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Research on the application prospect of GFRP in reinforced concrete structure

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Abstract. The field of civil engineering needs to take advantage of new technologies to improve the quality of construction. The use of fiber-reinforced polymers (FRP) to improve the strength, durability, and sustainability of buildings is the main focus of this paper. Through the research and analysis of material properties, it was determined that the most suitable material in the field of civil engineering is glass fiber reinforced polymer (GFRP). Then find out the strengths of the method and existing problems, and analyze the future research direction. It is found that GFRP has made certain contributions to civil engineering, but there are still some shortcomings such as insufficient performance and not being familiar with by the society. In the future, it is necessary to study the design specifications and Aged Test methods of FRP, and find new materials possible to improve the performance of FRP at the same time.

Keywords: GFRP, strength, durability, sustainability, RC structure

1. Introduction

The rapid growth of the civil engineering has led to the requirement for continuous material improvements in terms of strength, ductility, density, control of expenditure, and sustainability to meet increasingly high building standards, which requires the integration of new technology and materials into the traditional construction industry. Fiber reinforced polymer (FRP) has played a key role in the field of strengthening existing constructions and will be significant in future design as an essential material. In the paper, the properties of FRP and the influence of GFRP on concrete structures will be analyzed, which will play a significant role in the use of advanced sustainable materials in the civil engineering industry.

2. Introduction of FRP

Fiber reinforced polymer (FRP) is a combination of two main materials, fibers and polymer resin, and sometimes other auxiliary materials. FRP is different from traditional reinforcement, which is anisotropic, while common reinforcements such as steel and aluminum are isotropic. So, the proper layout of FRP can show better properties. In addition, the fiber is a brittle material that carries loads along the fiber's direction and provides strength and stiffness, while the resin matrix is a ductile material that can withstand a large strain. The FRP formed by them is hard and lightweight, with a high strength-to-density ratio and excellent corrosion resistance. It can replace metal materials in many structures, especially in aggressive environments [1].

3. Properties of FRP

FRP is also divided into different categories according to different fiber material choices and properties. The most commonly used fiber reinforced polymer in civil engineering structures are Glass Fiber Reinforced Polymer (GFRP), Carbon Fiber Reinforced Polymer (CFRP) and Aramid Fiber Reinforced Polymer (AFRP). [2]

3.1. Comparison

3.1.1. Coefficient of linear expansion. The coefficient of linear expansion refers to the capacity of the material to expand in volume at high temperatures, which affects the temperature stress of the reinforced concrete. As is shown in Table 1 that the longitudinal coefficient of linear expansion of FRP is lower than that of steel.

Table 1. Comparison in coefficient of linear expansion.

Direction	Coefficient of linear expansion			
	CFRP	GFRP	AFRP	Reinforcement
Longitudinal	-4~-2	6~10	-6~-2	11.7
Transverse	23~32	21~30	60~80	11.7

3.1.2. Mechanical property. Mechanical properties are highly related to the most critical index in structure and strength. In reinforced concrete structures, the concrete is mainly responsible for bearing the pressure, while the reinforcement is responsible for carrying the tension. Therefore, the material with higher tensile strength can withstand more tension, so the strength of the structure is improved, but the tensile strength should be balanced with the compressive strength that the concrete can withstand, otherwise, it will cause waste of materials.

Table 2. Comparison in mechanical property [3].

Material	Density (Kg/m^3)	Elasticity modulus (Mpa)	Tensile strength (Mpa)	Ultimate strain (%)
CFRP	1800	2×10^6	3600	1.6
GFRP	2580	6.6×10^4	2890	2.4
AFRP	1440	1.2×10^5	3500	2.8
Reinforcement	7850	2.1×10^6	400	10

3.1.3. Durability. The durability of materials is closely related to the durability and service life of the entire building, which is also an essential index of structure. Details are in the following Table 3.

Table 3. Comparison in durability propert.

Resistance	CFRP	GFRP	AFRP
Alkali	95%	15%	92%
Acid	100%	100%	60~85%
Dynamic fatigue	85%	23%	70%
Freeze-thaw cycle	100%	100%	100%
Ultraviolet radiation	100%	81%	45%
Hyperthermia	80%	80%	75%
The value is the percentage of ststic strength of materials			

3.2. Benefit

Specific tensile strength: GFRP is a kind of lightweight and high-strength material, whose density is only approximately 1/4 of that of carbon steel in a situation of similar tensile strength, more than 10 times the strength of ordinary steel [4].

