

The Application of Nanomaterials in the Lightweighting of New Energy Vehicles

*Junjie Deng**

School of Mechanical Engineering, Lanzhou University of Technology, No. 36 Pengjiaping, Gansu province, China

Abstract. Due to the global drive for carbon neutrality and the fast-growing electric vehicle (EV) market, there is a need for effective lightweighting technology to cut down EV heavy battery weight and increase the range. In this paper, the approach of using advanced nanomaterials such as nanocellulose, short-cut carbon fiber reinforced polymers and graphene reinforced rubber integral solutions as solutions to vehicle weight reduction were examined: Nanocellulose is getting recognition because of its really good specific strength and sustainability for internal parts and semi-structural ones. Short-cut carbon fiber reinforced polymer applications on battery module casing: it has good stiffness and electromagnetic shielding ability. Additionally, the study investigates the role of graphene-reinforced rubber in enhancing tire durability and reducing rolling resistance. Research assesses the technology of these materials and it has issues like being able to spread out, they stick together, making them complicated to make, and it cost a lot of money. This paper puts forward its recommendations for industrial applications on the basis of mechanical and functional comparison of the advantages of nanocomposites and concludes that overcoming process barriers is key to realize the wide adoption of lightweight new energy vehicles.

1 Introduction

Recently, the world is making efforts to deal with climate change and energy crisis because of the carbon neutrality, and electric vehicles are manufactured and developed very quickly and have been considered as the mainstream in the future vehicle industry [1]. But due to the large battery packs, the car becomes heavier and much bulkier as well, incomparable to an ordinary automobile. Due to the cruising range of new energy cars is connected to their weight. And also it contributes greatly to the cruising range with less weight. Relevant studies show that the increase in cruising range of new energy vehicles is approximately 6%~8% for every 10% reduction in body weight. To improve the performance and endurance of new energy vehicles [2] Therefore, overall lightweight technology should be implemented on the vehicle, before a significant breakthrough in the energy density of batteries. How to make vehicles lighter has become a focal point for automakers.

* Corresponding author: jareddeng771@gmail.com

Except for the weight, electric cars will also have higher new demands in terms of batteries, body structure change and tire changes so as to improve the max range in safety and reliable attempt. The key problem is how to reduce overall weight but maintain existing performance. Traditional light materials like high strength steel and aluminum alloys pretty much hit the peak of their physical properties over the last few decades. Therefore the creation of new material is ongoing [3].

In this case, the proposal of the nanomaterials application is made. Compared with traditional material structures, nanomaterials can be used because they have advantages such as high mechanical properties and high specific strength. They are largely used in vehicle bodies, battery casings, and tires. Also improve its heat dissipation and reliability and also improve its mechanical performance. Academic circles have also made many studies on the use of nanomaterials for creating vehicle lightweighting. As Nurazzi et. al. pointed out that nanocellulose has been identified as an important green product in the automotive industry in terms of performance and sustainability. Nanocellulose is getting more use in non-load-bearing elements, it can supply great mechanical features—like strong tensile energy and firmness—that are like those found in old-fashioned manufactured materials. Besides the benefits of structure, this also has many environmental benefits: it can reduce the weight of vehicles and people's dependence on oil. In the end as a sustainable reinforcement material, it meets the industry's urgent demand for green-friendliness, i.e., eco-friendly vehicular manufacture, improving vehicle performance and reducing ecological impact [4]. Lin et. al. put forth that thermally treated short-cut carbon fiber reinforced monomer nylon composite materials are an important advance in automotive materials, with great overall performance and manufacturing efficiency. Their study shows composite materials have much better mechanical strength and stronger frictional properties, and also bring about considerable economic benefits such as low production cost and short processing time. With the combination of the strong durability and rapid, economical mass production qualities, it seems the material is becoming much more realistic in regards to manufacturing parts that are solid as well as parts that are under a great deal of pressure for the auto industry [5]. Liang et. al. state that due to the fact that it has a strong ability to greatly improve the mechanical performance of the nanocomposites, it has been widely used in the rubber industry. Their work shows that graphene is a great reinforcing filler and makes the rubber matrix better by making it stronger and more durable. Also, the group points out the essential part of Response surface methodology (RSM) as a nice statistical method in the formulating and processing of these graphene-reinforced composites. The time is to find the right balance of material, optimization can achieve the most performance efficiency, making graphene become a transformative material in next-generation rubber [6]: So using nanomaterials for lightweighting is a good way for EVs.

