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EXPLORING THE MECHANICAL PROPERTIES OF LEAF SPRINGS REINFORCED WITH FIBRE COMPOSITES

RAZISKOVANJE MEHANSKIH LASTNOSTI LISTNATIH VZMETI OJAČANIH Z VLAKNASTIMI KOMPOZITI

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To determine whether eggshell particles can be used as a filler material to improve mechanical properties, this study examines the mechanical characteristics of a hybrid material made of eggshell particles and glass-fiber-reinforced polymer (GFRP). To obtain the appropriate particle size, the eggshells are cleaned, crushed, and sieved as part of the experimental approach. The eggshell fragments are then mixed with resin and glass fibres using a vacuum-assisted resin-transfer moulding process to create GFRP composites. The produced GFRP composites' flexural strength, stiffness, fatigue stability, and other pertinent characteristics are evaluated with practical tests. Notably, certain qualities are enhanced with the inclusion of eggshell particles containing 110 % of the weight of fibroin. In comparison to conventional GFRP composites, which only consider fatigue life during the exhaustion testing phase, the results reveal a 15% increase in the enhancement rate. The findings imply that adding eggshell particles to GFRP composites has tremendous opportunities for progress, notably in automotive applications, and more specifically in the use of leaf springs. The hybrid material's better mechanical characteristics suggest that it may be possible to improve the performance and longevity of leaf-spring applications. This study advances the investigation of low-cost, environmentally friendly materials for improving composite materials' mechanical properties in the automobile sector. The application of eco-friendly and effective solutions in the production of automobiles may result from more study and development in this field.

Keywords: leaf spring, glass-fiber-reinforced polymer, composite materials, vacuum-assisted resin

Avtorji članka so želeli ugotoviti ali lahko uporabijo drobne delce jajčnih lupin kot polnilo za dodatno ojačitev oziroma izboljšanje mehanskih lastnosti hibridnega polimernega kompozitnega materiala ojačanega s steklenimi vlakni (GFRP, angl.: glass-fiber reinforced polymer). Da bi dosegli ustrezno velikost delcev so jajčne lupine očistili, zdrobili, zmleli in odsejali primerno frakcijo delcev (100 μm) za preizkuse. Izbrano frakcijo delcev iz jajčnih lupin so nato zmešali z epoksidno smolo in steklenimi vlakni ter z vakuumsko podprtim postopkom oblikovanja izdelali vzorce GFRP kompozitov. Na izdelanih vzorcih GFRP kompozitov so določili njihovo upogibno trdnost, togost, stabilno odpornost proti dinamičnim obremenitvam oz. utrujanju in druge primerne karakteristike. V vzorcih izdelanih kompozitov je bilo cca 110 *w*/% delcev iz jajčnih lupin glede na maso dodanih steklenih vlaken. V primerjavi s konvencionalnimi GFRP kompoziti so imeli kompoziti z dodatkom delcev iz jajčnih lupin cca 15 %-no višjo odpornost proti utrujanju oziroma dinamično trajno trdnost (angl.: fatigue life). Ta ugotovitev kaže na to, da dodajanje delcev jajčnih lupin v GFRP kompozite lahko predstavlja velik napredek pri razvoju listnatih vzmeti za avtomobile. Hibridni material ima boljše mehanske lastnosti kar pomeni izboljšanje njihovih obratovalnih lastnosti in daljšo dobo trajanja listnatih vzmeti. S to študijo so avtorji dokazali, da se lahko z okolju prijazno in poceni surovino znatno izboljša mehanske lastnosti kompozitnih materialov za avtomobilsko industrijo. Uporaba okolju prijaznih in učinkovitih rešitev v avtomobilski proizvodnji, kot je pričujoča, lahko pospeši nastajanje več novih raziskav in nove razvojne poti na tem področju.

