Exploration And Research on The Durability of FRP Composite Materials

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Abstract. Concrete cracking caused by steel corrosion is the main form of concrete structure deterioration at present. In order to solve the problem of steel corrosion, people begin to seek to replace steel with corrosion-resistant materials. Fiber reinforced polymer (FRP) has the advantages of high strength to mass ratio, good fatigue resistance, simple construction, corrosion resistance, etc., and has been widely used in engineering in recent years. In this paper, it analyzes the research status of FRP composites and introduces the properties of different kinds of FRP composites in detail. Then, by comparing with ordinary steel bar, the advantages of steel bar containing FRP material are highlighted. Subsequently, the durability of FRP composite materials in corrosion environment is studied. Finally, this paper introduces the practical application of FRP composites in engineering. The results are helpful to popularize the application of FRP composites in practical engineering.

Keywords: Fiber Reinforced Polymer; durability; corrosion environment.

1. Introduction

In the 1940s, Fiber Reinforced Polymer (FRP) composite was developed. Subsequently, researches of FRP in aviation, medical, transportation manufacturing and other fields have been rapid development [1]. Next, FRP is by virtue of its light weight, high strength and excellent durability characteristics, began to be applied in the field of civil engineering in the 1970s and 1980s. It mainly includes Carbon Fiber Reinforced Plastic (CFRP), Glass Fiber Reinforced Plastic (GFRP), Basalt Fiber Reinforced Plastic (BFRP) and Aramid Fiber Reinforced Plastic (AFRP) composite materials. Recently, the processing technology of FRP composite materials is becoming more and more mature, while the construction scale of domestic road, railway and other projects is growing, and the application of FRP composite materials in engineering construction will be very extensive. Therefore, it is very important to study the application of FRP composite materials in engineering. Recently, the researchers found that FRP composites provide strength and stiffness in one direction, while the resin matrix provides transverse support for the fibers, protecting them from corrosion, which provides a new way for us to further understand and explore FRP materials.

In this paper, four kinds of common FRP reinforced fiber materials are analyzed, and the differences between various FRP types and ordinary steel bars are compared. Then, the durability of FRP is analyzed and discussed. Finally, the application of FRP composite materials in engineering is introduced, which contributes to the popularization and application of FRP composite materials.

2. Research Status and Analysis of FRP

Fiber composite material is a new type of composite material with corrosion resistance and high strength, which is made by extrusion, winding and forming. The product was first produced in the United States in the 1930s and was widely used in naval and air equipment after the 1940s. In its composition, the material is made up of fibers that provide strength and stiffness, while the resin matrix provides chemical resistance and toughness.

FRP is divided into two main categories, synthetic and natural fiber reinforced composites. At present, the widely used synthetic fiber reinforced composites mainly include GFRP, CFRP, AFRP and BFRP. The following is a brief introduction of these fibers and resin matrix.

(1) Glass fiber is after high temperature melting paraffin stone, dolomite and other materials, and then through drawing, winding, weaving and other processes made. It is a nonpolar nonmetallic material. It is widely used in metallurgy, chemical industry, communication, electronics, construction, aerospace, transportation and other fields. Glass fiber has light weight, corrosion resistance, good insulation, strong designability and other excellent physical properties. The density of glass fiber is steel fiber 1/3, and the strength is comparable, can replace steel to greatly reduce the weight of the structure.

(2) Carbon fiber is made from high carbon content, heat treatment of non - melting man-made fiber. The production process includes heat stabilized oxidation treatment, carbonization treatment and graphitization treatment. Its carbon content varies from species to species, generally above 90%. Its excellent physical properties, showing outstanding heat resistance in non-oxidizing environment, axial tensile strength is 10 times that of steel, its resin composite tensile strength is 7-9 times that of steel.

