Research progress and development direction of durability assessment methods for CFRP reinforced concrete structural members

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Abstract. The construction industry is an important part of China's national economic development, in recent years with the economic development is to increase the investment in infrastructure. As time goes on, there be the phenomenon of building use function degradation, in addition, in many reinforced concrete structure, and part of the building is in a bad environment conditions, caused by a lack of concrete durability, reduce safety performance and the structure performance degradation, causing a large number of buildings can not reach the expected service life or the desired function. With the rapid development of reinforcement technology, the theoretical basis and practical engineering experience of concrete reinforcement technology in China have been gradually accumulated and improved, and a lot of achievements have been made. Based on the theoretical research and engineering practice of concrete structure reinforcement, the state and local governments have promulgated a series of codes and standards for the reinforcement and renovation of existing buildings, which provide a good technical guarantee for the reinforcement and renovation of concrete structures. Concrete structural members reinforced by adhesive still need to be affected by external environment in the use process, such as chemical corrosion environment, chlorine corrosion environment, freeze-thaw environment damage and long-term load. Therefore, the test and evaluation of the durability of the members of the load-bearing structure reinforced by adhesive plays an important role in the reinforcement of concrete structure system and the service process after the reinforcement of members. How to evaluate the durability of reinforced concrete structures is of great significance to the durability monitoring of reinforced concrete structures.

1. Introduction
Since the reinforced concrete structure construction methods are widely used in building structure reinforcement and reconstruction project, the reinforcement method has played an important role in the field of structure strengthening, at the same time based on the theory of reinforced concrete structure and related research and engineering practice has gained popularity, paste CFRP reinforced concrete member in reinforcement applications accounted for a larger proportion. Along with the national standard "reinforced concrete structure design code" GB50367-2013 and the construction quality acceptance of building structure reinforcement engineering GB50550-2010, the engineering
structure reinforcement material technical specification for safety appraisal GB50728-2011 promulgation and implementation of system specification for concrete structures strengthening engineering design and construction quality inspection and reinforcement material safety appraisal of each link. After the reinforcement of the system and components, the strength, stiffness and integrity of the structural system have been improved, but it is still necessary to consider that the reinforcement of concrete components is still affected by wet and dry conditions, temperature conditions, chemical corrosion environment and long-term load. With the increasing popularity of reinforcement construction, the durability of the structure after reinforcement has become the focus of attention in the process of engineering application. Therefore, it is necessary to consider whether the performance of the structure after reinforcement is degraded and whether the subsequent service life can reach the expected target in the process of putting it into use.

Adhesive reinforcement in concrete structures strengthening methods due to the construction of the paste CFRP concrete member in convenient operation, the craft is mature, CFRP performance is good, is widely used in the reinforcement engineering, paste CFRP concrete component in the structure reinforcement engineering, need to consider include: the factors which influence the durability of the temperature and humidity effect, load impact resistance, resistance to chemical corrosion and ultraviolet radiation, etc. In this paper, the factors influencing the durability of CFRP reinforced concrete members are summarized based on the above environment.

2. influencing factors of durability

2.1 influence of temperature on CFRP materials and reinforced concrete structures

In order to verify whether the performance of CFRP sheet material under temperature cycling is affected, Hutchinson et al. conducted mechanical performance tests on CFRP sheet material and adhesive under temperature cycling at -20~50℃. Every 24h is a cycle, in which temperature is increased for 5h, temperature is decreased for 17h, and temperature and humidity at each end are kept for 1h.[1] The test results show that the elastic modulus, tensile strength and ultimate strain of CFRP sheet under the action of temperature cycling do not decrease, but increase correspondingly.

Houssam, Toutanji, Balaguru et al. conducted representative tests on the mechanical properties of reinforced concrete columns coated with CFRP sheets under freezing-thawing cycles.[2]-[5] The following conclusions are obtained: under freezing-thawing cycle, the strength of concrete columns reinforced with CFRP decreases. The freezing-thawing cycle has no effect on the stiffness of CFRP reinforced columns, and the ductility decreases obviously. Compared with CFRP strengthened columns under room temperature and wet and dry cycling conditions, brittle failure is more likely to occur under freezing-thawing cycling conditions.