Ključne besede: listnate vzmeti, s steklenimi vlakni ojačan polimer, kompozitni materiali, vakuumsko podprt postopek izdelave kompozita, epoksidna smola

1 INTRODUCTION

The most common type of spring used in the suspension systems of wheeled vehicles is leaf springs, often referred to as laminated or carriage springs. They are a favoured option for automobile suspensions since they provide advantages over helical springs due to their capacity to steer the ends in a certain direction. Composite leaf springs constructed of fiber-reinforced composites are currently replacing traditional steel leaf springs with many leaves because they have less weight without sacrificing stiffness or load-bearing capability. In leaf springs, the use of composite materials enables lighter construction without sacrificing high strength or effective energy storage. Composites outperform steel in terms of strength-to-weight ratios and are more efficient at storing the elastic tension energy. However, there may be differences in the cost-effectiveness of employing composites over alternatives to steel.[1–3]

The capacity of leaf springs to tolerate vertical vibrations and impacts seen on uneven road surfaces is one of its key features. To maintain a compliant suspension system, the leaf spring should efficiently convert potential energy into strain energy and release it gradually. A leaf spring's ability to store more energy can improve the suspension's overall compliance. Leaf springs and other vehicle parts face a severe challenge from fatigue-related breakdowns. Early wear and failure are caused by a variety of fatigue loads, including shocks from road imperfections and rapid wheel strikes. Leaf-spring durability

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might be increased by using composite materials made of glass-fiber-reinforced plastic (GFRP), which have had their wear behaviour examined.[4–6]

The mechanical characteristics of leaf springs reinforced with fibre composites are the main focus of this work. It specifically looks at a substitute for the usual seven-leaf steel spring often seen in passenger cars: a single-leaf composite spring composed of glass and epoxy composites. The goal of the study is to evaluate the capabilities of fiber-reinforced composite leaf springs and contrast them with conventional steel leaf springs, taking into account properties like strength, elastic modulus, fatigue resistance, and wear behaviour. This research advances suspension systems in terms of sturdiness, weight loss, and overall vehicle performance by recognising the benefits and drawbacks of fiber-reinforced composite leaf springs.[7–9]

2 EXPERIMENTAL PART

The goal of the research's experimental component is to assess the mechanical qualities and performance of a composite material made of eggshell powder, E-glass fibres, and a chosen matrix material. The stages that follow give an outline of the experimental techniques used:

Composite Materials:

Composite materials are made by mixing two or more constituent materials, each of which has unique chemical or physical properties, to produce a compound that has special attributes that are distinct from the components alone. Because their components are kept distinct inside the finished structure, composites vary from mixes and solid solutions. Composites are made up of reinforcement components and a matrix (binder), where the matrix surrounds, supports, and improves the characteristics of the reinforcement. Through hybridization, the mechanical properties of the various components are changed. It is essential to choose the best matrix and reinforcing-component mix. The reinforcement must be moulded into the composite material, either before or after the matrix. Typically, the physical characteristics of composites are anisotropic, altering according to the direction of application.

Selection of Materials:

Because materials make up a large amount of a vehicle's cost, they have a substantial impact on the quality and performance of the vehicle. Due to their ability to reduce weight and ensuing financial advantages, composite materials have become viable substitutes for steel. One strategy for producing goods that are ecologically friendly is to substitute plant-based or "bio-based" fillers for a part of the polymer ingredient. However, plant-based fillers may function poorly at high production temperatures because they decompose and absorb moisture. Eggshells, which are frequently seen as garbage, have a high compressive strength and can cause contamination. Combining eggshell powder's high compressive strength, polyamide's high impact strength, and nylon black's high tensile strength gives possible benefits in this study.

Eggshell Powder Preparation:

Eggshells are washed, dried, and pounded into powder. The powder is then sieved to obtain a grain size of 100 m. To remove grit, the powder is treated with a sodium hypochlorite solution. The precipitate deproteinized layer is washed with purified water after layer separation. The cleaned precipitate is mixed with a 6 % isophthalic acid/ethanol solution. The precipitate is then dried at 140 °C in a kiln until it achieves a dry condition.

Fibre Selection:

Two popular glass fibre kinds are S-glass, which is made up of silica, alumina, and magnesium, and E-glass, an aluminium borosilicate glass with a low alkali content. By heating and forming glass crystals or pebbles, glass fibres are created. The glass is then quickly chilled, compacted to a small diameter, and pulled through tiny nozzles. Sizing chemical surface treatment enhances adherence to the resin substrate. Glass fibres have isotropic characteristics and benefit from features including high specific strength, chemical neutrality, X-ray translucency, neutrality towards chemicals, biocompatibility, and cost efficiency. For this investigation, E-glass fibre was chosen from a variety of fibre choices because of its low cost and excellent strength.

