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Optimization of Electric Car Engine Braking System Design by Using Composite Materials to Improve Efficiency and Safety

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The development of electric vehicles (EVs) requires innovation in braking system design to improve energy efficiency and safety. The use of composite materials, which have high strength and light weight, can be a solution to optimize braking performance and reduce energy consumption in electric vehicles. This research aims to optimize the design of braking systems in electric vehicles by using composite materials to improve efficiency and safety. The research method employed in this study is a qualitative approach, specifically a literature review. The use of composite materials in electric vehicle braking systems can improve vehicle efficiency and safety by reducing weight and replacing hazardous materials such as asbestos and copper. While it offers advantages such as increased strength and resistance to high temperatures, the main challenges to overcome are production costs and the complexity of the manufacturing process.

1. Introduction

The development of electric vehicle (EV) technology in recent years has experienced significant progress, driving the global transition towards more environmentally friendly vehicles. One of the main reasons why EVs are seen as the solution of the future is their ability to reduce dependence on fossil fuels that contribute to climate change (Nugraha et al., 2024). According to a report from the International Energy Agency (IEA), global greenhouse gas emissions from the transportation sector can be drastically reduced with the widespread adoption of electric vehicles (IEA, 2021). However, while EVs offer great potential in reducing carbon emissions and improving sustainability, there are major challenges that still need to be overcome to improve the performance of their main components, one of which is the braking system. Braking systems in electric vehicles play a very important role in driving safety and comfort, and affect overall energy efficiency.

The braking system in electric vehicles has different characteristics compared to conventional fuel vehicles. Most electric vehicles today rely on regenerative braking systems to convert kinetic energy during braking into electrical energy which is then channeled back to the battery (Chandak & Bhole, 2017). This technology allows the vehicle to save energy and increase the operating range, but at the same time, conventional disc-based braking systems and brake pads are still needed to stop the vehicle in an emergency or at low speeds (Malode & Adware, 2016). One of the main challenges in the development of electric vehicles is ensuring that the braking system is not only efficient in using energy but also powerful and durable enough to guarantee the safety of the driver and passengers. Therefore, it is necessary to optimize the design of the braking system that can improve energy efficiency without reducing safety aspects.

In electric vehicles, one of the parts of the braking

system that needs more attention is the brake disc and brake pad components, which often use traditional materials such as steel or aluminum. These materials have several disadvantages, such as considerable weight, low wear resistance, and limited heat dissipation capabilities (Veeman et al., 2023). This condition can lead to a decrease in braking performance, especially in repetitive braking, as well as affect the overall energy efficiency of the vehicle. Therefore, one of the interesting approaches to improve the performance of the braking system is to replace the materials used in these components with composite materials. Composite materials, known for their high mechanical strength, better heat resistance, and superior strength-to-weight ratio, offer great potential to replace conventional materials and improve the efficiency of braking systems in electric vehicles (Popescu et al., 2015).

Composite materials have a number of advantages over traditional materials such as steel or aluminum. Composites consisting of a resin matrix and reinforcing fibers, such as carbon fiber or glass fiber, can be designed to have mechanical properties tailored to the specific needs of the braking system (Crăciun et al., 2017). For example, carbon fiber-based composites are known to have higher tensile strength, resistance to high temperatures, and lighter, which is crucial for reducing vehicle weight and improving fuel efficiency (Elmarakbi, 2013). In addition, the composite also exhibits better resistance to wear, which can extend the service life of braking components. Thus, the use of composite materials in electric vehicle braking systems has the potential to not only improve the overall performance of the system, but also reduce energy consumption and vehicle maintenance costs.

However, although composite materials offer great potential, the main challenge in their implementation in braking systems is how to design brake components that can function optimally in various operating conditions of electric vehicles (Hamada & Orhan, 2022). Diverse operational conditions, from braking at high

speeds to emergency braking at high temperatures, require materials that are not only strong, but can also withstand a wide range of thermal and mechanical stresses. In addition, the cost of producing composite materials and their fabrication methods are also important considerations in the application of this material to electric vehicle braking systems in large quantities (Ghassemieh, 2011). Therefore, further research regarding the right material selection, optimal component design, and efficient production methods is urgently needed to ensure the successful adoption of composite materials in electric vehicle braking systems.