This paper talks about the various nanocomposites' implementation solutions in the lightweight applications of new energy vehicles, compares and examines the pros and cons of various substances and practices, and gives their own ideas. This paper is about: Part 1 is the introduction, explaining the research background and the importance of introducing nanomaterials; and part 2 introduces three examples in detail, introducing nanocellulose materials used for the body panels, short-cut carbon fiber reinforced polymer materials used for battery module brackets, and graphene-reinforced rubber used for tires, and explaining the three materials. The third point is on some urgent problems of nanomaterials which has to be faced and problems for big-scale use of nanomaterials. Fourth part presents development proposal and prospect from the industry development now. The fifth part gives a summary of the paper as a whole.

2 Case description

An Nanocellulose is a type of composite material, and it is produced by processing wood pulp into a polymer. The diameter of this enhanced phase ranges between 1-100nm. From the plant it comes but at the nano-level it is very strong and very low density compared steel aluminum. As this thing happens to be on a nanoscale, nanocellulose might have kind of a stick-to-itiveness for it. That's why nanocellulose is such a good light material to disgust metal, plastic components. Practical applications, in practice, nanocellulose has always been involved with the research of body parts of the lightweight automobile. For example, a researcher in Japan has carried out a large number of studies and has manufactured a light-weight prototype vehicle made of CNF materials. And other organizations like those at universities in America, such as Purdue University, are also developing new nanocellulose technologies, like for making the nanocellulose more durable for use in vehicles.

Short - Cut Carbon Fiber Reinforced Polymer is the material made by adding short - cut carbon fiber to thermoplastic resin. Short-cut carbon fiber has a rheological property that continuous fiber does not have and can be used for injection molding of complex geometric structural parts with great accuracy. Due to the fact that carbon fiber possesses an extremely high specific modulus, when using short-cut carbon fiber, it can achieve the lowest possible weight while having a much greater structural rigidity over traditional materials, which is why this makes it the optimal choice for battery brackets. When there's a vehicle shake or crash, it can stop getting bent and moved around. At the same time, as carbon fibers themselves are conductive, if the short-cut carbon fibers form an electrical conductive network in the resin matrix, the material is naturally an electromagnetic shielding cover. It can protect the internal BMS electronic device from electromagnetic interference.

Graphene rubber is a rubber-matrix composite, which is filled with a small amount of nano-rubber. Grapheme has a very large Young is modulus and specific surface area. Rubber: The strong physical cross-linked network is created by the many layers of rubber and greatly blocks the movement of rubber chains, making the rubber stronger and more wear-resistant. Adding graphene, it is also possible to reduce the unnecessary internal molecular friction in tires to a certain extent, reducing the hysteresis loss, and greatly increasing the driving mileage. At the same time, heat is also produced when the tire rolls; at this time, graphene can dissipate the heat, so it is less likely for the tire to blow up and burst because of excessive heat, and greatly improve the life of the tire.

3 Analysis and challenge

3.1 Nano-crystalline cellulose

In short, when looked at nanocellulose to find a big, fast car part that was also good for the environment, it was tiny, really strong, and could grow back: Light, Strong, Renewable vehicle parts Kinoshita et.al. [7] research pointed out that nanocellulose was mostly brought into use in the automotive field in the form of the polymer composite with the reinforcing element. Add ANCs, CNFs to either the thermoplastic matrices or thermosetting matrix via solution casting or melt compounding. Strong hydrogen bonding interactions, broad specific surface areas of nanocellulose made it so that stress could be transferred from the matrix to the reinforcement. Therefore, lightweight composites suitable for automotive interior panels, structure parts and semi-structured parts have all been created. The study showed that nanocellulose-based composites would not necessarily change the compatibility with conventional manufacturing technologies and met automotive processing requirements.

