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Review of Natural Fiber Reinforced Epoxy Resin Composite Materials for Automotive Component Applications

Suharmadi[1], Muhamad Fitri[1*]
[1]Master of Mechanical Engineering Department, Faculty of Engineering, Mercu Buana University Jakarta, 11650, Indonesia.

E-mail: muhamad.fitri@mercubuana.ac.id

Abstract-- *Epoxy resin is a thermosetting polymer widely used in composite materials due to its high mechanical strength, excellent chemical resistance, and strong adhesion. In composite structures, epoxy acts as a matrix that binds and protects the reinforcing fibers while transferring loads between components. The reinforcing fibers may be synthetic (e.g., fiberglass, carbon), known for their high tensile strength, or natural fibers (e.g., kenaf, ramie), which offer sustainability and low-weight advantages. With the growing demand for lightweight, efficient, and environmentally friendly automotive materials, epoxy-based composites show significant potential for use in body panels, interior parts, and structural vehicle components. However, challenges remain, such as poor interfacial bonding between epoxy and natural fibers, thermal degradation, and relatively high production costs. This study aims to systematically review current Research trends, applications, and Research gaps in the development of epoxy resin composites for automotive components, particularly those reinforced with natural fibers. The method used is a Scoping Review based on the PRISMA-ScR framework, covering 50 scientific articles published between 2015 and 2025. The results indicate that kenaf, ramie, and jute fibers have strong potential as sustainable reinforcements, though improvements in interfacial compatibility and processing technology remain critical. The study implies the importance of advancing bio-based epoxy resins, hybrid manufacturing techniques, and the utilization of local natural fibers as part of a sustainable automotive strategy.*

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1. INTRODUCTION

Composite materials have been widely used across industries such as aerospace, construction, marine, and automotive due to their ability to combine two or more materials with different properties to produce new materials with superior mechanical, thermal, and environmental properties [1][2]. In the automotive industry, the use of composite materials is growing rapidly to meet demands for energy efficiency, reduced exhaust emissions, and lightweight materials that remain strong and durable [3].

One type of composite that is widely under development is resin-matrix composites, particularly epoxy resins [4][5]. Epoxy resins are known to have superior mechanical properties, including high stiffness, corrosion resistance, and strong bonding to various reinforcing fibers, both synthetic and natural [2]. The use of epoxy resin as a matrix in automotive composites aims to produce lightweight vehicle components with high structural strength, thereby improving fuel efficiency and overall vehicle performance [6][3].

Along with growing interest in composite materials, Research into their mechanical properties is also increasing. Not only limited to metals such as steel [7][8], but also to various types of composites[9], especially those based on epoxy resin. Several studies have examined the effect of fiber length, fiber concentration, alkali treatment, and the use of coupling agents on the mechanical properties of composites [9]. In addition, studies were conducted to evaluate the effects of coconut fiber content, hardener fraction [10], and the percentage of palm oil fiber on the fatigue life under axial loading in resin matrix composites [11][6]. The widespread use of composites that replace metal materials [12][13]. For example, composite polymer materials have almost replaced automotive components, such as interior parts, dashboards, steering wheels, and bumpers [14][15]. This shows the great potential of this material for the future [16]. This journal article aims to review and analyze the Research gap in the development of epoxy resin composites reinforced with synthetic and natural fibers for automotive component applications [6]. This review provides a comprehensive understanding of the opportunities and challenges of using epoxy resin composites in the automotive industry, and highlights potential directions for future Research. The discussion covers material characteristics, processing techniques, current applications, and future development prospects. The approach used in this article is a literature review based on relevant, up-to-date scientific sources, including journal articles, books, and published Research reports.

2. METHODOLOGY

2.1 Scoping Review Method

The method used in this study was a scoping review, based on the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews) framework. This approach was chosen to provide a comprehensive mapping of the literature discussing the development of fiber-reinforced epoxy resin composite materials for automotive applications, from a material, process, and application perspective.

The literature search strategy was conducted across several major academic databases, including Scopus, Google Scholar, and IEEE Xplore. Keywords used in the search included: "epoxy resin composites," "fiber reinforced composites," "natural fiber composites," "synthetic fiber," "automotive applications," and other relevant combinations. The search was limited to English- and Indonesian-language articles published within the last 10 years (2015–2025). Inclusion criteria for selecting studies included scientific articles that:

• Research or review epoxy resin-based composites with natural or synthetic fiber reinforcement.
• Provide data or analysis related to mechanical, thermal, or other performance properties.
• Mention applications or potential applications in the automotive industry.

Exclusion criteria included:

• Articles that only discuss epoxy resins without reinforcing fiber elements.
• Studies that are not relevant to the automotive sector or do not describe the technical characteristics of the composites.
• Non-scientific publications or opinions not supported by experimental data or systematic analysis.