Several previous studies conducted such as the Khan et al. (2024) research, reviewed various advances in the use of composite materials in the automotive industry, focusing on improving vehicle performance and efficiency. Composite materials such as carbon fiber and glass fiber offer significant advantages over conventional metal materials, especially in terms of strength, durability, light weight, and corrosion resistance. This advantage is crucial in improving fuel efficiency and reducing emissions, especially in electric vehicles. The study also highlights the application of composite materials to vehicle components, including braking systems, which can reduce weight and improve braking performance, making them more responsive and efficient (Khan et al., 2024).

In the research of Barton (2004), it was explained that in the braking system, the main components that interact are friction pairs, which are friction materials that usually form static components (such as pads or brake shoes) and rotating brake discs or drums. Barton explained that friction materials are complex composites composed of various constituents with different functions, which are usually bonded in a phenolic binding matrix. The uniqueness of this material lies in its surface characteristics, which are more important than its physical properties, making it more difficult to model than conventional composites. In addition, Barton also discussed micromechanical modeling

techniques used to simulate complex tribological interactions that occur at friction interfaces. This research includes the selection of rotor materials, with materials such as gray cast iron being widely used, as well as the exploration of alternative materials such as coated aluminum matrix composites and silicon carbon composites being studied (Barton, 2013).

Finally, Venugopal and Karikalan (2020) emphasized the advantages of the two-stage arrangement of aluminum-alumina composites that aim to solve the problem of SiC particles, which serves to improve thermal conductivity. The authors explain that this composite material has the ability to reduce wear by using electron microscopes and optical microscopes to analyze the wear marks of CuSiCpMMC materials. In addition, this article also discusses the tribological shortcomings of single-phase materials and the function of various types of additives in improving braking performance (Venugopal & Karikalan, 2020).

This research aims to optimize the design of braking systems in electric vehicles by using composite materials to improve efficiency and safety. The main focus of this study is to analyze the influence of composite materials on the performance of braking systems, design systems that are energy efficient and lightweight without sacrificing safety, and identify the most suitable composite materials based on their mechanical and thermal properties. The expected benefits of this research include contributing to the development of electric vehicle technology by increasing its competitiveness in the automotive market, assisting the automotive industry in designing more efficient and safe braking systems, and opening up opportunities for further research in the field of composite materials and their applications in electric vehicle braking systems, which can enrich the scientific literature related to braking system design.

2. Research Method

The research method employed in this study is a qualitative approach, specifically a literature review. The primary objective of this study is to analyze existing research and theoretical frameworks related to the optimization of braking systems in electric vehicles (EVs) through the use of composite materials to enhance both efficiency and safety. The data sources for this study are peer-reviewed journals, conference papers, and books, sourced from reputable academic databases such as Google Scholar, Scopus, and Web of Science. These sources provide a comprehensive overview of the properties, applications, and performance of composite materials in automotive braking systems. The data collection technique involves systematic searching, selection, and analysis of relevant literature published over the last decade. Key inclusion criteria for selecting studies include relevance to electric vehicle braking systems, the use of composite materials, and published peer-reviewed papers. The data analysis method is thematic analysis, where the key themes and findings related to the design, efficiency, and safety of composite material-based braking systems are identified, categorized, and synthesized to draw conclusions and provide recommendations for future research and design improvements. This approach allows for the integration of various viewpoints and findings, offering a holistic understanding of the potential for optimizing braking systems in electric vehicles using composite materials (Braun & Clarke, 2006; Creswell & Creswell, 2017; Winchester & Salji, 2016).

3. Result and Discussion

In the literature review, five relevant articles were selected through a systematic search and screening process. These articles were chosen based on their relevance to the use of composite materials in automotive braking systems, with a specific focus on electric vehicles (EVs). The selected articles were evaluated for their contributions to improving the efficiency, safety, and

performance of brake systems through the use of advanced composite materials. The following table summarizes key findings from the selected studies.