Experimental Procedure:

Before grinding the eggshells into powder, clean and dry them. To attain a grain size of 100 m, sieve the powder. To get rid of the grit, use a sodium hypochlorite solution on the eggshell powder. Rinse it with filtered water after separating the precipitate-deproteinized layer. For an hour, stir the cleaned precipitate in a 6 % isophthalic acid in ethanol solution. The precipitate must be dried in a kiln at 140 °C until it is completely dry. Pick E-glass fibre, the right type of glass fibre in this circumstance. Glass crystals or pebbles are heated, and the molten glass is drawn through tiny nozzles to create fibres with tiny diameters. Apply sizing chemicals to the

Figure 1. Test samples

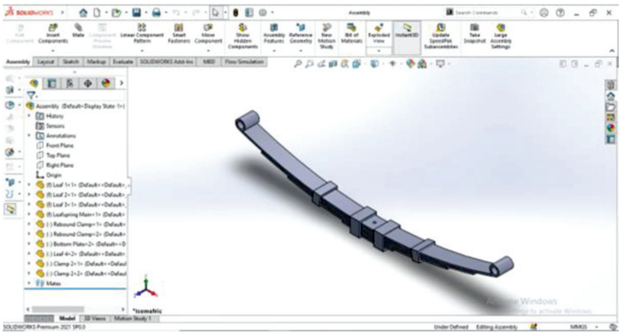


Figure 2: Isometric View

surface to improve the adherence to the resin substrate. Eggshell powder, E-glass fibres, and the preferred matrix material are combined to create the composite material. To assess the composite material's qualities, such as strength, stiffness, and fatigue resistance, perform mechanical characterization tests on it.

Test samples were prepared as shown in **Figure 1**. Using the test samples findings to decide whether the composite material is appropriate for leaf spring applications, taking into account elements including weight reduction, toughness, and performance.

ANSYS Model Preparation:

The ANSYS software is utilized to create a finite-element model as shown in fig 2 of the leaf spring made of an eggshell-strengthened GFRP composite. The model preparation involves several steps to accurately represent the leaf spring's geometry, material properties, and loading conditions.

Geometry and Measurements: The design parameters are utilized to determine the appropriate geometry and measurements of the leaf spring. These parameters define the shape, length, width, and thickness of the spring.

CAD Model Creation: Using computer-aided design (CAD) software as shown in **Figure 2**, a 3D model of the leaf spring is created. The CAD model accurately represents the shape and measurements of the spring based on the design parameters. It provides a visual representation of the leaf spring's geometry.

Importing the CAD Model into ANSYS: The CAD model of the leaf spring is imported into the ANSYS software. This allows for a further analysis and simulation of the mechanical behavior of the composite.

Material Properties: In ANSYS, the material properties of the eggshell-strengthened GFRP composite are specified as shown in **Figure 3**. This includes defining the elastic modulus, Poisson's ratio, and density of the composite material. These properties can be obtained from the literature or material testing.

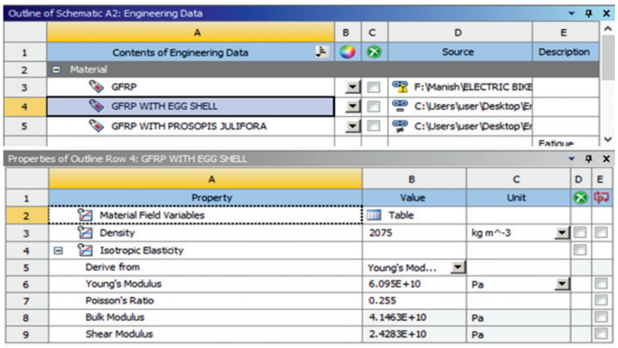
Finite Element Meshing: The leaf-spring model is meshed with finite elements in ANSYS. The meshing process divides the leaf-spring geometry into a network of interconnected elements. The number and size of the elements are chosen to accurately capture the shape and deformation behavior of the leaf spring under different loading conditions.

Applying Boundary Conditions and Loads: To replicate real-world loading conditions, appropriate boundary conditions and loads are applied to the model. For example, one end of the leaf spring may be fixed, and a force or displacement is applied to the other end to simulate the loading scenario.

