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Research Article

The analysis of thermoplastic polyolefin composite leaf spring for heavy commercial vehicle applications

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Abstract:

In the automotive sector, leaf springs are common in heavy vehicles because they have the advantage of spreading the load more evenly across the chassis of the vehicle. Because of the high strength-to-weight ratio, the automobile industry is increasingly interested in replacing steel springs with composite leaf springs. The maximum deflection decreases at PP/EPDM as the polymer composite plays a vital role in plasticity. The greater decrement at higher filling of graphite content (30%) demonstrates that fillers harden composites, reducing their ductility. The percentage difference of maximum deflection between steel and PP/EPDM is 177.37% while for the PP/EPDM and PP/EPDM/GR (30%) percentage difference is 85.72%.

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1. INTRODUCTION

The automotive industry for heavy commercial vehicles has shown keen interest in replacing steel leaf springs with polymer composite material leaf springs as popularity and demand increase in this type of material (Li et al., 2022, and A. Lakshmana, 2022). Leaf springs are much more durable than coil springs as they can withstand far greater loads with less deflection and are also easier to raise and lower. The most important task is to resist the variable vertical forces. Vertical vibrations and impacts are buffered by variations in spring deflection, allowing the potential energy to be stored in the spring as strain energy and then released slowly. Polypropylene / Ethylene Propylene Diene Monomer is the composite chosen in this project as the main material. This material has a low density, low cost, and is also highly durable, making it a common component in the automotive sector. Recent studies have demonstrated that replacing steel with polymer composite leaf springs in heavy vehicles can achieve significant weight reduction, improved production efficiency, and comparable or improved mechanical performance, supporting the growing trend of adopting polymer composites in heavy vehicle suspension systems (Li et al., 2022, and Priya et al., 2022).

2. METHODOLOGY

2.1 Materials

The Polypropylene (PP) used in this study is graded as S12232 G112 from Polypropylene Malaysia Sdn. Bhd. Ethylene Propylene Diene Monomer (EPDM) grade Vistalon 2504N used was obtained from ExxonMobil Chemical. The graphite powder/carbon black 500g 200 mesh was used as filler in this project.

Table 2.1 PP/EPDM/GR Composites formulation

Materials	wt%
PP	70
EPDM	30
Graphite (GR)	0,10,20,30

2.2 Mixing process

The composites were prepared using a Haake Polylab Mixing Machine. Each cycle lasted 30–35 minutes at 180 °C and 30 rpm. First, EPDM was discharged into the chamber to clean it. Then, PP was added and mixed for 10–15 minutes, followed by EPDM, which melted and blended completely. After 20–25 minutes of mixing, graphite powder was introduced and mixed for about 5 minutes before the material was discharged. The specimens were stored in labelled zip-lock bags. Finally, EPDM was again discharged for chamber cleaning, and the process was repeated.

2.3 Hot compression molding

The composites will be compression molded in a Gotech7014-H compression molding machine at a pressure of 170kg/cm2 to produce a 1.0mm dumbbell-shaped sample specimen. Pre-heating for 4 minutes before starting each cycle and followed by compressing at a constant temperature for 6 minutes and cooling under pressure for 3 minutes in the hot press procedure.

2.4 Tensile testing

The composites were tensile tested using an Instron machine model 5569 in accordance with ASTM D638. The experiment was carried out at a temperature of 25 + 3 degrees Celsius. The gauge length was set to 50mm, and the crosshead speed was set to 50 mm/min. Dumbbell shape (Type IV) specimens are required for reinforced composite testing, according to ASTM (D3039) (D638).

2.5 Design and Simulation

The design was made using CAD software, CATIA V5, and imported into the analysis system ANSYS ABAQUS to run the simulation. From the leaf spring design simulation, deflection and stress analysis were carried out.

3. FINDINGS

3.1 Experimental Result

Figure 3.1 shows the graph constructed based on Table 3.1. From the graph, the filler loading at 10% and 20% shows a slight growth in tensile strength from PP/EPDM at 0% and between. There is a major increase in tensile strength from 12.12 to 15.86 MPa with increasing graphite content from 20% to 30%. The rubber chain entangled with carbon black aggregates, as well as the number of cross-links, increases as the surface area of graphite increases. This trend is consistent with recent studies, which report that the addition of graphite to PP/EPDM or related composites significantly improves tensile strength due to increased cross-linking and filler-matrix interactions (Jiang et al., 2024; Rzeczkowski et al., 2019; Wang et al., 2021).

