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Application of corrosion resistance of FRP composites rebar in sea water sea sand concrete

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Abstract. In recent years, Fiber Reinforced Polymer(FRP) has been widely used as a reinforcement material to improve the flexural capacity of beams and slabs, and FRP has good corrosion resistance. And because of the wide variety of fiber materials, so more than the role of ordinary steel.This paper will discuss whether it can replace steel to improve building durability in alkaline environment such as seawater sea sand concrete.Due to the lack of natural river sand and water resources, people have been trying to use sea sand seawater instead in recent years. But there are many safety accidents because of the corrosion of steel bars. Due to the good corrosion resistance of FRP, this paper discusses the feasibility of its service as a steel bar in marine sand concrete, including its failure characteristics after corrosion and the problems and improvement strategies when working with Seawater-Sea Sand Concrete(SWSSC). The research object of this paper is Glass Fiber Reinforced Polymer(GFRP) steel bar and Carbon Fiber Reinforced Polymer(CFRP) steel bar. Glass fiber and carbon fiber are widely used materials in current production activities, mostly in the field of mechanical manufacturing. Although engineering materials have been used in recent years, the time is short. In this paper, it is discussed that in the simulated pore solution of concrete stirred by seawater and sea sand and exposed in the environment of seawater immersion, by increasing the temperature to accelerate the reaction rate, it is found that the corrosion resistance of the two kinds of steel bars is very different, but the corrosion mechanism is similar, both of them are caused by the dissolution of the resin matrix. The fiber is bare, and the internal fiber actually has the bearing capacity, but the ability of the material to bear the force is still reduced due to the loss of the bonding of the resin matrix. Therefore, this paper proposes that it is possible to find a more corrosion-resistant resin matrix or add a layer of medium at the interface between the fiber and the matrix to maximize the role of the fiber.

Keywords: GFRP steel bar, CFRP steel bar, corrosion resistance, Seawater-Sea Sand Concrete.

1. Introduction

In 2019, the annual consumption of sand and stone aggregate in China reached 21.3 billion tons, which is the largest mineral resource at present, accounting for about half of the world's annual output [1]. Excessive exploitation has caused a series of problems, such as excessive excavation of river sand, which will damage the riverbed, damage aquatic animals and affect the environment. Since the1990s, due to the scarcity of river sand and rising prices in mainland China, many coastal areas began to use desalted sea sand as fine aggregate in concrete for construction and civil infrastructure projects, such as Shoushan Port, Shanghai Baosteel Group [2]. Now most examples of sea sand used as concrete are desalted by washing with fresh water, for example, to avoid steel corrosion in reinforced concrete structures. China's " Technical specification for application of sea sand concrete" (JGJ206-2010) also has relevant provisions. However, this does not solve all the problems. It may be on account of the cost of desalination sea sand technology will increase relatively, the desalination results will not meet the requirements in the production process, resulting in excessive salt. The final result is that there have been large-scale cracks or even collapses in houses caused by corroded steel bars in sea sand.In the early 21st century, "sea sand houses" were found in Hangzhou, Ningbo, Quanzhou, and other coastal areas of China. These buildings will lose some bearing capacity in five to fifteen years and become dangerous. If not handled in time, sudden collapse may occur [3]. Since the 1940s, FRP materials have been widely used in the aviation, aerospace, shipbuilding, automotive, chemical, medical, and mechanical fields. In recent years, FRP has begun to be applied in civil and construction engineering structures with its advantages of high strength, light weight and corrosion resistance, and has attracted wide attention from the engineering community [4]. At present, the most commonly used fiber-reinforced polymer composites rebar in engineering field are mainly carbon fiber, glass fiber and aramid fiber reinforced resin matrix et al.Which are referred to as GFRP, CFRP and AFRP. In this paper, the application feasibility of corrosion resistance of GFRP and CFRP in SWSSC is only discussed.

2. Corrosion resistance of FRP steel bar

2.1. Corrosion reasons in seawater

It is generally believed that the chloride ion content has a significant impact on the corrosion of ordinary steel bars in reinforced concrete, and the chloride ion in seawater is abundant [5]. Table 1 shows the physical properties and chemical composition of seawater, in which the content of chloride ion is significantly higher than that of other components [6]. Chloride ions have good infiltration of the concrete through pores. If the concrete is not dense, it will lead to the corrosion of steel bars in reinforced concrete, thus causing concrete damage [7]. Studies have shown that when the free Cl concentration in sea sand reaches 0.3 %, the corrosion of reinforcement is obvious. The weight loss rate of corrosive steel in sea sand concrete increases with the increase of sea sand content and water cement ratio [8]. This should also be concerned in the corrosion test of FRP material.