Analysis and Simulation: The ANSYS software performs a simulation and analysis of the finite-element model. This involves solving the equations governing the mechanical behavior of the composite under the applied loads. The analysis provides information about the stress, strain, and displacement distributions within the leaf spring, as shown in **Figure 4, Figure 5 and Figure 6**.

3 RESULTS

Simulation Results and Evaluation: Simulation results and mechanical test results are two key components of evaluating the performance of the eggshell-strengthened GFRP composite leaf spring. Both of these evaluations help researchers to understand how well the composite material will perform in real-world applications. Simulation results involve using software to predict the behavior of the composite under different loading conditions. This involves running computer simulations that simulate the physical behavior of the composite material when it is subjected to different types of loading. Stress, strain, and displacement results are part of the simulation



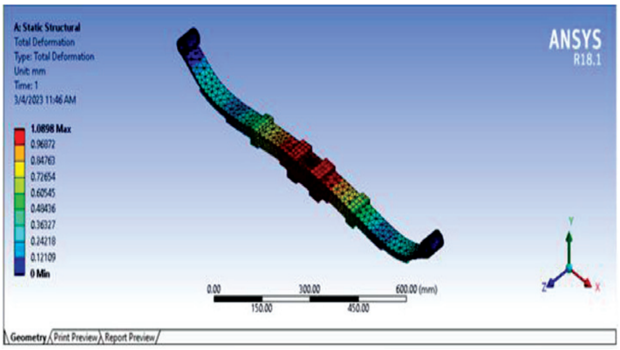
Outline of Schematic A2: Engineering Data

	A	B	C	D	E
1	Contents of Engineering Data			Source	Description
2	⊟ Material				
3	GFRP		☐	F:\Manish\ELECTRIC BIKE	
4	GFRP WITH EGG SHELL		☐	C:\Users\user\Desktop\Er	
5	GFRP WITH PROSOPIS JULIFORA		☐	C:\Users\user\Desktop\Er	
					Fatigue

Properties of Outline Row 4: GFRP WITH EGG SHELL

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Density	2075	kg m^-3	☐	☐
4	⊟ Isotropic Elasticity			☐	
5	Derive from	Young's Mod...			
6	Young's Modulus	6.095E+10	Pa		☐
7	Poisson's Ratio	0.255			☐
8	Bulk Modulus	4.1463E+10	Pa		☐
9	Shear Modulus	2.4283E+10	Pa		☐

Figure 3: GRPF with eggshell material properties



A: Static Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
3/4/2023 11:46 AM

Figure 4: Total Deformation

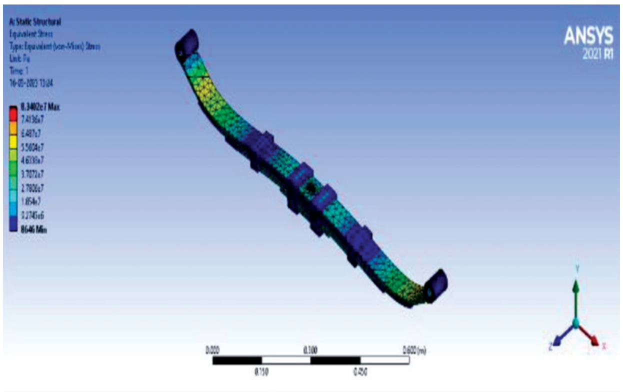


Figure 5: Equivalent Stress

output, and they help to determine how well the composite material can withstand different types of loads.

In the case of the eggshell-strengthened GFRP composite leaf spring, the simulation results show that it has improved mechanical properties compared to a regular glass fiber epoxy material. **Figure 4** shows the total deformation, which is the overall change in shape of the composite when it is subjected to a load. **Figures 5** and **6** show the equivalent stress and equivalent elastic strain, respectively. These simulations help researchers to optimize the composite material for maximum performance in leaf spring applications. The mechanical test results involve physically testing the composite material to determine its mechanical properties. In the case of the eggshell-reinforced GFRP composite, the results show that it offers significant improvements in key features such as tensile strength, flexural strength, and impact energy absorption.

