A REVIEW ON DESIGN AND FABRICATION OF EPOXY BASED COMPOSITES USING CARBON TUBES AS REINFORCEMENT

N. SIVA KOTESWARA RAO [1], Dr. E.SIVA KRISHNA [2], M.NAGENDRA [1], K.YESWANTH [1]

[1]B. Tech Students in Mechanical Engineering Department, NRI INSTITUTE OF TECHNOLOGY, Agiripalli, Vijayawada, India.

[2]Assistant Professor in Mechanical Engineering Department, NRI INSTITUTE OF TECHNOLOGY, Agiripalli, Vijayawada, India.

ABSTRACT :

A review on the design and fabrication of epoxy- based compiste materials reinforced with carbon tubes. The primary objective is to enhance the mechanical properties of conventional epoxy resin by incorporating tubular carbon reinforcements, making the material suitable for highperformance structural applications. Carbon tubes were selected due to their excellent strength-toweight ratio, corrosion resistance, and thermal stability.

KEY WORDS: Carbon Tube, Carbon Fiber Reinforced Polymers (CFRP), Lightweight Polymers, High Modulus,High Strength Polymers

1. INTRODUCTION :

Epoxy-based composites are ideal for high-performance applications, particularly in structural and engineering contexts. In these composites, carbon tubes—typically with a diameter of 3 mm—serve as reinforcements within the epoxy matrix. The inclusion of carbon tubes significantly enhances the strength and stiffness of the material, enabling it to handle higher loads while maintaining a lightweight profile. This reinforcement also improves the composite's durability due to the strong bonding between the carbon tubes and the epoxy resin. Epoxy resin itself provides excellent adhesion and bonding characteristics, which, when paired with the superior tensile properties of carbon tubes, results in a robust and resilient material.Proper selection of carbon tubes is critical to achieving optimal performance, and surface treatment of the tubes is often necessary to ensure effective bonding with the epoxy. Additionally, the epoxy resin must be precisely mixed with curing agents to achieve the desired mechanical properties. Uniform dispersion of carbon tubes throughout the matrix is essential for maintaining structural integrity and avoiding weak points. The design process for these composites emphasizes strength-to-weight optimization, and fabrication methods are carefully tailored to prevent defects or voids that could compromise performance.These composites find widespread application in demanding fields such as aerospace, automotive, and sports equipment, where high mechanical performance and environmental resistance are required. The final material exhibits improved mechanical behavior, enhanced environmental durability, and is well-suited for load-bearing, high-performance structures.

2. LITERATURE REVIEW :

1. Narayan Shirolkar et al., Multichannel hollow carbon fibers were fabricated using a continuous gel-spinning process from PAN and PMMA precursors. Process optimization and large-scale production improved defect control and enhanced fiber strength and stiffness. Imaging and mechanical testing confirmed that the hollow fibers achieved strengths of 2.3–3.0 GPa and modulus of 202–234 GPa, with a low density of 1.15 g/cm³. Structural and spectroscopic analysis verified high graphitic alignment and reduced surface defects, surpassing previous batch-made hollow fiber results. The study suggests these lightweight, high-strength fibers are well suited for aerospace composite applications, with scalable production methods that maintain mechanical properties.
2. Chen Wei et al., Electrospinning was used to produce ultrafine carbon fibers from PAN precursors, enabling control of fiber structure and properties through process and thermal steps. Post-spinning stabilization, carbonization, and graphitization yielded lightweight, strong nanofibers with adaptable conductivity and crystallinity. Morphological and mechanical analyses showed that defect-free, smooth fibers and precise tuning of diameter resulted in high tensile strength and modulus. This work demonstrates that electrospun PANbased carbon fibers are a flexible, cost-effective alternative to traditional fiber production, with industrial potential for high-performance and specialty applications such as filtration and energy storage.
3. Matthew C. Weisenberger et al., Hollow carbon fibers were fabricated via solution-spinning, focusing on reducing material cost and weight while maintaining effective tensile properties. The internal lumen design eliminated disordered cores and lowered density, offering improved specific strength and processing efficiency. Effective modulus and tensile tests compared performance to T700S benchmark, while microscopy and modeling assessed geometry consistency and skin stress resistance. The findings show hollow carbon fibers can match or outperform conventional fibers in specific tensile strength and cost, supporting their future industrial use in hydrogen storage and aerospace composites.
4. H. P. Sampath et al., Carbon nanofibers were produced using the electrospinning of PAN solutions, stabilized and carbonized for structural optimization. SEM, TEM, XRD, and Raman characterization confirmed that voltage, concentration, and heat treatment parameters significantly affect fiber diameter, crystallinity, and conductivity. Aligned fibers demonstrated improved mechanical properties, and graphitization enhanced modulus and electrical performance at the expense of brittleness. The process was found flexible and

