

# Comparative Analysis of Performance Impact: Car Bumper Made from Empty Palm Fruit Bunch (EPFB) and Polypropylene (PP)

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Empty Palm Fruit Bunch (EPFB), Low-Density Polyethylene (LDPE), Polypropylene (PP), Natural fiber, Frontal impact performance, Car bumper, Sustainable material, Static Structural Simulation

## Abstract

This study presents a comparative analysis of the performance impact of car bumpers made from empty palm fruit bunch (EPFB) composites versus those from conventional materials like polypropylene (PP). The use of EPFB fibers blended low-density polyethylene (LDPE) in polymer composites for production is low-cost and environmentally polluted, it is also lightweight when applied in car bumper applications. The bumper is a crucial safety component of the car that can absorb energy in a collision to ensure the passengers are safe. The research objectives were to evaluate the deformation, strain, and stress performance of EPFB composites and compare these properties to PP, identifying the most suitable EPFB composition as an alternative material for bumper application. ANSYS software is used in this research to examine the performance impact on car bumpers, which is by using features of static structural simulation. The results showed that the EPFB-LDPE 0.8% composites strike a good balance between flexibility and stiffness, performing a good alternative material as PP in stress while absorbing more energy. EPFB-LDPE composites may not be totally suited for direct usage as a bumper material in their current state due to significant deformation and strain, indicating probable shape retention and structural failure under heavy impact. While its ability to absorb stress is promising, the lack of stiffness complicates preserving structural integrity during crashes. Additionally, using EPFB composites supports sustainability by reusing agricultural waste and reducing reliance on non-renewable resources. In conclusion, the EPFB-LDPE 0.8% composite is a promising eco-friendly alternative to PP for car bumpers, combining reliable performance with environmental benefits and paving the way for greener innovations in the automotive industry.

## 1. Introduction

Over the last few years, the design and use of bumper materials have improved. The improvements are in the design and use of high-quality materials to manufacture passenger car bumpers. The car's bumper is an essential part of the car's body, designed to absorb impact energy and protect most of the vehicle's body parts [1]. These days, bumpers are mostly made of plastic because they are easier to build, lighter, more affordable, easily recyclable, and able to withstand impacts.

Car bumpers, a critical safety component, are traditionally made from polypropylene (PP) due to their excellent mechanical properties, including high impact resistance and durability [2]. However, PP is derived from non-renewable resources, has limited recyclability, and contributes significantly to environmental challenges such as long-term pollution and a high carbon footprint during production and disposal [3]. The limitations of recycling polypropylene further complicate its environmental impact, as it frequently requires complicated processes and is not as economically viable as other materials [4].

The challenges have driven the search for more sustainable alternatives such as natural composites like Empty Palm Fruit Bunch (EPFB). EPFB is a by-product of the palm oil industry and offers a promising solution as a natural fiber reinforcement in polymer composites [5]. EPFB fibers are abundant, renewable, and biodegradable, making them an ideal candidate for sustainable material development. When combined with Low-Density Polyethylene (LDPE), the resulting composite material has the potential to provide the necessary mechanical performance for automotive applications while addressing the environmental drawbacks associated with PP [6]. The EPFB-LDPE composite's nature helps to reduce overall vehicle weight, improve fuel efficiency, and minimize emissions, which is compatible with the automotive industry's goal for sustainability [7].