For example, the composite showed a 17% improvement in tensile strength compared to regular glass-fiber epoxy. This means that the composite material is stronger and more durable when subjected to a tensile load. Similarly, the flexural strength improved by 12 %, which means that the material is better able to withstand the bending loads. The impact energy absorption also increased by 17 %, which is a key feature for leaf spring applications. This means that the composite material is better able to absorb energy from impacts, which can help to reduce damage to the vehicle.

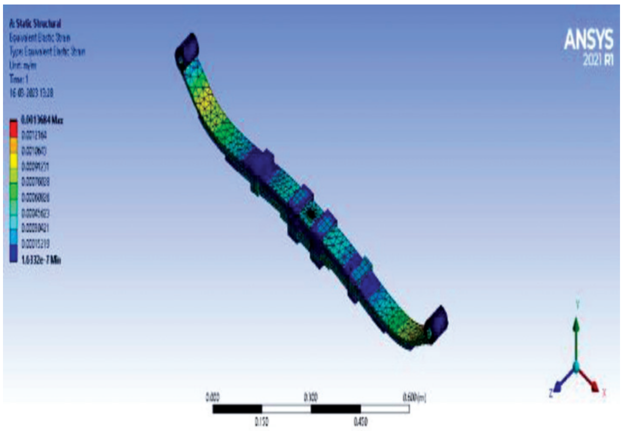


Figure 6: Equivalent Elastic Strain

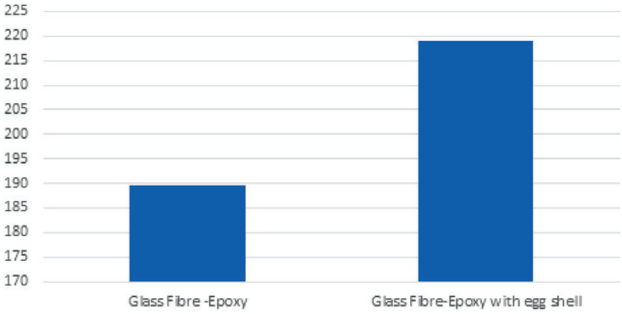


Figure 7: Flexural results showed a 17 % rise in the impact energy absorption compared to the glass-fibre epoxy and glass-fibre epoxy with eggshell

Overall, the simulation and mechanical test results show that the eggshell-reinforced GFRP composites have a place in the development of strong, lightweight leaf-spring designs. These composites offer greater strength, durability, and impact resistance than regular glass-fiber epoxy materials and are thus an ideal material for vehicle-suspension systems.

4 DISCUSSION

The mechanical testing of the combined sample yielded the following results: the tensile strength of the eggshell-reinforced GFRP composite exhibited an approximate 17 % increase compared to the glass-fiber epoxy. **Figure 7** illustrates the comparison between the tensile results of the glass-fiber epoxy and the eggshell-reinforced GFRP composite, showing a 12 % improvement in flexural strength. **Figure 8** demonstrates a 17 % rise in the impact energy absorption for the composite material when compared to both the glass-fiber epoxy and the eggshell-reinforced GFRP composite provides a comprehensive comparison of the effects of the glass-fiber epoxy and the eggshell-reinforced GFRP composite.

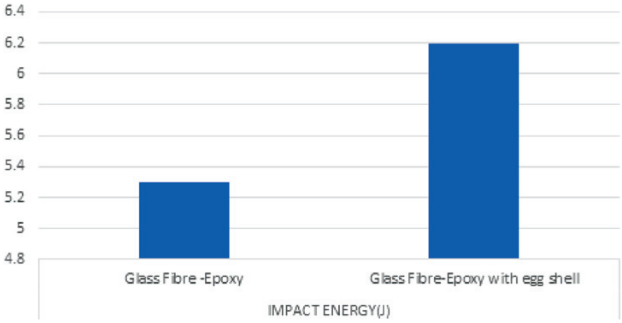


Figure 8: Comparison of the effects of glass-fibre epoxy and glass-fibre epoxy with eggshell

Based on theoretical and actual studies, the stresses and deflections of the leaf spring under static loading conditions were assessed. Mono composite leaf springs for automobile suspension systems were built utilising E-Glass/Epoxy and natural fibre epoxy, with the results being compared to those of structural steel, glass-fibre-reinforced plastic, and GFRP strengthened with eggshell particles. According to the design evaluation, the leaf-spring stresses were discovered to be well within the permitted range.