Wang fengxia et al. studied the properties of CFRP reinforced concrete under different environmental effects.[6] The results show that the freezing-thawing cycle has less effect on the compressive strength of CFRP reinforced concrete rectangular columns, and more on the tensile bond strength of reinforced concrete cubes. The theoretical analysis of the fiber of CFRP reinforced concrete column at the middle corner of the column height is obtained.

The strength of the carbon fiber sheet (CFS) under different temperature conditions is not affected, aci committee, Wang Jing, xiao-dong zhang for CFRP under the condition of environment related durability test, use black board compared to 63 + 3 ℃ temperature spray circulation, 18 min / 2 h using daylight natural aging tester for 2000 and 10000 h CFRP and rapid exposure test (equivalent to 10 a and 50 a natural exposure time) exposed to the atmosphere environment for a long time to test the tensile strength of carbon fiber cloth, the experimental results showed that: not found strength reduce phenomenon;[10] The tensile test of CFRP was carried out under the conditions of -54℃, 23℃ and 82℃ to test the dependence of CFRP on temperature. The test results showed that no strength reduction was found under the set temperature.

In recent years, the research on the freezing-thawing durability of concrete structures strengthened with FRP has accumulated some achievements at home and abroad. The performance characteristics
are summarized as follows: 1. Freezing-thawing circulation has a negative effect on the performance of the bond between FRP and concrete, and the degree of influence is related to the strength and frost resistance of concrete; 2. The freezing-thawing cycle has a significant adverse effect on the bonding section performance of ordinary concrete members used for FRP reinforcement; 3. For concrete structures strengthened with FRP materials with high frost resistance, the weakening effect of freezing-thawing on bond section strength is not obvious, but it can be seen from the change of failure mode that freezing-thawing has a certain adverse effect on bond interface. Furthermore, the mechanism of resistance attenuation of the whole structure was further discussed, and relevant theoretical models were established. On the premise of having a large amount of test data, the corresponding reduction coefficient of anti-freeze and thawing durability design is proposed to provide theoretical basis for the establishment of relevant durability specifications.

2.2 influence of humidity on CFRP materials and reinforced concrete structures
CFRP sheet and binder were exposed to a humid environment with a relative temperature of 30℃ and a humidity of 100% to verify the effect of humidity conditions on their strength.[1] The test results show that the tensile strength, elastic modulus of tensile strength and ultimate elongation of CFRP sheets do not decrease under the wet environment.

Houssam and Toutanji et al. conducted tests on CFRP sheets under wet and dry cycling conditions. The cycling test conditions (adding 35g salt in 1L of water to simulate seawater) lasted for 4h and the dry conditions (average temperature 35℃ and humidity 90%) lasted for 2h, lasting a total of 75d.[9] The experimental results show that the load carrying capacity of FRP strengthened beams under dry/wet cycling conditions is significantly higher than that of beams not strengthened with FRP at room temperature, but the load carrying capacity of FRP strengthened beams at room temperature is decreased.

Toutanji and Houssam et al. conducted experimental studies on concrete columns reinforced with CFRP, and preserved 36 specimens in a humid environment (temperature 25℃, relative humidity 90%) for 58d.[4] After that, the dry and wet cycle was carried out for 18 months, and the cycle times were 300 times. Each cycle under wet conditions (adding 35g salt to 1L of water to simulate seawater) lasted for 4h, and the dry conditions (temperature 35℃, relative humidity 90%) lasted for 2h. The cycle lasted for 75d. The other 18 times were placed at room temperature for 75d as a comparison specimen, and the pulse rate and mass of time were measured once every 30 times through the dry-wet cycle. The results show that the compressive strength of CFRP reinforced columns has no significant effect on the epoxy resin used as the matrix material. The ductility of concrete columns strengthened with CFRP does not decrease under wet and dry cycling conditions.

2.3 influence of seawater on CFRP materials and reinforced concrete structures
The water spray test was carried out at the test temperature of 35±2℃ by means of a nozzle brine spray device to test the seawater resistance of the CFRP fabric. The test time was 1a. The test results showed that there was no trend of decrease in tensile strength.[8]

The tensile properties of CFRP were tested by soaking CFRP in sulfate solution, and the bonding properties of CFRP and concrete were also studied. The mechanical properties and failure modes of CFRP reinforced concrete beams were also studied after accelerated deterioration in the severe environment of temperature and humidity alternating cycle and sodium sulfate salt fog.[10]1. Sodium sulfate solution has no effect on the tensile strength of CFRP and the elastic modulus of concrete, but the compressive strength of concrete is related to the soaking time; 2. The bond strength between CFRP and concrete was not affected by soaking in sodium sulfate solution; 3. Through the experimental study on the flexural performance of 9 reinforced concrete beams strengthened by CFRP sheets in the two erosion environments of alternating cycle of temperature and humidity and dry and wet cycle of sodium sulfate spray, the influence of accelerated environmental cycles on the flexural strength, crack development, ductility and failure model of CFRP strengthened beams was analyzed. The results show that the performance of reinforced concrete beams strengthened with CFRP...
decreases significantly under both accelerated degradation environments.

