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A review of the application of FRP materials in Asia-Pacific region

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Abstract. FRP (Fiber Reinforced Polymers) materials are being increasingly used in various engineering fields due to their high specific strength, designability and durability. Having been rapidly developing in recent years, the Asia-Pacific region is also equipped with a continuously expanding demand for the research and application of FRP materials. This paper summarizes the application of FRP materials in the Asia-Pacific region through literature and case analysis. Some of the current issues existing in the procedure of FPR materials application are discussed, and predictions on the development and application prospects of this kind of materials in the Asia-Pacific region are also briefly suggested. It is found that FRP materials have been widely utilized in various fields including concrete structures reinforcement, bridge engineering construction and new energy facilities in the Asia-Pacific region, where is equipped with a relatively broad and promising market. Meanwhile, the shortcomings relevant to this kind of materials in several aspects, such as expensive unit prices and imperfect technical specification systems, also restricted the application of FRP materials in this region.

Keywords: FRP, Asia-Pacific region, Application cases, Materials properties

1. Introduction

FRP, short for Fiber Reinforced Polymers, is considered as a kind of composite, which is combined with at least two constituent (parent) materials. By equipping with improved properties, composite materials own functional superiority compared with their parents. FRP materials are generally consist of high strength continuous fibers and polymer matrix; the former, which is embedded in a polymer matrix, acts as the main reinforcing elements, and the latter is considered as the binder in the material, and can not only keep the fibers protected but also promote the load transferring between these fibers.

Benefiting from the composition of the material, FRP possesses the advantages of high specific strength, high specific modulus, strong designability and favorable durability, especially for corrosion resistance. These features make FRP materials widely utilized in various fields such as buildings, bridges, marine engineering, hydraulic structures and underground structures.

As a region with strong vitality and rapid economic development in the world, the Asia-Pacific region has been rather active in the construction of infrastructure in recent years, and under such situations, FRP materials have also been developed and used to a greater content in this area. By exemplification and induction methods, this paper summarizes the application of FRP materials in the Asia-Pacific

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region, and analyzes some problems existing in the utilization of FRP materials, which provides constructive references for the construction of projects or facilities in this area.

2. Material application

2.1. FRP application in complex environment

As one of the most common materials in the field of engineering construction, reinforced concrete has been favored in scientific research, development and application for more than a century because of its high reliability and good economy. Steel bars, which are the main materials constituting traditional reinforced concrete structures, can greatly make up for the lack of tensile strength of concrete materials and enhance the mechanical properties of the structures. However, various reasons, such as insufficient consideration of the concrete cover, low quality concrete structures construction or corrosive factors in the environment (sea water, high moisture, etc.), could lead to the occurrence of cracking on concrete and the corrosion of steel bars to a certain extent. According to Schmitt (one of the administrators of the World Corrosion Organization), the global annual costs on downtime and maintenance caused by component corrosion exceeded 1.8 trillion US dollars (US$), which accounts for 3% to 4% of the average gross domestic product of industrialized countries [1]. This issue is even more severe for the Asia-Pacific region, where most of countries have relatively long coastlines and harsh environmental conditions. It is estimated that the total annual cost of repair and replacement resulted from the corrosion of steel bars in Australia could approximately reach 13 billion Australian dollars (AU$) [2]. As another major industrial country with growing need and rapid development on infrastructure projects in the Asia-Pacific region, steel bar corrosion also has an equally huge impact on China's engineering construction. In 2014 alone, China's losses due to the corrosion in the marine environment had already reached 700 billion Chinese Yuan (CNY) [3].

To fundamentally solve the problems related to the durability of concrete structures caused by the corrosion of steel bars, especially for scenarios with more severe environmental conditions such as coastal and marine areas, some scholars and engineers have begun to explore and practice the substitute materials for steel bars. As a category of materials that also have relatively high mechanical performance and superior corrosion resistance, FRP materials are considered to be capable of significantly improving the durability and extending the service life of reinforced concrete structures in coastal and marine scenarios. By reducing the frequency of repairs and replacement, reinforcing concrete structures with FRP bars could also improve the economy of the structures or facilities, which means a considerable value-in-use. Asia-Pacific countries represented by Japan, China and Australia have started the exploration and application of these materials since the end of last century, and the concrete structures reinforced by FRPs have been widely accepted and used in this region as a reasonable solution to harsh environments [4].

During the construction of the Pinkenba Wharf, which is located in Brisbane, Australia, in order to protect the project from marine corrosion, some facilities in the project adopted a completely non-metallic structural system. One of them is a 252-meter-long, 16-meter-wide wharf containing 191 precast geopolymer concrete decks reinforced by glass FRP (GFRP) bars. A total usage of 152 tons of FRP bars made it the largest single application of these materials in Australia [4]. Except for being utilized as the reinforcement in concrete beams, columns or slabs, FRP bars can also serve as other stress-bearing components in such environments. During the early design stage of Jurong Rock Caverns, which is the first underground cavern facility for the storage of liquid hydrocarbons in Southeast Asia, steel anchors grouted with resin polymers were supposed to be the anchoring structures for the caverns. Nevertheless, considering the high corrosive environment, more than 80,000 cement-grouted GFRP solid or tubular bars were finally employed to anchor the caverns, which has been proven to be another successful application of FRP materials in the complex environment in the Asia-Pacific region [5].