The applications significantly improved the mechanical and functional properties of the nanocellulose-based automotive material. Nanocellulose composite was compared to the clean polymer for having more tensile strength, more stiffness and more impact resistance at lower filler loading. One sample can be seen in Fig. 1: Performance improvements made it possible for lightweight vehicles to improve without losing structure, which was necessary for better fuel consumption and less emissions. In addition to mechanical improvements, Nanocellulose also came with beneficial changes in terms of Thermal Stability, and improved vibration-damping. After reading, it is found that nanocellulose was widely applied in instrument systems, door panels, seat components, and under-the-hood areas [7]. And its renewable and biodegradable nature fitted with what the car world wanted to move in terms of sustainability and doing things by recycling.

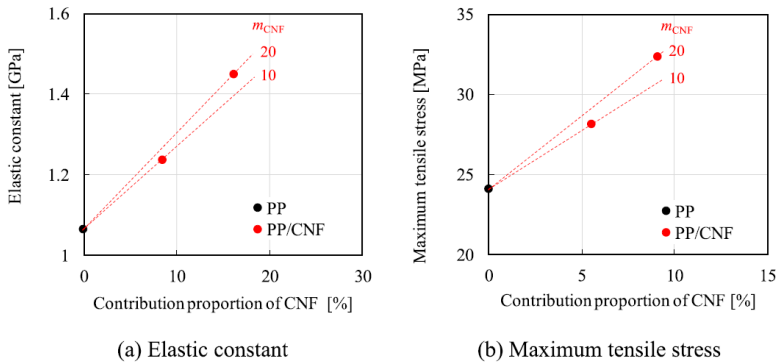


Fig. 1. CNT strengthened PP. CNT with relation to mechanical properties between addition [7].

But there are some problems although it has those benefits large scale application of nanocellulose for automobiles still run into some problems. Nanocellulose had a great problem with its hydrophilic property which caused the difficulty of getting dispersed in hydrophobic polymer matrix and created bad interfacial bonding and durability over relationships for the long run. It has doubts about its dimension and performance constancy due to it is also very sensitive to water. And it also needs surface modification as well as large production of Nanocellulose so it makes manufacturing complex. Industry wise, it was still a big problem to get uniform dispersion while good production processability at high throughput. Therefore Nanocellulose had a great potential for being a lightweight and sustainable automotive material, and the improvement for surface treatment and better moisture resistance and cost were needed to make it a large commercial use.

3.2 Short-Cut Carbon Fiber Reinforced Polymer

In short, short-cut carbon fiber reinforced polymer composites were widely used in advanced automotive applications for their lightweight and high performance quality which was mostly being applied onto the load-bearing structures like battery bracket for EVs. Sun et. al. research indicated [8], short carbon fibers were mainly incorporated into thermoplastic matrices like polyamide 6 via melt mixing and extrusion processes. Due to the use of short fibers, it was possible to achieve good reinforcement without sacrificing good processability for large scale manufacturing. Composite fabrication refers to the uniform distribution of surface treated carbon fiber in the polymer matrix to form an interfacial structure. This microstructural design met the high strength and high stiffness required of battery brackets in automobiles; it had a strong heat resistance too; the entire idea was to reduce the weight significantly. As for the good compatibility with common process like injection molding under this situation and additive manufacturing, short cut Carbon fiber composite can also be

deemed suitable materials for building auto structural components and semi-structural components. From Fig. 2 it was also shown that short-cut carbon fiber-reinforced polymer composites could be used for supporting bracket fabrication.

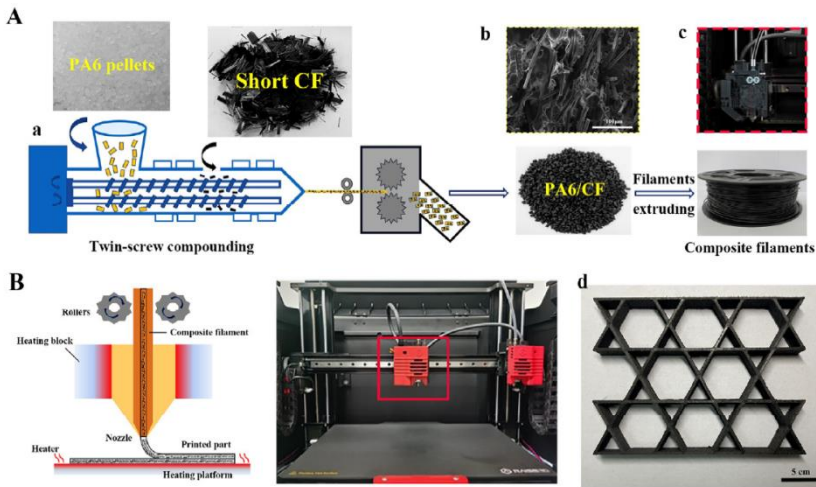


Fig. 2. The supporting bracket fabrication of short - cut carbon fiber reinforced polymer composite [8].