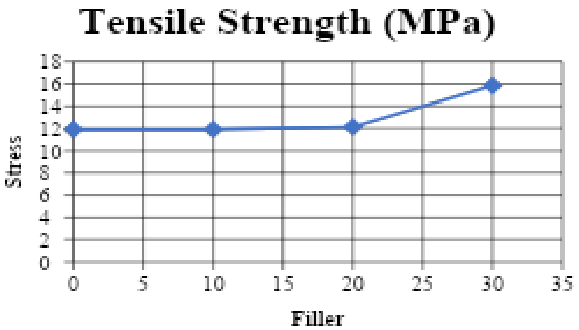

Figure 3.1 Tensile Strength PP/EPDM with and without filler average graph.

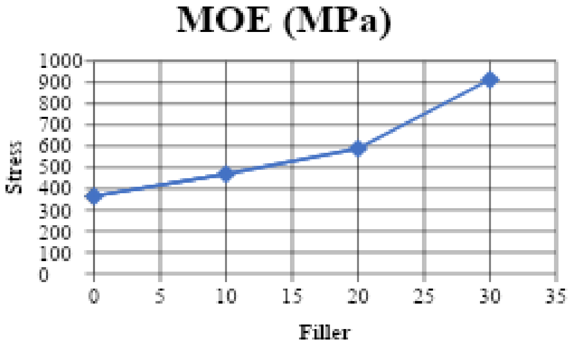

Figure 3.2 Modulus of Elasticity PP/EPDM with and without filler average graph.

From Figure 3.2 above, the graph shows that the modulus rises in proportion to the amount of graphite present. illustrating the filler particles' dominant contribution to the composite's modulus (Jiang et al., 2024).

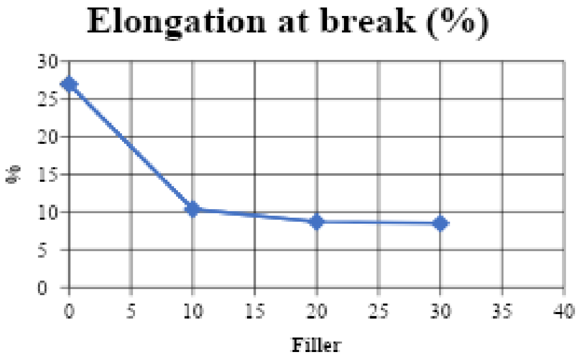

Figure 3.3 Tensile Strength PP/EPDM with and without filler average graph.

From Figure 3.3 above, the graph shows a decreasing trend in percentage. This is because the low content of polymeric matrix is insufficient to infiltrate graphite at higher graphite content due to its highly porous structure and high surface area; lack of percolation leads the composite to be more fragile and brittle, and can easily fracture even with small stress (Azizli et al., 2022, and Jiang et al., 2024).

3.2 Simulation Result

3.2.1 Reverse engineering: 2D and 3D design of leaf spring

Before the simulation begins, the leaf spring is drawn in CATIA V5 and then imported into ANSYS. Figure 3.4 shows the 2D isometric drawing with dimensions for drawing the leaf spring (M. Sarikanat et al., 2011).

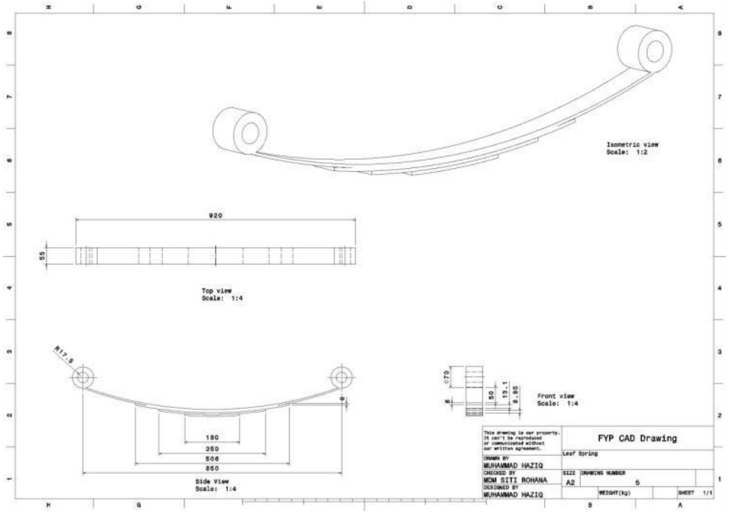

Figure 3.4 2D Isometric drawing with top, side, and front views of a leaf spring.