The sewage treatment system, whose corrosive media are slightly different from those in marine or coastal environment, is also a noteworthy scenario for the application of FRP materials. Sewage usually contains high concentrations of chlorine or other halogens, and these substances can also lead to serious corrosion to steel bars or other metallic components. For traditional steel bar reinforced concrete structures, the corrosion of steel bars would not only deteriorate the mechanical performance of reinforced structure, but also lead to an expansion of steel bars volume, then accelerating the cracking and damage of concrete, resulting in the leakage of sewage storage facilities, such as sewage tank. Besides, as an essential part of the sewage treatment system, sewage pipe network also faces the risks of severe corrosion, even if certain anti-corrosion treatment has been adopted on their inner surfaces.

In this kind of environment, FRP materials, which are extremely resistant to chlorine or other halogen corrosion, have become an effective solution. A study in 2020 pointed out that although using FRP materials to reinforce concrete sewage storage tank will incur higher initial costs, if a life cycle cost analysis is introduced in the comparison and evaluation for all possible reinforcement solutions (black steel, steel with coating, stainless steel and GFRP), using FRP bars as the reinforcement of concrete tank is still owning the highest economy among them [6]. According to the studies related to sewage pipelines, similar conclusions could be obtained, that is, from the perspective of the entire life cycle, using pipelines made or coated by FRP materials is more economical compared with metallic materials [7]. The research related to the reinforcement of storage facilities in sewage treatment system is mainly based on engineering cases in North America, and such application is relatively scarce in the Asia-Pacific region. However, researchers in China have conducted a series of studies focusing on applying these materials in sewage pipe networks in recent years, which also reflects a promising application prospect in this region [8].

2.2. *FRP application in complex loading situations*

Affected by various complex loading combinations (such as the coupling effect of wind, snow and traffic load, etc.), some transportation engineering projects, especially bridge projects, may suffer from the performance degradation caused by fatigue, creep and other factors, leading to an insufficient performance in a long-term service life. It has also become a major issue that how to reduce the structural weight and improve the mechanical properties for the bridge structures with large spans, to achieve a balance between the reliability and economy of the projects. To achieve the goals above, except for using some performance enhancement technologies for main traditional materials such as steel and concrete, the utilization of FRP materials in such scenarios has also gradually become a widely accepted and applied method.

The application of FRP materials in bridge engineering is relatively diversified, they can be used as reinforcing and strengthening members of the concrete bridge structure, or served as the main material constituting the main body of the bridge, taking their advantages of high specific strength. In the aspect of bridge reinforcement construction, more advanced and targeted methods of FRP reinforcement have emerged in these years, such as a complete set of tension anchoring technology developed for embedded BFRP bars reinforcement, and a combined reinforcement technology on BFRP bars and grids, which has been successfully practiced in the repairing project of Nanjing Yangtze River Bridge in Eastern China [9]. By bonding the BFRP grids to the decks or the main beams at the bottom of the bridge, or embedding bars on the bridge decks, it could significantly enhance the bearing capacities of bending moment and shearing forces, and prevent the cracking on the decks.

FRP materials have also been proven to be applicable as the basic unit of bridge structures. According to related statistics, there are currently hundreds of bridge projects built with FRP (as the main material) in the world. In another Asia-Pacific country, Japan, since the completion of the first FRP bridge, the Okinawa Road Park Footbridge, in March 2000, a series of footbridges using FRP materials have been built. To guarantee the rationality and reliability of this type of bridge structure, the Committee of Hybrid Structures of Japan Society of Civil Engineers published the Guidelines for Design and Construction of FRP footbridges in 2011, which enriched the design and construction system for the bridges built with FRP materials in this country [10].

Another application scenario of FRP materials under complex loading conditions is the blades of wind turbines. Blade is one of the crucial components of these equipment, and the materials used to produce blades should be in compliance with following requirements, and which are exactly the features of FRP materials: (1) the density is small; (2) the fatigue resistance is considerable and (3) the elasticity, the inertia during rotation and the vibration frequency could remain normal. Meanwhile, to ensure the performance of wind turbines, the blades need to be designed and produced based on aerodynamic principles, which corresponds to one of the advantages of FRP materials, high designability and processability.

As the areas with abundant wind resources, the amount of newly installed wind power generation facilities increased annually in the Asia-Pacific region. In 2015, the total installed capacity of onshore wind power in the Asia-Pacific region was approximately 161GW, and in 2021, this number had increased to 358MW [11]. In the sector of offshore wind power, the market vitality in the Asia-Pacific region is equally astonishing. According to relevant predictions suggested by “Global Offshore Wind Report 2023” released by the Global Wind Energy Council (GWEC), by 2032, there will be a total capacity of more than 380GW offshore wind power facilities, while half of them will be built in Asia-Pacific region [12]. The rapid development of the wind power industry has promoted the consumption and application of FRP materials in this region, and will also drive the production, exploration and development of FRP materials in the countries of the Asia-Pacific region to a certain extent.

