Applicability of Epoxy Materials for Repairing Wet and Underwater Concrete

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Abstract. Concrete structures in wet or underwater environment are damaged by erosion of water medium and other external factors for a long time. The working environment is bad, and they need to be repaired in time after diseases occur. Otherwise, it will have a serious impact on the safe use and durability of the whole structure. Because there is a large amount of water in the construction environment, the repair and reinforcement of such structures often need wet or underwater construction. Based on the above background, the purpose of this study is to study the applicability of epoxy materials for wet and underwater concrete repair. In this study, the influence of steel sheet, substrate and surface treatment on the underwater bonding ability was discussed. The EM underwater performance of different curing agent and curing agent compounding was studied. The basic principle of curing agent compounding was put forward, and the comprehensive performance of EM optimized formula was tested. The results show that the underwater properties of different curing agents are very different, but it is difficult for a single curing agent to meet the comprehensive performance requirements; the use of different kinds of curing agent compounding technology is an effective means to improve its underwater properties, but the effect of different compounding methods is significantly different, when using the modified alicyclic amine and phenolic amine compounding system, After optimization, the water pull-down shear strength of epoxy solution is 20.1mpa, air pull-shear strength is 22.7mpa, air tensile strength is 41.6mpa, air compressive strength is 100.9mpa, elastic modulus is 2.53gpa, the underwater positive pull bonding strength of epoxy mortar is 4.31mpa and the failure mode is cohesive failure of base mortar block. The underwater long-term bonding performance of epoxy mortar is excellent, After immersion for one year, the strength of the specimens has not decreased significantly, which can fully meet the actual engineering needs.

Keywords: New Epoxy Mortar, Epoxy Grouting Material, Concrete Defect, Underwater Repair

1. Introduction
In recent years, the field of structural repair and reinforcement has been developed rapidly. Epoxy materials are widely used in this field because of their excellent adhesion, outstanding mechanical properties, small curing shrinkage, good process performance and storage stability, and become one of the most important building materials in structural reinforcement and repair engineering. Concrete structures in wet or underwater environment are damaged by erosion of water medium and other external factors for a long time. The working environment is bad, and they need to be repaired in time after diseases occur. Otherwise, it will have a serious impact on the safe use and durability of the whole structure. Because there is a large amount of water in the construction environment, the repair and reinforcement of such structures often need wet or underwater construction.

A large part of the early hydraulic structures in China are in urgent need of reinforcement and maintenance, and even in recent years, new projects have been damaged to varying degrees, especially the underwater structure [1]. The south is rich in rainwater and groundwater, so it is easy to cause the whole concrete matrix of underground engineering to be affected by long-term water flow, resulting in erosion damage [2-3]. In the past, due to the lack of suitable materials and corresponding construction technology, the repair of underwater concrete has not been a good solution [4-5]. At present, the epoxy materials are better for concrete repair, but the epoxy mortar used in the wet or underwater environment is very few, and the general epoxy mortar is only suitable for use in the dry environment [6]. When used in the wet or underwater environment, the curing agent in epoxy mortar reacts with water and carbon dioxide to produce white ammonium salt, which leads to the sharp decrease of bond strength, and the engineering repair fails to achieve the effect, thus limiting the scope of use of epoxy mortar [7-8]. Moreover, the construction process is often complex and difficult, even unable to achieve the repair effect, resulting in increased cost [9-10].

Therefore, the purpose of this study is to solve many problems of concrete buildings, such as the leakage caused by the poor quality of concrete itself, the erosion caused by the high-speed water flow, and so on, based on the research and development of new epoxy materials, through the indoor simulation of different types of concrete damage repair technology. Through the research of this paper, the construction technology of new epoxy material repair is proposed, which can provide some guidance for the reinforcement of underwater concrete structure, increase the construction efficiency of concrete defect repair, and achieve the purpose of cost saving.

2. Method

2.1 EM Underwater Bonding and Application

Underwater polymer mortar is mainly composed of resin, water curing agent (or corresponding curing measures), filler (sand, etc.) and additives. At present, there are four systems of polymers for underwater and wet interface, including polyester resin system, ethylene resin system, epoxy resin system and composite system. The curing products formed by polyester resin system are soft and low strength; the ethylene resin system needs to be added with solvent, which is not conducive to construction, incomplete curing in water and environmental protection; the epoxy resin system has good adhesion, which is stable in water and can be cured at room temperature; the composite system can achieve special application requirements through different combinations, but the relevant research is relatively lacking. The underwater environment has its particularity. The difficulties of epoxy underwater repair and reinforcement are as follows:

1. At present, there is no simple and mature experience in underwater construction at home and abroad. It is difficult to solve the problems of underwater repair interface treatment, underwater construction machinery, safety protection of underwater construction personnel, etc.

