test
The early mechanical properties of rapid hardening epoxy mortar determine the structural reliability of underwater prefabricated hydraulic structures, so the compressive strength, flexural strength and bond strength of epoxy mortar after 1 d were tested based on Test procedures for polymer modified mortar (DL/T5126-2001).

3. Result Analyses

3.1. Influence of factors on mechanical properties of epoxy mortar
Test results of compressive strength, flexural strength and bond strength of epoxy mortar after 1 d are shown in Table 3. For any one of the factors, at the level \( i = 1,2,3 \), its average values of compressive strength, flexural strength and bond strength are respectively written as \( k_{ci} \), \( k_{fi} \) and \( k_{bi} \) \( (i = 1,2,3) \). These values can reflect the influence of the F/L, curing agent, C/S and diluent changing on the compressive strength, flexural strength and bond strength of epoxy mortar, and the corresponding optimal level is represented by the maximum value. The variation rules of \( k_{ci} \), \( k_{fi} \) and \( k_{bi} \) values of each factor are shown in Figure 2.

Table 3. Results of mechanical properties of epoxy mortar after 1 d.

|     | Compressive strength (MPa) | Flexural strength (MPa) | Bond strength (MPa) |
|-----|---------------------------|-------------------------|---------------------|
| H1  | 50.3                      | 24.6                    | 3.5                 |
| H2  | 45.6                      | 19.8                    | 2.3                 |
| H3  | 29.3                      | 10.9                    | 2.0                 |
| H4  | 29.7                      | 11.7                    | 2.1                 |
| H5  | 48.2                      | 22.8                    | 3.1                 |
| H6  | 40.0                      | 15.2                    | 2.7                 |
| H7  | 43.8                      | 17.1                    | 2.7                 |
| H8  | 31.7                      | 10.2                    | 2.4                 |
| H9  | 46.0                      | 18.7                    | 2.8                 |
As the bond material for the underwater prefabricated hydraulic structures, to adapting to high water pressure and complex underwater environment, rapid hardening epoxy mortar should have high strength, low brittleness and sufficient bonding strength development speed. The test results reveal that the increase of F/L will decrease the flexural strength of epoxy mortar by 16.8%. Such fact is due to that with the increase of the specific surface area of the filler, the epoxy resin is not enough to fill the pores between the fillers, resulting in more connected pores in the epoxy mortar [10,11].

It is important to note that with the increase of C/S, the bond strength of epoxy mortar revealed a trend of decline after rising first, indicating that the hardening strength of curing reaction between epoxy resin and curing agent is not entirely decided to bonding performance of epoxy mortar, particle size of filler and suitable particle size distribution are also important. The deviation of C/S from the reasonable scope, such as the filler in fineness is too large or too small and particle size distribution become unsuitable, will probably reduce the diversification and liquidity of liquid phase material composed of epoxy resin and curing agent. Therefore, reasonable particle size distribution can reduce pores and defects in the bonding surface and improve the filling effect of liquid material on the pore interface of solid phase packing when the specimen is forming, and can also reduce the porosity in the fresh mortar, improve the uniformity of the mixed slurry, and then enhance its bond strength with the concrete base surface.

On the other hand, increasing the content of diluent will reduce the compressive, flexural and bond properties of epoxy mortar in different degrees, and the effect on the bond strength with the maximum decrease of 50.5% is the most significant. High content of diluent reduces the curing crosslinking density of epoxy mortar, and weakens the mechanical properties of epoxy mortar. In addition, with the increase of curing agent content, the mechanical properties of epoxy mortar will decrease by 7.0%~16.3%, which indicates that with the increase of curing crosslinking density, the brittleness of epoxy mortar will gradually increase.

3.2. Extremum difference analysis
According to the data in Table 3 and Figure 2, extremum difference analysis was conducted for each
factor, and the results were shown in Figure 3.

![Extremum difference analysis of each test index](image)

Figure 3. Extremum difference analysis of each test index.

The results of extremum difference analysis reveal that the F/L, content of curing agent, C/S and content of diluent are the most important factors affecting the flexural strength, compressive strength, bond strength and compressive strength of epoxy bonding mortar. In order to meet the requirements of strength, brittleness and bond performance of joint bonding materials of underwater prefabricated hydraulic structures, the corresponding level of each maximum \( k_i \) value is determined according to Table 3. Finally, the optimum proportion of rapid hardening epoxy mortar is a F/L of 2:1, a curing agent does of 100% (referenced by the mass of epoxy resin), a C/S of 2, and a diluent does of 10%.

4. Conclusions
(1) The optimum proportion of rapid hardening epoxy mortar includes a ratio of filler to liquids of 2:1, a curing agent dose of 100% (referenced by the mass of epoxy resin), a ratio of cement to sand of 2:1 and a diluent dose of 10%. It can be used for joint bonding of underwater prefabricated hydraulic structures.

(2) Diluent has the most significant effect on the mechanical properties of epoxy mortar, and the maximum diluent content leads to the compressive strength, flexural strength and bonding strength of epoxy adhesive mortar reduced to 62.7%, 49.5% and 62.3% of the optimal content.

(3) Ratio of cement to sand has less effect on the compressive strength and flexural strength of epoxy mortar, but high ratio of cement to sand will damage the bond strength of epoxy mortar.

(4) Curing agent mainly affects the overall performance of epoxy mortar by changing the crosslinking density of epoxy resin. Therefore, increasing the dose of curing agent will improve the brittleness of epoxy mortar and reduce its flexure strength.

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