3.2.2 3D leaf spring design

The leaf spring is drawn in CATIA V5 and then imported to the ANSYS ABAQUS. Figure 3.5 below shows the 3D isometric view of the leaf spring.

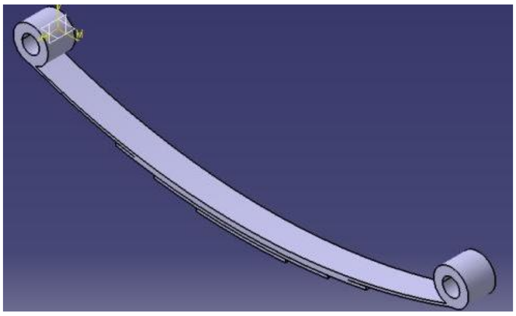

Figure 3.5 3D isometric view of a leaf spring.

3.2.3 Simulation Result for Steel Leaf Spring

For this phase of simulation, the data was taken from Patunkar et al., 2011, by using 60si7 steel grade for spring, with 219e5 GPa for the Young's Modulus, with a force of 2500N. The results for maximum deformation applied to a leaf spring are shown in Figure 3.6 below, which is

919.4mm for conventional leaf springs. In the middle of the leaf spring, the maximum deformation was observed. The von Mises stress, as shown in Figure 3.6, is for a conventional steel leaf spring. 2.120e5 MPa is the maximum stress.

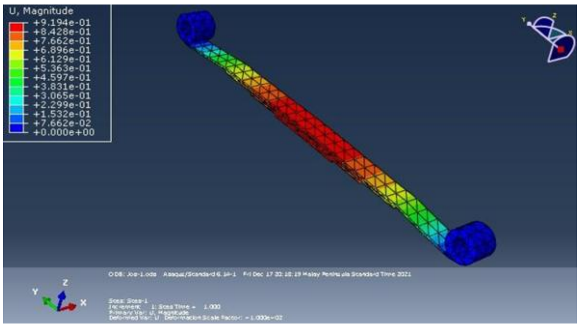

Figure 3.6 Deflection on conventional steel leaf spring

3.2.4 Simulation Result PP/EPDM (0%)

Figure 3.7 shows the maximum deflection applied to a PP/EPDM composite leaf spring, which is 55.13mm for compositions of PP/EPDM without filler loading (0%). The leaf spring's maximum deflection was concentrated in the middle, pushing the leaf spring upward. The load used is 2500N. This observation is consistent with recent studies on polymer composite leaf springs, which report that composite springs, depending on material composition and geometry, exhibit significant central deflection under static loads, with values and deformation patterns comparable to those predicted by simulation and confirmed by experimental testing (Vijayalakshmi et al., 2024; Singh & Chandra, 2024).

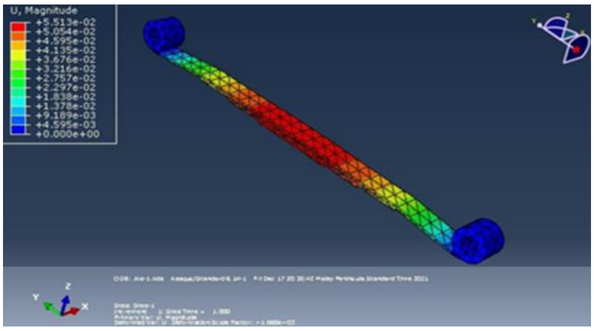

Figure 3.7 Deflection on PP/EPDM without filler (0%) composite leaf spring.

3.2.5 Simulation Result PP/EPDM (30%)

The maximum deflection applied to a PP/EPDM/GR (30%) composite leaf spring composition is 22.05mm, as shown in Figure 3.8. The maximum deflection of the leaf spring was concentrated in the middle, pushing the leaf spring upward. The load is 2500N. This demonstrates that the addition of graphite or similar fillers significantly increases stiffness and reduces deflection under static loads compared to unfilled composites. In 2024, Vijayalakshmi et al. showed that composite leaf springs with optimized filler content can achieve lower deflection values under equivalent loading, confirming the effectiveness of graphite reinforcement in enhancing load-bearing capacity and reducing deformation.

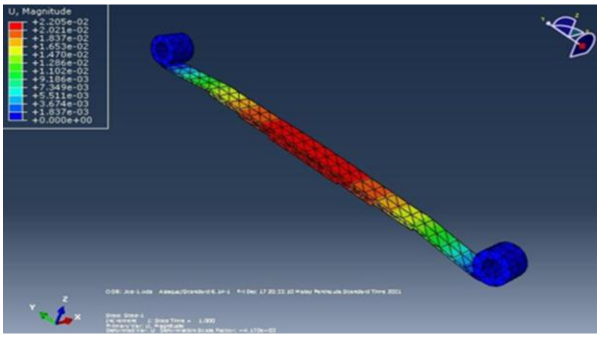

Figure 3.8 Deflection on PP/EPDM/GR (30%) composite leaf spring.