2. It is difficult to ensure the wetting effect of the colloid on the interface in the water environment. The water molecule itself is also a polar molecule, which has a strong adsorption capacity on the steel sheet and concrete substrate. It is difficult for the colloid to replace the water on the surface of the substrate to replace the air. The presence of water will significantly reduce the adhesion of the epoxy resin, and the water flow will also affect the wetting effect of the colloid on the substrate.
3) The dissolution of colloid in water will change the mixture ratio, affect the interfacial adhesion, and may also affect the surrounding environment.

4) The solidification of colloid in water is not the same as that in air. Due to the slow heat exchange between air and colloid, the solidification reaction of colloid is an exothermic process. When the reaction reaches a certain degree, it is often accompanied by the phenomenon of heat accumulation, which will obviously accelerate the solidification speed of colloid, while the phenomenon of heat accumulation caused by the exothermic reaction of colloid in water is relatively difficult to appear. After the colloid reaction is exothermic, the heat is transferred to the water in contact with it. After the water absorbs the heat, the temperature rises and the water with a slightly lower temperature forms temperature difference convection. This flow of water can quickly dissipate the heat released by the colloid reaction, so the colloid curing temperature in water can basically keep the same with the water environment. In the environment with low water temperature, the curing time of colloid is long, and the dissolution of colloid by water has adverse effect on the performance of colloid. In this case, it may be necessary to use low-temperature underwater curing adhesive for repair.

2.2 Interface Bonding Mechanism

The bonding strength of the interface mainly depends on the curing agent. At present, the commonly used amine curing agent, on the one hand, will form a film on the surface after absorbing water, which will isolate the bonding layer. After absorbing water, the amine will react with the carbon dioxide contained in the water to produce "whitening" reaction to form amine salt, which will lead to the failure of the bonding strength. On the other hand, The curing agent of unmodified aromatic amine, ring amine and aliphatic amine dissolves in water, resulting in the loss of curing dose required by epoxy resin and the decrease of bonding strength.

The modified amine curing agent is obtained through grafting modification of phenolic amine and ring amine curing agent, which changes the hydrophilic group into hydrophobic group, is insoluble in water, does not react with carbon dioxide in water, and solves the "whitening" phenomenon of epoxy products in underwater use. Due to the difference of on-line expansion coefficient between the new epoxy mortar and the original concrete, the bonding surface may be damaged due to the influence of temperature and curing shrinkage. Based on the assumption and conclusion of thin structure analysis of epoxy mortar, the calculation formula of shrinkage stress caused by temperature and curing of new epoxy mortar can be obtained:

$$\sigma = -\frac{E(e_s + aT)}{1-\mu^2} \left(1 - \frac{ch\beta s}{ch\frac{BL}{2}}\right)$$

(1)

$$\beta^2 = \frac{C_s(1-\mu^2)}{HE}$$

(2)

Where,

$E$ is the elastic modulus of the epoxy mortar, $\mu$ is the Poisson's ratio of the epoxy mortar, $e_s$ is the strain caused by curing shrinkage, $T$ is the linear expansion coefficient, is the internal temperature of the structure, $L$ is the length of the epoxy mortar sheet, $C_s$ is the interface shear stiffness coefficient, and $B$ is the thickness of the epoxy mortar sheet.

3. Experiment

3.1 Experimental Materials

Epoxi resin: cyd-128, butyl glycidyl ether: Bge, industrial grade, Yueyang Baling Huaxing Petrochemical Co., Ltd.; benzyl glycidyl ether: 692, industrial grade, Changzhou Mingtai Chemical
Technology Co., Ltd.; acetone, chemical purity, Xilong Chemical Co., Ltd.; ethyl acetate, n-butyl acetate, ethanol, toluene, industrial grade, commercial; ordinary portland cement: 42.5 grade, Fujian Cement Co., Ltd; Triethylenetetramine, polyetheramine d-230, polyetheramine d-400, industrial grade, Changzhou Mingtai Chemical Technology Co., Ltd.; modified phenolic amine x1, modified phenolic amine X2, modified phenolic amine X3, modified phenolic amine X4: self-made, physical properties are shown in Table 1.

| Table 1. Physical properties |
|-------------------------------|
| Homemade curing agent         |
| Viscosity(25°C)/(mPa·s)        |
| 50                            |
| 1400                          |
| 25000                         |
| 1500                          |
| Amine value/(mgKOH/g)         |
| 500±20                        |
| 500±20                        |
| 220±20                        |
| 200±20                        |

3.2 Experimental Instruments
Utm5305 electronic universal testing machine, Shenzhen sansizheng Technology Co., Ltd.; ndj-8s Digital Viscometer, Shanghai Sunny Hengping Scientific Instrument Co., Ltd.; DHG series intelligent constant temperature drying oven, Shanghai Jingmai Instrument Equipment Co., Ltd.; dzf-6030 vacuum drying oven, Shanghai Jinghong Experimental Equipment Co., Ltd.

