

A REVIEW ON REINFORCED COMPOSITE BRACKET DESIGN FOR IMPROVED DURABILITY IN MATERIAL HANDLING CRANES

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ABSTRACT

The design and application of reinforced composite materials in structural components have become increasingly relevant in the material handling industry, particularly in overhead cranes, where durability and structural integrity are critical. This review article examines the current advancements in reinforced composite bracket design aimed at enhancing the durability and performance of overhead crane systems. Focusing on the unique mechanical properties of composite materials—such as high strength-to-weight ratios, corrosion resistance, and flexibility in tailored reinforcement—this review analyzes various design approaches, material choices, and reinforcement techniques utilized to optimize bracket performance. Key topics include stress distribution in composite structures, fatigue resistance under repeated loading, and innovative design strategies to improve longevity in high-stress environments.

Furthermore, the review explores the advantages of using composites over traditional materials in terms of weight reduction, ease of maintenance, and overall system reliability. By synthesizing recent studies and practical case analyses, this article highlights both the challenges and potential of composite bracket designs to improve durability in cranes, ultimately contributing to safer, more efficient material handling operations. This comprehensive review offers valuable insights for engineers and researchers focused on advancing the design and reliability of composite structural components in heavy-duty applications.

Keywords: Finite Element Analysis, Structural analysis, Material optimization comparative analysis, Material handling crane.

1. INTRODUCTION

Material handling systems, particularly overhead cranes, are essential in industries that require the lifting, transportation, and precise positioning of heavy loads. The structural components of these systems, such as brackets, play a critical role in ensuring safety, reliability, and performance under demanding operating conditions. Traditionally, these brackets have been constructed from metals such as steel and aluminum, which provide the necessary strength but come with inherent challenges, including weight, susceptibility to corrosion, and increased maintenance requirements. In response to these limitations, reinforced composite materials have emerged as a promising alternative due to their superior strength-to-weight ratio, corrosion resistance, and ability to be customized for specific structural needs. Reinforced composites, typically consisting of a polymer matrix combined with reinforcing fibers such as glass, carbon, or aramid, offer a unique combination of properties that make them particularly suitable for heavy-duty applications. Their anisotropic nature allows engineers to tailor the material properties according to the load paths and stress concentrations within the structure. For overhead crane applications, the use of composite materials in brackets can reduce overall system weight, lower energy consumption, and enhance durability, resulting in improved performance and reduced operational costs. However, the shift to composite materials brings new challenges in design, analysis, and manufacturing that must be carefully addressed to ensure reliability under dynamic and cyclic loading conditions typical of material handling applications. This review aims to explore recent advancements in the design and application of reinforced composite brackets specifically for overhead cranes, with a focus on improving durability and structural integrity. The analysis covers a range of topics, including material selection, reinforcement strategies, load-bearing performance, and failure mechanisms in composite brackets. Studies on stress analysis have shown that composites behave differently than metals when exposed to high-stress regions, such as the mounting points of crane brackets, necessitating new design methodologies to fully leverage their properties. Additionally, advancements in manufacturing techniques, such as resin transfer molding (RTM) and filament winding, have expanded the design possibilities for composite brackets, enabling complex geometries and optimized fiber orientations that were previously unattainable with metals. In summary, the adoption of reinforced composite materials in overhead crane brackets represents a significant advancement in the material handling industry. The integration of composites promises not only to enhance the structural durability of these components but also to contribute to safer, more energy-efficient crane systems. This review aims to serve as a valuable resource for engineers, researchers, and industry professionals interested in the practical applications of composite materials in heavy-duty structural components. Through an in-depth analysis of current trends, challenges, and future potential,

this paper seeks to advance the understanding of composite bracket design, ultimately contributing to the development of more robust, lightweight, and durable material handling systems.

1.1 Scope

The design of reinforced composite brackets in material handling cranes must address a wide range of performance requirements, including load-bearing capacity, impact resistance, and durability under dynamic and cyclic loads. This review explores the design principles necessary for developing robust composite brackets that can effectively withstand the high-stress and demanding conditions typical of crane operations. This includes an analysis of factors such as stress distribution, failure mechanisms, and the influence of geometric configurations on bracket performance. Material handling cranes are subject to dynamic loads, repetitive stress, and sudden impacts. The scope of this review includes an examination of the fatigue and impact performance of reinforced composite materials used in crane brackets. Insights into how these materials behave under cyclic loading, their resistance to cracking or failure, and the role of reinforcement fibers in enhancing durability are discussed in detail.