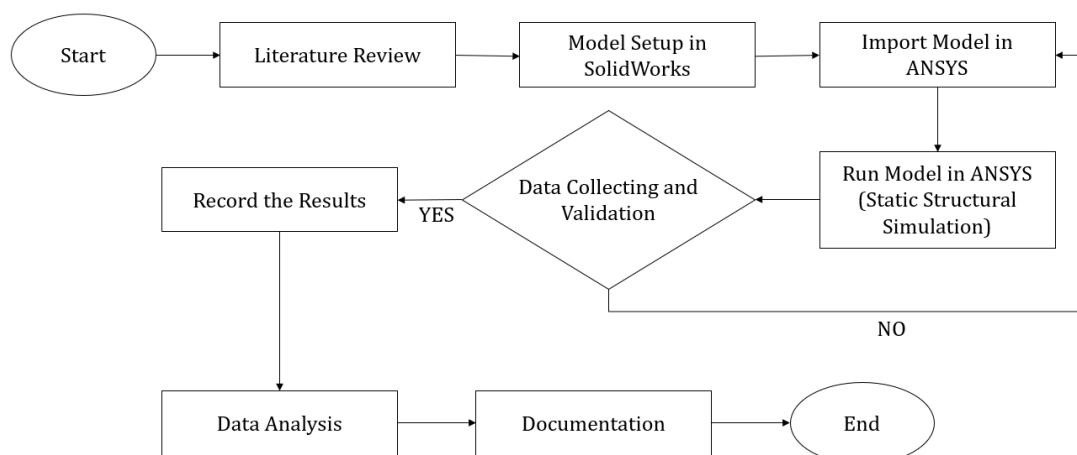
This study aims to evaluate the performance of car bumpers made from EPFB-LDPE composites (0.2%, 0.4%, 0.6%, 0.8% and 1.0%), focusing on deformation, strain, and stress characteristics. Using ANSYS software for static structural simulations, the research identified the best EPFB composition, specifically the 0.8% EPFB-LDPE blend, and compared its performance to that of PP. The results highlight the ability of EPFB composites as an alternative material for PP to balance flexibility and stiffness, absorb impact energy effectively, and maintain structural integrity, all while reducing reliance on non-renewable resources and addressing agricultural waste management challenges.

In conclusion, EPFB-LDPE composites were considered as the most essential criteria that need to be focused on in this study. It demonstrated the feasibility of replacing conventional material which is polypropylene (PP) as alternative material with natural fiber composites, paving the way for greener innovations and supporting global efforts to achieve environmental conservation and a circular economy. This paper has been organized in the following way. In Section 2, the materials and methods focus on the research framework of the project, the static structural feature in ANSYS software was used on the car bumper model for the impact simulation. Section 3 discusses the outcome of the results from the research done. This includes deformation, strain, and stress for all the bumpers under the same applied load. Finally, the conclusion is stated in the last section of the article which is in Section 4.

## 2. Materials and Methods

### 2.1 Research Framework

Figure 1 displays a flowchart for conducting the methodology process for impact or crash simulation from the beginning to the end of the research. The first step is to do some research for the literature review which is related to this study. Next, prepare a bumper model and set the model by using SolidWorks software, then import the bumper model into ANSYS software. After importing into ANSYS, the model was run using static structural simulation for the frontal impact. Lastly, the data and results were collected and analyzed.



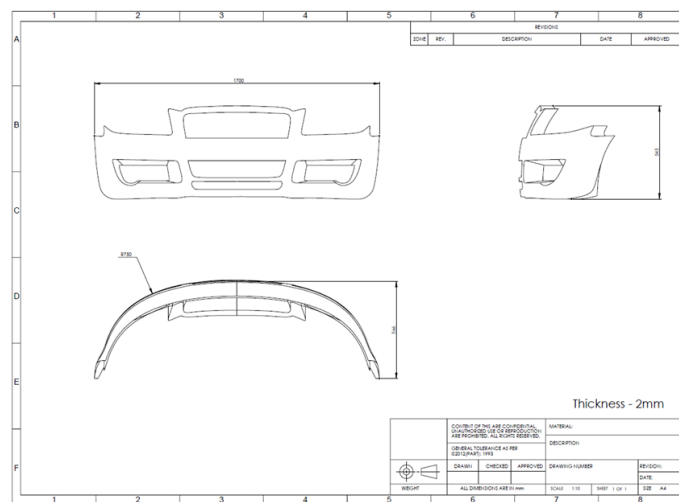
**Fig. 1:** Flowchart of the overall project

## 2.2 Model Setup

The bumper model in Figure 2 setup began by importing a detailed 3D model from GrabCAD into SolidWorks to ensure it reflected realistic dimensions and structural elements [8]. Figure 3 shows the specifications of the base model of the bumper drawn in SolidWorks based on the standard dimensions that are representative of typical car bumpers. After the verification in SolidWorks, the bumper was imported into ANSYS to subdivide into a fine mesh to prepare for the simulation. The completed model setup was then run for the simulation in ANSYS using static structural simulation.