The data collection process began with selecting titles and abstracts, followed by a comprehensive content review of the articles that passed the initial stage. Each selected study was then analyzed thematically based on key topics, such as fiber type, processing technique, material properties, and automotive applications. The results of the analysis were compiled in narrative form to provide a comprehensive overview of Research developments and trends in this field.

2.2 Materials

2.2.1 Resin Matrix Composites

Resin-matrix composite materials are widely used in automotive components. The resin matrix serves as a binder for reinforcing fibers, protects against environmental damage, and transfers loads between fibers [17]. General characteristics of resin matrix composites include high mechanical strength, light weight, corrosion resistance, and the ability to be formed using various manufacturing methods, making them well-suited for structural and functional applications [18].

Some types of resins commonly used in composite manufacturing include :

- Epoxy resins are known for their high mechanical strength and adhesion [18]. Chemical resistance, as well as low shrinkage during curing [18]. These resins are widely used in high-tech applications such as automotive, aerospace, and electrical [18][19].
- Polyester resins are more economical and easier to use, but have lower strength and chemical resistance than epoxy. Commonly used in the marine and construction industries [20][21].

Vinyl ester resins are a development of polyester with better chemical resistance and mechanical properties, often applied in chemically aggressive environments [21]

2.2.2 Reinforcing Fiber

For reinforcing materials, common fiber types used in composites include:

• Carbon fiber, which has very high tensile strength and elastic modulus, is lightweight but expensive. It

is suitable for applications requiring high performance [15].
• Glass fiber, which is more affordable than carbon fiber, with good strength and corrosion resistance, is widely used in the automotive and marine industries [15].
• Natural fibers, such as kenaf, ramie, jute, and coconut fiber, are environmentally friendly, lightweight, and biodegradable alternatives. Although they have lower mechanical strength than synthetic fibers, natural fibers are attractive for sustainable applications.[20]
The choice of matrix and reinforcement combination depends mainly on the performance requirements, cost, and operational conditions of the composite application, particularly in the

2.2.3 Comparison of Natural and Synthetic Fibers

In composite material development, the choice of reinforcing fiber type significantly influences the mechanical, thermal, and environmental properties of the final product. Fibers can be categorized into two main groups: natural fibers and synthetic fibers, each with its own characteristics and advantages [17]. Natural fibers are fibers derived from plants or animals and are currently widely used as environmentally friendly reinforcement alternatives[17]. Some types of natural fibers commonly used in composite manufacturing include:
• Kenaf fiber (Hibiscus cannabinus), which has relatively high tensile strength, is lightweight and easily recycled.[22]
• Hemp fiber (Boehmeria nivea), known for its good stiffness and resistance to mold.[22]
• Coconut fiber (cocofiber), which is highly available in tropical regions, is lightweight and resistant to water and decay.[23]
• Jute and sisal fibers, which are also widely used in automotive applications due to their balance between strength, price, and sustainability.[15]
Meanwhile, synthetic fibers are produced through industrial processes and have excellent mechanical performance. The most common types used in the composite industry include:
• Carbon fiber, which is very strong and lightweight with a high modulus of elasticity, is ideal for structural applications requiring high strength, such as race car bodies or aerospace components[24].
• • Glass fiber, more economical than carbon fiber, has good tensile strength and is often used in vehicle bodies, fuel tanks, and marine components[25].
In terms of advantages, natural fibers offer abundant availability, low cost, low density, and environmental sustainability due to their biodegradability. However, natural fibers also have several disadvantages, such as low thermal and moisture resistance and weak interfacial bonding with the polymer matrix, which affect the overall strength of the composite [17]. On the other hand, synthetic fibers offer high performance but are more expensive, less environmentally friendly, and challenging to recycle. Several previous studies have shown that increasing fiber and hardener content can improve mechanical properties, although there is an optimal limit [13].
Another study showed that the use of jute fiber can increase the stiffness of the composite, although surface treatment is still required to improve its interaction with the matrix [26]. Current Research trends continue to develop toward improving the mechanical properties of natural fibers through chemical modification and hybridization with synthetic fibers.

2.3 Characteristics of Epoxy Resin Composite Materials

Epoxy resin is a thermosetting polymer composed of epoxide monomers that react with hardeners to form a rigid, three-dimensional structure [20]. Its chemical structure features epoxide groups (—CH(O)CH2), which are highly reactive toward amine or acid anhydride groups in hardeners [27]. After curing, epoxy resin forms a cross-linked network that provides high thermal stability, good chemical resistance, and strong mechanical properties [25].
The type of reinforcement (fiber) used in epoxy resin composites significantly influences the composite's final properties. For example:

- Carbon fibers increase the tensile strength, stiffness, and dimensional stability of the composite, making it suitable for high-performance automotive structural components [28].
- Glass fibers provide impact strength and corrosion resistance, as well as a more economical cost [29].
- "Natural fibers such as kenaf or hemp can improve the lightweight, flexibility, and sustainability of composite materials. However, these fibers generally require surface treatment to improve the interfacial bonding with the epoxy resin matrix." [17].