The strength and ductility of concrete columns strengthened with FRP are decreased after the dry-wet cycling of salt solution, and the dry-wet cycling resistance of CFRP columns is better than that of GFRP columns. While while, jean surplus, li zhao by carbon fiber cloth (CFRP) and glass fiber cloth (GFRP) all gummed reinforced concrete columns wrapped paste reinforcement and stripe intervals in the solution of salt dry-wet circulation under the action of axial compression test, analysis of environmental effect, the types of fiber cloth, fiber cloth paste way affect the performance of concrete columns axial compression test and research.[12] In this paper, it is suggested that in the dry and wet circulation environment of salt solution, the concrete structure can be strengthened by FRP bonding, which can not only improve the mechanical performance of concrete structure, but also delay the erosion of concrete by FRP bonding and prolong the life of concrete structure.

As for the influence of seawater environment conditions on the interfacial properties of cfrp-concrete, wangjizhong used 42 CFRP sheets to conduct the physical and mechanical properties test of CFRP materials, and 72 single shear specimens of concrete were used to test the interfacial bonding properties of cfrp-concrete under seawater environment.[13] The results show that: the durability of CFRP material is good, and the physical properties of CFRP material are not affected by long-term seawater corrosion. The bonding strength of cfrp-concrete decreases with the increase of corrosion time. Long-term seawater corrosion has a negative effect on the interfacial ductility, but has no significant effect on the interfacial strain development law and the bond slip relationship.

2.4 influence of acid-base environment on CFRP materials and reinforced concrete structures
The compressive strength of CFRP reinforced concrete columns under acid environment is lower than that under other environments, and the degree of reduction is related to the strength of concrete and the duration of environmental action. The tensile strength of CFRP reinforced concrete cube under acid environment is lower than that under other environment.[6] Under the action of aqueous solution -- water environment, acid environment and alkali environment, the bonding failure of positive tensile specimen is more likely to occur.

CFRP was impregnated in 50℃, 50% strong acid and NaOH solution, and various concentrated acid and liquid bromo solution at room temperature to test its acid-base resistance. The impregnation time was 250d. The test results showed that the tensile strength and elastic modulus of CFRP were not decreased.[8]

In order to study the durability of frp-concrete interface bond performance under the corrosive environment, wuyutao conducted double-sided shear tests on frp-concrete bond specimens eroded by hydrochloric acid solution, sodium hydroxide solution and sodium sulfate solution. The conclusions are as follows :(1) when the load is small, the slip value increases slowly;[13] When the load reaches about 20% of the ultimate load, cracks begin to appear at the bonding interface. The cracks gradually develop to the loading end, and the slip value increases rapidly. When the load reaches 80% of the ultimate load, the bond slip curve generally appears gentle section. As the load continued to increase, the specimen showed obvious signs of one-time failure. (2) the strain of the FRP sheet is transferred from the loading end to the free end gradually, and the strain distribution curve changes from concave to convex. Using equivalent conversion method, the average shear stress of the specimens in the limit state is generally 2~ 3.5mpa. (3) the bearing capacity of bonded specimens was decreased most seriously after being eroded by hydrochloric acid solution, followed by sodium sulfate solution, and sodium hydroxide solution had almost no effect.