**Fig. 2:** Base model of bumper



**Fig. 3:** Base model with dimension

## 2.3 Run Model in ANSYS

After transferring the model into ANSYS software, the static structural simulation was chosen to run the frontal impact simulation. The simulation calculated critical responses like deformation, strain, and stress after the impact which provide insights into the design’s structure and performance.

### 2.3.1 Engineering Data

The process began by accessing the Engineering Data module and the option to add or duplicate material was selected. Then, the new material was assigned a new material name. The next step involves entering the material’s mechanical properties such as Young’s modulus, Poisson’s ratio, density, and yield strength of the materials. The values of these material properties in Table 1 were obtained from previous research [9].

**Table 1:** Material properties

Materials	Density ( $kg/m^{-3}$ )	Young’s Modulus (MPa)	Poisson’s Ratio	Shear Modulus (MPa)	Tensile Strength (MPa)
EPFB-LDPE 0.2%	715.74	7.54	0.30	2.900	0.57
EPFB-LDPE 0.4%	675.54	7.38	0.30	2.840	0.60
EPFB-LDPE 0.6%	607.12	11.45	0.30	4.405	0.58
EPFB-LDPE 0.8%	599.38	15.68	0.30	6.031	0.52
EPFB-LDPE 1.0%	660.56	17.30	0.28	6.758	0.54
Polypropylene (PP)	910	1550	0.36	569.850	37.20

### 2.3.2 Defining Geometry

Defining geometry in this simulation entailed determining the physical shape and structure of the car bumper to be analyzed. The procedure began by visiting the Geometry tab in the ANSYS Workbench environment. The Replace Geometry option was then selected to replace the geometry with a file imported from a compatible format, such as STEP, IGES, or Parasolid. The file "Bumper Psm2 Tiqah.x\_t" was used for this simulation.

### 2.3.3 Model Analysis

The Model analysis steps entailed refining the geometry for analysis and ensuring that it was ready for the simulation, which by opening the mechanical interface to assign material properties and meshing process. The material such as polypropylene (PP) or EPFB-LDPE was assigned to the car bumper and the thickness of the bumper which is 2mm was inserted. Next, the bumper model was meshed into smaller and finite elements as in Figure 4, which allowed ANSYS to calculate deformation, strain, and stress across the structure. This step ensured the model was fully prepared for applying forces in the next steps.

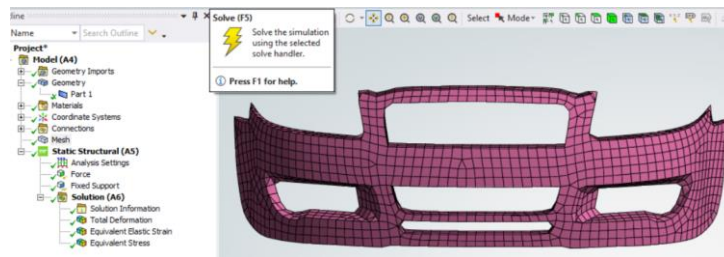


Fig. 4: Meshing process

### 2.3.4 Setup or Static Structural

Setup or static structural tab was used to insert the force and fixed support. For fixed support, the desired surfaces were chosen to fix the bumper model in place to prevent any movement during the simulation. The force value 141666N for speed 30 km/h was inserted because 30 km/h is commonly used for car bumper frontal crash tests as it aligns with international automotive safety standards by the United Nations Economic Commission (UNECE) and ASEAN New Car Assessment Program (NCAP) which recommend crash tests at speeds of 30 km/h to 35 km/h [1]. The value was calculated as shown below:

Mass of the car with bumper (without passenger) = 1400 kg

Average weight of passenger of five people = 300 kg

Total weight = 1400 + 300 = 1700 kg

Initial velocity = 0 m/s

Final velocity =

$$30 \text{ km/h} = \frac{30(1000)}{(60 \times 60)} = 8.3333 \text{ m/s}$$

Time = 0.1 sec

Equation of motion:

$$v = u + at \quad (1)$$

$$a = \frac{(v - u)}{t} \quad (2)$$

$$a = \frac{(8.3333 - 0)}{0.1} = 83.333 \text{ m/s}^2$$

Equation of force:

$$F = ma \quad (3)$$

$$F = 1700(83.333) = 141666 \text{ N}$$

### 2.3.5 Solutions

During the Solution phase of Static Structural Simulation, data of deformation, strain, and stress were calculated and analysed using the materials, meshing, and force. The Solution tab was used to insert the different results. Once, the required were chosen, the Solve button was pressed to run the simulation. After some time, depending on the model's size and mesh complexity, the results were displayed, allowing the performance to be evaluated by analysing the deformation, strain, and stress of the bumper. These outputs helped to assess the design's behaviour and identify areas that needed further improvement.

## 3. Results and Discussion

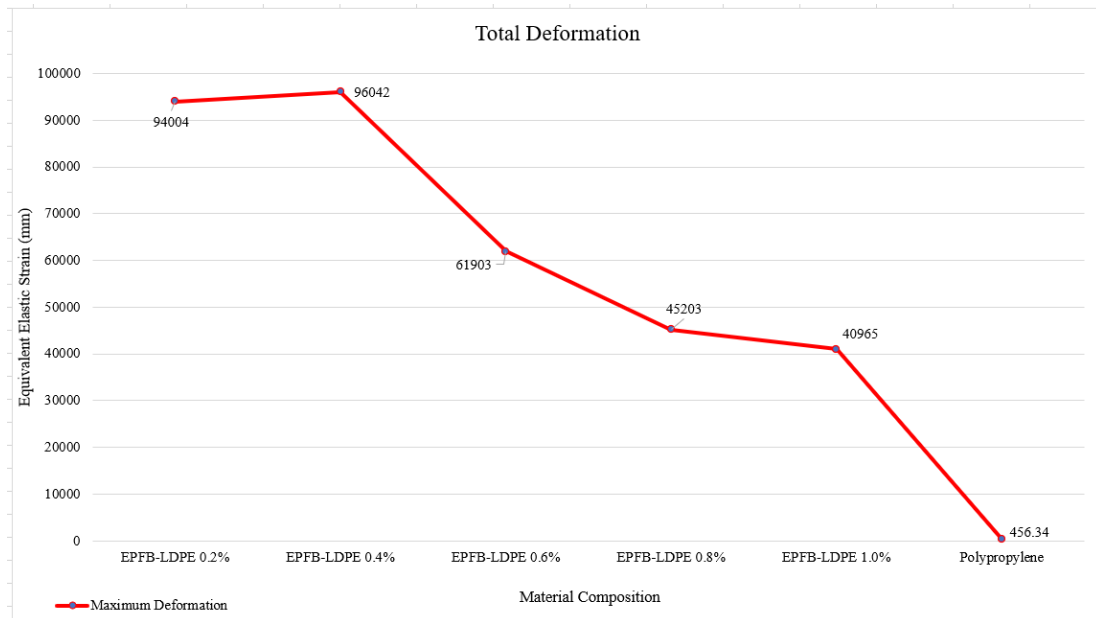
The results and discussion chapter presented the research findings and analyzed them in light of the study objectives and current literature. The study compared the performance of car bumpers manufactured from Empty Palm Fruit Bunch (EPFB) reinforced low-density polyethylene (LDPE) to conventional materials like polypropylene (PP). The data were carefully analysed, revealing changes in mechanical parameters like deformation, strain, and stress under simulated impact situations. These investigations were reviewed to gain insight into the viability of EPFB composites as a sustainable and efficient alternative to traditional materials, which was in line with the study goal of fostering eco-friendly advances in vehicle design.