Table 1. Physical properties and chemical composition of seawater.

Specific gravity	pH	Na(ppm)	K(ppm)	Ca(ppm)	Mg(ppm)	Cl(ppm)	SO_4(ppm)	CO_3(ppm)
1.022	7.77	9290	346	356	1167	17087	2378	110

2.2. Changes of tensile strength of FRP steel bar in simulated pore solution corrosion environment of sea sand concrete

It has been found that FRP steel has better corrosion resistance than ordinary steel [9]. Under the simulated environment of sea sand hole solution, through accelerated corrosion test, the tensile strength retention rate of GFRP steel at 25 °C after 84 days of corrosion reaches 88.6 %, while that of CFRP steel exceeds 90 %. Fig. 1 of normalized tensile strength of epoxy-based G / CFRP bars immersed in SWSSC pore solution at 25 °C, 40 °C and 55 °C for 21 days, 42 days, 63 days and 84 days shows that the degradation degree of standardized tensile strength of CFRP reinforcement is significantly smaller than that of GFRP reinforcement [10]. This is because carbon fibers are not corroded in SWSSC solution, while glass fibers are corroded and destroyed in the corroded area. It can be seen that CFRP reinforcement has better corrosion resistance than GFRP reinforcement. However, in practice, the service temperature of FRP rib under SWSSC package rarely reaches 55 °C. And this experiment simulates the situation that seawater has reached the surface of steel bar through concrete-driven SWSSC solution in the marine environment.

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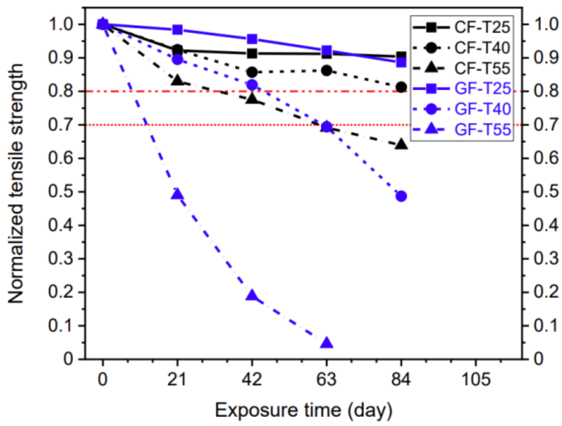

Figure 1. Normalized Strength Degradation of Epoxy G / CFRP Bar[10].

2.3. The failure mode of FRP steel bar under corrosion in seawater environment

Sun Li artificially prepared a solution of five times the mass concentration of seawater, and studied the change of compressive strength of GFRP reinforcement in seawater immersion environment[11]. They found the same results as other reaschers.The resin matrix in GFRP reinforcement, which plays a protective and bonding role, was first eroded. As the erosion area increased, the fiber and resin were peeled off, resulting in damage. Shear failure is the main failure mode in compression, and the probability of splitting failure increases with the increase of corrosion. The internal structure of glass fiber reinforced plastic (GFRP) bars before and after erosion was observed by SEM. The results show that the fiber and resin of GFRP bars are tightly bonded and the fiber is full before erosion. After erosion, the bond between GFRP fiber and resin becomes loose and debonding occurs. With the increase of stress level and erosion time, this phenomenon becomes more obvious, as shown in Figure 2 [12].

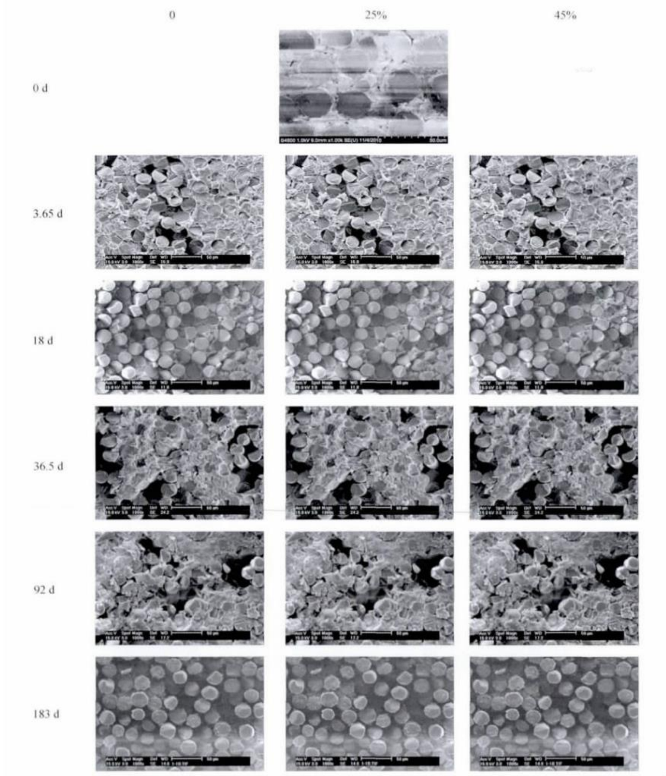

Figure 2. SEM image of the GFRP rebars at different levels before and after being exposed to alkaline solution[12].