(3) Aramid fiber is a new high-tech synthetic fiber, which was invented by DuPont in 1971. Aramid fibers are less dense and less conductive than carbon fibers. It has good rigidity and tensile toughness, higher ultimate elongation than carbon fiber, but also larger relaxation rate in wet environment. The elastic modulus and tensile strength of aramid fiber are lower than that of carbon fiber. The tensile strength of aramid fiber is 2600MPa ~ 3500MPa and the elastic modulus is 83GPa ~ 186GPa. The mechanical properties of aramid fiber will be decreased by direct ultraviolet irradiation.

(4) Basalt fiber is a kind of inorganic nonmetallic fiber material which is made from basalt as raw material after melting at 1500℃. Its melting point of basalt is up to 1500 ~ 1700℃, so basalt fiber has excellent high temperature resistance. Its mechanical properties can exceed 30% of the general-purpose glass fiber. It has high elastic modulus, high tensile strength, low creep rate, good fatigue resistance, and excellent high and low temperature resistance.

(5) The role of resin is to act as a matrix to bond the fibers together, so that the fibers are stressed evenly. The main function of matrix is to provide transverse support for fibers, protect fibers from physical and chemical corrosion of the surrounding environment, and transfer shear force [2]. The most commonly used resins in FRP products are unsaturated polyester, epoxy and phenolic resins. The properties of resin have a very important effect on the properties of FRP.

As described above, the mechanical properties of various FRP bars are compared with ordinary steel bars in Table 1, which shows that FRP has the characteristics of low density, high strength and good elastic modulus compared with ordinary steel bars [3].

Table 1 Comparison of basic physical and mechanical properties of FRP bars and rebar [3]

Type of bar material	Density (g/cm^2)	Coefficient of linear expansion (10-6/℃)	Ultimate tensile strength (MPa)	Yield strength (MPa)	Modulus of elasticity (GPa)	Ultimate elongation (%)
GFRP	1.25~2.10	6.0~10.0	483~690	--	35~51	1.2~3.1
CFRP	1.5~1.6	-9.0~0	600~3690	--	120~580	0.5~1.7
AFRP	1.25~1.40	-6.0~2.0	1720~2540	--	41~125	1.9~4.4
BFRP	1.90~2.10	9.0~12.0	600~1500	--	50~65	1.2~2.6
Rebar	7.85	11.7	483~690	276~517	200	6.0~12.0

3. Research Status of Corrosion Resistance of FRP Composites

3.1. Influence of Environment on Durability of FRP Bars

Durability of materials refers to the property that materials are durable and not easy to be damaged or lose their original properties under physical, chemical and biological effects, which reflects a comprehensive property of materials, such as frost resistance, weathering resistance, chemical erosion

resistance, fatigue performance, impact toughness, etc. [4].The corrosion resistance and non-conductivity of FRP bars make it widely used in concrete structures, especially in Marine buildings with harsh corrosion environment, bridge panels and pavement exposed to deicing salt, and buildings susceptible to electromagnetic field interference such as nuclear magnetic resonance rooms. However, the strength and stiffness of FRP bars are also sensitive to environmental conditions, such as temperature, moisture, acid, alkali, salt and UV [2].

3.1.1 Damage principle of FRP bars in corrosive environment

The damage of FRP materials in corrosion environment can be divided into three parts. (1) The resin matrix will hydrolyze with water and solution molecules, resulting in decreased bonding property and loss of bonding ability to fibers. (2) Due to the damage of the resin matrix, the bonding force of the resin-fiber interface decreases, resulting in the gradual loosening of FRP. (3) The further development of corrosion process leads to fiber damage and rapid deterioration of FRP material strength. The corrosion degree of various solutions to FRP materials is as follows, alkali solution, acid solution, salt spray (neutral) solution. High temperature can significantly accelerate the corrosion rate of FRP. The type of resin matrix has a crucial impact on the corrosion resistance of FRP materials [5].