### 3.1 Results of Total Deformation

Total deformation is the total displacement of a structure or material due to an external force or load and measures how much the structure changes form in response to an applied force. Total deformation reveals how much a car bumper deforms during impact, providing information about its ability to absorb energy and protect the vehicle and its passengers. Table 2 and Figure 5 show the results of total deformation for EPFB-LDPE (0.2%, 0.4%, 0.6%, 0.8%, 1.0%) and polypropylene (PP).

**Table 2:** Results of total deformation

<b>Materials</b>	<b>Total Deformation (mm)</b>
<b>EPFB-LDPE 0.2%</b>	94004
<b>EPFB-LDPE 0.4%</b>	96042
<b>EPFB-LDPE 0.6%</b>	61903
<b>EPFB-LDPE 0.8%</b>	45203
<b>EPFB-LDPE 1.0%</b>	40965
<b>Polypropylene (PP)</b>	456.34



**Fig. 5:** Total deformation of each material

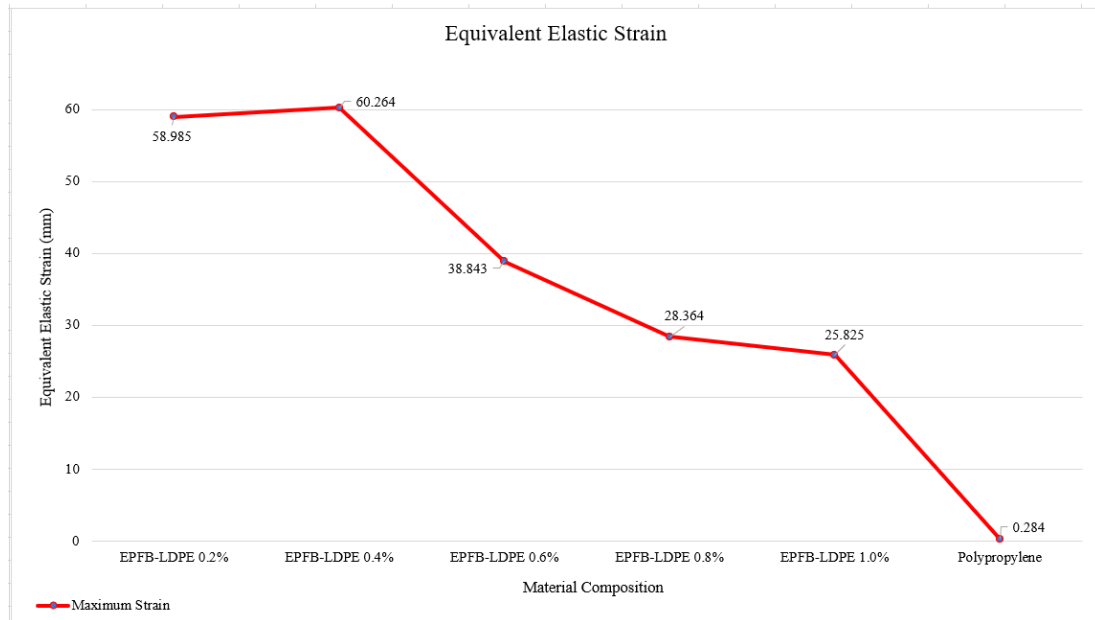
The graph revealed that EPFB-LDPE composites have higher total deformation than PP under applied impact forces due to their lower elastic modulus. This allowed greater flexibility and energy absorption [10]. PP, as a synthetic thermoplastic, has a higher rigidity, which limits its deformation which is 456.34mm. The deformation decreased with increasing EPFB content among all the EPFB-LDPE samples. The EPFB-LDPE 0.4% composites showed the highest deformation at 96042mm because it has lower fiber content, while the EPFB-LDPE 1.0% composites had the lowest deformation at 40965mm due to the higher EPFB fiber content which can increase stiffness and rigidity. For bumper applications, flexibility can be advantageous to absorb impact, but the extreme difference between PP here might compromise the material's structural integrity.

