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ORIGINAL PAPER

Comparing non-biodegradable plastic with environmentally friendly natural fibre composite on car front bumpers design

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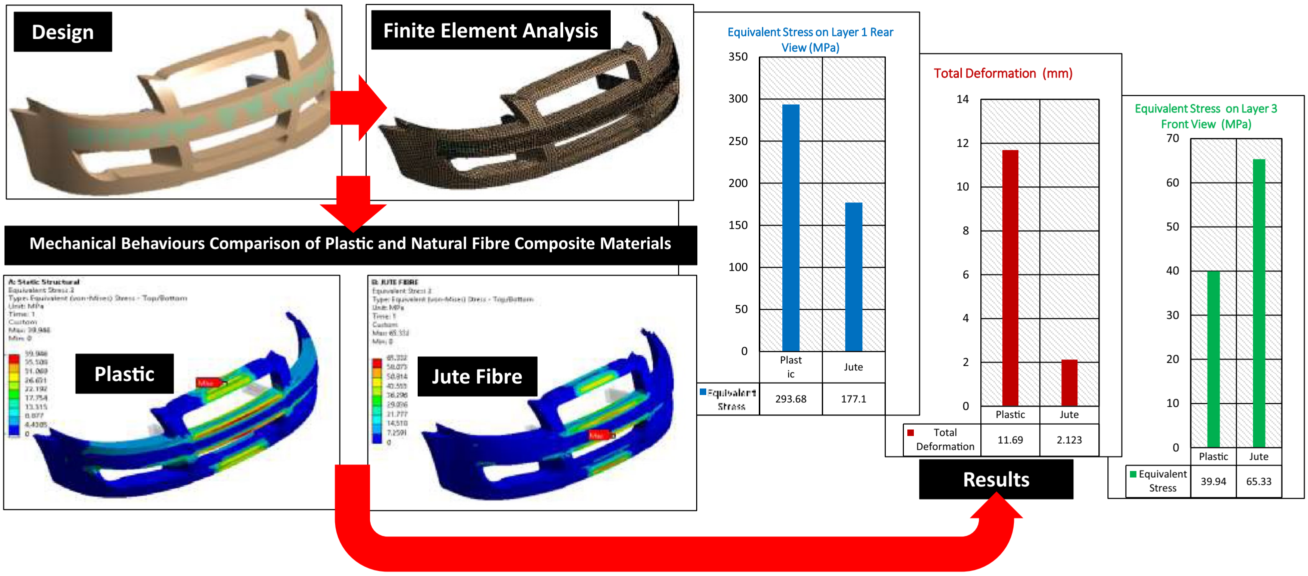
Abstract

Production of plastic is growing, and plastics are used in a variety of products. However, plastics are not biodegradable and do not decompose easily. To overcome the problems in decomposition of plastics, the use of a specific type of natural fibre composite (NFC) material for front-bumper in cars is considered in this investigation. NFCs have the advantages of being environmentally friendly, light weight and high strength. The use of jute fibre is adopted for the design of a car front bumper and compared with the plastic bumper through Finite Element Analysis. The aim is to identify their performances in terms of impact energy, strength and resilience. The results show that when both materials were simulated under the same impact force, jute fibre has a lower equivalent stress with 177.1 MPa compare with 293.18 MPa on plastic material. This finding indicates that jute fibre has greater yield limit and more resilient to fracture. The simulation result also shows that jute fibre has a higher equivalent stress of 65.55 MPa on the front bumper compare with a lower equivalent stress of 39.94 MPa on plastic. This suggests that plastic material will yield soon when an impact force is higher. The total deformation after the same impact force in jute fibre is 2.1 mm, which is significantly less than the deformation in plastic with 11.7 mm. Therefore, this research concludes that jute fibre can potentially replace plastic as a green composite material application to minimise environmental damages.

Graphical abstract



Keywords Design simulation · FEA · Automotive industry · Plastic · Jute fibre · Environmentally friendly

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List of symbols

E	Young's modulus, GPa
F	Applied force of impact, kN
L	Initial length, m
A	Cross section square area, m^2
M	Bending moment, Nm
I	Moment of inertia of the areas of a cross section, kg m^2
σ	Bending stress, MPa
y	Distance of fibre endpoints from the neutral axis, mm
m	Mass of car, kg
v	Velocity of car, m/s
KE	Kinetic energy, kJ
W	Work done, kJ
d	Deformation or displacement, mm
ρ	Density, Kg m^{-3}
K	Bulk Modulus, GPa
μ	Shear Modules, GPa
σy	Yield Strength, MPa
Et	Tangent modulus
ν	Poisson ration, unitless quantity