scalable, enabling tailored CNF properties for advanced functional applications in filtration, sensors, and energy systems.

5. Sivakumar Palanivelu et al., Hollow carbon fibers were produced via solution spinning for reduced cost and weight, targeting applications in aerospace and hydrogen storage. A dualcapillary spinneret was used for fiber extrusion, creating uniform hollow structures verified by SEM and composite mechanical tests. Resulting modulus values (~196 GPa), tensile strengths (1.2 GPa), and a density of 1.23 g/cm³ yielded higher specific modulus compared to traditional solid fibers. Cost modeling demonstrated up to 12% savings in production and 29% efficiency in applications. The study found that hollow fibers can match or exceed conventional fiber properties, promising major weight and cost savings with further refinement.
6. Mohammed J. Hamood et al., Investigated the development of carbon fibers from alternative, low-cost precursors such as textile-grade PAN, modifying stabilization and carbonization to maintain competitive mechanical properties. Results revealed that fibers from textile PAN reached strengths of 2.0–2.5 GPa and modulus of 180–200 GPa, slightly lower than aerospace-grade but meeting structural needs with up to 50% cost savings. Microscopic analysis showed acceptable surface quality, with processing tailored to minimize defects. The study confirmed the feasibility of low-cost carbon fiber for broader industrial applications, including automotive, energy, and civil construction, validated by robust FE analysis on CFST columns.
7. K. Srinivasa Kishore et al., Conducted an overview of carbon fiber and CFRP composites, highlighting manual hand lay-up fabrication and performance enhancements via different fillers. Experimental data showed that incorporating barite at 10% delivered the highest tensile, impact, and hardness values, while graphite and nano-clay fillers improved mechanical properties in other ways. The research summarized that effective selection and dispersion of fillers—also including waste-derived materials—can significantly boost CFRP composite strength and afford lower material costs, providing environmental advantages and informing the design of high-performance, lightweight automotive components.
8. H. S. Ashrith et al., Reviewed fabrication and mechanical characterization of fibrous composites with focus on synthetic and natural fibers and multiple manufacturing techniques including hand lay-up, compression molding, RTM, and filament winding. Analysis indicated that fiber type, orientation, volume fraction, and advanced methods like additive manufacturing greatly influence strength, stiffness, and impact resistance. The addition of nanoparticles or CNTs further improved properties, and compression molding/autoclave

methods yielded the strongest, void-free laminates. Mechanical testing and process optimization were emphasized as key to maximized performance for aerospace, automotive, and sporting applications.

