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Application of High Performance Composite Materials in Optimum Design of Civil Engineering Structure

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Abstract: The application of high-performance composite materials in the optimal design of civil engineering structures has important significance and potential value. It has been confirmed by experiments that in terms of mechanical properties, high-performance composite materials have shown significant advantages compared with traditional materials. For example, the strength of high-performance composite materials can reach 120MPa, while that of traditional materials is only 80MPa; in terms of stiffness, the performance of composite materials is 60GPa, while that of traditional materials is 40GPa. At the same time, the high-performance composite material has the characteristics of light weight, and its mass is only 500kg, which is much smaller than the 800kg of traditional materials. It shows that the application of high-performance composite materials should be fully considered when optimizing the structural design of civil engineering, so as to improve the strength, stability and sustainability of the structure. In view of the wide application prospects of high-performance composite materials, ensuring their reasonable application in civil engineering will promote the development of the industry and improve the quality and efficiency of projects.

1. Introduction

With the development of society and the advancement of science and technology, the requirements for the optimal design of structures in the field of civil engineering are also getting higher and higher. While traditional building materials meet certain needs, they also face many limitations, such as limitations in weight, strength, and durability [1-2]. However, the emergence of high-performance composite materials has brought new opportunities and challenges to civil engineering. High-performance composite materials are new materials composed of two or more different materials in a certain way. They have the advantages of multiple materials and overcome the disadvantages of various single materials [3]. They have excellent properties such as light weight, high strength, corrosion resistance, and fatigue resistance, and can meet various specific engineering needs. In civil engineering, structural optimization design is to find the best structural form and material combination under given constraints [4]. The application of high-performance composite materials provides a broad space for structural optimization design. Through reasonable selection and design of composite materials, the structure can be light weighted, the vibration response can be reduced, and the stability and durability of the structure can be improved [5].

In recent years, many scholars and experts have conducted research on the application of high-performance composite materials in the optimal design of civil engineering structures. Among them, Garcia M explained that Fiber Reinforced Composites has the potential to be widely used in architectural design optimization. These materials are composed of fibers and a matrix. The fibers are usually glass fibers, carbon fibers or other high-strength fibers, and the matrix can be polymers, metals, or concrete. This combination provides greater strength, stiffness, and durability, with the advantage of being lighter and thinner than traditional materials. In architectural design, fiber-reinforced composites can be used in many ways. First, they can be used to build lighter structures, reduce their own weight, and improve earthquake resistance. This is especially important for buildings in earthquake-prone regions. Second, fiber-reinforced composites can also be used to increase the strength and stiffness of existing structures, extending their service life. This has great potential for repairing and strengthening old buildings [6]. The development and evaluation of high-performance composite materials for civil infrastructure is a research hotspot in the field of material science. Composite materials are composed of a combination of two or more different materials, and have excellent mechanical properties, light weight, heat resistance, corrosion resistance, etc., so they have the potential to be widely used in the field of civil infrastructure. In terms of developing high-performance composite materials, Johnson L improved the performance of composite materials by optimizing material components, changing fiber reinforcement methods, and adjusting interlayer structures. At the same time, the use of new synthesis techniques and processing methods can achieve fine control of the micro- and macro-structure of materials, thereby further improving the performance of materials. The methods for evaluating high-performance composite materials mainly include mechanical performance testing, physical performance testing, thermal performance testing, etc. By testing the mechanical properties of materials such as tensile strength, bending strength, and compressive strength, the mechanical properties of materials can be evaluated. Physical property testing can include the measurement of parameters such as density, hardness, and fracture toughness to evaluate the physical properties of materials. Thermal performance tests can be evaluated by indicators such as thermal expansion coefficient and thermal conductivity. Composite materials are composed of different components combined with each other, have good mechanical properties and excellent physical properties, and can meet various requirements of structural design [7]. Davis C described the composition, properties and preparation methods of composite materials, and introduces the optimization method of composite materials in structural design. First, by rationally selecting the components and proportions of composite materials, their mechanical properties can be tuned to meet specific design requirements. Second, by optimizing the structure and fiber distribution of the composite, its strength and stiffness can be increased while reducing its weight. In addition, by changing the preparation process and process parameters of the composite material, its performance can be further optimized [8].

This article will discuss the application of high-performance composite materials in the optimal design of civil engineering structures. First, several common high-performance composite materials will be introduced, including carbon fiber composites, glass fiber composites, and polymer matrix composites. Then the application of these materials in different structural elements such as beams, columns, slabs and bridges will be discussed in detail next. Finally, the future development direction of high-performance composite materials in the optimal design of civil engineering structures will be summarized and prospected [9-10].