### 3.2 Results of Equivalent Elastic Strain

Equivalent elastic strain is a measure of the material's strain under applied force, specifically within its elastic limit. In automotive bumpers, for example, equivalent elastic strain is an important measure for determining the material's flexibility and energy absorption capacity while a higher elastic strain number indicates greater flexibility and the ability to absorb more impact energy without causing permanent deformation. The results of equivalent elastic strain for EPFB-LDPE (0.2%, 0.4%, 0.6%, 0.8%, 1.0%) and polypropylene (PP) as in Table 3 and Figure 6.

**Table 3:** Results of equivalent elastic strain

Materials	Equivalent Elastic Strain (mm)
EPFB-LDPE 0.2%	58.985
EPFB-LDPE 0.4%	60.264
EPFB-LDPE 0.6%	38.843
EPFB-LDPE 0.8%	28.364
EPFB-LDPE 1.0%	25.825
Polypropylene (PP)	0.284



**Fig. 6:** Equivalent elastic strain of each material

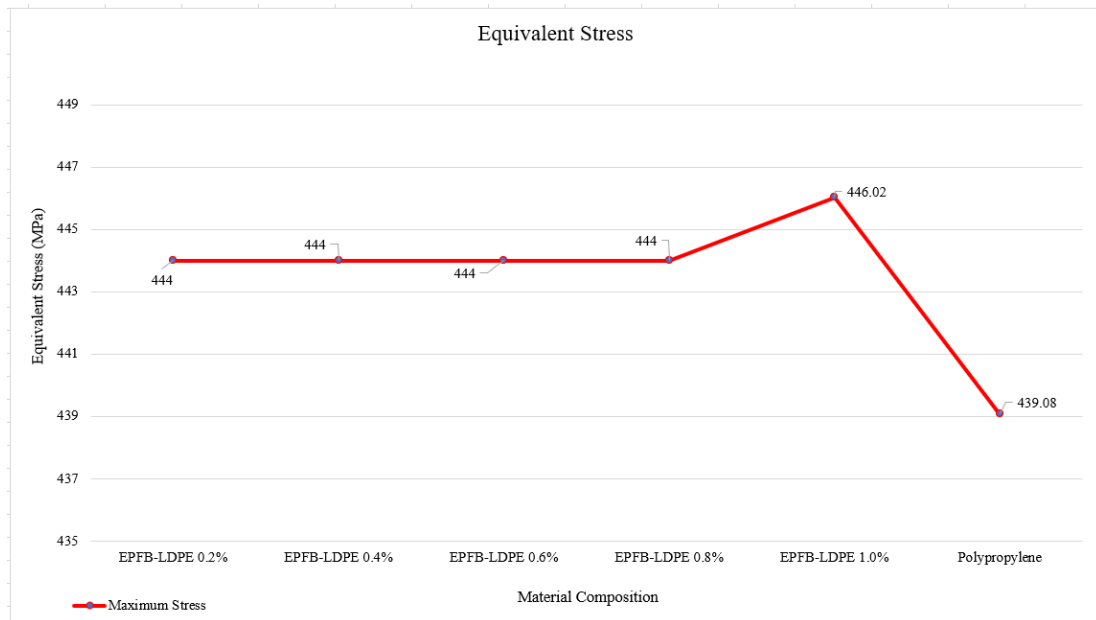
The results in the graph showed that EPFB-LDPE composites had much higher equivalent elastic strain than polypropylene (PP) due to their lower stiffness, flexible LDPE matrix, and less reinforcement from EPFB fibres at lower compositions [11]. This flexibility enables EPFB-LDPE to absorb more impact energy, resulting in greater strain values. Among all the EPFB-LDPE composites, EPFB-LDPE 0.4% had the highest strain which is 60.264mm because of the lower EPFB fiber content and due to less effective fiber-matrix interaction, which allowed greater elastic deformation. While 1.0% EPFB-LDPE composition had the lowest strain which is 25.825mm and reduced the elastic deformation. PP had the lowest strain at 0.284 mm, indicating higher stiffness and resistance to elastic deformation. Flexibility can be useful in bumper applications to cushion shock, however the extreme variance between PP could undermine the material's structural integrity.