Corrosion resistance: GFRP has higher corrosion resistance than traditional reinforcement, which is resistant to acids, alkalis, organic solvents, and microorganisms' activities.

Fatigue resistance: The tensile property of GFRP is excellent. The fatigue resistance of the general metal materials is 40% to 50% of their tensile strength, but that of the composite materials can be as high as 70% to 80% [5]. As a result, the fatigue resistance of GFRP is better than that of steel bars.

Designability: Various forms of GFRP can be used to strengthen the existing structures and future designs in order to improve the performance of different aspects of the structures, such as sheet, grid, bar, etc.

Bond with concrete: The linear expansion coefficient of GFRP is similar to that of concrete, so the volume expansion caused by temperature is smaller than that of traditional steel, and the temperature stress is thereby reduced. Therefore, the deterioration of the bond between the two main components will not be caused by the temperature variation.

3.3. Drawback

Elasticity modulus: GFRP has a low elastic modulus and poor deformation resistance, so it is not suitable for bearing large dynamic loads, but it can replace some auxiliary reinforcement to improve the durability of constructions.

Compressive strength: The compressive strength and shear strength of GFRP are much lower than its tensile strength.

Long-term high temperature resistance: Under a fire environment, it is easy to be ignited, and the resin matrix is prone to soften, so the mechanical properties of GFRP will be decreased, and it is necessary to add a fireproof coating to the surface in case of emergency. [5]

Lack of design specification: There are considerable standards and literature to guide the designer in determining the reinforcement nowadays. But GFRP, as a new material, does not have this advantage. This can lead to design hesitation by engineers or insufficient construction capacity.

3.4. Influence factor

Composition and process: Different types of fibers have different properties, and different resin matrices have different corrosion resistance. And only those made in strict accordance with the proper conditions and processes can have enough quality.

Pretreatment: Physical or chemical treatment can be used to change the fiber surface and its internal structure, so as to increase the adhesion at the interface and the combination of the resin matrix and fiber to improve the performance of GFRP. [6]

There are some more complex factors that will affect the performance of GFRP, such as size effects, confinement methods, cross section, fiber volume and fiber orientation.

4. Potential problems in existing structures

4.1. Strength

Poor initial design, construction and maintenance can all lead to damage and loss of strength in the structure. Moreover, in severe situations such as earthquakes and hurricanes, the strength of the structure may not be enough to carry these sudden loads.

4.2. Durability

In civil engineering and infrastructure construction, structural degradation can also be caused by low durability, especially in areas with high levels of chloride in the air, such as coastal areas. After the original structure has eroded, the additional expense of repairing the degraded structure and replacement

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costs is often more than double the original building cost [2]. Therefore, it is essential to determine appropriate ways to prevent premature deterioration of buildings and extend their service life.

4.3. Sustainability

Sustainable development has become a widely concerned issue, and according to the current trend of environmental protection, this will become more important in the future and extend to other fields. So, how to improve the sustainability of buildings should not only be considered from aspects of design, such as green roofs and improving the utilization rate of natural light and ventilation, but also innovative materials to reduce pollution from the source.

5. Solution with GFRP

5.1. Strength

The mechanical properties of existing structures can be effectively improved by pasting or embedding GFRP into the tensile surface. The most effective reinforcement method for concrete structure columns is grid winding strengthening, which can change the failure mode of concrete columns and improve their construction shear resistance and ductility to resist earthquakes [7]. The main improvement in concrete beam and plate bending resistance is to paste GFRP sheets, which is to use structural adhesive to stick to the main stress parts of the members, in order to enhance the bending, shearing, torsion, and section ability of reinforced concrete structural members [8]. However, because the elastic modulus of GFRP is lower than steel and the GFRP sheet is deformed under the secondary load of the original structure rather than in perfect combination with the structural member, this method cannot exploit the full strength of the GFRP sheet, which will cause waste. [9]

As an organic combination of glass fiber and resin matrix, GFRP has some advantages that steel cannot match. Its density is much lower than that of steel bars, so its quality is very low, which can effectively reduce the self-weight of the buildings and increase the carrying capacity of the structures. The tensile strength of GFRP is higher than that of traditional reinforcement, so it can improve the seismic and fatigue resistance of concrete structures. The linear expansion coefficient of GFRP is smaller than that of steel reinforcement, which can slightly reduce the temperature stress and deformation of concrete structures caused by high temperatures, making the structure safer and more reliable.