3.3 Experimental Preparation Method
Use a disposable plastic cup to weigh 150g of prepared grouting material, mark the liquid level height, place it in a 50 °C incubator for curing, and record the curing time, mass loss rate and gel height change rate. The "8" mortar block shall be made according to GB / t16777-2008, and it shall be pulled off after standard curing for 28 days without damaging the pulled off surface. After the "8" block is taken out of water, it shall be placed at room temperature for 2 days, that is to say, the fracture surface shall be bonded; after the "8" block is taken out of water, the free water shall be wiped off with a rag, and then the fracture surface shall be coated with slurry, and the butt joint shall be bound with a rubber band. After standard curing for 28 days, the bonding performance test shall be carried out

4. Discuss
4.1 Analysis of Underwater Bonding Performance of Epoxy Mortar
In general, the flexural and tensile strength of the polymer modified cement mortar is higher than that of the blank sample, while the compressive strength will decrease to a certain extent, because the polymer itself has low modulus of elasticity and good tensile performance, and the addition of polymer enhances the adhesion of the hydration products and aggregates. The good tensile and adhesive properties of waterborne epoxy resin play an important role in improving the flexural strength and adhesive properties of cement paste. In this study, the compressive strength, flexural strength and normal tensile strength of six kinds of water-based epoxy modified cement mortars were used. The polymer ratio of the modified mortars was 10%, and the water binder ratio was 0.335. Considering the adverse effect of water on the adhesive capacity and curing of the water-based epoxy resin, the specimen was cured by a curing plan, i.e. one day formwork removal and 27 days dry curing. The test time of compressive and flexural strength is 3D, 7d, 14d and 28d. The normal tensile bonding strength is divided into dry interface and wet interface. The test time is 28d. The test results are shown in Figure 1 and Figure 2.
Figure 1. Effect of waterborne epoxy on EMCM compressive strength

From Figure 1, it can be seen that the compressive strength of the modified mortar at each age has a certain degree of decline compared with the blank sample, and the development speed of the compressive strength of different water-based epoxy modified mortar at each age has a certain difference. Compared with the blank sample, the 28d compressive strength of modified mortar made the least. The compressive strength of MA1, MA3, MB1, MB2 and MC1 decreased significantly at 28d. It can be seen from Figure 2 that the correspondence between the development law of flexural strength and that of compressive strength is not obvious. The flexural strength of blank samples developed rapidly from 3D to 7d, and that of 7D to 14d increased faster than that of modified samples. The flexural strength of modified mortar develops rapidly from 3D to 7d, relatively slowly from 7d to 14d, and very slowly from 14d to 28d, which shows that the curing of epoxy resin in the early stage plays a certain role in improving the flexural strength.

Table 2. Effect of waterborne epoxy on EMCM bonding strength

| Modified mortar | Positive tensile bond strength |
|-----------------|--------------------------------|
|                 | Wet interface | Saturated surface dry interface |
| M0              | 1.59           | 2.41                      |
| MA1             | 1.43           | 2.05                      |
| MA2             | 2.23           | 3.01                      |
| MA3             | 1.97           | 2.38                      |
| MB1             | 1.35           | 1.73                      |
| MB2             | 1.39           | 1.89                      |
| MC1             | 0.97           | 1.42                      |
As shown in Table 2, the fresh mortar of group MA1, MB1 and MB2 has a large amount of air entrainment, which results in a large number of macro pores affecting the strength in the final hardened mortar, so the compressive strength decreases significantly. The addition of water-based epoxy has no effect on the flexural strength and bonding strength. Because of the use of ionic water-based epoxy system in MC1, the demulsification of mortar occurs in the process of mixing, and the cohesion of mortar is poor during molding, so the strength performance is poor. There is no obvious air entraining phenomenon in Ma3, and the obvious decrease of its strength may be related to the lower strength of the cured epoxy. The mechanical properties of ma2 group are outstanding, and the compatibility of waterborne epoxy resin A2 with cement mortar is better. It can be seen that the curing time, air entraining size, emulsification mode and mechanical properties of the waterborne epoxy resin are the important factors affecting the modification effect of cement mortar.

5. Conclusion
According to the requirements of the code and the actual engineering construction, the performance test of the new epoxy mortar and underwater epoxy grouting material is carried out systematically. According to the test results, it is concluded that the two materials are suitable for the repair of three main types of underwater concrete damage, and the indoor simulated repair of various types of underwater concrete damage is carried out in combination with different construction processes, The repair effect of the material combination process is verified, and the performance of the repaired concrete is further improved.

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