Based on Composite Materials, the Development and Performance Research of Integrated Wall Panels with Concealed Dry-Hanging Fixtures

Hao Pei, Yuping Wang*, Dandan Sun, Jia Zhou, Yuehan Qin

State Grid Beijing Electric Power Company, Xicheng District, Beijing, 100031, China

*sszy1234567@126.com

Abstract. In the construction industry, increasing demands for enhanced material performance have driven the adoption of composite materials in wall panel systems. This study investigates the development of integrated wall panels using glass fiber reinforced plastic (GFRP) and carbon fiber reinforced plastic (CFRP), focusing on their mechanical, thermal, and durability aspects. Results confirm that these composites meet structural needs, improve aesthetics, and enhance environmental adaptability of buildings, offering valuable insights for innovations in construction materials and technology.

Keywords: Composite materials, integrated wall panels, invisible mounting fixtures

1 Introduction

In modern architectural applications, wall panel systems encounter several challenges, including significant weight, complex installation requirements, and limitations in aesthetic flexibility. This study seeks to address these issues by developing an advanced solution using integrated wall panels with invisible dry hanging clips, constructed from composite materials[1]. The primary materials selected for this purpose are glass fiber reinforced plastics (GFRP) and carbon fiber reinforced plastics (CFRP), known for their favorable strength-to-weight ratios and ease of processing. Leveraging the benefits of GFRP and CFRP, the study incorporates innovative structural design techniques and advanced manufacturing processes, including injection molding and compression molding, to produce lightweight yet highly durable wall panels. Additionally, by integrating high-strength bonding technology with mechanical fixation, an aesthetically pleasing and straightforward installation method for an invisible dry hanging system is realized. This study's distinctiveness lies in its combined approach of utilizing advanced composite materials, pioneering design concepts, and cutting-edge manufacturing techniques, ultimately delivering a unique, practical wall panel system solution tailored to modern construction industry needs.

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2 Design and Manufacture of Composite Integrated Wall Panels

2.1 Selection and Performance Analysis of Composite Materials

In selecting composite materials for wall panel systems, crucial factors such as strength, stiffness, durability, and machinability are prioritized[2]. This study focuses on two composite types: Glass Fiber Reinforced Plastic (GFRP) and Carbon Fiber Reinforced Plastic (CFRP). GFRP is known for its cost-effectiveness and solid mechanical performance, making it well-suited for applications with moderate load requirements. In contrast, CFRP stands out due to its exceptional strength and stiffness, albeit with higher costs, making it ideal for high-performance applications[3]. The mechanical characteristics of these composites are assessed through various tests, including tensile, compression, and bending tests, each providing insights into their suitability for structural applications. For example, tensile properties of GFRP and CFRP are measured using the ASTM D3039 standard test method, where tensile strength and modulus are essential metrics for material selection. The stress-strain curves obtained from the tensile tests, as illustrated in Figure 1, reveal that CFRP has a steeper initial slope and higher failure strength, underscoring its superior strength and stiffness compared to GFRP. These findings highlight the complementary qualities of GFRP and CFRP, ensuring that each material's specific strengths can be effectively utilized in the design of integrated wall panels.

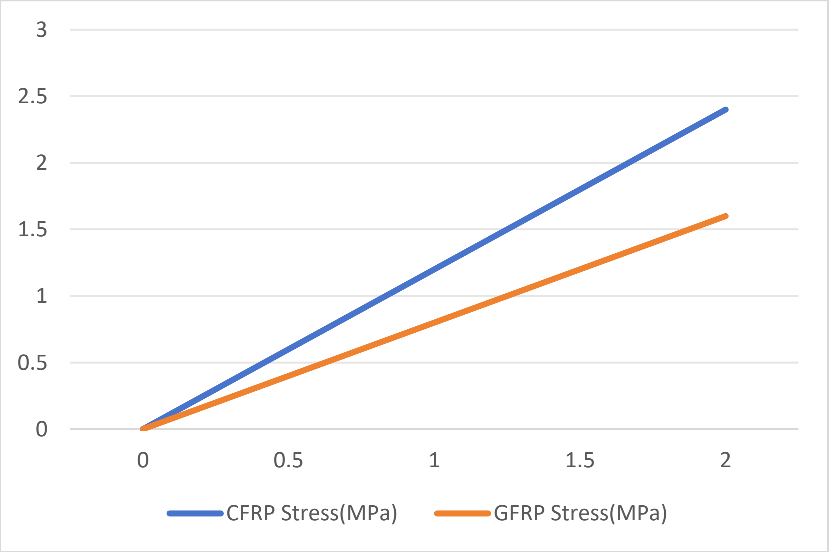

Fig. 1. Stress-strain curves of different composites in tensile tests.