5.2. Durability

As an organic material, GFRP does not react with chloride ions to affect its performance, so it is not as easy to rust or be corroded as steel bars, which makes it more adaptable to the coastal environment with high humidity and high chloride ions. Even in a daily environment, it has a longer service life than traditional steel-bar-reinforced concrete structures. Furthermore, this material also has excellent resistance to acid, alkali, organic solvents and microbial growth, so it is even more suitable for use in a variety of environments than stainless steel. At present, it is often used in chemical construction, underground engineering and underwater special engineering construction. [10]

5.3. Sustainability

During material transportation, GFRP is lighter than steel bars, which can save on cost and pollutant emissions during transportation. During the construction process, GFRP is easier to cut and form with less dust and noise than steel processing, which will reduce environmental pollution on the construction site. Compared with steel manufacture, GFRP processing requires lower temperatures and less energy consumption. Although the construction cost of GFRP is slightly higher than that of rebar, the service life of the building can be greatly extended, reducing future inspection and maintenance costs. So, in the long term, GFRP has a higher cost performance, which is more in line with the concept of sustainable development.

Pavlović, Donchev, Petkova, and Staletović asserted that they had performed a Life Cycle Assessment (LCA) of FRP and steel materials and found that the environmental impact of FRP was lower than that of theoretical 100% recycled steel and much lower than original steel in all 18 midpoint categories, which means FRP materials can improve the feasibility of sustainable construction [11]. The thermal conductivity of FRP is low enough that FRP doors and windows have better heat insulation than ordinary components, which can reduce heat loss, thus reducing the use of air conditioning and heating to save energy [12].

6. The prospect of FRP

6.1. Existing structures

FRP sheets can restrain concrete. The direction of the fiber in the GFRP is perpendicular to the direction of the restrained member, so as to increase the ductility of the structural member, and thus improve the seismic performance of the structure. In the bending strengthening of beams and slabs, the FRP sheet can be pasted on the tension side surface of them, and if the fiber direction of the GFRP is consistent with the member direction, the bending capacity of the member can thereby be increased. [13] In addition, GFRP grid, which is generally bonded to the existing structure by a polymer such as epoxy resin, can also improve the strength.

6.2. Future design

Replacement of reinforcement: GFRP replaces some of the steel bars to improve the durability and load-bearing capacity of the structure. Furthermore, GFRP has excellent electromagnetic wave permeability and is one of the best choices for some special building facilities, such as MRI rooms in hospitals and highway toll station passageways that use radio-frequency technology to identify prepaid customers. [14]

Bridge system: GFRP composites have been proven to be feasible materials in bridge construction. Bridge systems can use GFRP as the main material for bridge components, such as girder, deck and slab bridge systems. Compared to reinforced concrete decks, GFRP concrete decks show higher durability and less stiffness degradation under ultimate design loading. [15]

Pipeline system: Due to the excellent durability of GFRP, it can be combined with concrete as the main material of the underground pipeline system, because the environment is relatively complex, making the steel bars easier to rust. GFRP can make the entire pipeline system more durable, and its carrying capacity is not worse than steel pipe. [16]

There may be more full-FRP constructions in the future as well.

7. Conclusion

The advantages outweigh the disadvantages, and it can be used in many places. The main methods are cloth winding, embedding, and pasting. In the future, GFRP can replace more of the traditional reinforcement, and this proportion can be continuously improved, which will improve the strength, durability, and sustainability of the construction. However, there are a few uncertainties, such as high prices, being unfamiliar in the field of civil engineering, and other issues, which means GFRP needs further study about its nature and process to produce cheaper and better GFRP in all aspects. Regrettably, there is no personal experiment to determine the accurate properties of various FRP due to the condition limitation. In the future, new technology to produce FRP with more varieties of fiber and to improve the manufacture of FRP at a lower cost should be focused on. In addition, more sustainable methods to recycle FRP and more precise measures in the aging test of FRP are also useful research directions. Improving the substitution rate of FRP for traditional reinforcement and the recovery rate of FRP can promote the application of FRP at higher altitudes.

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