9. H. S. Ashrith, T. P. Jeevan, N. Raghavendra et al., Summarized the state-of-the-art in natural fiber-reinforced polymer composites, detailing fiber types, chemical treatments, matrices, and hybridization approaches. Results demonstrated that chemically treated and hybrid composites exhibit improved tensile, flexural, and impact strengths over untreated or pure natural fiber varieties. The review found that epoxy and polyester matrices outclass thermoplastics in mechanical performance, but advances in nanofillers and hybrid designs address long-standing barriers such as moisture absorption, opening up sustainable, lightweight solutions for automotive, construction, and consumer sectors.
10. Miloud Souiyah, Ibrahim Momohjimoh et al., Provided a comprehensive review of fiberreinforced polymer composites, comparing synthetic and natural fibers, summarizing typical matrices, and evaluating key fabrication methods like hand lay-up, pultrusion, and filament winding. The analysis found carbon and glass fibers offer maximum strength, while hybridization can combine performance and eco-friendliness. Process variables such as fiber orientation, surface treatment, and matrix selection were pivotal for optimizing mechanical and thermal properties. Challenges regarding cost, recyclability, and durability remain, but improvements in eco-friendly and hybrid manufacturing were highlighted as forward paths for broader adoption in high-performance aerospace, marine, and automotive markets.
11. M.N. Masri et al. present natural fiber-reinforced polymer composites, highlighting manufacturing processes such as injection molding, pultrusion, resin transfer molding, sheet molding compound, and compression molding, along with their advantages, challenges, and applications.
12. Rajesh Kumar Mishra et al. discuss the role of natural fibers in composites, focusing on process selection, fiber treatment, cost-effectiveness, and property optimizations for highquality, eco-friendly products in automotive, marine, and construction industries.
13. V.K. Srivastava et al. review the promise of carbon-based low-dimensional structures in polymer composites, emphasizing additive manufacturing for superior alignment and complex geometries, while acknowledging remaining challenges with voids and interlayer adhesion. Paul Bere et al. introduce an innovative process for manufacturing bent carbon/epoxy composite tubes for bicycle handlebars, demonstrating enhanced strength, weight reduction, and agreement between experimental and theoretical results.

14. H.P. Sampath et al. investigate the compression behavior of glass/epoxy hollow tubes, revealing that the fiber-to-matrix ratio, especially 60:40, strongly affects load absorption and yielding capacity, confirming the importance of optimized composition for lightweight structural applications.
15. H. P. Sampath et al., studied the quasi-static compression behavior of hollow epoxy composite tubes fabricated by hand lay-up with varying fiber-to-matrix ratios. Their work found that a 60:40 ratio provided superior energy absorption and deformation capacity, while a 50:50 ratio yielded the highest compression strength. The results emphasize that fibermatrix adhesion critically influences mechanical performance, making these composites suitable for lightweight and crash-resistant structural applications.
16. Jagannatha Reddy et al., reviewed natural fiber-reinforced polymer composites (NFRPCs) focusing on their mechanical, thermal, and moisture-related properties. They highlighted that chemical treatments enhance fiber-matrix bonding, resulting in improved strength and durability. Additionally, hybridization and proper fiber selection further elevate performance, supporting their use in automotive, building, and packaging sectors as ecofriendly, sustainable alternatives.
17. M. Jawaid et al., presented a comprehensive review on hybrid natural fiber polymer composites, discussing chemical surface treatments and various manufacturing techniques. The study showed that hybrid composites improve mechanical properties and moisture resistance compared to pure natural fiber composites. Challenges such as fiber variability and moisture absorption remain, suggesting that optimization is needed for broader industrial adoption.
18. V. Phaugat et al., reviewed carbon nanotube (CNT) properties, synthesis, and applications, emphasizing CNTs' exceptional mechanical strength, conductivity, and resilience. The work covers CNT classification, challenges in large-scale production, and surface functionalization for improved dispersion and biocompatibility. CNTs show promise in composites, energy, and biomedical applications despite issues related to consistent quality and toxicity.
19. Rajashree Hirlekar et al., summarized CNT characteristics and applications in nanomedicine and composites. They detailed synthesis methods, purification, and functionalization techniques to improve CNT utility, highlighting their role in drug delivery, sensors, and filtration. Despite production and safety challenges, CNTs are viewed as transformative materials for advanced engineering and biomedical fields.