Introduction

Front bumpers are important for cars because they play an important role in reducing the impact of energy during a collision. Bumpers are designed and fitted in a car to reduce and minimise impact to passengers (Basith et al. 2021). Bumpers are usually made of metal alloys or use a mix of plastics and composite materials. Metal bumpers consist of metal beams and are attached in both the front and rear portions of a car. Metal bumpers are designed to protect the headlights, taillights and cooling systems, and their design is focused on resilience (Zhang et al. 2018). Metal bumpers are made of chromium-plated steel, they are heavier and are expensive to manufacture. Due to their weight, the efficiency of cars was reduced (Akhshik et al. 2019). In addition, metal bumpers were vulnerable to denting and expensive to repair (Begum et al. 2020). To overcome these disadvantages, modern cars use plastic and a mixture of composite materials in bumper, thus making them strong and impact absorbent (Agarwal et al. 2020).

In recent years, automotive manufacturers have fully shifted to plastic bumpers. Most car bumpers are made of thermoplastic olefins, rubber and reinforcing filler. Materials such as fibreglass, composite plastic or aluminium are used in their design (Tadele et al. 2020). Plastic bumpers provide the advantage as polypropylene and polycarbonates are used due to their resistance to impact. Plastic bumpers are also resistant to weather conditions and do not develop rust (Khalid et al. 2021a). Though plastic is more vulnerable to denting, the design allows the bumper to crack by absorbing the impact energy instead of transferring the impact energy to a car (Khalid et al. 2021b). On the positive side, plastic bumpers are not heavy and do not add significant weight, so its fuel efficiency is higher than steel bumpers. The major disadvantage of plastic bumpers is that they are toxic, non-biodegradable, and has a negative impact to the environment (Arif et al. 2022; Chatys et al. 2018).

Fibre-based composite materials provide the strength and resilience for absorbing impact and are potentially ideal for car bumpers (Khalid et al. 2022). Composite fibre-based plastics and materials are also considered as an alternative to steel-based alloy bumpers that are usually much heavier (Khalid et al. 2022). On the positive side, the application of natural composite materials could replace traditional car bumpers for reducing its environmental impacts (Wegmann et al. 2022). Natural composite fibres depend upon the nature of their materials and can be categorised as eco-friendly or green (Khalid et al. 2021c, d). Therefore, these materials have differences in their mechanical properties (Roy et al. 2019).

NFC materials are high strength natural fibres and developed using a combination of two materials (Ilyas et al. 2021). The utilisation of NFC in different applications for their sustainability has made it popular in different industries. NFC materials, apart from high in strength and stiffness, and they also do not emit toxic fumes when it encounters heat. Hence, NFCs are considered less hazardous and are much safer (Qin et al. 2020). In the automobile industry, NFC is used in the car's interiors and as bumpers, both front and rear. Some commonly available NFC materials are coconut fibre, jute, flax, wool, banana leaf fibres, bamboo, wheat straw and many more (Karimah et al. 2021). NFC materials are preferred for their high energy absorption capacity, high specific stiffness, specific strength and eco-friendliness (Khan et al. 2022).

In this research, the design and development of NFC for the front bumper of a car is analysed by measuring its mechanical properties performance. NFC is chosen for its high strength and lightweight and is viewed as an alternative to bumpers used by modern cars. However, the producers of natural composite fibres do not follow standardised processes for collecting, treating, processing and post-process usage (Peças et al. 2018). These drawbacks are important deterrents that impede its usage in different applications, including the automobile industry. Therefore, it is essential to identify a replacement for plastic bumpers while achieving strength, efficiency and environmentally friendly.

The purpose of this work is to provide reference and guidance for future use of NFC to reduce the use of plastics in car bumpers by adapting NFCs while retaining the stiffness and impact energy absorption performance through in-depth analysis of the advantages of NFC. In this research investigation, the design of an automotive front bumper with different materials is presented. The design in NFC and plastic materials for the front bumper of a car are analysed by comparing their mechanical behaviours performance through the finite element analysis (FEA) method. The main reason for choosing this specific type of NFCs, because they are environmentally friendly, high strength, lightweight and can absorb higher impact energy, and therefore is viewed as an alternative material use by modern cars design. The next section presents a review of current approaches of car bumper design, and it was found that there is a lack of investigation of comparing jute fibre and plastic materials through design simulation as proposed in this research. Therefore, a novel approach of using FEA is presented in the methodology section. The results presented and discussed that NFC can potentially replace plastic as a green composite material application as well as minimize the potential environmental damages.