The selection of reinforced composite materials for crane brackets involves balancing performance and cost. The review addresses the economic considerations in material selection, focusing on the cost-benefit analysis of using advanced composites, including initial material costs, manufacturing costs, and potential savings in terms of reduced maintenance, weight reduction, and increased longevity of crane systems. The economic feasibility of using composite materials in large-scale applications like material handling cranes is also discussed.

2. LITERATURE SURVEY

The use of reinforced composite materials in structural components of material handling cranes, particularly in brackets, has garnered significant attention due to their potential to enhance performance, durability, and overall system efficiency. Several studies have explored various aspects of composite material applications in crane systems, focusing on the mechanical behavior, stress analysis, fatigue performance, and design optimization of these materials.

Jones and Smith (2019)[1] investigated the design optimization of composite materials for heavy-duty crane applications, emphasizing the need for tailored material properties to withstand high loads and dynamic stresses. They demonstrated that composites, when properly designed, can provide substantial weight reduction and improved structural integrity compared to traditional materials. Similarly, Cheung et al. (2000) examined the stress distribution in composite strips with circular cutouts under tension, highlighting the unique stress behaviors exhibited by composites, which can be leveraged for efficient design of crane brackets.

Santos and Moreira (2020)[2] focused on the mechanical behavior and fatigue performance of reinforced composites, emphasizing the importance of long-term performance under cyclic loading conditions, typical in material handling cranes. This aligns with the findings of Teng and Liu (2021), who explored the durability and environmental resistance of composite materials, addressing the challenges of material degradation in harsh crane operating environments. Zhang and Li (2018)[3] explored the innovative applications of reinforced composites in crane systems, providing insights into the benefits of these materials in reducing weight while maintaining structural robustness. Gao and Yao (2020) further supported this notion, investigating the application of fiber-reinforced polymers (FRPs) in crane structural brackets, focusing on their ability to resist impact and high-stress concentrations. In addition to material performance, several studies have delved into the manufacturing and fabrication techniques of composite materials for crane brackets. Xu and Wu (2017)[4] discussed the design and fabrication processes of composite structural components for heavy machinery, underscoring the need for advanced manufacturing methods that can meet the complex requirements of crane applications. Cheng and Liu (2019) evaluated the impact behavior of composite materials in overhead crane systems, contributing valuable insights into their performance during sudden load applications and shock events. Further, Marques and Soares (2021)[5] provided an overview of fiber-reinforced polymer composites in heavy machinery brackets, discussing the key advantages, such as high strength-to-weight ratios and corrosion resistance, which make them ideal for crane applications. Hassan and Khan (2020)[6] evaluated the performance of reinforced composites in material handling cranes, considering factors such as structural integrity, reliability, and operational efficiency. In conclusion, the literature on reinforced composite bracket design for material handling cranes highlights significant advances in material selection, stress analysis, and performance optimization. The research emphasizes the unique properties of composites, such as high strength, lightweight characteristics, and environmental resistance, which make them highly suitable for use in crane systems. However, challenges such as fatigue resistance, impact behavior, and long-term durability in real-world crane operations remain critical areas of ongoing investigation. Future research should focus on refining material properties, improving manufacturing techniques, and addressing these challenges to further enhance the performance of composite materials in heavy-duty crane applications.

3. MATERIAL SELECTION

The selection of appropriate materials is a critical aspect of designing reinforced composite brackets for material handling cranes. Brackets in crane systems are subjected to high dynamic loads, fatigue, impact, and environmental stresses, making the choice of material integral to ensuring durability, reliability, and optimal performance. This section reviews the key considerations and material options for reinforced composite brackets used in overhead cranes, focusing on the properties required to withstand harsh operating conditions.

3.1. Matrix Materials

The matrix material in composite structures binds the reinforcing fibers together and transfers loads between them. The choice of matrix material affects the overall mechanical properties, environmental resistance, and ease of manufacturing of the composite material.

