



# A Review of the Application and Research Progress of Composite Bonded Joints

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## **Author's contribution**

*The sole author designed, analyzed, interpreted and prepared the manuscript.*

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## **ABSTRACT**

In this paper, the mechanical connection, adhesive connection, hybrid connection (adhesive mechanical), suture connection (Z-Pin chain connection) of composite materials are introduced, the advantages and disadvantages of each connection are described in detail, and the structural form of the most widely used adhesive connection, the application and innovation in engineering practice are explained in detail. The challenge that the adhesive joint can not be further studied under the existing experimental conditions is put forward. In addition, two methods are given to improve the mechanical properties of the bonded joint. One is to improve the conditions of the adhesive itself, that is, the use of stripping cloth or sandblasting. The other method is to modify the adhesive, add nanoparticles or mix the adhesive. It provides a new direction for future research.

**Keywords:** *Composite material bonding technology; adhesive bonding mechanism; performance optimization and engineering application.*

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## 1. INTRODUCTION

Composite materials are a new material made of two or more materials with different physical and chemical properties in a certain way. In terms of mechanical properties, they are better than many traditional homogeneous materials. Composite materials are generally composed of matrix and reinforcement materials. The most common matrix is made of various resins. The most common reinforcement materials are various fibrous materials, mainly carbon fiber, glass fiber, aramid fiber, etc. Composite materials, especially glass fiber reinforced composite materials, are increasingly being used in bridges, building reinforcement, ship structures, wind power blades, and aviation structures.

In the process of applying composite materials, the connection of composite materials is a very worthy of attention. Conventional connection methods include mechanical connection, adhesive connection, hybrid connection (adhesive-mechanical), suture connection, melt welding and other connection methods (Jindong et al., 2023). Among these connection methods, adhesive bonding is the most widely used and most obvious connection method. This article will introduce the differences and advantages of adhesive bonding compared with other connection forms, existing adhesive bonding methods and the latest research progress.

## 2. BASIC STRUCTURE OF BEARING

### 2.1 Traditional Mechanical Connection Forms

The traditional mechanical connection forms of composite materials mainly include bolt connection, pin connection, and rivet connection (Xinlin et al., 2023). Mechanical connection is also the most widely used connection method at present.

Its advantages are that it can be repeatedly assembled and disassembled during manufacturing, repair and replacement, which is convenient for inspection and easy to repair; it has no residual stress influence and is less affected by the environment, and has high reliability; there is no special requirement for the surface of the part and no thickness limit.

However, the disadvantage is that local stress concentration is easily generated around the hole

positions of mechanical connections, which reduces the reliability of the connection; the local strength of the composite plate will also decrease after drilling, and the requirements for the hole positions of the punched on the material are high; the contact between the steel connecting members and the composite material will also cause electrochemical corrosion.

### 2.2 Adhesive Connection

Adhesive bonding is a connection process in which adhesive is used to connect parts into an unremovable whole. This connection method allows the metal to be seamlessly connected to the composite material, and can carry a large stretch, shear and torque, while at the same time, the properties of the material are less changed. Thanks to the richness of the product, the flexibility of the design and the convenience of the process, it is one of the most widely used methods of connecting composite materials.

The advantage of glue connection is that it can effectively connect the same or different materials without mechanical processing and no additional damage; compared with mechanical connection, there will be no stress concentration caused by drilling; and there is no corrosion problem, the characteristics of glue connection make the joints using this connection method regular in shape, obtain a smooth pneumatic shape.

The bonding connection has the following disadvantages. First of all, before bonding, in order to obtain good connection effect, the connected surface is generally required. After connection, the adhesive joint cannot be detached, making material recycling a problem. In addition, the peel strength of the glue connection is low, making it difficult to bond with thicker structures, and transmits larger loads.

### 2.3 Hybrid Connection

The hybrid connection of resin-based composite materials is based on bonding and bolts or rivets, combining the load advantages of mechanical connections and the lightweight and high strength of bonding. Through reasonable structural design, various connection advantages are complementary and interrelated and coordinated, thus ensuring that the structural parts have irreplaceable safety and reliability advantages.

Hybrid connections can prevent or delay the expansion of glue layer damage, improving performance such as peeling, impact, fatigue and creep resistance (Yao and Mingqiao, 2017). With sealing, shock absorption and insulation, it further increases the connection strength, improves load transfer capabilities, isolates metal fasteners and composite materials, and does not have electrochemical corrosion. The hybrid connection mainly includes the glue screw mixing connection and the glue rivet mixing connection.

