

Summary of Durability Analysis of Concrete Structures

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Abstract: The service life of concrete is closely related to the durability of concrete structure, with the development of infrastructure construction in our country, more and more attention has been paid to the study on the durability of concrete structure. This paper mainly analyzes the relevant factors affecting the durability of concrete structures, such as sulfate corrosion, chlorine salt corrosion, steel corrosion and concrete carbonization. At the same time, this paper studies from the perspective of life prediction of concrete structure to provide some reference for durability design of concrete structure.

Keywords: Concrete; Durability; Life prediction.

1. Introduction

Concrete plays an important role in the history of human construction engineering, and it is still one of the most widely used and used building materials[1]. At present, concrete in service environment faces the influence of high ground stress, high osmotic pressure, high ground temperature and strong corrosive substances[2]. Therefore, it is urgent to study the change of durability of concrete during long-term use, which is of great significance to extend the service life of concrete. In this paper, the relevant factors affecting the durability of concrete structures are summarized, aiming at providing reference for the research of concrete durability.

2. Influencing Factors of Durability of Concrete Structure

2.1. Corrosion of reinforcement

The corrosion of steel bar is one of the main factors affecting the durability of concrete, and it is also the focus of research on the durability of concrete structures. The prerequisite for the corrosion of steel bars is the instability of the passivation film on its surface. Once the passivation film is damaged, the Yin and Yang poles will be formed on the surface of steel bars, resulting in electrochemical corrosion, and the accumulation of rust layer on the surface of steel bars, resulting in concrete cracking.

Zhang Xide[3] conducted an experimental study on the whole process of corrosion and failure of reinforced concrete flexural members under load, conducted a comprehensive analysis on the deformation development process of specimens and the strain development process of concrete, and summarized the characteristics of corrosion and failure of steel bars under continuous load, drawing the following conclusions: The compressive strain of concrete in the compression zone increases with the increase of corrosion amount, and the increasing amplitude is related to the load size. There are three types of corrosion failure modes: adhesive anchorage failure mode, shear failure mode and fracture failure mode.

Jin Weiliang[4] established the expression formula of steel rust expansion force of concrete at the moment of expansion through theoretical analysis, and discussed the factors affecting steel rust expansion force. The results show that the steel rust corrosion rate has a great influence on steel rust

expansion force. The effect of concrete strength grade on steel rust expansion force is very small. The influence of concrete protective layer thickness on steel rust expansion force is much less than that of steel bar diameter.

2.2. Carbonization of concrete

The basic substance in concrete makes the surface of the steel bar in the concrete form an oxide film, which plays an effective role in protecting the steel bar and preventing the corrosion of the steel bar. However, carbon dioxide in the atmosphere reacts with the alkaline substances in the concrete to produce carbonate and water, which reduces the PH value of the concrete and forms the phenomenon of concrete carbonization[5], thus losing its protective effect on the internal steel bars.

Tu Yongming[6] conducted experimental research on prestressed concrete specimens in carbonization environment. By comparing the durability of prestressed concrete structures and ordinary concrete structures, he analyzed and summarized the damage and deterioration mechanism and law of concrete structures under the combined action of stress and carbonization. The effects of water-cement ratio, protective layer thickness and other factors on the carbonation rate of concrete were studied under stress-free state, tensile stress state and compressive stress state respectively. The results show that the tensile stress accelerates the carbonation rate of concrete, and the carbonation rate of concrete increases with the increase of tensile stress. The durability of prestressed concrete structure is better than that of ordinary concrete structure.

In order to study the change of durability of concrete after high temperature, Lu Limin[7] conducted experiments on C30 strength grade concrete after high temperature of 100~800°C, and summarized the carbonization law of concrete after high temperature. Five carbonation times of 0, 3, 7, 14 and 28d were set in the test. When the specimen reached the corresponding carbonation time, it was taken out for carbonation depth test. The test found that with the increase of temperature, the carbonation rate of concrete also increased rapidly.

2.3. Carbonization of concrete

Concrete sulfate corrosion is one of the most common erosion modes suffered by concrete, which mainly refers to the complex physical and chemical reactions that occur when sulfate ions in the environment (atmospheric environment,

soil environment and water environment) invade into the specimen through pores and cracks formed at the beginning of concrete forming[8]. With the gradual accumulation of corrosion, more and more expansion products, resulting in greater and greater internal stress, concrete began to produce some subtle cracks, cracks gradually developed, the length and width continue to increase, some pores inside the concrete through, connect, and finally form cracks on the surface of the concrete. The formation and development of these cracks provide more channels for the entry of sulfate ions and the dissolution and precipitation of corrosion products, and the corrosion is further aggravated[9][10].