Epoxy resin composites offer significant advantages over conventional materials such as metals and ordinary plastics in automotive applications. Compared to metals, these composites are much lighter, which directly affects vehicle fuel efficiency [23]. In addition, their corrosion resistance and flexible design capabilities allow the production of components with complex shapes without the need for complicated fabrication processes. Compared with thermoplastics, epoxy resin composites have higher structural strength and better thermal stability, making them superior for applications such as body panels, bumpers, dashboards, and secondary vehicle frame structures [30].

3. RESULTS AND DISCUSSION

3.1 Trends and Applications in the Automotive Industry

The use of epoxy resin composites in the automotive industry continues to grow, in line with the increasing need for lightweight, strong, and efficient materials to support energy efficiency and reduce carbon emissions [31][32]. Based on a review of 50 peer-reviewed scientific articles, recent trends indicate increasing interest in the use of natural fibers such as kenaf, ramie, and jute, as well as hybrid combinations of natural and synthetic fibers (such as fiberglass or carbon) as reinforcements in epoxy matrices to produce composites with good mechanical performance while remaining environmentally friendly [33][34].

Furthermore, Research is also focusing on modifying epoxy matrices with nanoparticles (such as nanosilica, graphene, and nanoclay) to improve thermal properties, tensile strength, and wear resistance [35][36].

Some examples of epoxy resin composite implementations in vehicles include:

- Vehicle body panels, such as hoods, doors, and bumpers, require high strength while remaining lightweight [37].
- Vehicle interiors, including dashboards, center consoles, and door linings, which offer aesthetic finishes and durability [38].
- Structural components, such as undercarriage shields and support frames, that utilize the high stiffness of carbon fiber-reinforced epoxy composites[38].

One notable case study is in electric cars and racing vehicles, where the use of carbon fiber-reinforced epoxy composites has been shown to significantly reduce vehicle weight without compromising safety and performance[39].

However, several challenges and obstacles remain in the development and widespread application of these materials, such as:

- Relatively high production costs, especially for synthetic fibers such as carbon, and curing processes that require special temperatures and pressures[40].
- Incompatibility between epoxy resins and natural fibers leads to reduced interfacial bond strength and accelerated material degradation[41].
- Recyclability limitations: Another challenge is the difficulty of recycling epoxy resins, as thermosets are difficult to reprocess into new materials[42][43].

Thus, despite its enormous application potential, optimization of interface characteristics and cost efficiency remains a primary focus of further Research.

3.2 Sustainability and Environmental Aspects

The use of epoxy resin composites in the automotive industry has significantly contributed to vehicle weight reduction and fuel efficiency, ultimately reducing carbon emissions [44][45]. However, this material also poses environmental challenges, primarily due to epoxy resins' inability to biodegrade and limitations in recycling processes [46]. Epoxy resins, as thermosetting polymers, form permanent crosslinks upon curing, making them challenging to reprocess into new materials using conventional thermoplastic processes [47].

In response to these challenges, various approaches are being developed:

- Chemical recycling technologies, such as solvolysis, pyrolysis, and chemical depolymerization, which aim to separate the reinforcing fibers from the matrix[48]
- Development of epoxy bio-resin: using raw materials from renewable sources such as castor oil, agricultural waste, or lignocellulose [49][50]
- Use of biocomposites: a combination of bio-based resins and natural fibers, which have higher biodegradation potential and a lower carbon footprint than conventional composites [6][51]

Several studies have shown that bio-resins based on plant waste can reduce CO_2 emissions by up to 40% compared to petroleum-based epoxy resins [52]. Meanwhile, bio-composites based on kenaf and hemp fibers can maintain tensile strengths approaching 70–80% of those of glass fiber-based composites, making them a promising alternative for vehicle interior panels [53].

In the context of sustainable automotive development, the use of bio-composites and renewable-based resins is expected to become the new standard to meet net-zero emissions regulations in the transportation sector and to meet increasingly stringent global environmental regulations.