### 3.3 Results of Equivalent Stress

Equivalent stress, also known as von Mises stress, is a scalar value used in engineering to express a complicated, multi-axial stress situation with a single equivalent stress. For automotive bumpers, equivalent stress is critical for assessing how the material will react to the impact forces. High equivalent stress levels may suggest that the bumper will yield or fail after a collision. The study's equivalent stress data were analyzed for each material used on the car bumper to ensure the stress levels remained within acceptable limits. The stress results for EPFB-LDPE (0.2%, 0.4%, 0.6%, 0.8%, 1.0%) and polypropylene (PP), as shown in Table 4 and Figure 7.

**Table 4:** Results of equivalent stress

Materials	Equivalent Stress (MPa)
EPFB-LDPE 0.2%	444
EPFB-LDPE 0.4%	444
EPFB-LDPE 0.6%	444
EPFB-LDPE 0.8%	444
EPFB-LDPE 1.0%	446.02
Polypropylene (PP)	439.08



**Fig. 7:** Equivalent stress of each material

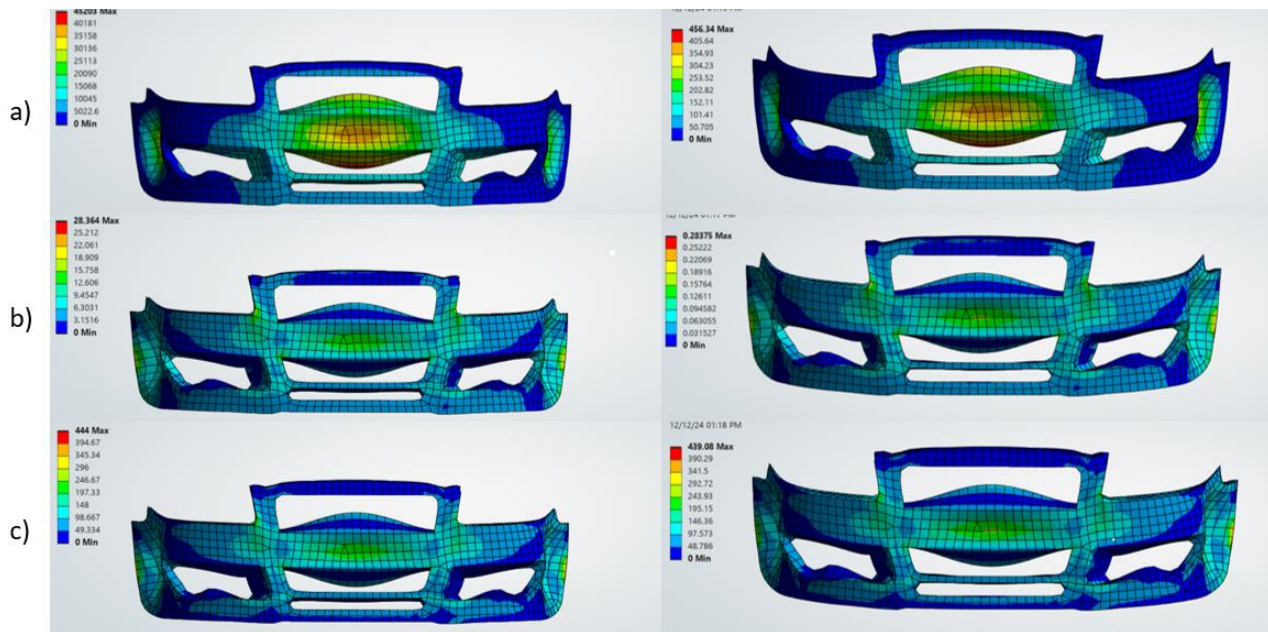
The graph illustrated that EPFB-LDPE composites exhibit higher equivalent stress compared to PP due to their heterogeneous microstructure, weaker fiber-matrix bonding, and less efficient stress transfer mechanisms [12]. Despite this, EPFB-LDPE composites are nevertheless good in the absorption of energy and sustainability, making them an acceptable replacement for PP. The EPFB-LDPE composites of 0.2%, 0.4%, 0.6%, and 0.8% showed similar stress levels of 444 MPa. This is because the fiber content changes from 0.2% to 0.8% did not affect the stiffness or stress distribution. Meanwhile, the EPFB-LDPE 1.0% composites had the highest stress at 446.02 MPa due to the higher Poisson's ratio value, which increased rigidity and stress concentration. In comparison, PP showed slightly lower stress which is 439.08 MPa, indicating its capacity to efficiently distribute stress under impact. These findings demonstrate the possibility of EPFB-LDPE composites for automotive applications.