Gao Rundong[11] studied the law of damage and deterioration of concrete with different mix ratios under the action of dry and wet cycling by sulfate attack. Four different mix ratios (0.57, 0.44, 0.35, 0.28) were set up in the test, and the basic mechanical properties and microscopic observation of concrete under the action of dry and wet cycling were studied. The results show that the damage and deterioration of concrete are accelerated by the dry-wet cycle of sulfate. The damage degree of high strength concrete is less than that of ordinary strength concrete, and its resistance to sulfate attack is stronger.

Liu Zanqun[12] studied the morphology of concrete products after sulfate attack from a microscopic scale, analyzed the reasons for the deterioration of concrete samples in sulfate, and found that crystals such as ettringer and gypsum generated in the interfacial transition zone were the main reasons for the damage and deterioration of concrete.

2.4. Chloride attack

Chloride ions exist in the raw materials of concrete, such as water reducing agents containing chloride, slag quenched with seawater, fly ash drained with seawater, etc. Chloride ions exist not only in sea water, but also in roads, and can cause harm to concrete structures in many ways. The infiltration process of chloride ions in concrete is regarded as a diffusion process, and the main ways of chloride ions invading concrete are capillary action, osmosis, diffusion and electrochemical migration. The study on chloride ions diffusion is mainly based on Fick's second law to establish a life prediction model. According to Fick's second law, the diffusion time of chloride ions to the surface of the steel bar is proportional to the square of the thickness of the protective layer.

Xing Feng[13] used a self-designed loading device to study the chloride ions permeability of plain concrete mixed with different admixtures under load level. The test mainly investigated the relationship between penetration depth and load level, and found that for concrete under the same load level, the permeability coefficient would change with different dosage of admixtures.

Jin Zuquan[14] studied the law of chloride ions bonding in single chloride salt solution, salt lake brine solution and composite solution for concrete with different dosage of fly ash, silica fume and mineral powder. In addition, X-ray diffraction technology and thermogravimetric analysis were used to study the microscopic mechanism of chloride ions erosion of concrete. It was found that the binding ability of chloride ions in the composite solution decreased with the increase of sulfate concentration.

2.5. Alkali aggregate reaction

Alkali aggregate reaction refers to the destructive

expansion reaction between the alkaline hydration products in concrete and the active components in aggregate, and the alkali aggregate reaction is one of the factors affecting the durability of concrete[15]. Because the active aggregate is evenly distributed in the concrete after mixing, once the alkali aggregate reaction occurs, all parts of the concrete will produce expansion stress and crack the concrete. This reaction is different from other concrete diseases, its cracking damage is often integral, and no effective repair method has been found, so the alkali aggregate reaction is called "concrete cancer". Yang Changhui[16] studied the expansion of third-class alkali slag cement mortar caused by alkali aggregate reaction, and pointed out that the possibility of alkali aggregate reaction is still much lower than that of ordinary cement even when the alkali content of alkali slag cement is high. Wang Zijia[17] listed the detection technologies of alkali aggregate reaction, including concrete prism method, mortar bar rapid method and petrographic method, and proposed prospects for the development direction of alkali aggregate reaction in the field of concrete.

2.6. Freeze-thaw failure

The freeze-resistant durability of concrete refers to the resistance of water-saturated concrete to freeze-thaw cycles. The necessary conditions for concrete freeze-thaw failure are that concrete is saturated with water and the freeze-thaw cycle is alternating, so the freeze-thaw failure of concrete generally occurs in cold areas. The freeze-thaw failure of concrete is mainly due to the volume expansion of water in the freezing process, resulting in tensile stress in the concrete. When the stress exceeds the tensile strength of the concrete itself, tensile failure will occur. At the same time, along with the temperature rise and fall, there will be a cold melt cycle, further damaging the internal structure of concrete, resulting in concrete damage.

Jia Xianhua[18] studied the effects of concrete water-binder ratio, air content, admixtures and coarse aggregates on the freezing resistance of concrete through concrete freeze-thaw failure tests, and the results showed that adding admixtures could greatly improve the freezing resistance of concrete and improve the internal structure of concrete.

Wu Haotian[19] carried out experimental research on the freeze-thaw cycle mechanism and low temperature working performance of iron tailings concrete, and found that with the increase of the number of freeze-thaw cycles, the connectivity rate between the internal pores of concrete greatly increased, the original cracks further developed until the penetration, and the freeze-thaw failure phenomenon of concrete intensified.