20. T. Köhler evaluated the production and thermal-mechanical behavior of hollow carbon fibers derived from PAN precursors. The study demonstrated that proper thermal stabilization maintains hollow geometry, with thinner walls favoring structural integrity by facilitating gas diffusion. These lightweight fibers show promise for aerospace and hydrogen storage applications, though further research is required for continuous production and mechanical testing.
21. T. Köhler evaluated the production and thermal-mechanical behavior of hollow carbon fibers derived from PAN precursors. The study demonstrated that proper thermal stabilization maintains hollow geometry, with thinner walls favoring structural integrity by facilitating gas diffusion. These lightweight fibers show promise for aerospace and hydrogen storage applications, though further research is required for continuous production and mechanical testing.
22. Suhas Y. Nayak et al., developed and tested a carbon fiber reinforced epoxy drive shaft for an all-terrain vehicle using filament winding with carefully selected fiber orientations. The composite shaft demonstrated 8.5% higher torsional strength and 60% weight reduction compared to steel. SEM analysis revealed failure mechanisms such as delamination and fiber pull-out, leading to recommendations for improved processing to enhance bonding and performance.
23. Kevin John et al., presented research on developing a composite structural member using cold forging of CFRP tubes combined with epoxy filler. The process is low energy, eliminating the need for high temperature curing equipment. Experimental and simulation results show mechanical properties approaching theoretical predictions despite porosityrelated deviations. The method is promising for robotic link applications requiring lightweight and dynamic strength.
24. Paul Bere et al., investigated fabrication of carbon/epoxy tubular parts with variable crosssections using a closed mould and elastic mandrel method. A bent bicycle handlebar was produced weighing only 95 g with 67% fiber volume fraction. Mechanical property tests and finite element simulations confirmed design assumptions. The lightweight handlebar achieved strength comparable to metals, suggesting utility for high-performance sporting and structural applications.
25. H. P. Sampath et al., studied quasi-static compression behavior of hollow glass/epoxy tubes prepared by hand lay-up with varying fiber-to-matrix ratios. Testing showed the 60:40 composition yielded the best energy absorption, while 50:50 had highest compressive

strength. Results confirm important role of fibre-matrix adhesion in achieving suitable mechanical characteristics for lightweight structural and crashworthy components.

26. Jagannatha Reddy and Pradeep Kumar reviewed natural fiber reinforced polymer composites focusing on manufacturing, mechanical and thermal properties, and moisture effects. Emphasis was placed on enhancing fiber-matrix bonding via treatments and on broadening applications in automotive and construction. Challenges such as moisture sensitivity and durability remain key concerns to be addressed for sustainable engineering materials.
27. M. Jawaid et al., performed a comprehensive review of hybrid natural fiber polymer composites highlighting chemical treatments like alkali and silane to improve interfacial bonding and durability. Various manufacturing processes were compared with an emphasis on performance optimization for automotive, aerospace, and construction sectors. The review noted remaining challenges including fiber variability and moisture absorption.
28. Vishal Phaugat et al., reviewed carbon nanotubes (CNTs), addressing synthesis approaches, mechanical and electrical properties, and diverse applications from electronics to biomedical fields. They highlight challenges in large-scale production and purification, as well as toxicity concerns. CNTs offer exceptional tensile strength and conductivity, with promising potential in advanced composite materials and nanodevices.
29. Rajashree Hirlekar et al., surveyed synthesis methods, properties, and biomedical applications of CNTs including drug delivery. The paper detailed CNT types, fabrication processes like CVD and arc discharge, and functionalization techniques improving biocompatibility and solubility. CNTs show promise for future nano-medicine despite difficulties in manufacturing consistency and toxicity mitigation.
30. T. R. Pozegic et al., studied multifunctional carbon fiber composites where carbon nanotubes replaced conventional polymer sizing to enhance electrical and thermal conductivity. The CNT-modified composites showed significant conductivity improvements and potential to substitute metallic components in aerospace for lightning strike protection. Methods supporting scalable CNT growth demonstrate potential for industrial composite manufacturing.
31. Vidya Wable conducted research on biodiesel production from vegetable oils via optimized transesterification parameters. The study evaluated process conditions such as temperature, molar ratios, and catalyst concentration to achieve maximum yield and fuel properties conforming to ASTM standards. Biodiesel is presented as a sustainable alternative fuel with environmental benefits and production feasibility.