3.3 Comparison and discussion between steel and PP/EPDM with and without Graphite

Switching from steel to PP/EPDM composites significantly increases maximum deflection, reflecting the higher plasticity and lower stiffness of polymer materials. However, adding graphite filler (30%) to PP/EPDM sharply reduces deflection, as the filler increases composite stiffness and decreases ductility. This trend is widely supported: composite leaf springs show greater deflection than steel, but higher filler content (like graphite) hardens the composite, making it less flexible and more resistant to deformation (Malik & Afaq, 2020; Vijayalakshmi et al., 2024; Tadesse & Fatoba, 2022).

Table 3.3 Comparison between Steel, PP/EPDM, and PP/EPDM/GR (30%) composite leaf spring.

Materials	Maximum Deflection (mm)	Maximum Stress (MPa)
Steel	919.4e-3	0.2.12
PP/EPDM	55.13e-3	2.127
PP/EPDM/GR (30%)	22.05e-3	2.127

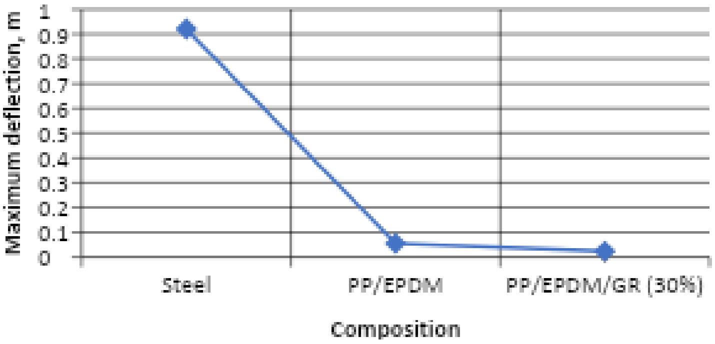

Figure 3.9 Maximum deflection comparison.

4. DISCUSSION

The toughness of the composites is influenced by the graphite content, but the tensile modulus decreases as the graphite content rises. At low amounts, polymer composites have more matrix accumulation; however, as the content was increased, the porous structure and high specific surface area of the polymer matrix became inadequate to penetrate the graphite content. Since the polymer composite plays an essential role in plastic deformation, the maximum deflection skyrockets at PP/EPDM. The greater decrease in flexural strength at higher filling of graphite content (30%), as shown in the graph, indicates that fillers harden composites, reducing their ductility.

Key effects of graphite content:

Toughness: According to Lei et al. 2018 and Fotoohi et al., 2023, small amounts of graphite can enhance toughness and fracture resistance due to better stress transfer and matrix reinforcement. However, excessive graphite can lead to agglomeration and poor matrix infiltration, reducing toughness (Gül & Kamali, 2024).

Tensile Modulus: Rzeczkowski et al., 2019, Gül & Kamali, 2024, and Pandey et al., 2017 explain that the tensile modulus often increases with graphite addition at low to moderate levels but may decrease or plateau at high loadings due to poor dispersion and matrix.

Ductility and Flexural Strength: Rzeczkowski et al., 2019, Gül & Kamali, 2024, and Pandey et al., 2017 studies also agreed that high graphite content reduces ductility and flexural strength, as the composite becomes more brittle and less able to deform plastically. This is due to the rigid, porous structure of graphite and the insufficient polymer matrix to bind the filler at high concentrations.

5. CONCLUSION

The experiment method shows how composite materials were made and tested. From the previous study, the mixing process shows that PP/EPDM polymer is the most compatible polymer composite, while Graphite has the composition of composite and nanocomposite, which is Graphene, making it harder to predict the outcome. The tensile test done gives the result for the new composite. The weight was reduced while the composite gives more lightweight. The comparison between Steel, PP/EPDM, and PP/EPDM/GR 30% leaf spring was made. The maximum stress increases and remains constant after the PP/EPDM composition. The deflection increases with increasing graphite from 10% to 20% content, but the higher filling of graphite content at 30% exhibits a significant decrement. This demonstrates that fillers reduce the ductility by hardening the composites, thus validating the previous findings. Graphite acts as a strong filler, but with a higher composition, it might be stiffer and brittle for composites.