3. Existing issues in FRP application

Although researchers and engineers around the world have been exploring, developing and applying FRP materials to engineering practices for decades, these materials still have some shortcomings in terms of their material composition, mechanical properties and application system.

Firstly, as a kind of materials that will be widely and increasingly utilized in engineering projects, the material and production costs of FRPs are still relatively high compared to traditional materials (such as carbon steel or aluminum alloy), which can affect the economy of the structures and projects. According to a study based on the reinforcement materials for a sewage storage tank located in Canada, if the indicator referring to the economy is ‘cost/unit volume of tank’, the initial cost of using FRP as reinforcing materials is nearly two times of the solution with black steel, and 1.5 times of steel with epoxy resin anti-corrosion treatment [6]. Higher initial investment means a longer cost return period, which could increase the risk of construction investment to a certain extent.

In terms of material durability, FRP materials also have weaknesses. As the binder of fibers, resins are supposed to show a downward trend in their performance when the ambient temperature exceeds 50℃. If exposed to such an environment for a long time, it could eventually lead to the deterioration of FRP materials and then result in the damage or failure of the overall structure.

On the aspect of engineering practice, another major factor restricting the application of FRP materials is the imperfection or even the lack of relevant design and construction codes or specifications. The relatively complete standards or code systems related to FRP materials in the world mainly come from North America. However, in the Asia-Pacific region, where the demand for FRP materials is rapidly increasing, there is still a certain lack of specifications that are relevant to them [4]. Even Japan, which is the country that published the first standard related to FRP bars, is also in urgent need of supplementary on technical specifications or codes for the engineering structures and facilities based on FRP materials [10].

4. Trending development of FRP materials

The directions and prospects of future development for FRP materials in the Asia-Pacific region can be elaborated from the following aspects. As one of the primary utilizations of FRP materials, which is to reinforce concrete structures, is still equipped with a promising market. Manalo estimated that more than 2.5 million meters of GFRP bars were installed in the projects over Australia between 2012 to 2018, and the market value of FRP bars reached approximately AU$ 5 million in 2017, which would still continue to increase with an annual growth rate of 13% [13]. Considering the environmental factors such as climate change, the probability of corrosion caused by chloride will increase by 5% to 15%, which will make FRP materials more and more adopted in the repair and reinforcement of concrete structures [14].

Except for being used as reinforcement materials for concrete structures, FRP materials can also serve as the replacement of some traditional materials such as steel in the form of profiles to build the main body of structures or facilities. Most of these application scenarios require a light structural weight, satisfactory mechanical properties and a qualified durability when being utilized in harsh environments. One possible scenario of such application is using FRP materials to appropriately replace steel or aluminum alloy as the component materials of mounting structures in solar power project, which is also experiencing rapid growth in the Asia-Pacific region in recent years. Additionally, based on the fact that most countries in this region own sufficient marine resources, components or structures (such as pipes, fences or grid panels, etc.) made of FRP materials could also be extensively adopted in marine or coastal engineering including offshore operating platforms and seaport facilities. Moreover, as a precondition for a kind of materials that could be utilized in engineering practice reasonably, efficiently and wholescale, optimized production procedure and supporting technical specifications related to the production, design and construction can also be expected to be a focus point on the subsequent development of FRP materials application.

5. Conclusion

This paper summarizes and discusses the current application status of FRP materials in the Asia-Pacific region based on related research and relevant engineering cases, as well as the difficulties and issues currently faced, and finally puts forward several potential directions or aspects of the application and development of FRP materials in this region: FRP materials have been widely utilized in concrete structures reinforcement, pipeline engineering, traffic engineering (especially for bridge engineering) and new energy engineering in the situations of complex environmental or loading conditions in the Asia-Pacific region, due to their outstanding mechanical properties, designability and durability. The relevant market is vast and also showing a trend of continuous expansion, which indicates a promising prospect of FRP materials application in this region.

This paper mainly focuses on the application of FRP materials in complex environmental and loading conditions. In addition, due to the various advantages of this kind of materials, direct utilization of FRP materials to form the building facades or structural components has gradually become mainstream in the current building industry. Besides, resulting from their satisfied durability, FRP materials are often used for anti-corrosion treatment of buildings or structures in the form of coatings or wraps, etc. This paper does not provide a more detailed introduction and discussion on the application of FRP materials in other aspects that include these two points above, and might underestimate the market prospects of these materials in the Asia-Pacific region to a certain extent.

The main constraints on the application of FRP materials in engineering practices in the Asia-Pacific region and even around the world at present, are more than some shortcomings of the materials themselves, including high manufacturing costs and a relatively imperfect standard system. The research and development for FRP materials in the future could also appropriately focus on the supplement and improvement of codes or technical specifications, as well as the enhancement and optimization of the manufacturing technologies for FRP materials, to fulfill the demands of mass production and standardized utilization.

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