3. Joint work of FRP steel bar and SWSSC

From the above research results on corrosion, it can be considered that the service effect of CFRP reinforcement in SWSSC may be the best. From the specific strength and specific modulus, the application effect of carbon fiber material is also the best in use. However, other papers found that the elongation of carbon fiber material is very small, and the ductility of FRP reinforcement is mainly through the bonding of resin matrix and concrete. So after a certain degree of corrosion. Although FRP reinforcement has strength, it fails to play a role due to the loss of bonding performance with concrete and cause many cracks at inter face.

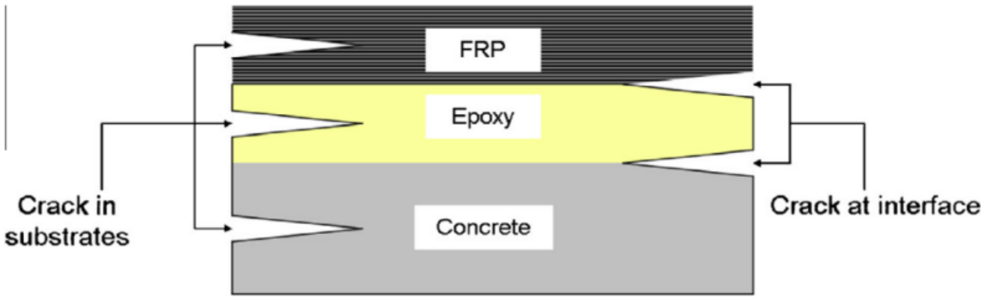

Figure 3. A tri-layer system consisting of concrete,epoxy, FRP.[13].

According to the three-layer system of FRP, epoxy and concrete in the figure, it can be seen that there are two kinds of failure modes when the steel bar and concrete work together. Crack in substractes generally depends on the strength of the matrix, and crack at interface is largely related to the bonding ability of these three components. Epoxy is the most important intermediate layer among them, which ensures the synergistic force of the fiber, and is also the part of the contact between the steel bar and the concrete. Therefore, the key to ensure the cooperative work of the steel bar and the concrete is still the durability of the epoxy resin. However, according to the above research, the resin matrix is also the first part to be directly corroded. Due to the weak alkalinity of seawater and sea sand concrete, even if the alkali resistance of epoxy resin is good [14], it is still unable to withstand the corrosion directly in the alkaline solution environment for a long time. This result is obviously unfavorable to the engineering structure. Therefore, more engineering examples and durability experiments are needed to verify whether the strength degradation level of FRP steel bars and seawater sea sand concrete can meet the conditions of structural design service life required by various national specifications.

4. Conclusion

FRP materials have not been produced for more than 60 years, and only 40 years have been used in civil engineering. In the actual environment, there are many factors that jointly affect the durability of FRP materials. Among the application examples in China, there are examples of FRP structure failure due to durability, and there are engineering examples that have been applied for more than 20 years. As a result, more research is required. In view of the fact that the corrosion resistance of epoxy resin can not reach the ideal state in the experiment, but because the current simulation experiment research generally simulates the possible changes of materials in decades by increasing the temperature to accelerate the reaction rate, it is impossible to obtain the influence of various harsh environments on the performance of epoxy resin[15]. Therefore, more engineering examples and experiments are needed to verify the change process and speed of long-term contact between epoxy resin and seawater sea sand concrete. My point of view is that the resin matrix is critical to the cooperative working ability and durability of FRP with seawater sea sand concrete combination.

In the contrast experiment of GFRP and CFRP, because the carbon fiber is not corroded, the strength decrease of CFRP is obviously less than that of glass fiber, but in fact, the reason for the decrease of strength is that the fiber cannot cooperate with the force caused by the corrosion loss of resin matrix. It is worth noting that the ductility of carbon fiber is poor. Compared with ordinary steel bars, this will adversely affect the construction and the creep of concrete in the later stage. As a result, it is impossible

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to say that CFRP is superior to GFRP. It can be considered to mix carbon fiber with other fibers to achieve better ductility.

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