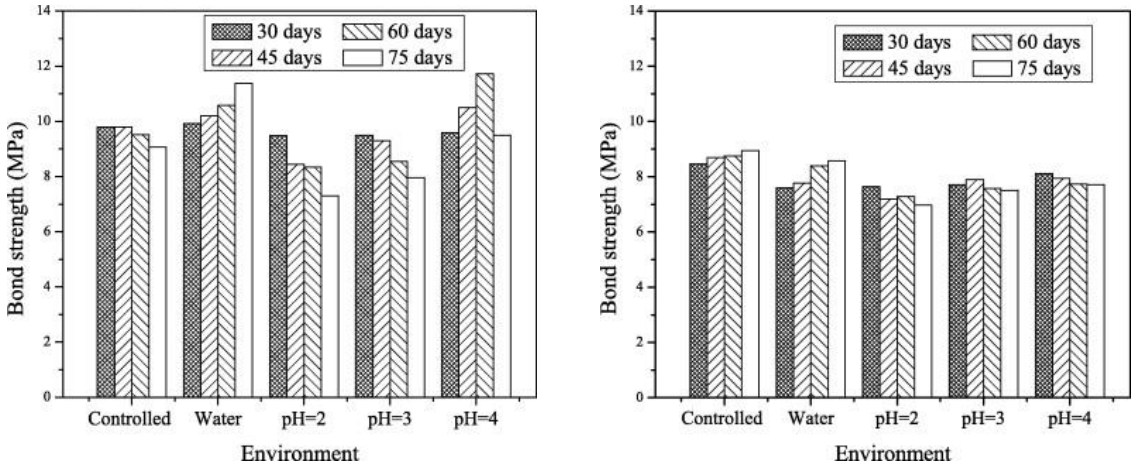
3.1.2 Influence of FRP bars in solution

(1) The influence of FRP bars in alkali solution

Micelli et al. [6] studied the changes of tensile strength and shear strength of short beams when FRP bars were immersed in alkali solution composed of 1.4%KOH+1.0%NaOH+0.16%Ca (OH)2 (pH=12.6) at room temperature and 60℃. The short beam test facility (ASTM 4475) was used to study the transverse and longitudinal mechanical properties. The test results show that the alkaline environment causes embrittlement of GFRP bars and produces micro-cracks. The increase of soaking temperature intensifies the erosion of alkali on polymer matrix, weakens the protection of fiber matrix and accelerates the deterioration of FRP bars. The transverse and longitudinal mechanical properties decrease with the increase of soaking time and soaking temperature.

(2) The influence of FRP bars in acid solution

An experiment showed that they used 120 GFRP bars and steel bars and concrete drawing test results, as shown in Fig. 1 [7]. As can be seen from Fig. 1, after soaking GFRP bars in tap water, pH=2, pH=3 and pH=4 for 75 days, the bond strength of GFRP bars and concrete decreases by 11%, 22%, 17.2% and 14%, respectively, compared with that under natural conditions. After soaking the steel bar at pH=2 and pH=3 for 75 days, the bond strength between the steel bar and concrete decreases by 19.6% and 12.3%, respectively, compared with the bond strength under natural conditions. With the decrease of pH value, the bond strength of GFRP bars and steel bars with concrete decreases, but the bond strength of GFRP bars decreases slightly.



(a) Rebar (b) GFRP

Fig. 1 Bonding strength of samples and concrete under different environmental conditions [7]

(3) The influence of FRP bars in high temperature environment

High temperature condition in engineering refers to fire. The high temperature resistance of FRP bars is determined by the matrix. Because the matrix is not resistant to high temperature, generally to 150~200℃, the matrix softens, melts or ignites. Fiber itself also has a certain high temperature resistance, such as aramid fiber resistance 200℃, glass fiber resistance 300 ~ 500℃, carbon fiber can resist 800 ~ 1000℃ high temperature under the condition of no oxygen. Tanano et al studied the influence of temperature increase on the tensile properties of a variety of aramid fiber and carbon fiber reinforced polymers [8]. The results show that the elastic modulus of AFRP and CFRP decreases with the increase of temperature, but the tensile strength of AFRP decreases with the increase of temperature. Therefore, the CFRP bars have good high temperature resistance. The degradation of FRP bars under the action of high temperature and strong alkali is the most serious, and the strength retention rate decreases by 20% ~ 30% after 120 days of corrosion [9] .