Table. Literature Review

No	Author	Tittle	Conclusion results
1.	(Wazeer et al., 2023)	Composites for electric vehicles and automotive sector: A review	The study found that composite materials, such as carbon fiber and glass fiber, can reduce vehicle weight by up to 10%, improve the efficiency of electric vehicles, and reduce environmental impact.
2.	(Veeman et al., 2023)	Tribo-mechanical performance of brake composite material: a comprehensive review	The study found that the composite materials used in braking systems, with special attention to fastening elements, fibers, and reinforcements, affect the tribological performance and wear of friction materials, which are essential for the design of safe and efficient braking systems.
3.	(Sathyamoorthy et al., 2022)	Brake friction composite materials: a review on classifications and influences of	The study found that natural and synthetic friction materials can replace hazardous materials such as asbestos, with optimal performance

		friction materials in braking performance with characterizations	and potentially support environmentally friendly braking.
4.	(Gebrehiw et et al., 2023)	Application of composite materials in aerospace & automotive industry	The study found that composite materials, with a higher strength-to-weight ratio, are widely used in the aerospace and automotive industries, including applications such as MESC, Isogrids, and FML, as well as the future prospects of these materials.
5.	(Rajak et al., 2022)	Role of composite materials in automotive sector: potential applications	The study found that composite materials, especially bio-composites, replace conventional materials in vehicles, improve fuel efficiency, reduce emissions, and improve vehicle safety and performance.

Composite Materials in Electric Vehicles

A number of studies have shown that the use of composite materials in the automotive sector, especially in electric vehicles, can result in significant performance improvements. Rajak et al. (2022) noted that composite materials have great potential to replace traditional materials in vehicle components, such as braking, due to their lighter weight and superior mechanical properties. By replacing conventional materials, electric

vehicles can experience weight reductions that have a direct impact on improving fuel efficiency and reducing emissions, this is in line with the findings in the research of Wazeer et al. (2023), which underscore the ability of composite materials to improve energy efficiency and reduce environmental impact. Therefore, the use of composite materials in electric vehicle braking systems not only improves braking performance, but also provides additional benefits in terms of energy efficiency and carbon emission reduction.

Advantages of Mechanical and Thermal Properties

Previous studies have shown that composite materials excel in terms of strength, resistance to high temperatures, and mechanical durability. Sathyamoorthy et al. (2022) mentioned that composite materials such as carbon fiber and aramid fiber offer outstanding advantages in braking performance thanks to their tensile strength and resistance to high temperatures. This is very important in electric vehicle braking systems that often operate at extreme temperatures, both in heavy braking and in use in various road conditions. This finding is also in line with the research of Venugopal and Karikalan (2020), which stated that aluminum and alumina-based materials can offer a much-needed combination of mechanical strength and thermal conductivity in vehicle braking system applications. Therefore, these material characteristics allow for a more efficient and safe braking system design for electric vehicles.

Innovation with Bio-Composites

Regarding the use of more environmentally friendly materials, a number of studies have also shown that bio-composites can be an attractive option for electric vehicle applications. Gebrehiwet et al. (2023) emphasized the potential of bio-composites that combine natural materials with metals and polymers, offering advantages in terms of sustainability and efficiency. This is especially relevant in the context of electric vehicles that are

increasingly focused on sustainability. These natural material-based composites not only provide environmental advantages, but also have sufficient mechanical properties for use in braking systems. With the development of environmentally friendly composite technology, the automotive sector can integrate these solutions to improve efficiency as well as reduce negative impacts on the environment.

Improved Braking Performance and Safety

Safety is an important factor in the design of electric vehicle braking systems, and the use of composite materials makes a major contribution to this. Venugopal and Karikalan (2020) stated that composite materials can increase wear resistance and corrosion resistance, thereby extending the life of braking components. This means that electric vehicles can have a more reliable and safe braking system in the long run. Sathyamoorthy et al. (2022) also showed that composite materials can help reduce vibrations and noise generated during braking, providing better comfort to the rider. These advantages therefore make composites an ideal choice for improving the safety of electric vehicles, especially in the face of the challenges of braking at high speeds or poor road conditions.