Tough adhesives should be used for hybrid connections, so as to coordinate the deformation of the adhesive joint with the deformation of the mechanical connection. It is necessary to improve the matching accuracy of the fastener and the hole, otherwise it is easy to cause shear damage to the glue layer and reduce the connection strength.

Evers et al., 2025 investigated the performance and environmental resilience of hybrid bolted-bonded joints using two different adhesive systems (a two-component polyurethane and an epoxy), by conducting a series of comprehensive tests exposed to the maritime climate of Helgoland Island in the North Sea. Research shows that after the test of temperatures, humidity, and other environmental stressors. The hybrid bolted-bonded joints confirm the robustness of these joints. It still has a certain

ability to bear the load, showing a stable bearing capacity.

### 2.4 Stitching Connection

The stitching connection has been used in the field of composite materials for only a few decades. Its principle is to enhance the composite material in the direction perpendicular to the laying plane through suture, thereby improving the damage tolerance between the materials. Some papers also classify Z-Pin connection as a type of suture connection. Z-Pin technology borrows the discontinuous suture method in suture composite materials to directly embed rigid short rods into the thickness direction of prepreg or foam interlayer before curing. This short rod is usually called Z-Pin (it is usually made of metal or carbon fiber or glass fiber).

The suture connection can effectively prevent the delamination of the plate and resist bending damage. Especially after the parts are damaged, the suture can connect the fragments together to avoid more dangerous catastrophic damage in the future, which is conducive to preventing damage expansion (Zhaohui, 2023).

Combining the characteristics of the above various connection methods, as shown in Table 1 (Zhaohui, 2023). In practical applications, bonding has become one of the most widely used methods for connecting composite materials.

**Table 1. Several forms of composite connection**

Property	Traditional mechanical connection forms	Adhesive connection	Hybrid connection	Stitching connection
Connectivity	Generally, the opening is larger, and the transfer load is larger	adhesive	A combination of at least two connections	Suture through the connection
Connecting different materials	Yes	Have a bad effect	Have a bad effect	Yes
Appearance	Relatively bad	Good	Bad	Relatively good
Connection material thickness	Relatively thick	thin	Relatively thick	Relatively thick
Static strength	High	Relatively low	High	Relatively high
Fatigue strength	High	Relatively low	High	Relatively high
Connection efficiency	Relatively low	Relatively low	Low	Relatively low
Cost	Low	Low	Low	Low

## 2.5 Application and Innovation of Adhesive Bonding Technology

With the development of the times, the application of composite materials has become more common in various fields. Composite materials are widely used in aircraft, ship structures, and wind power blades. Since the invention of composite materials, adhesive bonding has always been one of the most widely used connection methods.

## 2.6 Application of Adhesive Bonding Technology

The forms of adhesive connection include single overlap, double overlap, single slope connection, step-type connection, etc.as shown in Fig. 1.

Zhang et al., 2023 conducted a study on the bonding of aviation-grade carbon fiber reinforced resin-based composite materials, introducing the existing bonding theory, common composite surface treatment technology, and surface interface performance and bonding performance characterization methods. The focus is on comparing different forming processes, different matrix materials properties, and the differences in bonding between the same and different materials.

Saeedifar et al., 2023 summarizes the application of composite materials in marine structures, pointing out that adhesive bonding is introduced as an alternative solution to traditional joining methods, which can provide the ability to connect different materials without increasing weight costs without affecting structural integrity. A comprehensive integrity evaluation method for full-size bonded double-material joints for

maritime applications is also proposed. Techniques such as acoustic emission (AE), fiber optic sensor (FOS) and digital image correlation (DIC) are used to evaluate the integrity of the connector when it is subjected to quasi-static loads until it is finally failed.

Al-Khudairi et al., 2015 pointed out that adhesive connection is one of the most important connection technologies for bonding composite structures, and using glass fiber, carbon fiber and Kevlar fiber as research objects, the failure behavior of composite materials in skin reinforcement materials of wind turbine blade structures was studied.

## 2.7 Innovation in Adhesive Bonding Technology

### 2.7.1 Innovation in adhesive type system

People have been trying to improve the performance of composite bonding using adhesives of different chemical components. Powell et al., 2021 and others list some commonly used adhesive ingredients and their characteristics. Methacrylates, for example, are probably the most famous adhesive composite adhesives, which provide very high strength bonding and high peel strength and fast curing. Epoxyadhesives can be used to connect most materials, have good strength, no volatiles produced during curing, and have low shrinkage. However, they may have low peel strength and flexibility and are brittle. Cyanoacrylates usually solidify in seconds, making them ideal for establishing a strong bond very quickly in applications where high impact or peel resistance is not required. Hybridadhesives combines the quality of different adhesives for bond strength, speed and durability.