Introducing the short-cut carbon fibers greatly improved the mechanical and functional behavior of the material for making the car's battery brackets. Compared with neat polymer materials, carbon-fiber-reinforced composites showed more tensile strength, more flexural strength, and higher stiffness at around 50% fiber loading. These changes made batteries strong enough to handle mechanical forces, vibrations, and getting hit by cars while driving. And also added some more thermal stability from carbon fiber which made it fairly good for use in batteries because after all it could reach some higher temperatures than normal when being charged or discharged. The studies also showed that improving the optimized fiber orientation and post-processing techniques, also greatly improved interlaminar bonding and load transfer efficiency. So it can also have more structural reliability [8]. Short-cut carbon fiber composites' good specific strength and stiffness directly promoted vehicle lightweighting, a must for getting better driving range and energy efficiency in EVs.

Although it had these advantages, large scale application of short-cut carbon fiber composites in automotive battery brackets still encountered a number of problems. Due to short fiber's random orientation, material anisotropy was created which decreased its ability to get the best mechanical performance as compared to continuous fiber. Also due to fiber agglomeration and void defects created because of processing it's an issue for long term durability and structure. Carbon fibers are also relatively more expensive and require strict control of processing parameters, which makes the manufacturing process more difficult. From an industrial standpoint, it is still difficult to strike a balance between industrial mechanical superiority, frugality, and quantity. Therefore, although short-cut carbon fiber reinforced composite shows great promise for structural application such as automotive battery brackets, the further development along the fiber dispersion, interface bonding, and cost reduction is still necessary in order to reach commercialization.

3.3 Graphene-reinforced rubber

In general, the research on the graphene-enhanced rubber composites was mainly because of their excellent mechanical strength, large specific surface area, and wear resistance as high-performance material in automotive tires. Singh et. al. studies showed [9] that most of the graphene and its derivatives had been introduced into rubber matrixes such as natural rubber and styrene-butadiene rubber as reinforcing fillers. The composite process was carried out through traditional rubber compounding: solution mixing and melt mixing, then vulcanization. Graphene sheets were dispersed inside the rubber matrix during the process, and then they made a kind of network-like formation with the polymer chains. This microstructure made it easy to pass stress from graphene to the rubber part. Therefore, the work successfully produced and prepared a graphene enhanced rubber compound, which could also be used for tire tread and the tire sidewall areas. It was compatible with current manufacturing methods for tires.

The rubber component that went into cars became far better thanks to a vast improvement made to it by graphene. Compared with traditional carbon black-filled rubber, lower amount of graphene-improved rubber composites had higher tensile strength, higher modulus, and better wear resistance. These performances improved and had more tire strength and had less tire weakening over a long time. And it improved the wear resistance and the hysteresis loss of the G- Rubbers. Therefore, this enhanced the reduction of tire rolling resistance directly correlated with better fuel economy and lower energy use. And also studies also proved that the addition of the graphene could increase the thermal conductivity and heat dissipation ability of the rubber compound at the same time. This is also a very important point for the high speed and high load tires [9, 10]. In addition, optimized dispersion of graphene can improve fatigue resistance and crack propagation resistance of material, it also improved the safety and service life of tire for automobile.

