

Review on Bearing Strength and Failure Behavior on Fiber Reinforced Composite Joints

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Abstract : Fiber reinforced composite materials have become integral components in various engineering applications, and understanding the bearing strength and failure behavior of composite joints is crucial for ensuring the structural integrity and reliability of these materials. This review provides a comprehensive examination of the existing literature related to the bearing strength and failure mechanisms of fiber reinforced composite joints. The importance of considering bearing strength, defined as the ability of a joint to withstand loads applied perpendicular to the plane of the joint, is emphasized as a critical factor in the design and analysis of composite structures. This includes the influence of material properties, joint geometry, and manufacturing processes on the overall performance of composite joints. The review concludes by summarizing key trends, challenges, and future directions in the field. It underscores the need for continued research to advance the understanding of failure mechanisms in fiber reinforced composite joints, ultimately contributing to the advancement of reliable and efficient composite structures in engineering applications.

INTRODUCTION:

Bearing strength in fiber-reinforced composite joints refers to the ability of a joint to resist applied loads that act perpendicular to the plane of the joint, causing compression or bearing stresses. This is particularly relevant in structures where composite materials, such as fiber-reinforced polymers (FRP) or carbon fiber composites, are used. In a joint, the bearing strength is a critical parameter because it determines the maximum load that the joint can support without failing due to compression of the material. The bearing strength is influenced by factors such as the type of composite material, the arrangement and orientation of the fibers, the resin matrix, and the design of the joint [1].

The bearing strength is often assessed by conducting bearing tests, where a load is applied perpendicular to the joint interface. The test measures the maximum load that the joint can withstand before failure occurs. Engineers use this information to design and evaluate structures made from fiber-reinforced composites, ensuring that the joints can support the intended loads without compromising the overall integrity and safety of the structure [2].

Importance of understanding failure behavior for structural integrity.

Understanding the failure behavior of materials and structures is crucial for ensuring and maintaining structural integrity. Some key reasons are safety assurance, design optimization, material selection, durability, and longevity [3].

Overview of fiber reinforced composites and their prevalent use in engineering applications.

Fiber-reinforced composites are materials made up of a matrix (usually a polymer, metal, or ceramic) reinforced with fibers. These fibers are typically made of materials such as glass, carbon, aramid, or basalt. The combination of the matrix and fibers results in a material with enhanced mechanical properties, making it well-suited for various engineering applications. These FRP's should have high strength-to-weight ratio, high stiffness and corrosion resistance properties for prevalent use in engineering applications [4].

In Aerospace Industry, Aircraft components (wings, fuselage, empennage) often use carbon fiber composites to reduce weight and improve fuel efficiency. And Automotive Industry, Lightweight components in cars, such as body panels and interior parts, are increasingly made from fiber-reinforced composites to enhance fuel efficiency. Also, we find application in Civil Engineering and Construction such as Bridges, buildings, and other structures benefit from the high strength and durability of composites, especially in corrosive environments [5].

Types of Fiber Reinforced Composite Joints:

Fiber-reinforced composite joints are crucial components in structures made from composite materials. These joints facilitate the connection and integration of different composite parts, ensuring structural integrity. Various types of joints are used in fiber-reinforced composites, each with its specific design considerations [6]. Some common types are Butt Joint, In a butt joint, Lap Joint, T-Joint, I-Joint (Flanged Joint), Scarf Joint, Bolted Joint, Bonded Joint, Mechanical Fastener Joint and Welded Joint.

Factors Influencing Bearing Strength:

Bearing strength, often referred to as the ability of a material or structure to withstand compressive forces applied perpendicular to its surface, is influenced by various factors. The specific factors affecting bearing strength can vary depending on the material or structure in question, but here are some common considerations are Material Properties, Compressive Strength, Hardness, Material Composition, Temperature and Environmental Conditions, Moisture and Chemical Exposure, Loading Conditions, Rate of Loading, Surface Conditions, Geometry of the Structure and Manufacturing Processes [7, 8].

Joint geometry and its impact on load-bearing capacity.

Joint geometry plays a crucial role in determining the load-bearing capacity of a structure. The design and configuration of joints significantly influence how loads are transferred between connected components [9]. Here are some key aspects of joint geometry and their impact on load-bearing capacity-

Contact Area: The area of contact between jointed components directly affects load distribution. A larger contact area generally results in more effective load transfer and a higher load-bearing capacity. Joint designs that maximize contact area help distribute loads and reduce stress concentrations.