2.5 influence of stress on CFRP reinforced concrete structures
In order to grasp the effect of CFRP on the performance of concrete components under long-term load, Yamaguchi et al. conducted relevant experimental studies, pointing out that under the duration equivalent to 50a, the final strength of CFRP was inferred to be 93% of the initial strength [14] The test was conducted at room temperature, and the linear relationship was obtained based on the test data of 100h, and the creep fracture stress of CFRP after 50a was inferred to be 79% of the initial strength.
In addition, Tavakkolizadek et al. tested the fatigue resistance of beams repaired by CFRP sheets under repeated loads. According to the test results, the fatigue life of beams strengthened with CFRP sheets externally is 3.5 times longer than that of beams not reinforced with cracked beams.[15] In the logarithm and stress curve (s-n curve) of CFRP load cycles, the average strength decline rate is 5%~8% every 10 years. After one million cycles, the fatigue strength is 50% to 70% of the initial strength and is unaffected by the humidity and temperature of the exposed concrete structure. The study of 10 million load cycles shows that the s-n curve has a downward trend of 5%~8% every 10 years (Critis P.T).

2.6 influence of ultraviolet radiation on CFRP reinforced concrete structures

Yang yongxin et al. conducted experiments on the bond strength of CFRP reinforced concrete beams under ultraviolet conditions. The results showed that the bond strength between CFRP and concrete did not decrease after 2000h of ultraviolet irradiation. In the cut-and-paste test, the failure of the specimens occurred in the concrete and the bond strength did not decrease.[16]

According to above analysis and research results of each part, can be summarized as the following aspects of CFRP paste characteristics on the impact of the durability of concrete structural components:

1. Influence of temperature factor: through the paste CFRP reinforced concrete structures in high and low temperature alternating, high temperature and low temperature environment under the condition of mechanical properties test analysis shows that temperature had no effect on the performance of CFRP materials, the effect on the overall performance of CFRP reinforced concrete structure is not obvious.

2. Influence of humidity factors: the experimental study of cfr-bonded concrete structural members under humidity conditions and dry-wet alternating circulation conditions shows that the effect of humidity environment has no influence on CFRP sheet metal, and the effect of humidity environment has no significant influence on the bearing capacity of CFRP sheet metal reinforced concrete structural members. 3. Influence of medium environment: the experiments of CFRP sheet and CFRP bonded concrete structural members in seawater and acid-base environment show that CFRP sheet is not affected in seawater environment, and the performance of CFRP bonded concrete structural members in seawater environment is affected to some extent; Under the condition of acid and base, CFRP sheet is not affected, and the bearing capacity of CFRP sheet is affected. 4. Under stress and external irradiation, CFRP bonded concrete structural members are affected to a certain extent.

3. existing problems

CFRP reinforced concrete members are widely used in domestic reinforcement and transformation projects, and the durability of CFRP reinforced concrete structural members at home and abroad is becoming more and more mature and perfect. In the engineering structure reinforcement material technical specification for safety appraisal GB50728-2011, for the engineering structure with the durability of reinforcement materials also put forward the corresponding technical indicators, to reinforce the long-term performance of the adhesive for resistance to wet and heat aging, thermal aging, resistance to freezing and thawing ability, long-term stress ability, resistance to fatigue stress ability, resistance to corrosion medium of salt fog, and the roles of seawater immersion, alkaline medium, and the roles of acid medium and other technical indicators put forward clear requirements, but this kind of experimental study on the most complete in the laboratory, and to accelerate the simulation environment test. Due to the lack of durability analysis of reinforced concrete members under real conditions, as well as the lack of experimental studies under a variety of external influence conditions, and the lack of relevant data, it is still unable to provide sufficient theoretical data basis for the durability research of CFRP bonded concrete members.

4. Research and development trends

In construction structure reinforcement and reconstruction process, research on the durability of CFRP reinforced concrete member and large amount of research and analysis to improve the verification,
evaluation for the durability of building structure after reinforcement is a blank, the current direction of research, set up after the durability of CFRP reinforced concrete structures system evaluation, establish the durability assessment method, calculation theory has important significance. In the process of structural reinforcement design, it is necessary to consider not only the integrity, strength and stiffness of the structural system, but also the durability after reinforcement. In the comprehensive design concept of reinforcement design, the durability factors of materials and the combination of materials and concrete body are taken into account, and the factors affecting the durability of materials such as the normal service life of materials and the performance of the combination of materials and concrete body and the environmental conditions used are also taken into account.

To protect the factors that affect the durability of CFRP reinforced concrete structural members, it is also a focus worthy of further study in the future related inspection and evaluation work. While improving the durability test of reinforced materials, it is necessary to study the durability of reinforced structures, design, evaluate and maintain the durability, and take comprehensive improvement of durability as an important goal of reinforced structures.

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