Although the following benefits were achieved by the graphene-enhanced rubber composite materials, it's still confronted with lots problems when being widely applied in the auto tire. Because of the strong clustering tendency of graphene sheets, it still found hard to get even distribution in the rubber matrix. Since relatively average and poor dispersion, and the support was reduced, so there was a weakness on this mechanical quality of the material. In contrast, material cost is relatively high and special processing techniques or surface modification process is needed so that the cost for material and fabrication technology further increased. At the same time, it should be pay attention to the influence of graphene on processing and vulcanization of rubber so as to guarantee stable production. The industrial application view point, the problem of balancing the performance improvement, the cost - effectiveness and the manufacturability on large scale was still a key point. Therefore, even though graphene-reinforced rubber demonstrated considerable possibilities for improving the wear resistance and energy efficiency of tires, further improvements were still necessary in dispersion technology, processing strategies and cost control so as to put it into general use in the automotive tire industry.

4 Summary & suggestion

Various lightweight material was compared in Table 1. Nanocellulose is very appropriate for automotive lightweighting because it has higher tensile strength, better rigidity and great impact toughness and is a sustainable material. The problem with industry right now is, it has some tech blocks: they have a tough time putting hydrophilic fibers across hydrophobic stuff, and they need extra steps because they absorb water when they're manufactured. Looking forward, nanocellulose is suitable for non-structural components and interior components because it meets industrial transformation trends best, and it is environmentally beneficial.

Although it is currently expensive to process, if advanced surface modification technique was used, those dispersion-related problems will be overcome. Therefore, with processing technology advancements, the material's performance will be improved.

Table 1. Compared the pros and cons of various lightweighting material.

Material	Progress	Challenges
Nano-crystalline cellulose	-higher tensile strength -increased stiffness -superior impact toughness	-hard for disperse -high manufacturing complexity
Short-Cut Carbon Fiber Reinforced Polymer	-high specific stiffness -good processing compatibility -enhanced thermal stability	-material anisotropy limits -high production costs
Graphene-reinforced rubber	-superior wear resistance -reduced rolling resistance -excellent heat dissipation	-high material expense -complex processing control

Short cut carbon fiber reinforced polymer is used as effective structural integrity solution at high specific stiffness and improved thermal stability but still holding good process compatibilities with injection molding and 3D printing. On the contrary, there are problems like material anisotropy and fiber orientation properties, fiber cluster defects, etc., which also impact the long-term stability, and the production cost is also relatively high. But in light of mechanical failures, which will occasionally happen, it would be a good candidate for something which takes a load like the battery bracket: Anisotropy is a big problem but not a death knell—it can be handled by better controlling fiber direction when it gets injected. Although it is expensive, due to its ability to specifically protect the car battery from impacts and electromagnetic interference, it is unavoidable. Therefore, sufficient funds should be invested in its production.

Graphene-reinforced rubber is revolutionizing tire technology because it shows great performance in wear resistance, reduces rolling resistance and has very good heat dissipation. These features are mainly suitable for the heavy load and range requirements of EVs. The fact that despite some problems with severe particles in aggregation forming structural vulnerabilities, and high material costs with difficult processing control to avoid vulcanization issues - the outlook for it being used for the tires remains quite positive. Recommend focus on application for high performance electric vehicle tires, as lowered rolling resistance becomes range advantage for electric vehicles, a hot selling point. Even though there were some troubles with aggregations, it can be seen there is lots of room to save operational costs through better fuel efficiency and longer tire lifespans once dispersion technology is developed enough for large scale production; then it will be a very bright future for graphene tires.

It is also a major change in the future development of new energy vehicles, the production of this nanomaterial has reduced the weight of the vehicle, and also increased the functionality. Future development of industries may be in the integration of these materials in where nanocellulose will work together with the structural rigidity of carbon fiber, high performance of graphene to build up a multi material vehicle structure. Future development will surely focus more on adopting standardized process technologies to address common problems like dispersing and gathering to reduce the difficulty and price of manufacturing, which is currently a bottleneck for widespread application. As manufacturing technology

matures, nanocomposites will shift from high-end prototypes to standard components, driving next-generation vehicles to achieve carbon neutrality and maximize energy efficiency.

5 Conclusion

This paper takes a deep look at nanomaterials making sure the new energy vehicles can get lighter. The traditional material types, like high strength steel and aluminum are hitting their max performance, it gives us new ways to make cars lighter while keeping them strong and working well using new advancements in nanomaterial. The three parts of the study are about nanocellulose used in body and interior elements, chopped carbon fiber filled polymers used for battery holders, and graphene enhanced rubber for high performance tires.