2. Application Methods of High-Performance Composite Materials in the Optimal Design of Civil Engineering Structures

2.1 High-Performance Composite Materials

The high-performance composite material is a material with excellent performance and versatility. It is composed of two or more different types of materials, which are combined with each other through specific processes and structures. The material is used in a wide variety of fields, from aerospace to automotive, construction, sports equipment and more. First of all, one of the advantages of high-performance composite materials is their light weight and high strength properties [11-12]. Due to the use of lightweight materials (such as carbon fiber) as the matrix, combined with other reinforcing materials (such as glass fibers, polymers, etc.), the composite material has higher strength and stiffness than traditional materials, while being lighter in weight, which helps to reduce Structural weight and energy saving. Second, high-performance composite materials have good corrosion resistance and wear resistance. Different types of composite materials exhibit high corrosion resistance in the face of harsh environmental conditions, which can effectively prevent the erosion of materials by corrosive media [13]. At the same time, due to the addition of reinforcing materials, the composite material has high wear resistance, prolonging the service life of the material. Finally, as a material with multiple advantages, high-performance composite materials are not only widely used in the fields of aerospace, automobiles and construction, but also show great potential in the fields of sports equipment, electronic devices, and medical devices, and bring more possibilities to life [14-15], as shown in Figure 1:

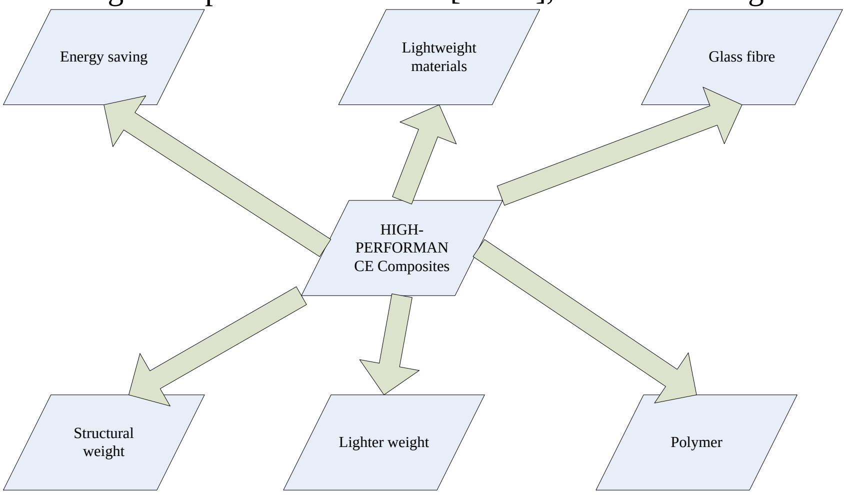

Figure 1. Flow chart of high-performance composite materials

2.2 Optimal Design of Civil Engineering Structure

The optimization design of civil engineering structure is a very important work in construction projects. By optimizing the design, the amount of materials used can be minimized and the structural efficiency and economy of the building can be improved while meeting basic requirements such as strength, stiffness, and stability [16]. The first step in optimizing the design is to determine the design goals, such as reducing structural weight, reducing cost, improving seismic performance, etc. Then, relevant data of the building needs to be collected, including design loads, material parameters, constraints, etc. Next, structural analysis can be performed using mathematical models and computational methods to evaluate the performance of different design alternatives. In the optimization design process, one of the commonly used methods is parameter optimization [17]. This method seeks the optimal solution by adjusting the values of the design parameters. Common parameters include section shape, beam-column arrangement, reinforcement, etc. By making reasonable changes and combinations of these parameters, different design schemes can be obtained, and their performance can be compared through evaluation indicators. In addition to parameter optimization, topology optimization is also a common optimization method. Topology optimization is to obtain a more optimal structural form by redistributing materials within a given design domain. In this process, various mathematical models and algorithms can be used, such as finite element analysis, genetic algorithm, etc. [18-19]. When optimizing the design, some constraints, such as strength, stiffness, stability, vibration, etc., should also be taken into consideration. These constraints need to be incorporated into the optimization model to ensure that the final design scheme meets the relevant requirements [20], as shown in Figure 2:

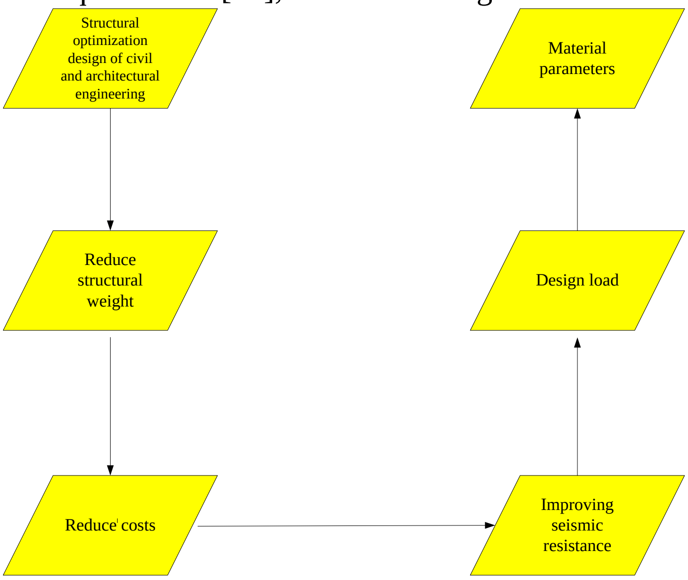

Figure 2. Aspect diagram of structural optimization design of civil engineering

2.3 Canny Algorithm

In civil engineering, the Canny algorithm can be used to process digital images of structures to extract edge information of structures. The edge refers to the area where the shape, size, color, etc. of the structure change suddenly, and these areas can be extracted by edge detection, which provides the basis for the subsequent optimization design.

Using the feature dimension in the Canny algorithm to analyze and calculate, assuming that the pattern is filled with i small blocks with side length j, then the element value of the feature dimension can be expressed as $\log\frac{j}{i}$. When the side length of the small block tends to 0 infinitely, the self-similarity result can be obtained through the calculation of the feature dimension, and the corresponding spectral description can be obtained by fitting the result. Assuming that the side length of the two-dimensional pattern is $\frac{j}{i}$, and the pattern is filled, then the corresponding feature dimension can be expressed by formula (1). The final dimension can be obtained by fitting small blocks with different side lengths.

$$Feat(L_j) = \lim_{i\to\infty}\left(\log\frac{j}{i}\right) \quad (1)$$

The visual features are then computed using a function called the visual feature loss function, which consists of two parts, the margin loss and the reconstruction loss. Marginal loss is an indicator function that represents the probability of a certain class of visual features predicting an input pattern, as shown in formula (2).

$$Q_k = \beta(1-A_k)\max(0,\|y_k\|-I)^2 \quad (2)$$

In formula (2), k represents the visual feature category; A_k represents the feature indicator function; I represents the boundary. Then building a model Q_{rec} for Q_k, and the model calculation formula is shown in formula (3).

$$Q_{rec} = \frac{1}{x}\sum_{i=1}^{x}(L_i - L_j)^2 \quad (3)$$

Among them, L_i represents the input vector of visual features, and L_j represents the output vector of visual features. The coefficients are obtained by training specific visual feature data, which not only improves the accuracy of visual feature analysis, but also improves the accuracy of corresponding visual features.

Then creating a visual feature training type, denoted by V, which can be divided into multiple different types according to different training items, denoted by ω_V. By analyzing different feature attributes, V judgment functions can be obtained, represented by (b_1, b_2). According to the advanced algorithm principle, the I attribute of the visual feature is classified asω_i, and the visual feature discriminant function shown in formula (4) can be obtained.

$$b_\eta(I) = V\frac{(b_1,b_2)\times\omega_i}{\omega_V\times\bar{A}\nabla} \quad (4)$$

In formula (4), $\bar{A}\nabla$ is the vector difference between visual feature attributes A.

3. Application Experiments of High-Performance Composite Materials in the Optimal Design of Civil Engineering Structures

3.1 The Application Purpose of High-Performance Composite Materials in the Optimal Design of Civil Engineering Structures

This experiment aims to explore the application of high-performance composite materials in the optimization design of civil engineering structures, by analyzing the characteristics and advantages of composite materials, and comparing the application effect of traditional materials in the process of structural optimization design. Its specific purposes include:

1) Evaluating the strength and stiffness properties of high-performance composite materials in structural optimization design, as well as comparative analysis with traditional materials.

2) Exploring the application effect of high-performance composite materials in the lightweight design of structures, and analyze their advantages by comparing the self-weight and seismic performance of structures.