The GFRP and eggshell-reinforced GFRP-composite measurements showed comparable endurance to substantial deformations. However, both materials' strong breaking resistance is their main drawback. This was addressed by carefully planning and testing the laminate to strike a compromise between the weight reduction and the capacity to endure a predefined set of static external stresses, taking into account the tension and displacement constraints. A significant weight reduction of 40 % may be achieved by swapping out steel, GFRP, and eggshell-reinforced GFRP composite leaf springs with lighter eggshell-reinforced GFRP-composite leaf springs.

These results demonstrate the GFRP composite with eggshell reinforcement's potential as a material for leaf-spring applications. Compared to conventional glass-fibre epoxy, the composite material has improved tensile strength, flexural strength, and impact-energy absorption. The design of leaf springs can be improved to obtain better performance, greater fuel efficiency, and a lighter total vehicle by utilising the eggshell-reinforced GFRP composite's decreased weight and enhanced mechanical capabilities. On improving the design and investigating the use of eggshell-reinforced GFRP-composite leaf springs in automobile suspension systems, more research and development may be carried out.

5 CONCLUSIONS

The experimental findings show that adding eggshell reinforcement to the GFRP composite for leaf-spring applications significantly improves its performance. The composite material's tensile strength improved by around 17 %, as compared to the glass fibre epoxy, showing improved mechanical performance. Comparing the flexural strength to the glass fibre epoxy and eggshell-reinforced GFRP composite, the flexural strength exhibited a 12 % improvement and the impact energy absorption rose by 17 %. The eggshell-reinforced GFRP composite has a lot of promise for use in leaf springs since it offers higher strength, durability, and impact resistance, according to these studies. The composite material is a practical substitute for conventional steel leaf springs due to its capacity to tolerate static external stresses and severe deformations. In addition, the significant weight reduction of 40 % made possible by substituting steel with GFRP, for enhancing fuel efficiency and overall vehicle performance, and eggshell-reinforced GFRP composite with lighter eggshell-reinforced GFRP-composite leaf springs.

The findings show that eggshell-reinforced GFRP composites can be used to create leaf-spring designs that are strong, lightweight, and environmentally friendly, helping to advance the design of effective and long-lasting vehicle suspension systems. To effectively utilise the composite material's mechanical qualities and realise its promise in real-world applications, additional research and development can concentrate on optimising the design and manufacturing process while taking particular loading requirements and displacement constraints into account. In addition to improving the mechanical properties of the composite, using eggshell waste as a reinforcing material offers a sustainable alternative for waste reduction and repurposing in a variety of sectors.

Future Scope

The future scope of eggshell-reinforced GFRP-composite leaf springs is promising. Considering the simulation and mechanical test results, the materials could be used to produce stronger and more durable leaf springs for vehicles' suspension systems. Some possible future areas of research in this field include:

1. Optimization of the composite material: Researchers could conduct further studies to determine the optimal composition of the eggshell-reinforced GFRP composite for leaf spring applications. This would involve investigating the effect of varying the proportion of eggshell to resin, as well as the fiber orientation and thickness of the composite.
2. Performance testing in real-world situations: The eggshell-reinforced GFRP-composite leaf springs would need to be tested in real-world scenarios to understand how they perform in a variety of conditions. This testing would provide insights into the durability and reliability of the composite material.
3. Manufacturing techniques: Future research could focus on developing new manufacturing techniques to produce eggshell-reinforced GFRP composite leaf springs at a larger scale. This could involve exploring the use of new equipment and procedures that streamline the manufacturing process while maintaining the quality of the product.
4. Other applications: Eggshell-reinforced GFRP composites could potentially be used in other applications beyond leaf springs, such as aircraft and marine materials, biomedical implants, and sporting goods. Future research could investigate these additional applications and the potential benefits these materials could bring to these industries.

In conclusion, the results of the simulation and mechanical tests on eggshell-reinforced GFRP-composite leaf springs are promising. The findings offer new opportunities to develop stronger, lighter, and more reliable vehicle suspension systems. There is significant potential for further research in this field to optimize composite material composition, explore new manufacturing techniques, and develop other applications for these materials.

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