Review of car bumper design approaches

Reddy and Reddy (2020) point out that that most cars have reinforced thermoplastic bumper because it is cheaper to manufacture and absorbing more energy during impacts. To overcome the limitations of bumpers made from different materials, natural fibre composites are highly recommended. Composite materials are usually made of resins and reinforcements, and the advantages of NFCs are (Fogorasi and Barbu 2017):

- Lightweight due to low density
- Resistance to corrosion
- High strength
- Impact-absorbing capacity
- Stability and low cost
- Non-conductive

Use of bio-composites for car bumpers

Different automotive companies develop different car bumper designs to provide protection. Material selection is important in car bumpers to achieve a reasonable level of stiffness, strength and energy absorption. Based on the nature of the materials, bio-based composites are classified as either green or partly eco-friendly. The performance of natural fibre is directly dependent on the fibre length, shape, fibre counting and the interfacial adhesion in the matrix or hybrid composite. Natural fibre is classified based on its origin, namely plant, mineral or animal (Khalid et al. 2021e). Plant fibre is commonly accepted by the industry and analysed widely in the literature (Jagadeesh et al. 2021). Natural fibre provides multiple benefits in terms of low-cost, low-density, energy savings in manufacturing and biodegradable (Le Duigou et al. 2020).

There are two important criteria for an effective bumper design with natural fibre composites: stiffness and energy absorption. The car bumper must distribute or absorb the impact energy transmitted to the vehicle frame (Qi et al. 2020). For example, Yuan et al. (2019) presented a series of different bumper designs using origami patterns and evaluated their energy absorption performance when subjected to impact using a numerical frame. This study highlights the need for an optimal design and material to ensure the bumper can effectively absorb impact energy, thus minimising the energy for passengers and the automobile.

Research on bumper material selection is focused on developing lightweight designs and high energy absorption capacity without compromising its sustainability. For example, steel bumpers can deform during impact, and it is tedious to develop. Carbon fibre is expensive to produce but lightweight and can resist all load types compared to other materials (Babu and Bhattacharya 2020). Plastic bumpers are lighter, can withstand impact energy and are cost-effective, but they add to plastic pollution (Kannan et al. 2020). Nowadays, bumpers are mostly made with polymers and plastics and designs are developed for improving stiffness and energy absorption (Begum et al. 2020). Plastic material is also known as Acrylonitrile Butadiene Styrene (ABS) that has high stiffness and can withstand impact force. ABS is used for bumper production and for designing other car parts (Baker 2018).

Olorunnishola and Adubi (2018) explain the use of NFC in the automotive industry which is popular for its advantages such as light weight, reduced costs, recyclability, stiffness and high energy absorption characteristics. The authors provide a comparative analysis on a hybrid composite bumper developed using a combination of jute and glass fibre (GF-C). Adekunle et al. (2020) used recycled plastic waste polyethene terephthalate, high-density polyethylene and polypropylene to study the presence of raw materials in ethylene glycidyl methacrylate co-polymer compatibiliser to produce bumper for automobiles. The results were compared with car bumpers made using standard materials and they found that the bumper made with this recycled plastic mixture provided promising results related to stiffness and impact energy.

Natural fibre composite for automobile bumpers

Adesina et al. (2019) reveal that lightweight materials in automobile bumpers can achieve fuel efficiency and reduce pollution. NFC has numerous advantages in being low-density, recyclable, bio-degradable and available at a relatively low cost (Khalid et al. 2021f). There are many studies to analyse the mechanical behaviours of materials in NFCs.

For example, a slow speed impact study based on International Institute for Highway Safety (IIHS) regulations was conducted to identify the strength of a car bumper and the material it used. FEA method was applied to analyse the crashworthiness design at low-speed impact, considering the shape, thickness, impact conditions and bumper-material parameters (Rashid et al. 2021). Natarajan et al. (2021) provided a low-speed impact analysis of car bumpers. The authors analysed the impact in the central region and corner regions during a collision. The authors state that the bumper with increased thickness will provide more stiffness to impact at low speed. However, increasing the thickness of the bumper can result in an increase in weight, cost and material usage.