Epoxy Resin: Epoxy is widely used as a matrix material in FRPs due to its excellent mechanical properties, low shrinkage, and high adhesion strength. It offers superior resistance to environmental factors such as moisture, chemicals, and high temperatures, making it a suitable choice for crane applications where exposure to harsh conditions is common.

Polyester Resin: Polyester resins are cost-effective and commonly used in applications where ultimate mechanical performance is not the primary concern. They offer good mechanical properties but have lower chemical and thermal resistance compared to epoxy resins. Their use is more appropriate for cranes operating in milder environments.

Vinyl Ester Resin: Vinyl ester resins provide a good balance between cost and performance. They offer better corrosion resistance and mechanical properties than polyester, making them a viable option for crane systems exposed to more aggressive environments, such as saltwater or high-humidity conditions.

3.2. Hybrid Composites

Hybrid composites, which combine different types of fibers (e.g., glass and carbon fibers) within the same matrix, are another promising option for crane bracket applications. Hybrid composites aim to combine the best properties of individual fibers, such as the low-cost and high-impact resistance of glass fibers with the superior strength and stiffness of carbon fibers. This approach can offer an optimal balance between performance, cost, and weight reduction, making them ideal for material handling crane applications that require both strength and impact resistance.

3.3. Metal Matrix Composites (MMC)

Although fiber-reinforced polymers dominate the composite materials used in crane brackets, metal matrix composites (MMCs) are another option to consider for certain applications. MMCs consist of a metal matrix (such as aluminum, magnesium, or titanium) reinforced with ceramic fibers or particles. These materials offer excellent wear resistance, high-temperature stability, and enhanced strength compared to traditional metals.

Aluminum Matrix Composites (AMC): Aluminum-based MMCs can be used to provide lightweight and high-strength properties while maintaining good thermal and electrical conductivity. These composites are suitable for crane applications where both weight reduction and wear resistance are crucial.

Magnesium Matrix Composites (MMC): Magnesium is one of the lightest metals, and when reinforced with ceramic particles, it provides enhanced strength and wear resistance. MMCs based on magnesium are ideal for applications where minimizing weight while maintaining mechanical properties is essential.

3.4. Environmental Resistance

Durability in crane applications is not only about mechanical properties but also about how well the material performs under environmental stress. Crane systems are often exposed to factors such as humidity, UV radiation, saltwater, and temperature fluctuations, which can degrade materials over time.

Corrosion Resistance: Crane components are often exposed to corrosive environments, especially in coastal or industrial areas. Composite materials like CFRPs, GFRPs, and hybrid composites with corrosion-resistant resins (such as epoxy and vinyl ester) are ideal for ensuring long-term durability without the need for frequent maintenance or replacement.

3.5. Cost Considerations

The selection of composite materials is also influenced by cost considerations, particularly in large-scale applications like material handling cranes. While carbon fiber composites provide superior performance, they come at a higher cost compared to glass fiber and hybrid composites. The overall cost-effectiveness of the material should consider both the initial material cost and the long-term benefits of reduced maintenance, weight savings, and improved performance.

Material selection for reinforced composite brackets in material handling cranes is a balance between mechanical performance, environmental resistance, weight reduction, and cost. The combination of high-strength fibers such as

carbon, glass, and aramid with appropriate matrix materials such as epoxy or vinyl ester resins provides excellent opportunities for optimizing the durability and functionality of crane brackets. Furthermore, hybrid composites and metal matrix composites offer additional options for specific performance needs. As the demand for more efficient and durable crane systems grows, advancements in composite materials and manufacturing techniques will continue to play a vital role in shaping the future of crane component design.

3.6 Material properties:

Particularly Cu-containing metal matrix composites show improved thermal and tribological properties. Due to this, LM25 aluminum alloys are becoming more and more popular among researchers across the world for the development of specialized parts for aerospace and industrial counterparts, notably for the construction of structural elements like vehicle panels, heat sinks for transformers, high-strength beams and columns that are often subjected to fatigue stresses, as well as circuit breakers

It is the most often used hard phase for reinforcement in aluminium composites due to its ability to interact wettably with aluminium particulate and its relatively uniform dispersion ratio. The covalent bonds between the carbon and silica in its structure form a tetrahedron that is up to 90% stronger. Because of its excellent tribology, shock absorption, hardness, and thermal characteristics

Table 4.1 LM25 alloy Chemical composition

Elements	Si	Fe	Cu	Mg	Ni	Mn	Zn	Ti	Pb	Cr	Remaining
Content (wt. %)	7	0.5	0.15	0.5	0.15	0.55	5	0.1	0.15	0.35	Al.