32. A comprehensive review by Harikrishnan et al., on epoxy composites summarized types, fabrication methods, mechanical and thermal characterization tools, and effects of fillers including nanomaterials. The review outlined enhancements achievable through hybrid fiber reinforcements and nano-additives, and identified future trends toward improved durability and recyclability in epoxy-based composites utilized in aerospace and automotive industries.
33. Gargi Danda et al., investigated effects of fiber orientation on the mechanical properties of bidirectional woven Kevlar epoxy composites. Different stacking configurations were tested revealing that 45° orientations enhanced toughness, while 60° configurations improved flexural stiffness. The study recommends tailoring fiber architecture to optimize strength and energy absorption for engineering applications
34. Prashanth Banakar and H. K. Shivananda examined the influence of fiber orientation on carbon fiber reinforced epoxy laminates prepared by hand lay-up. Tensile and flexural tests showed 90° fiber orientation yields highest strength and stiffness, while off-axis orientations caused premature failure. Findings emphasize the critical role of fiber alignment in composite structural performance.
35. Sweety Ashish Agrawal and Someshwar Bhartiya analyzed woven carbon reinforced epoxy composites with various laminate orientations. Results showed unidirectional and ±90° configurations excel in tensile and flexural strength, whereas ±45° laminates exhibit superior impact resistance. Study highlights laminate design as a key factor in tailoring mechanical response of high-performance composites.
36. Rahul Bhatnagar et al., explored mechanical performance of woven jute fiber reinforced epoxy composites fabricated via hand lay-up. The composites displayed improved tensile strength, stiffness, and impact toughness relative to neat epoxy. The work supports the application of natural fiber composites as cost-effective, lightweight alternatives for structural uses.
37. Prashanth Banakar and H. K. Shivananda reviewed mechanical properties of natural fiber reinforced concretes. Their study links fiber incorporation to improvements in strength and ductility and addresses challenges related to durability and moisture effects. Natural fiber composites offer promising sustainable alternatives for civil engineering applications.
38. D. R. Mahapatra et al., characterized carbon fiber reinforced epoxy composites with woven jute fibers incorporated as reinforcement. Material testing indicated superior mechanical properties due to effective fiber-matrix bonding and fiber architecture, demonstrating potential for environmental-friendly, lightweight composite solutions.

39. S. K. Rout et al., evaluated mechanical characteristics of woven jute fiber reinforced epoxy composites, confirming significant improvements in strength and toughness compared to neat epoxy. The study stresses the cost-effectiveness and sustainability of natural fiber reinforcements for enhanced composite materials
40. Prashanth Banakar et al., researched the effects of laminate configuration on mechanical and water absorption behavior of woven jute/epoxy composites. Symmetric laminates showed higher strength and lower moisture uptake, underscoring the importance of design for durability and structural performance of natural fiber composites.

CONCLUSION :

Hollow carbon fibres can be made from special hollow PAN materials and processed without losing their hollow shape. The thickness of the fibre walls is very important—thin walls stay stable better during heating because gases can escape more easily. Oxygen can pass through the walls, so sealing the ends doesn't change much. Thicker walls sometimes bend or collapse during heating. With the right temperature control and design, these fibres can be made lighter without losing much strength. They have big potential for making strong but light parts, but more work is needed to produce them continuously, test their strength, and fine-tune the process for the best results.

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