In terms of thermal properties, thermal stability and thermal decomposition characteristics are assessed using Differential Scanning Calorimetry (DSC) and Thermogravimetric Analysis (TGA)[4]. Carbon fiber and glass fiber composites generally withstand continuous operating temperatures up to 200°C, making them suitable for various environmental conditions[5].

2.2 Design and Manufacturing of Integrated Wall Panels and Concealed Dry-Hanging Fasteners

1)Wall Panel Structure Design

The geometric dimensions of the wall panels are designed based on structural requirements and aesthetic considerations. The optimal thickness (t) and length (L) of the wall panels are calculated using the following formula[6]:

$$t = \sqrt{\frac{6M}{L^2E}} \tag{1}$$

Where M represents the moment under specific load conditions, and E is the modulus of elasticity of the material.

The supporting structure design must provide sufficient strength to resist external loads[7]. The required dimensions for the supporting structure are calculated using:

$$F = \frac{K \cdot L}{d} \tag{2}$$

Here, F is the maximum force required for support, K is the load coefficient for the specific area, and d is the support spacing.

The connection method design combines high-strength bonding techniques with mechanical fasteners to enhance connection reliability. The connection strength is designed using[8]:

$$P = A \cdot \sigma \tag{3}$$

Where P is the maximum tensile force the connection can withstand, A is the connection area, and σ is the allowable stress of the material.

2)Concealed Dry-Hanging Fastener Design

The design of the dry-hanging fasteners considers their load-bearing capacity and ease of assembly. The safety factor n of the fasteners is calculated based on the material's yield strength (σ_y) and allowable maximum stress (σ_{max}), the safety factor (n) of the fixture is calculated:

$$n = \frac{\sigma_y}{\sigma_{max}} \tag{4}$$

A safety factor of not less than 2.0 is required. The assembly gap δ is calculated using:

$$\delta = d - (d_{nom} + tol) \tag{5}$$

Material selection must consider mechanical properties, corrosion resistance, and machinability, with common materials including stainless steel and aluminum alloys.

3)Manufacturing Process

The manufacturing process includes material pre-treatment, forming, and post-processing steps. The preheat temperature T_p for the materials is determined using:

$$T_p = T_g - 20°C \tag{6}$$

Where T_g is the glass transition temperature of the material.

3 Manufacturing Process of Integrated Wall Panels and Fasteners

3.1 Material Preparation

Material preparation is an essential phase in the manufacturing process of integrated wall panels and fasteners, involving thorough pretreatment steps to ensure optimal performance. This phase includes cleaning, surface treatment, and preheating, all crucial for enhancing material quality and process efficiency. The cleaning process utilizes mechanical, chemical, and ultrasonic techniques to effectively eliminate surface contaminants, thus facilitating the bonding and coating steps that follow. Surface treatments, including phosphating or anodizing, are applied to improve coating adhesion and enhance the material's corrosion resistance, which is critical for ensuring durability. Preheating is tailored to the specific thermal properties of the materials, such as the glass transition temperature of epoxy resin, to achieve optimal molding results. Setting the correct preheating temperature based on these properties enhances material malleability during the molding phase. The effectiveness of this pretreatment is evaluated through assessments of surface roughness, contact angle, and adhesive strength, which provide a comprehensive understanding of the material's readiness for subsequent processing steps. These pretreatment measures collectively enhance the durability, stability, and performance of the finished wall panels and fasteners, laying a solid foundation for the final product quality.

3.2 Selection of Forming Process

In selecting the forming process for manufacturing invisible dry hanging components and integrated wall panels, factors such as component size, complexity, and material characteristics are carefully considered. Injection molding and pultrusion molding have emerged as the preferred technologies due to their suitability for the unique requirements of this project. Injection molding is highly effective for creating intricate shapes and details, making it an ideal choice for producing invisible dry hanging components with varying geometries. This process allows for precise control over dimensional accuracy and height consistency, thereby meeting the strict precision standards outlined in this study. On the other hand, pultrusion molding is specifically advantageous for manufacturing elongated components with uniform cross-sections, such as the extended parts of integrated wall panels. The continuous nature of pultrusion molding significantly enhances production efficiency and material uniformity, as it allows for uninterrupted production of consistently shaped elements. This dual approach ensures that both the detailed and extensive components of the wall panel system are manufactured to high standards, optimizing both functionality and production efficiency for large-scale application.