### 3.4 The Best EPFB-LDPE Composites as Alternative Material to PP

The automotive industry is constantly looking for new materials to increase performance, decrease environmental impact, and enhance the safety of vehicles and passengers. The EPFB-LDPE 0.8% blend stands out for its ability among all the EPFB-LDPE composites to balance the mechanical performance and environmental benefits. So, Table 5 and Figure 8 show the comparison between EPFB-LDPE 0.8% and polypropylene (PP).

**Table 5:** Comparison between EPFB-LDPE 0.8% and PP

Properties	EPFB-LDPE 0.8%	Polypropylene (PP)
<b>Total Deformation (mm)</b>	45203	456.34
<b>Equivalent Elastic Strain (mm)</b>	28.364	0.284
<b>Equivalent Stress (MPa)</b>	444	439.08



**Fig. 8:** The differences between EPFB-LDPE 0.8% (left-hand) and PP (right-hand), which a) Total deformation, b) Equivalent elastic strain, and c) Equivalent stress

From the data, it shows that the results of total deformation for EPFB-LDPE 0.8% are 45203 mm and PP is 456.34 mm while the equivalent elastic strain for EPFB-LDPE 0.8% is 28.364 mm and PP is 0.284 mm. The significant differences suggested that EPFB-LDPE 0.8% is far more flexible or less rigid compared to PP. Flexibility can be useful in bumper applications for absorbing impact, but the severe difference could affect the substance's structural integrity. For equivalent stress, the results depicted a small difference between EPFB-LDPE 0.8% composites and PP which are 444 MPa and 439.08 MPa. Both materials show comparable stress values, indicating that EPFB-LDPE 0.8% composites can withstand similar load levels as PP without failure.

#### 4. Conclusion

In conclusion, this research demonstrated the feasibility of using Empty Palm Fruit Bunch (EPFB) reinforced with Low-Density Polyethylene (LDPE) composites as an eco-friendly alternative to polypropylene (PP) for automotive applications such as bumper. The EPFB-LDPE 0.8% composites were chosen as the best composition to compare with PP because they strike a balance between flexibility and stiffness while offering enhanced energy absorption. Based on the data and results, EPFB-LDPE 0.8% composites may not be fully suitable for direct use as a bumper material in their current form because of the excessive deformation and strain. This indicates potential issues with shape retention and structural failure under high impact. While its ability to absorb stress is promising, the lack of stiffness presents challenges for maintaining structural integrity during collision.

Overall, to address this limitation the EPFB-LDPE composites need some modifications such as increasing the filler content. This modification should be considered to improve stiffness and reduce the deformation. Additionally, further testing is recommended to validate its impact resistance, durability, and energy absorption capacity. For applications where flexibility is desirable, such as specific impact zones, EPFB-LDPE composites could be used in combination with stiffer materials in hybrid bumper designs to optimize performance.

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