3. Durability and Life Prediction of Concrete Structure

The service life prediction of concrete structure is becoming more and more important in engineering practice, and the results of concrete durability research will inevitably transition to life prediction. Domestic and foreign scholars have carried out a comprehensive study on the durability life prediction of concrete structures.

Li Yao[20] took concrete mixed with different amounts of fly ash as the research object, and carried out the freeze-thaw damage test of concrete under clear water and different sulfate concentrations, and analyzed the appearance, quality, compressive strength, dynamic elastic modulus and splitting

tensile strength of concrete, etc. At the same time, based on the Weibull model, the compressive strength, dynamic elastic modulus and quality were taken as the indexes, and the life prediction model of concrete under the action of dual factors was established. At the same time, based on the Weibull model, the life prediction model was established under the effect of dual factors by taking compressive strength, dynamic elastic modulus and mass as indicators. It was found that the freeze-thaw cycle of concrete under water and sodium sulfate solution was the best when the fly ash dosage was 10%.

Based on the theory of freeze-thaw damage, Yang Dongpeng[21] carried out freeze-thaw damage tests using concrete prisms, established a concrete freeze-thaw damage model based on the Weibull model, and at the same time proposed a concrete life prediction method based on the model. After repeated tests, it is found that the life prediction method can be applied in engineering entities.

Lu Chenggong[22] predicted the life change of reinforced concrete in a corrosive environment based on the Wiener stochastic process model, and the results showed that the durability life of reinforced concrete decreases with the increase of chloride ions and sulfate ions concentration, and the sensitivity of concrete life to sulfate is large in comparison with the sensitivity of reinforcing steel life to chloride salts.

Clifton[23] summarized the life prediction methods of concrete in 1993, which mainly include the following: empirical estimation method, accelerated test method and comparative prediction method. Most of these methods are mathematical model methods related to physical and chemical deterioration process and probability prediction methods based on random process. At present, the accelerated experiment method and mathematical model method have achieved more results in concrete life prediction, and the probabilistic analysis method based on random process has also achieved some results.

Guan Bowen[24] also took the fatigue load effect into consideration in the research on prediction of concrete sulfate corrosion life, and reduced the fatigue load to the diffusion coefficient of sulfate ions, and finally obtained the calculation formula of concrete sulfate corrosion life, both of which showed that fatigue load can significantly accelerate the deterioration of concrete.

Qiao Hongxia[25] designed an accelerated indoor test simulating the real environment, took the value of mass and dynamic elastic modulus as the deterioration characteristics of durability, established a reliability function based on Wiener function, and predicted the life of concrete on the basis of collecting part of the life data.

Based on the evolution equations of freeze-thaw failure and corrosion damage of concrete, Yu Hongfa[26] predicted the life of concrete in Qinghai Salt Lake and Beijing urban overpass structure through concrete freeze-thaw failure test and corrosion damage test, and solved the life design problem of major concrete projects in non-ocean areas.

Li Peng[27] conducted experimental research on concrete under sulfate, chloride and bending loads, analyzed the change law of concrete dynamic elastic modulus under different factors, predicted the life of concrete through the diffusion model of sulfate ions, and found the law of sulfate ions diffusion coefficient decay with time.

4. Conclusions

The durability of concrete has aroused sufficient attention of scholars at home and abroad, and a lot of research has been

done on steel corrosion, concrete carbonization, sulfate corrosion, chloride ion erosion, alkali aggregate reaction, freeze-thaw damage, etc., and effective research results have been obtained. Carbonization, chemical corrosion and alkali aggregate reaction of concrete are important factors affecting the durability of concrete. Strengthening the early curing of concrete and improving the working environment of concrete structure can improve the durability of concrete structure. Starting from the microscopic point of view is also the main means to reveal the deterioration mechanism of concrete, which needs further study.