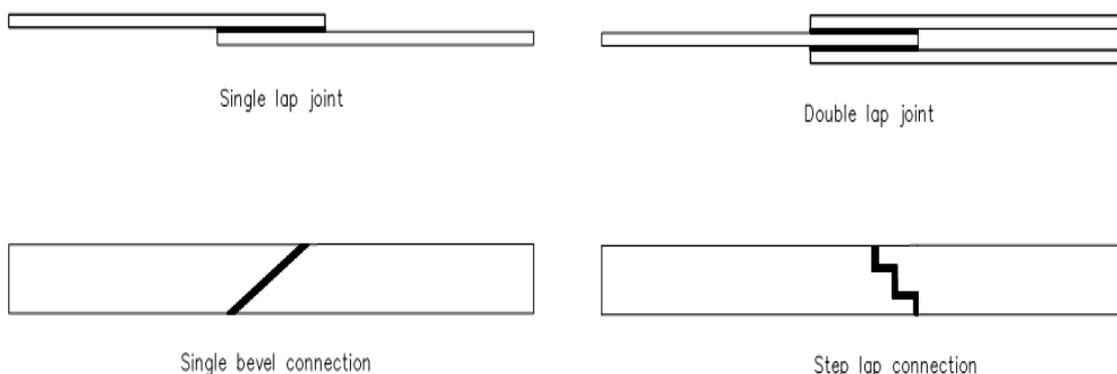


Fig. 1. Several forms of composite connection

### **2.7.2 Improvement of surface treatment technology**

By treating the surface of the adherend to a large extent, many scientific workers have proposed many methods for surface treatment. Among them, chemical methods include plasma treatment, solvent cleaning, flame treatment and other methods. Powell et., 2021 studied the effect of laser activation on the bonding surface of carbon fiber reinforced composite materials, and improved the bonding effect between the adherend and the adhesive through different lasers, so that the bonding strength further increased.

Or the surface of the adhered object is roughened to increase the bonding strength of the adhesive joint, such as sandblasting or mold release fabric technology. Seong-Min et al., 2020 measured their static and fatigue strength by sandblasting, mold release fabric treatment on carbon fiber composites, and sandblasting and mold release fabric treatment. It was believed that sandblasting and mold release fabric treatment had the best effect, followed by mold release fabric, and sandblasting only had the worst effect.

## **3. TECHNICAL CHALLENGES AND DEVELOPMENT DIRECTIONS OF ADHESIVE CONNECTION**

In the process of applying adhesive bonding, although various industries have formed their own application rules, people still face various problems in the field of engineering and research. Many researchers have proposed methods such as improving the chemical composition of adhesives and surface treatment of adherends to solve problems encountered in practical applications.

### **3.1 Currently Facing Technical Challenges**

Wei et al. 2024 believes that in the current research, the problem faced is that in the experiment, simple static loading no longer meets the current research needs of bonding failure modes, and it is necessary to study the failure mode and mechanical properties of bonding joints at high rates.

Simple mechanical tests conducted under simple temperature and humidity environments can no longer be truly evaluated for the performance

and performance of glued joints in complex environments. It is necessary to comprehensively consider the impact of light, temperature, humidity, corrosion, aging and other factors on the performance of glued joints. In actual projects, many damages are often not caused by the adhesive reaching the load bearing limit, but are often structural damage caused by high temperature, humidity, salt spray corrosion, light aging, etc. How to deal with the impact of environmental factors on the bonding joints is an aspect that scientific researchers urgently need to solve in the future.

### **3.2 Future Development Direction of Adhesive Bonding Technology**

The future development direction of bonding and bonding technology is the first to develop environmentally friendly adhesives. Traditional epoxy adhesives contain organic solvents, which may produce toxic and harmful gases during production, use and waste, causing pollution to the environment. Due to the environmental challenges faced by all parts of the world, the global manufacturing industry is accelerating the green transformation of materials, and the demand for the application of green and environmentally friendly bonding materials in the industrial field continues to rise.

In order to further explore the environmentally friendly preparation methods and application fields of high-temperature resistant epoxy adhesives, Zhang et al. 2025 prepared a new type of environmentally friendly adhesive by adding epoxy toughening agent to the epoxy resin system, providing research directions for the preparation of more environmentally friendly adhesives.

In order to enhance the mechanical properties of the adhesive, Akpınar et al. 2017 so pointed out another development direction, by modifying the adhesive itself and adding nanomaterials to the adhesive.