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References

Li, B., Zhang, Q., Yang, J., Li, W., Wu, H., & Zheng, X. (2022). Research on the Application of New Composite Leaf Springs for Commercial Vehicles. Innovation in Science and Technology. https://doi.org/10.56397/ist.2022.09.05

A, Lakshmana. (2022). Design and Analysis of a Heavy Vehicle Leaf Spring. International Journal for Research in Applied Science and Engineering Technology. https://doi.org/10.22214/ijraset.2022.45687

Priya, K., Kumar, K., Suresh, G., Ganesamoorthy, R., Ravi, R., & Meenakshi, C. (2022). Analyzing the Fatigue Behaviour of E-Glass Fiber Reinforced Interpenetrating Polymer Networks (EP/VP/EV) Leaf Spring. Materials Science Forum, 1065, 35 - 45. https://doi.org/10.4028/p-qx682s

Jiang, S., Zhang, R., Ding, S., Yang, S., & Wang, H. (2024). One facile route to prepare high performance radiation resistant EPDM rubber composites through graphite modification technology. Polymers for Advanced Technologies. https://doi.org/10.1002/pat.6525

Rzeczkowski, P., Krause, B., & Pötschke, P. (2019). Characterization of Highly Filled PP/Graphite Composites for Adhesive Joining in Fuel Cell Applications. Polymers, 11. https://doi.org/10.3390/polym11030462

Wang, W., Zhou, L., Li, Y., Li, P., Chen, G., & Yang, S. (2021). Study on the Ablation Properties of Nano-graphite

Modified EPDM Insulators. Journal of Physics: Conference Series, 2133. 6596/2133/1/012019

Azizli, M., Barghamadi, M., Rezaeeparto, K., & Parham, S. (2022). Improvement of mechanical, morphological and thermal properties on PP-enriched graphene oxide/PP-g-MA/EPDM blend compatibilized: PP-g-MA compatibilizer and graphene oxide nanofiller role. Journal of Polymer Research, 29. https://doi.org/10.1007/s10965-022-03182-4

M. Sarikanat *et al.*, "Preparation and mechanical properties of graphite filled HDPE nanocomposites," *Arch. Mater. Sci. Eng.*, vol. 50, no. 2, pp. 120–124, 2011.

Patunkar, M. M., & Dolas, D. R. (2011). Modelling and Analysis of Composite Leaf Spring under the Static Load Condition by using FEA. International Journal of Mechanical and Industrial https://doi.org/10.47893/ijmie.2011.1001

Vijayalakshmi P, Pazhanivel K, Praveen Raj P, Muruganantham K. "Investigation on the effects of changing automotive vehicles leaf springs from steel to hybrid polymer composite leaf springs." Materials Research Express, 11. https://doi.org/10.1088/2053-1591/ad1b02

Singh, R., & Chandra, H. (2024). Study of Composite Light Weight Leaf Spring. International Journal for Research in Applied Science and Engineering Technology. https://doi.org/10.22214/ijraset.2024.64073

Malik, S., & Afaq, K. (2020). Stress Analysis of Composite Leaf Spring – Comparative Approach. IOP Conference Series: Materials Science and Engineering, 899. https://doi.org/10.1088/1757-899X/899/1/012013

Tadesse, B., & Fatoba, O. (2022). Theoretical and finite element analysis (FEA) of coated composite leaf spring for heavy-duty truck application. Materials Today: Proceedings. https://doi.org/10.1016/j.matpr.2022.04.782

Lei, F., Zhang, C., Zepeng, C., Yang, J., Sun, H., & Sun, D. (2018). Epoxy toughening with graphite fluoride: Toward high toughness and strength. Polymer. https://doi.org/10.1016/J.POLYMER.2018.07.084

Fotoohi, A., Ghasemi, F., Fasihi, M., & Rajaee, P. (2023). Mechanical behavior and essential work of fracture of surface modified exfoliated graphite filled polypropylene/ethylene vinyl acetate blend nano composites. Journal of Applied Polymer Science. https://doi.org/10.1002/app.53841

Gül, A., & Kamali, A. (2024). Effect of Mechanically Exfoliated Graphite Flakes on Morphological, Mechanical, and Thermal Properties of Epoxy. Journal of Composites Science. https://doi.org/10.3390/jcs8110466

Pandey, A., Singh, K., & Kar, K. (2017). Thermo-mechanical properties of graphite-reinforced high-density polyethylene composites and its structure–property corelationship. Journal of Composite Materials, 51, 1769 1782. https://doi.org/10.1177/0021998316683782