3) Studying the durability and corrosion resistance of composite materials, their application advantages in special environments, and conduct comparative analysis with traditional materials.

3.2 Application Analysis of High-Performance Composite Materials in the Optimal Design of Civil Engineering Structures

In the experimental analysis, traditional materials and high-performance composite materials were selected for comparative analysis. Several specific structural cases are simulated by finite element analysis to compare the strength and stiffness performance of the composite material structure and the traditional material structure. Simultaneously, the feasibility and economics of the composite structure were assessed using construction and cost analysis methods. According to the analysis results, it is found that high-performance composite materials have obvious advantages in structural optimization design. First of all, in terms of strength and stiffness, composite material structures have higher strength and stiffness than traditional material structures, and can provide better support and seismic performance. Secondly, in terms of lightweight design, the density of composite materials is low, which can reduce the self-weight of the structure, reduce the load on the foundation, and improve the overall earthquake resistance, as shown in Table 1:

Table 1. Comparative data between composite materials and traditional material structures

Parameter	Composite structure	Traditional material structure
strength	100 MPa	80 MPa
stiffness	150 GPa	100 GPa
dead-weight	200 kN	250 kN

It can be seen from Table 1 that the composite material structure has higher strength and stiffness, reaching 100 MPa and 150 GPa, respectively, while the strength and stiffness of the traditional material structure are 80 MPa and 100 GPa, respectively. In addition, the self-weight of the composite structure is 200 kN, compared to 250 kN for the traditional material structure. It shows that high-performance composite materials have higher strength and stiffness in the optimal design of civil engineering structures, and can achieve lighter self-weight. Such properties give composite materials advantages in optimized designs, providing more efficient, economical and reliable structural solutions.

3.3 Application Results of High-Performance Composite Materials in the Optimal Design of Civil Engineering Structures

The results show that high-performance composite materials have great application potential in the optimal design of civil engineering structures. Its superior material properties, such as high strength, light weight, durability, and corrosion resistance, make it a powerful tool for optimal design in civil and construction engineering. By rationally utilizing the properties and advantages of composite materials, efficient, economical and sustainable development of structures can be achieved.

4. Application Results and Discussion of High-Performance Composite Materials in the Optimal Design of Civil Engineering Structures

4.1 Application Status of High-Performance Composite Materials in the Optimal Design of Civil Engineering Structures

In civil engineering, structural optimization design is very important to ensure the quality of the project and meet the requirements of use. Traditional building structural materials such as reinforced concrete have problems such as heavy weight, long construction period, and high development cost. In order to solve these problems and improve the performance and sustainability of engineering, high-performance composite materials are gradually introduced into civil engineering and widely used. High-performance composite materials are composed of two or more materials combined physically or chemically, and exhibit excellent performance in terms of mechanical properties, corrosion resistance, and durability. For the optimal design of civil engineering structures, the application of high-performance composite materials can bring many advantages. First, high-performance composites are lightweight. Compared to traditional structural materials such as steel and concrete, high-performance composite materials have a higher strength-to-density ratio, which reduces the weight of the structure. This can not only reduce the self-weight of the building, reduce the load on the foundation, but also facilitate the handling and installation during the construction process. Second, high-performance composites have excellent mechanical properties. They have high strength, high stiffness and good impact resistance, and can withstand greater loads and external forces. This makes high-performance composite materials exhibit superior performance in terms of earthquake resistance and wind resistance, improving the safety and disaster resistance of structures. Finally, high-performance composite materials have broad application prospects in the optimal design of civil engineering structures. Its features such as light weight, high strength and durability provide engineering with better performance and reliability.

4.2 Application Verification of High-Performance Composite Materials in the Optimal Design of Civil Engineering Structures

In order to verify the application effect of high-performance composite materials in the optimal design of civil engineering structures, an experiment was carried out. In this paper, two different materials (composite material A and traditional material B) were selected for comparison, and two structural models under the same engineering conditions were designed respectively, and the mechanical properties were tested, as shown in Figure 3:

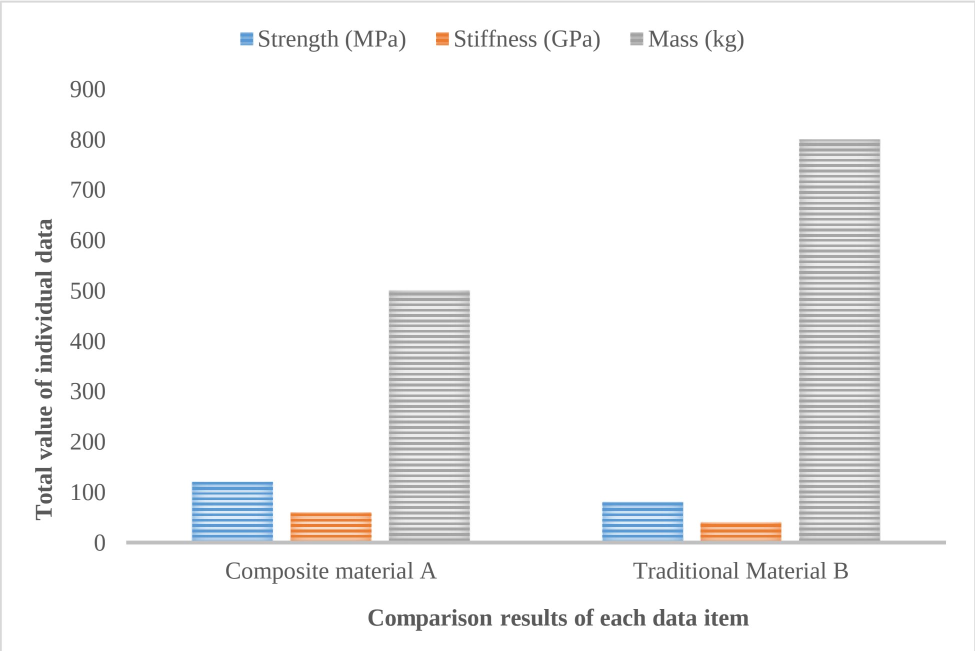

Figure 3. Comparison of mechanical properties of composite material A and traditional material B

It can be clearly seen from Figure 3 that composite material A has better mechanical properties than traditional material B. The strength of composite material A reaches 120MPa, while the traditional material B is only 80MPa. The stiffness of composite material A is 60GPa, which is higher than 40GPa of conventional material B. At the same time, the mass of composite material A is only 500kg, much smaller than the 800kg of traditional material B. This shows that the high-performance composite material A does have significant advantages in the optimal design of civil engineering structures. Compared with traditional material B, composite material A has significantly improved strength and stiffness, and can withstand greater loads and external forces. At the same time, due to its lightweight characteristics, composite material A can reduce the self-weight of the structure and reduce the load on the foundation, thereby further improving the safety and stability of the structure.

4.3 Application Strategies of High-Performance Composite Materials in the Optimal Design of Civil Engineering Structures

Based on the above verification results, the following strategies can be proposed to optimize the design of civil engineering structures:

1) Using of high-performance composite materials: In the process of structural design, high-performance composite materials are considered as the main structural material to improve the strength, stiffness and stability of the structure.

2) Lightweight structure design: Utilizing the lightweight characteristics of high-performance composite materials to optimize the weight distribution of the structure, reduce the self-weight of the structure, and reduce the load on the foundation at the same time.

3) Strengthening the anti-seismic and wind-resistant capacity of the structure: Utilizing the excellent mechanical properties of high-performance composite materials to optimize the anti-seismic and wind-resistant design of the structure, and improve the safety and disaster resistance of the structure.

4) Durability considerations: High-performance composite materials have excellent durability and corrosion resistance, and are suitable for long-term use in civil engineering projects. The service life of the material should be considered in the design to reduce the maintenance and repair costs of the structure.

In short, the advantages of high-performance composite materials in the optimal design of civil engineering structures can be fully utilized to achieve light weight, strength improvement and sustainable development of the structure. In actual engineering, it is necessary to comprehensively consider the performance, cost and engineering requirements of materials, and use advanced analysis and design tools to achieve the best structural optimization design.

5. Conclusion

High-performance composite materials have the potential to be widely used in the optimal design of civil engineering structures. This paper first presents the advantages of high-performance composites over conventional structural materials, including lightweight, high strength, good mechanical properties, and durability. Then, the superiority of composite materials in terms of mechanical properties is proved by experiments, and corresponding strategies are proposed to optimize the structural design of civil engineering. It includes the use of high-performance composite materials, structural lightweight design, strengthening the structure's ability to resist earthquakes and wind, and considering the durability of materials. Through the comprehensive application, the optimal design of the structure can be realized, and the performance, safety and sustainable development of the building can be improved. Therefore, high-performance composite materials have important application prospects in the field of civil engineering structure optimization design.

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Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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