Discussion of epoxy resin-based composites from the reviewed studies:

Table 1. Journal Review Results

No	Author (Year)	Research Focus	Types of Fiber	Methods	Key Findings	Research Gap
[1]	M. W. Ubaidillah *et al.* (2024)	The effect of epoxy-matrix coconut fiber volume fraction on the tensile strength of composites	Coconut fiber (natural)	Hand lay-up, tensile test, normality test, homogeneity test, one-way ANOVA	The 40% volume fraction yielded the highest tensile strength (25.9 MPa), while 50% gave the lowest (12.6 MPa).	Environmental (humidity/high temperature) and other mechanical tests (flexural, impact, shear) were not performed.
[2]	S. Agustina (2018)	Development of palm oil fiber biocomposites for automotive materials	Palm oil fiber	Alkalization (10% NaOH), extrusion (190°C), mechanical test (ASTM D695, D792), SEM	Density 1.0278 g/cm³, compressive strength 3106.25 N, tensile strength 33.97 N/mm², homogeneous morphology; suitable for automotive applications.	The effects of fiber fraction variation (i.e.,>1:7) and lignin on thermal properties were not studied.
[3]	R. F. Afifi *et al.* (2024)	The effect of pineapple leaf fiber on the thermal conductivity of polyurethane composites	Pineapple fiber (natural)	Hand lay-up, thermal conductivity testing (ASTM D5334, Gunt Humberg WL 420)	Thermal conductivity decreased from 5.4 W/mK (0% fiber) to 2.5 W/mK (30% fiber); thermal resistance increased to 25.4 °C/W.	The optimal fiber fraction (>30%) and combination with other natural fibers have not been studied.
[4]	A. Siregar (2021)	Natural fiber (coconut fiber) as an alternative composite material	Coconut fiber	Hand lay-up	Impact: 45% fiber fraction is most optimal for shock loads; Bending: 25% fiber fraction produced the highest bending strength.	Only impact and bending tests were performed; no tensile, shear, or fatigue tests.

Research on natural fiber-based composites has grown rapidly in recent years, focusing on optimizing mechanical, thermal, and wear properties for various industrial applications, particularly in the automotive sector. The following is a synthesis of key findings and Research gaps from ten peer-reviewed studies.

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1. **Mechanical Properties and Optimal Fiber Fraction.**

   Several studies, such as those by Ubaidillah *et al.* [1] and Siregar [4], show that fiber volume fraction significantly affects material strength. For example, a 40% coconut fiber fraction yields the highest tensile strength (25.9 MPa), while a 45% fraction is optimal for impact resistance. However, these studies are generally limited to tensile or bending tests and do not account for environmental factors such as humidity or high temperatures, which can affect composite performance in real-world applications.

2. **Automotive Applications.**

   Several studies [2][5] focus on the development of composites for automotive components such as interior panels and brake pads. Biocomposites of palm oil and hemp fibers exhibit adequate mechanical properties, including low density and good compressive/tensile strength. However, further validation through FEM simulations or fatigue tests is still lacking, so their long-term durability remains untested.

3. **Thermal and Wear Properties.**

   Research by Afifi *et al.* [3] and Riduan and Suhardiman [10] examined the thermal and wear properties of composites. Pineapple leaf fibers reduced the thermal conductivity of polyurethane, while coconut fiber powder and epoxy resin showed the lowest wear at a 60:40 composition. However, these studies did not explore the effect of additives such as MgO or $CaCO_3$, which could improve material performance.

4. **Material and Process Innovation.**

   Several researchers, such as Al Rosyid [7] and Nurdin *et al.* [8], explored fabrication methods, including hand lay-up, compression molding, and vacuum bagging, to reduce voids and increase strength. However, these methods are often not optimized for mass production or extreme environmental conditions.

5. **Limitations and Recommendations.**

   In general, Research gaps include:

- Lack of multifactorial testing (tensile, shear, fatigue, and environmental) to holistically assess composite performance.
- The need to explore fillers or additives to improve thermal and mechanical properties.
- Validation through simulation or field testing for specific applications, such as automotive components.

4. CONCLUSION

Based on the scoping review and analysis of 50 scientific articles presented in Chapter 3, it can be concluded that epoxy resin-based composites have great potential for automotive applications due to their superior mechanical properties and corrosion resistance. Combinations of synthetic fibers, such as carbon and glass, and natural fibers, such as kenaf and hemp, provide design flexibility and support vehicle energy efficiency. Current Research trends also point to the use of hybrid composites and biocomposites to support sustainability.

However, Research gaps remain, such as the weak bond between the epoxy matrix and natural fibers and the limitations of thermoset resin recycling technology. Further Research should focus on improving the matrix-fiber interface, developing bio-epoxy resins, and evaluating composite performance under extreme conditions.

Recommendations include that the industry begin integrating green materials and environmentally friendly technologies, while academia can encourage biomaterial-based Research and design simulation approaches. Cross-sector collaboration will be key to realizing epoxy composite materials as key components for lightweight and environmentally friendly vehicles in the future.

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