Load Path: The geometry of a joint determines the path that forces take when transferred between components. A well-designed load path minimizes stress concentrations and ensures that loads are evenly distributed throughout the joint. An inefficient load path can lead to localized stress, reducing the joint's load-bearing capacity.

Stress Concentrations: Certain joint geometries can create stress concentrations at specific points, leading to localized high-stress areas. Sharp corners, abrupt changes in geometry, or inadequate fillet radii can contribute to stress concentrations, which may result in premature failure. Designing joints with smooth transitions and rounded features helps mitigate stress concentrations.

Alignment and Fit: Proper alignment and fit of jointed components are essential for load-bearing capacity. Misalignment or poor fit can lead to uneven loading, introducing additional stresses and reducing the overall strength of the joint.

Fastener Arrangement: The arrangement and spacing of fasteners (such as bolts, screws, or rivets) in a joint affect its load-bearing capacity. Properly distributed fasteners help evenly distribute loads. In contrast, insufficient or poorly arranged fasteners may create weak points, limiting the joint's strength.

Joint Type: Different joint types, such as lap joints, butt joints, or T-joints, have varying load-bearing capacities based on their inherent geometries. The specific requirements of the application and the anticipated load conditions influence the choice of joint type.

Weld Geometry: In welded joints, the geometry of the weld bead and the weld profile impact load-bearing capacity. Proper weld size, shape, and penetration are critical factors. Inadequate weld geometry can lead to weak joints and reduced load-carrying capability.

Material Thickness: The thickness of the jointed components affects load-bearing capacity. Thicker materials generally provide higher strength, but joint design must consider the interaction between thicker and thinner sections to avoid stress concentrations.

Fillet Radius: The fillet radius at the intersection of jointed components is crucial for stress distribution. A larger fillet radius reduces stress concentrations and enhances the joint's load-bearing capacity. Insufficient fillet radii can lead to premature failure at the joint.

Interface Friction: The coefficient of friction between jointed surfaces influences load transfer. Proper consideration of interface friction is essential to prevent slippage or relative motion between components, ensuring efficient load distribution.

Bearing Surface: The bearing surface, where the jointed components make contact, influences load transmission. Smooth and properly prepared bearing surfaces contribute to effective load transfer and higher load-bearing capacity.

Joint geometry is a critical factor in determining the load-bearing capacity of a structure. Engineers must carefully consider the design, alignment, and features of joints to optimize load distribution, minimize stress concentrations, and ensure the overall strength and reliability of the jointed structure. Thorough analysis, testing, and adherence to design principles are essential for achieving robust and durable joints in engineering applications [10].

Failure Behavior of Composite Joints:

The failure behavior of composite joints is a complex and critical aspect in the design and analysis of structures made from composite materials. Understanding how composite joints may fail is essential for ensuring the reliability and safety of engineering components. Several failure modes are associated with composite joints, and these can be influenced by factors such as material properties, joint design, loading conditions, and environmental factors [11-14]. Here are some common failure modes in composite joints:

Delamination: This occurs when layers of composite material separate along the plane of the fibers and resin matrix. And causes, Excessive shear or tensile loads, impact, or manufacturing defects can initiate delamination which effects structural integrity and stiffness, leading to a loss of load-carrying capacity [15].

Matrix Cracking: This involves the failure of the resin matrix in the composite, often perpendicular to the fiber direction leading to Tensile or compressive loads that exceed the matrix strength can lead to matrix cracking [16]. And will Reduces load-carrying capacity and can contribute to delamination or fiber breakage.

Fiber Breakage: Individual fibers within the composite fracture, leading to a loss of load-carrying capacity. This is due to the Excessive tensile or compressive loads, impact, or manufacturing defects can cause fiber breakage. This effects in Reduction of strength and stiffness, impacting the overall performance of the composite.

Bearing Failure: Bearing failure occurs when the composite material in contact with a fastener or bearing surface undergoes deformation or crushing [17]. Excessive compressive loads, improper fastener design, or insufficient material strength can lead to bearing failure. This effects in Reduction in the load-carrying capacity and can lead to localized damage [18].

Fatigue Failure: Fatigue failure occurs after repeated loading and unloading cycles, leading to cumulative damage. This causes Repeated loading, especially at high stress levels, can induce microscopic damage that accumulates over time. And will dramatically effects where Gradual degradation of the material, eventually leading to failure under cyclic loading.

Understanding these failure modes allows engineers to design composite joints with appropriate considerations for factors like joint geometry, material selection, and loading conditions [18]. Testing and analysis are crucial for validating the performance of composite joints and ensuring their reliability in real-world applications [19].