4 Performance Testing and Validation

4.1 Mechanical Performance Testing

Mechanical performance testing is a critical step in evaluating the structural integrity and reliability of the composite materials used in the integrated wall panel system. This testing includes tensile strength, compression strength, and bending strength assessments, each designed to simulate real-world mechanical stresses. The tensile test, in particular, measures the material's fracture resistance by gradually applying an increasing tensile force until the material fails, thus revealing its ultimate tensile strength. Compression tests similarly assess the material's ability to withstand compressive forces, while bending tests measure resistance to bending moments. Table 1 presents the detailed results of these tests, including tensile forces of 500 N on a cross-sectional area of 10 mm² resulting in a calculated strength of 50 MPa. Compression tests reached 1000 N with a strength of 100 MPa, while bending strength was calculated at 40 MPa. These evaluations not only provide insights into the material behavior under various loads but also confirm compliance with necessary safety and performance standards, ensuring the composite materials are suitable for practical and structural applications in construction projects.

Table 1. Mechanical Performance Test Results.

Test Type	Test Type(N)	Cross-sectional Area (mm²)	Calculated Strength(MPa)
Tension	500	10	50
Compression	1000	10	100
Bending	200 (Nm)	N/A	40

4.2 Durability Testing

Durability testing includes long-term load testing, environmental aging testing, and corrosion resistance testing. As shown in Table 2, long-term load testing monitors material deformation by applying continuous force. Environmental aging testing simulates high temperature, high temperature, and ultraviolet conditions to determine how material properties degrade over time. Corrosion resistance testing evaluates the weight loss of materials in chemical erosion environments.

Table 2. Durability Test Results.

Test Type	Conditions	Performance after Test
Long-term Load	500 N, 1000 mm	0.00025 mm
Environmental Aging	1000h UV Exposure	45 MPa
Corrosion Resistance	3%Saltwater Solution, 30 days	2%Weight Loss

5 Conclusion

This study successfully developed an integrated wall panel system utilizing glass fiber reinforced plastic (GFRP) and carbon fiber reinforced plastic (CFRP), which has shown notable improvements in strength, durability, and adaptability to diverse environmental conditions. The findings underscore the effectiveness of these composite materials in enhancing structural performance and installation efficiency, providing a valuable solution for the construction industry. However, certain limitations persist. Although laboratory tests highlight the impressive material properties, further research is needed to confirm the long-term stability and durability of these panels in real-world applications. Additionally, while this study focused on material characteristics and structural design innovations, it did not fully explore the cost-effectiveness or practicality of scaling the system for widespread construction use. Therefore, future research should prioritize evaluating long-term performance in real-world environments, further examining the panels' adaptability to various climates, and refining manufacturing techniques to lower production costs. These steps are essential to improve the feasibility and attractiveness of this integrated wall panel system for broader industry adoption and practical implementation.

References

1. Hart R, Khatib-Shahidi B, Patton E G, et al. Modeling Dynamic Failure of Woven Carbon Fiber Thermoplastic Composites Using Empirical-and Multiscale-Based Material Cards in LS-DYNA MAT054. SAE International Journal of Materials and Manufacturing, 13(3): 241-256 (2020).
2. Kumar V R , Gopinath S .NOVEL TEXTILE-REINFORCED CONCRETE-COLD FORM STEEL CAVITY WALL PANEL SYSTEM FOR FAST TRACK CONSTRUCTION.The Indian concrete journal, (6):95 (2021).
3. Cordero B, Alfonso García-Santos, Overend M. Thermal performance of novel frame-integrated unitised curtain wall. Revista De La Construcción, 2015, 14(1):23-31.
4. Wei-Dong Z, Xu Z, Wei L, et al.CONSTRUCTION PROCESS OF DRY-HANGING RESIN PANEL DECORATED INTERIOR WALL.Architecture Technology, (2013).
5. Gay D. Composite materials: design and applications. CRC press, (2022).
6. Patent Issued for Panel level metal wall grids array for integrated circuit packaging (USPTO 11670600).Electronics Newsweekly, (2023).
7. Chen Y, Ma Y, Yin Q, et al. Advances in mechanics of hierarchical composite materials. Composites Science and Technology, 214: 108970 (2021).
8. Sonkaria S, Hwang S K, Kim H J. Laboratory of Adhesion & Bio-Composites, Major in Environmental Materials Science, Department of Agriculture, Forestry and Bioresources, Center for Adhesion Research & Development (Smart CARD), Seoul National University, Seoul, Republic of Korea (2022).