4. DISCUSSIONS

The design and use of reinforced composite materials for brackets in material handling cranes have garnered significant attention in recent years due to their potential to improve durability, reduce weight, and enhance performance in demanding environments. A comprehensive analysis of the available literature provides insights into material selection, mechanical performance, and application techniques, highlighting both the opportunities and challenges in implementing these materials for crane brackets.

Jones and Smith (2019) emphasize the importance of design optimization in composite materials to improve the mechanical properties of crane components, particularly under heavy-duty operational conditions. The study suggests that materials with high strength-to-weight ratios, such as carbon fiber reinforced polymers (CFRP), are particularly suited for structural components like crane brackets. These materials offer superior fatigue resistance, high tensile strength, and minimal weight, which are essential for cranes that operate under dynamic loading and constant use. Similarly, Santos and Moreira (2020) explored the fatigue behavior of reinforced composites, providing evidence that these materials exhibit better fatigue performance than traditional metallic materials. The high fatigue resistance is crucial for crane components, as they are subjected to repeated loading and unloading cycles, often leading to premature failure in conventional materials. In this context, the reinforced composite brackets present a promising alternative by extending the lifespan and reducing the maintenance frequency of crane systems.

Cheung et al. (2000) provide a detailed analysis of stress distribution in composite materials with circular cutouts, which is relevant for the design of crane brackets, where such geometric features are commonly present for bolting and fastening purposes. Their study highlights that composite materials, especially those reinforced with fibers, can handle stress concentrations better than isotropic materials. This is critical in crane applications where high-impact loads and localized stress are frequently encountered. The work of Teng and Liu (2021) builds on these findings by investigating the environmental resistance of composite materials used in crane brackets. They show that the performance of composites is highly dependent on their exposure to harsh environmental conditions, such as UV radiation, moisture, and temperature fluctuations. Composite materials like CFRP and glass fiber reinforced polymers (GFRP) exhibit improved resistance to corrosion and environmental degradation, which is especially beneficial for cranes operating in outdoor or industrial environments. Their durability in these challenging conditions is a significant advantage over metals, which often suffer from rust and fatigue under similar circumstances.

Marques and Soares (2021) review the various manufacturing methods used to fabricate fiber-reinforced polymer composites for heavy machinery brackets, including crane applications. Techniques such as resin transfer molding (RTM), automated fiber placement (AFP), and additive manufacturing (AM) are highlighted for their ability to produce complex geometries and ensure consistent quality. While these

methods offer high precision and material efficiency, the cost remains a significant factor to consider, as advanced manufacturing techniques can increase production costs compared to traditional methods. The economic feasibility of adopting these technologies in large-scale production, especially for cost-sensitive applications, remains a key consideration.

5. CONCLUSION

In conclusion, the reviewed literature highlights the significant advantages of reinforced composite materials in the design of structural components, particularly crane brackets, where durability, weight reduction, and performance under dynamic stresses are critical. Studies such as those by Jones and Smith (2019) and Zhang and Li (2018) emphasize the importance of optimizing composite materials for heavy-duty crane applications, underscoring their superior mechanical properties compared to traditional materials. The fatigue resistance and impact behavior of composites, as discussed by Santos and Moreira (2020) and Cheng and Liu (2019), make them ideal for handling the repetitive loading and shock impacts typical in crane operations. Furthermore, advancements in manufacturing techniques, including those explored by Marques and Soares (2021), have improved the feasibility of using fiber-reinforced polymers in these applications. However, challenges related to environmental resistance and cost-effectiveness, as highlighted by Teng and Liu (2021) and Gao and Yao (2020), must still be addressed for broader adoption. Overall, the future of reinforced composites in crane brackets looks promising, with ongoing research focused on optimizing material properties, enhancing manufacturing processes, and improving performance in harsh operational conditions.

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