References

- [1] LI V C. High-performance and multifunctional cement-based composite material[J]. *Engineering*, 2019, 5(2): 250–260.
- [2] Liu Juanhong, Ma Hongbo, Duan Pinjia, et al. Corrosion resistance of ultra-deep well wall concrete under sulfate dry-wet cycling environment[J]. *Materials Herald*, 2021, 35(12): 12081-12086.
- [3] Zhang Xide. Research on some problems of durability of reinforced concrete members [D]. Guangxi University, 2004.
- [4] Jin Weiliang, Zhao Yuxi, Yan Fei. Mechanism of uniform reinforcement rusting and expansion forces in reinforced concrete members[J]. *Journal of Water Resources*, 2001(07): 57-62.
- [5] Yao Jitao, Gu Hui, Zhang Yijiu, et al. Probabilistic design expression for carbonation durability of concrete structures[J]. *Journal of Xi'an University of Architecture and Technology(Natural Science Edition)*,2015,47(01):1-5.
- [6] Tu Yongming, Lv Zhitao. Experimental study on carbonization of concrete under stress [J]. *Journal of Southeast University (Natural Science Edition)*,2003(05):573-576.
- [7] Lu Limin, Xu Weihao, Wang Shouxing, et al. Experimental study on carbonization and chloride ion erosion of concrete after high temperature [J]. *Concrete*,2023(01):53-57+63.
- [8] Ferraris C F, Stutzman P E, Snyder K A. Sulfate resistance of concrete: a new approach[J]. *R&D Serial*, 2006, 2486: 301-313.
- [9] Da Chen, Yu Xiaotong, Liao Yingdi, et al. Progress of research on sulfate erosion of concrete [J]. *Journal of Chongqing Jiaotong University (Natural Science Edition)*,2016,35(02):24-30.
- [10] Chen J, Jiang M. Long-term evolution of delayed ettringite and gypsum in Portland cement mortars under sulfate erosion[J]. *Construction and Building Materials*, 2009, 23(2): 812-816.
- [11] Gao Rundong, Zhao Shunbo, Li Qingbin, et al. Experimental study on the deterioration mechanism of sulfate attack on concrete under dry and wet cycle[J]. *Journal of Civil Engineering*, 2010, 43(02):48-54.
- [12] Liu Zanqun, Deng Dehua, Geert De Schutter, et al. "Microanalysis of sulfate crystallization damage in concrete (II)-concrete[J]. *Journal of Silicates*,2012,40(05):631-637.
- [13] Xing Feng, Leng Faguang, Feng Naiqian, et al. Effect of long-term continuous loading on chloride ion permeability of plain concrete[J]. *Concrete*,2004(05):3-8.
- [14] Jin Zuquan, Sun Wei, Zhao Tiejun, et al. Curing degree of concrete to chloride ions in different solutions[J]. *Journal of Silicate*,2009,37(07):1068-1072+1078.
- [15] Shi C, Shi Z, Hu X, et al. A review on alkali-aggregate reactions in alkali-activated mortars/concretes made with alkali-reactive aggregates[J]. *Materials and Structures*, 2015, 48: 621-628.

- [16] Yang Changhui, Pu Xincheng, Wu Fang. Study on alkali aggregate reaction expansion of alkali slag cement mortar[J]. Journal of Silicate,1999(06):651-657.
- [17] Wang Zijia. Damage of concrete structure by alkali aggregate reaction and chemical restraining measures [J]. Guangdong Chemical Industry,2023,50(18):62-63+44.
- [18] Jia Xianhua. Analysis of factors affecting freeze-thaw damage and durability test of concrete[J]. Construction Machinery, 2022(09):61-63.
- [19] Wu Haotian. Mechanism of freeze-thaw cycle failure of iron tailings concrete [D]. Liaoning Shihua University,2023.
- [20] Li Yao. Durability study and life prediction of hydraulic concrete under freeze-thaw and sulfate composite [D]. Xi'an University of Technology,2023.
- [21] Yang Dongpeng, Guo Weimin, WANG Baomin. Prediction and application of freeze-thaw damage life of concrete based on Weibull model [J]. Journal of Water Resources, 2022, 53(08): 977-983.
- [22] Lu Chenggong, Wei Zhiqiang, Qiao Hongxia, et al. Durability life prediction of reinforced concrete in underground corrosive environment based on Wiener stochastic process[J]. Journal of Hunan University (Natural Science Edition),2021,48(07):119-128.
- [23] CLIFTON J R.Prediction the service life of concrete[J].ACI Mater J,1993,90(6): 611-617.
- [24] Guan Bowen, Chen Shuanfa, Li Huaping, et al. Prediction of sulfate corrosion life of concrete under fatigue load [J]. Journal of Building Materials,2012,15(03):395-398.
- [25] Qiao Hongxia, Zhu Binrong, Lu Chenggong, et al. Accelerated life test of concrete based on Wiener stochastic process[J]. Journal of Construction Materials, 2016, 19(06): 1023-1027+1061.
- [26] Yu Hongfa, Sun Wei, Ma Haiyan, et al. Concrete life prediction method based on damage evolution equation[J]. Journal of Building Science and Engineering,2012,29(01):1-7.
- [27] Li Peng. Durability and life prediction of concrete under load and salt solution coupling [D]. Yangzhou University,2014.