Zamani et al. 2021 evaluated the effect of the addition of nanoparticles (graphene and silica) in the adhesive on the four-point bending fatigue behavior of aluminum composites. The study involved the preparation of four different binder groups, with samples containing nanoparticles undergoing cohesive failure, while pure epoxy resin samples exhibiting a bond failure pattern. Furthermore, the use of a combination of graphene nanosheets and nanosilicon dioxide

particles in the binder (0.5% by weight per percentage) results in higher static failure loads and longer fatigue life.

In addition, Machado et al. 2018 pointed out in an article that by combining two or more adhesives in one bonding joint, combining their properties, performance can also be obtained due to the original single adhesive product.

#### 4. CONCLUSION

Through the analysis of mechanical connections, adhesive connections, hybrid connections, and suture connections (Z-Pin connections) of composite materials, the current application status, challenges and development directions of the most commonly used adhesive connections in the industry are summarized.

For adhesive joints, the first thing is to comply with international requirements, develop environmentally friendly adhesive, and achieve green production. In the research, in order to meet the challenges of practical engineering and improve the strength of the bonded joint, the configuration of the joint itself can be improved, and the mechanical properties can be improved by adjusting the direction of the fiber on the surface of the adhesive or changing the length and thickness of the bonding. Or surface treatment of the adhesive, sandblasting or using a stripper cloth. The adhesive can also be innovated by adding nanoparticles (graphene and silica) to the adhesive or mixing the adhesive to improve its bonding strength by complementing the adhesive with different modulus.

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Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

#### COMPETING INTERESTS

Author has declared that no competing interests exist.

#### REFERENCES

Akpinar, I. A., Gültekin, K., Akpinar, S., et al. (2017). Experimental analysis on the single-lap joints bonded by a nanocomposite adhesives which obtained

by adding nanostructures. *Composites Part B: Engineering*, 110, 420-428.

Al-Khudairi, O., & Ghasemnejad, H. (2015). To improve failure resistance in joint design of composite wind turbine blade materials. *Renewable Energy*, 81, 936-951.

Evers, T., Viehöfer, M. A., Vallée, T., & Yokozeki, K. (2025). Durability of hybrid bolted-bonded joints under environmental aging on Helgoland. *The Journal of Adhesion*, 1–21.

Machado, J. J. M., Gamarra, P. M. R., Marques, E. A. S., et al. (2018). Numerical study of the behavior of composite mixed adhesive joints under impact strength for the automotive industry. *Composite Structures*, 185, 373-380.

Park, S. M., Roy, R., Kweon, J. H., et al. (2020). Strength and failure modes of surface treated CFRP secondary bonded single-lap joints in static and fatigue tensile loading regimes. *Composites Part A: Applied Science and Manufacturing*, 134, 105897.

Powell, J., & Green, S. (2021). The challenges of bonding composite materials and some innovative solutions. *Reinforced Plastics*, 65(1), 36-39.

Qing, X., Huang, Y., Yan, J., et al. (2023). Damage monitoring technology of bolted joint structures of advanced carbon fiber reinforced composites. *Aeronautical Manufacturing Technology*, 66(17), 14-25.

Saeedifar, M., Saleh, M. N., Krairi, A., et al. (2023). Structural integrity assessment of a full-scale adhesively-bonded bi-material joint for maritime applications. *Thin-Walled Structures*, 184, 110487.

Schmutzler, H., Popp, J., Büchter, E., et al. (2014). Improvement of bonding strength of scarf-bonded carbon fiber/epoxy laminates by Nd: YAG laser surface activation. *Composites Part A: Applied Science and Manufacturing*, 67, 123-130.

Wang, Y., & Zhu, M. (2017). Overview of standard GFRP material node connections. *China Standardization*, (22), 240-241.

Wang, Z. (2023). Analysis of resin-based composite connection technology. *Fiber Composites*, 40(02), 86-90.

Wei, Y., Jin, X., Luo, Q., et al. (2024). Adhesively bonded joints—a review on design, manufacturing, experiments, modeling and

- challenges. *Composites Part B: Engineering*, 276, 111225.
- Zamani, P., Jaamialahmadi, A., & Da Silva, L. F. M. (2021). The influence of GNP and nano-silica additives on fatigue life and crack initiation phase of Al-GFRP bonded lap joints subjected to four-point bending. *Composites Part B: Engineering*, 207, 108589.
- Zhang, J., Li, C., Liu, G., et al. (2025). Research progress on bonding of aviation-grade carbon fiber reinforced resin-based composites. *Journal of Composite Materials*, 1-15.
- Zhang, Y., Chen, H., & Yu, X. (2025). Preparation and performance research of new environmentally friendly epoxy adhesive. *Chinese Adhesives*, 34(01), 46-51+70.

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