Based on the research basis, the conclusion of the three materials is as follows:

1. Nanocellulose: This material is a good sustainable reinforcement material, which can greatly improve tensile strength and impact toughness. Despite it fitting in with the circular economy strategy, it's hard to make extensive use of it because of its hydrophilicity which makes it difficult for it to disperse in polymer matrices and it also increases its moisture sensitivity.

2. Short carbon fiber reinforced polymers: Short carbon fiber reinforced polymers have excellent specific modulus and thermal stability, effectively protecting battery components from mechanical deformation and electromagnetic interference. However, the material faces challenges such as material anisotropy and fiber agglomeration. If the injection molding process is not tightly controlled, it will affect long-term structural reliability.

3. Graphene-reinforced rubber: When adding graphite to rubber the wear resistance and heat conduction will go way up and the rolling resistance will drop. But due to the strong tendency of graphene sheets to be aggregated, which is also a major technical difficulty that hinders its improvement effect and increases the manufacturing cost.

In summary, although each material has unique advantages in weight reduction and performance improvement, its widespread commercial application is currently constrained by manufacturing complexity and cost-effectiveness issues. In the future, it is necessary to improve surface modification technology and dispersion technology to guarantee the material consistency. In the end, it is the successful incorporation of such nanocomposites that will be critical pieces of making carbon neutrality and pushing towards peak efficiency in next generation EVs reality.

References

1. M.S. Hossain, L. Kumar, M.M. Islam, J. Selvaraj, A comprehensive review on the integration of electric vehicles for sustainable development. *Journal of advanced transportation* **2022**, 3868388 (2022)
2. M. Lučić, J. Lukić, I. Grujić, Statistical analysis of trends in Battery Electric Vehicles: Special reference to vehicle weight reduction, electric motor, battery, and interior space dimensions. *The Archives of Automotive Engineering–Archiwum Motoryzacji* **104**, 63-96 (2024)
3. D.D. Mohite, V. Chaturvedi, S. De, V.S. Jadhav, Nanomaterials in automotive applications: a review and its technical aspects. *Int. J. Contemp Archit New ARCH* **8**, 2 (2021)
4. N.M. Nurazzi, M.A. Jenol, S.H. Kamarudin, H.A. Aisyah, L.C. Hao, S.M. Yusuff, et al., Nanocellulose composites in the automotive industry. In *Woodhead Publishing Series in Composites Science and Engineering, Industrial Applications of Nanocellulose and Its Nanocomposites*, Woodhead Publishing (2022). pp. 439-467

5. J. Lin, Z. Mai, P. Zhang, C. Lin, Y. Cheng, Z. Zhang, Superior mechanical and tribological properties of short-cut carbon fiber reinforced monomer casting Nylon composites after heat treatment. *Materials Letters* **338**, 134005 (2023)
6. Y.L. Leong, H.N. Lim, I. Ibrahim, Graphene in rubber formulations: a comprehensive review and performance optimization insights. *Molecular Systems Design & Engineering* **8**, 1229-1251 (2023)
7. T. Kinoshita, T. Yamamoto, C. Luo, K. Ide, K. Aoki, Y. Uetsuji, Mechanical characterization and design of hybrid reinforced polypropylene composites with talc fillers and cellulose fibers. *Composites Part B: Engineering* **266**, 110971 (2023)
8. B. Sun, S. Mubarak, G. Zhang, K. Peng, X. Hu, Q. Zhang, et al., Fused-deposition modeling 3D printing of short-cut carbon-fiber-reinforced PA6 composites for strengthening, toughening, and light weighting. *Polymers* **15**, 3722 (2023)
9. H. Singh, A. Verma, S.P. Vadapalli, M. Kotal, B.K. Das, C. SekharTiwary, J. Bhattacharya, Green Graphene Reinforcement to Enhance Mechanical and Wear Performance of Styrene–Butadiene Rubber - Based Composites. *Journal of Applied Polymer Science* **142**, e57492 (2025)
10. G. Aswin, V. Prakash, N. Subasree, V. Arul, P. Paramasivam, L. Gnanasekaran, et al., Recent advances in corrosion behaviour and interfacial failure of rubber–metal composites. *npj Materials Degradation* **10**, 9 (2025)