4. Application of FRP Composites in Engineering

4.1. Application in Reinforcement Engineering

For FRP materials, it is mainly mixed with fiber materials, so it has obvious advantages in material strength and other aspects. This also makes FRP material is widely used in the civil engineering industry for strengthening engineering, which can significantly improve the construction quality and safety of civil engineering [10].

(1) Beam reinforcement

The steel plate structure was pasted on the exterior of some beams to be reinforced with epoxy resin. In this way, the bending strength of the beam can be effectively increased by about 15%, and the construction operation is relatively simple.

(2) Pillar reinforcement

The FRP is used to wrap the structure surface. In this way, it can produce a certain closed wrapping effect on the pillar structure, so as to form an effective protective layer and achieve the goal of reinforcement. In the actual construction process, if the pillar itself is not a cylinder shape, the construction personnel are required to carry out some treatment work on the surface of the pillar first.

(3) Reinforcement of concrete slab

In the reinforcement work of concrete slabs with FRP materials, the specific application strategy is basically consistent with the reinforcement method of beam. The difference is that in the actual construction process, FRP materials should be effectively affixed to or effectively embedded in the tensile part of the concrete slab structure. This is to protect the concrete slab from related problems such as damage and cracking.

4.2. Application of FRP Bars

For FRP bars, it has the characteristics of high strength and light weight, simple process, corrosion resistance, good electromagnetic insulation, so at present in the concrete structure of FRP bars, shield technology and slope reinforcement have a wide range of applications. At present, there are two main applications of FRP materials. One is to wrap FRP around the column, which is mainly used for repair and reinforcement; the other is to pour concrete in FRP tube, which is mainly used in new construction projects [11]. Compared with the ordinary steel bar, it shows excellent performance. If used properly, it can effectively replace the steel bar or steel cable in the corresponding structure.

(1) Application in shield technology

FRP bars are widely used in shield technology of subway stations because of their advantages of good durability, easy cutting and high strength. In the specific application process, FRP bars are mainly used to replace the ordinary steel bars in the past to build a reinforced concrete maintenance structure, which can not only meet the requirements of the maintenance structure, effectively ensure

the smooth passage of the shield machine, but also reduce the damage caused by the maintenance structure to the blade of the shield machine during drilling.

(2) Application in slope reinforcement

Because FRP bars have strong durability and corrosion resistance, they are widely used to replace steel bars in slope reinforcement engineering. For example, in a section of National Highway 209 in Xuan 'en County, as the upper slope on the right side reaches about 30m in height with steep slope, the corresponding formation lithological rock is also argillaceous siltstone, which is characterized by low strength and easy weathering. In order to ensure the safety and smooth development of construction, multi-layer FRP anchor bolt is used for reinforcement. The slope stability has been greatly improved.

(3) The application of FRP bars and concrete structures

At present, it has been widely used in freeze-thaw and high-saline-alkali areas, which can effectively avoid the damage caused by corrosion problems on the structure, significantly reduce the maintenance cost, and effectively extend the service life of the structure.

5. Conclusion

The unique microchemical structure and composition of carbon fiber, glass fiber, aramid fiber, basalt fiber and their composites make them have excellent mechanical, heat resistance, corrosion resistance and other comprehensive properties. Therefore, these composites can be used to produce highly durable buildings and serve the national community. In this paper, four kinds of common FRP materials are studied, respectively, and the application of FRP composite in engineering is introduced. Compared with traditional steel, wood, cement, concrete building materials, FRP has light weight, high strength, corrosion resistance, design and other performance advantages. FRP can better meet the development needs of the construction industry, improve the efficiency and quality of the construction process. At the same time, it can also be fully applied in engineering to ensure its safety and promote the healthy development of civil industry.

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