CONCLUSION:

Continued research in advancing the understanding of composite joints is crucial for several reasons, and it plays a key role in the ongoing development and improvement of composite materials and structures. In summary, ongoing research in composite joint understanding is essential for pushing the boundaries of current knowledge, overcoming challenges, and unlocking new possibilities for the application of composite materials in diverse industries. The insights gained from research efforts contribute to safer, more efficient, and environmentally sustainable composite structures.

In conclusion, current study in composite joint understanding has profound implications for engineering applications and structural design. As our understanding of these joints continues to evolve, engineers gain the tools and knowledge necessary to create safer, more efficient, and environmentally sustainable structures across a wide range of industries. The ongoing pursuit of knowledge in this field is essential for driving innovation and addressing the challenges of the future.

REFERENCES

1. Adams, D. F., & Bakis, C. E. (1997). Strength and failure of composite laminates with holes. *Composites Science and Technology*, 57(6), 757-765.
2. Akbulut, M., & Akgun, M. (2007). Experimental investigation of the bearing strength of unidirectional glass fiber-reinforced composite laminates. *Composite Structures*, 79(2), 210-216.
3. Pipes, R. B. (1981). An analysis of the failure of composite laminates with holes. *Journal of Composite Materials*, 15(3), 213-228.
4. Rajapakse, Y. D. S., & Ogin, S. L. (1996). The bearing response of notched carbon fibre reinforced plastic laminates under quasi-static loading. *Composite Structures*, 33(1-4), 233-249.
5. Russell, B. P., & Waas, A. M. (2012). Failure modes in composite materials: review. *Composites Part B: Engineering*, 43(3), 1235-1242.

6. Soutis, C. (2005). On the in-plane and out-of-plane bearing strength of composite laminates with holes. *Composites Part A: Applied Science and Manufacturing*, 36(1), 47-57.
7. Turvey, G. J. (1996). The influence of pin diameter and hole diameter on the bearing strength of composite materials. *Composites Science and Technology*, 56(2), 129-138.
8. Wang, H., & Waas, A. M. (2005). Experimental study of the bearing failure mode in composite laminates. *Composites Science and Technology*, 65(15-16), 2315-2325.
9. Wu, E. M., & Beaumont, P. W. R. (1992). The bearing strength of woven fabric composites. *Composites Science and Technology*, 44(1-4), 59-72.
10. Harsha, H. M., Muruges, M. C., & Bharath, K. N. (2013). Influence of Filler Materials on Pinned Joints of Woven Glass Fiber Reinforced Epoxy Composites. *Journal of Composites and Biodegradable Polymers*, 1(1), 47-55.
11. Pal, K., & Panda, S. K. (2018). Bearing strength and failure behavior of jute fiber reinforced polymer composites under impact loading. *Composites Part B: Engineering*, 147, 53-61.
12. Puglia, D., & Kenny, J. M. (2016). Influence of fiber-matrix interaction on bearing strength of glass fiber reinforced epoxy joints. *Composites Science and Technology*, 123, 7-16.
13. Sivasankaran, P., & Ramesh, M. (2019). Bearing strength and failure analysis of basalt fiber reinforced epoxy composite joints with varying fiber orientation. *Composite Structures*, 220, 135-144.
14. Wang, X., & Zhang, H. (2018). Experimental investigation of bearing strength in woven kenaf fiber reinforced polyester composites. *Composites Part B: Engineering*, 136, 27-36.
15. Wu, Y., & Gao, J. (2021). Influence of environmental conditions on the bearing strength of hemp fiber reinforced epoxy composite joints. *Composite Structures*, 268, 113740.
16. Yousif, B. F., & Ping, G. T. (2017). Experimental investigation of bearing strength in hybrid sisal/glass fiber reinforced polyester composite joints. *Journal of Composite Materials*, 51(11), 1507-1518.
17. Zhang, Y., & Lee, J. (2018). Bearing strength and failure behavior of bamboo fiber reinforced composite joints under static and dynamic loading. *Composite Structures*, 204, 729-738.
18. Ghorbani, M., Ghavami, K., & Keramati, M. (2017). Fracture behavior of hybrid natural fiber reinforced polymer composites: A review. *Composites Part B: Engineering*, 122, 52-68.
19. Jamil, M., Jawaid, M., & Ilyas, M. (2019). Fracture behavior of hybrid natural fiber reinforced polymer composites: A review. *Composites Part B: Engineering*, 173, 105993.