Energy Efficiency in Braking Systems

On the other hand, research also shows that composites can improve the energy efficiency of electric vehicles through weight reduction. Rajak et al. (2022) identified that the use of composites in vehicles can reduce vehicle mass, which in turn reduces the workload of the braking system. With a lighter weight, electric vehicles are not only more efficient in energy use but also easier to control when braking. This is particularly relevant in the design of future electric vehicles, where energy efficiency and emission reduction are the two top priorities. This reduction in the weight of braking components also leads to savings in production and maintenance costs, as also revealed in the Wazeer

et al. (2023) study.

Challenges and Opportunities for Further Research

While great benefits have been seen, the use of composite materials in electric vehicle braking systems also faces several challenges, including higher production costs and challenges in the processing of composite materials. Sathyamoorthy et al. (2022) revealed that although composites offer many advantages, their complex and expensive production processes are a major barrier to mass adoption. Therefore, further research needs to be conducted to explore solutions that can reduce production costs without sacrificing material quality. More in-depth research on bio-material-based composites or the development of new, more efficient production techniques could open up great opportunities for the application of composites in electric vehicle braking systems in the future, as suggested by Gebrehiwet et al. (2023).

Discussion

The use of composite materials in the design of electric vehicle braking systems has great potential in improving efficiency and safety. The use of composite materials in the components of the braking system of electric vehicles allows for a significant reduction in vehicle weight. A number of studies, such as those revealed by Rajak et al. (2022) and Wazeer et al. (2023), show that composite materials can replace heavier traditional materials, such as metals, so that vehicles are lighter and more efficient in using energy. Electric vehicles with a lighter weight are not only more energy-efficient but also more responsive in braking. In this case, the lighter braking system provides a double advantage: energy savings and efficiency in braking performance. The application of composite materials in electric vehicle braking systems must consider the balance between weight and braking performance. Despite the lighter weight, braking quality and effectiveness should remain a top priority. The use of carbon fiber-based composite materials or aramid fibers is a

promising choice due to its superior mechanical properties.

One of the main advantages of composite materials is their mechanical properties and resistance to high temperatures. As described in research by Sathyamoorthy et al. (2022) and Venugopal & Karikalan (2020), composites such as carbon fiber and alumina offer excellent strength in extreme conditions, including repetitive braking that can cause high heating of braking systems. Composite materials have better resistance to wear and heat effects compared to traditional materials, thereby increasing the durability and life of braking components. The advantages of composite materials in the face of high temperatures are especially relevant for electric vehicles, which are often used in intensive braking conditions, especially in high-performance vehicles. This presents a great opportunity to optimize the design of braking systems that are more durable and safe, even though the use of composite materials requires higher production costs.

A number of studies also show the potential use of natural material-based composites (bio-composites) as an environmentally friendly alternative in electric vehicle braking systems. Gebrehiwet et al. (2023) showed that bio-composites can replace conventional materials that are often difficult to recycle. The use of these natural materials not only contributes to the reduction of environmental impact but also increases the attractiveness of electric vehicles in a market that is increasingly prioritizing sustainability. Sustainability is a very important aspect in the design of future electric vehicles. The use of bio-composites offers great potential in reducing a vehicle's carbon footprint. However, the main challenge is to develop bio-composite materials that are not only environmentally friendly but also have the same strength and durability as conventional composite materials.

Safe and efficient braking systems are crucial in electric vehicles, which often operate at high speeds. Research by Venugopal & Karikalan (2020) revealed that composite materials

have better resistance to wear, corrosion, and environmental influences, which improves user safety and comfort. The composite material can also reduce the vibration and noise generated during braking, providing more comfort for the rider. Composite resistance to vibration and sound is an important aspect in improving driving comfort. The reduction of noise during braking not only improves comfort but also reduces wear and tear on the components of the braking system. Therefore, further research to optimize these characteristics is essential so that electric vehicles can offer a better and safer driving experience.

Despite the many advantages offered, the use of composite materials in electric vehicle braking systems is not without its challenges, especially related to production costs and complex manufacturing processes. As revealed in the research of Sathyamoorthy et al. (2022), the complex and expensive composite production process is a major obstacle to mass adoption. This is also revealed by Rajak et al. (2022), who mentioned that higher costs can hinder the application of composite technology in more affordable electric vehicles. Challenges related to the cost and process of composite production need to be overcome by finding innovative solutions, such as the use of more efficient production techniques and the development of composite materials at more competitive prices. Therefore, further research to find alternatives that can keep costs down while still maintaining quality is urgently needed.

In the future, composite materials are expected to play a greater role in the design of electric vehicle braking systems. Research conducted by Wazeer et al. (2023) shows that composites can lead to more efficient and environmentally friendly braking system designs. Further developments in composite technologies based on natural fibers and recycled materials could be key to creating more sustainable braking systems. The development of composite technology based on recycled and environmentally friendly materials should be a priority in braking system research and

innovation. With the increasing attention to sustainability, further research on efficient and environmentally friendly processing of composite materials could open up opportunities for the application of this technology in the global automotive industry.

Optimizing braking system design in electric vehicles using composite materials offers a wide range of potential to improve efficiency and safety. The use of composite materials in the components of the braking system allows for a significant reduction in vehicle weight, which contributes to energy savings and increased performance efficiency. A number of studies have shown that composite materials, such as carbon fiber and aramid fiber, are lighter and stronger than traditional materials such as metals, thus not only reducing vehicle weight but also improving the responsiveness of braking systems. With a lighter vehicle weight, electric vehicles can optimize energy use, extend mileage, and improve overall braking performance.

In addition, composite materials exhibit mechanical advantages and resistance to high temperatures, which are especially important in extreme conditions, such as repetitive braking in electric vehicles. Composite materials such as carbon fiber and alumina have excellent strength in handling the high heat generated during intensive braking. The composite's resistance to wear and heat influences makes it an ideal choice for improving the durability and life of braking system components, especially in electric vehicles that often face heavier braking conditions. Although the production cost of composite materials tends to be higher, the advantage in resistance to high temperatures and wear is a decisive factor in improving the safety and durability of braking systems in electric vehicles.

However, the main challenge in the application of composite materials in electric vehicle braking systems lies in higher production costs and complex manufacturing processes. This high cost can hinder the mass adoption of composite materials in

electric vehicles, especially in more affordable models. Therefore, research and development to find innovative solutions, such as more efficient production techniques and the development of composite materials at more affordable prices, is urgently needed. In addition, the use of natural materials (bio-composites) and recycled materials offers great potential to create more sustainable and environmentally friendly braking systems, reduce carbon footprints, and strengthen the competitiveness of electric vehicles in an increasingly sustainability-oriented market. By continuing to focus on innovation and efficiency in production, composite materials can play a greater role in optimizing the braking system design of electric vehicles in the future.

4. Conclusion

Based on the research that has been conducted, the use of composite materials in the design of electric vehicle braking systems shows great potential to improve vehicle efficiency and safety. Composite materials have a higher strength-to-weight ratio compared to conventional materials, which allows for reduced vehicle weight and improved energy efficiency. In addition, composites, especially bio-composite-based ones, offer environmentally friendly solutions that can replace hazardous materials such as asbestos and copper in braking systems. The improved mechanical properties and resistance to high temperatures in composite materials also contribute to better braking performance, reduced wear, and improved vehicle safety. While the use of composites in braking systems offers a variety of advantages, the main challenges that need to be overcome are the cost of production and the complexity of the manufacturing process.

Based on the findings of this study, to improve the implementation of composite materials in electric vehicle braking systems, several important steps are needed. Further research should be focused on the

development of composite materials with lower production costs without sacrificing quality and performance, so that they can be more easily applied in the automotive industry en masse. In addition, more efficient and environmentally friendly manufacturing technologies need to be developed to accelerate the adoption of composite materials, making the production process more affordable and reducing cost constraints. The use of natural bio-composites should also be increased to replace conventional materials that are not environmentally friendly, with priority on research to develop stronger and more durable bio-composites. Finally, collaboration between the automotive industry and academia is essential to create innovative, efficient, safe, and sustainable composite technologies in electric vehicle braking systems.

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