Mahmood et al. (2020) analysed the effect of cyclic olefin co-polymer particles in epoxy matrices reinforced with unidirectional carbon fibres. This composite shows significant results related to maximum heat efficiency. Bhanupratap (2020) evaluated the effect of Kevlar and jute fibre on their thermal behaviour by using dynamic mechanical analysis. This study concludes that heat resistance could be achieved in Kevlar fibre that is reinforced with jute overlays. The study by Ali et al. (2019) investigated the advantages of NFC by improving the performance and functionality of natural fibres when NFC is used along with synthetic fibres. This study shows that an increased use of jute fibre, the flexural strength is decreased. This study indicates that when the percentage of jute fibre increases, the damaged area in automobiles also increases. Kumar et al. (2019) examined the use of natural fibre reinforced polymer composites in industrial applications to highlight its use for car bumper design. The natural fibres studied were compared with synthetic materials such as glass and carbon, to investigate their tensile strength. The study concludes that temperature stability is an issue in natural fibre reinforced polymer composites.

Ramachandra (2017) adapted ANSYS to investigate the crash of car bumpers that made with different materials. The impact analysis was developed using steel and composite material with glass-fibre reinforcement. The results demonstrate that glass fibre composite is an effective bumper material with 64% safety factors and can achieve a cost savings of 80%. Sivakumar et al. (2016) studied the impact analysis of car bumpers using different materials with maximum safety and minimum stress criteria. Ansys software was used to model the loads, materials and design. The study was conducted for titanium alloy, steel, thermoplastic olefin, polypropylene and stainless steel. The result shows that thermoplastic olefin provides better performance than other materials, and hence thermoplastic olefin is suitable for automobile bumpers. Murugu Nachippan et al. (2021) examined the characteristics of car bumpers through FEA. FEA simulation was focused on deformation, von-mises stress, and strain for glass-fibre reinforced composite with hybridised glass fibre natural fibre reinforced composites. FEA results show that when treated with hemp fibre reinforced epoxy composite, glass fibre has less deformation and is more suitable for automobile bumpers. In another study, Chinnasamy et al. (2021) point out that front car bumpers made of natural composites increase safety during a collision are low cost due to the reduction of vehicle's weight.

In summary, composite materials, particularly NFCs can provide significant weight reduction and improve automobile performance. Many authors have highlighted the usefulness of composites for car bumpers and studied the mechanical composition of jute-based hybrid composites using different techniques. The jute-based composites were studied for their impact strength and compared with other natural composites and show good performance against impact energy. However, there is a lack of investigation of comparing jute fibre and plastic materials through design simulation as proposed in this research. The methodology and results are therefore shown in the following sections.

Methodology section

This section presents the methodology of design, materials selection, impact force calculation and the simulation steps of using FEA.

Design and materials methods

Bumpers are designed to reduce the impact for the vehicle and passengers during a collision. The isometric views of the bumper is shown in Fig. 1 which is designed using a natural fibre and degradable material, jute.

Energy absorber is an important component in the bumper as it will absorb impact energy and distribute the energy in a perpendicular direction to the vehicle chassis. The energy absorber can be noted as a separate shaded area as shown in Fig. 1. The mechanical properties of jute and epoxy resin are given in Table 1.

Jute fibre is economically efficient, and cross-plied jute fibre is strengthened with environmentally friendly epoxy resin (Yang et al. 2020). Young's modulus is the measure of elasticity. This is the ratio of stress acting on jute to the strain produced. Young's modulus is also known as elastic modulus and provides the stiffness of the material. The equation of calculating Young's modulus is:

$$E = (tensile\ stress)/(tensile\ strain) = FL/A \tag{1}$$

E is Young's modulus in Pa (Pascals), F is the applied fore, L is the initial length, A is the square area. Poisson's ratio is used to measure the jute's expansion or contraction in a direction perpendicular to the direction of the applied force.

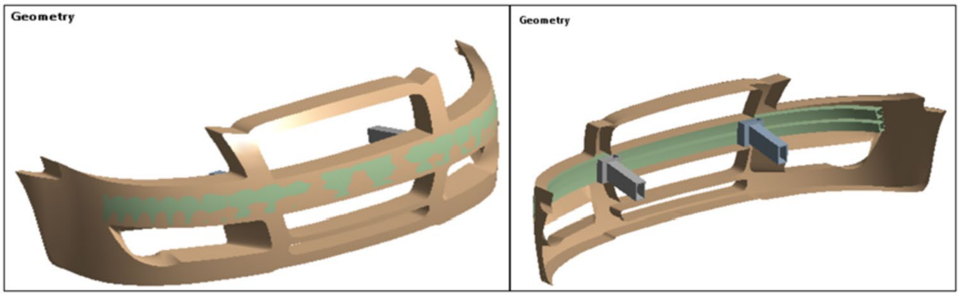


Fig. 1 Isometric views of the bumper design

Table 1 Mechanical properties of jute fibre (Arunavathi et al. 2017; Rangasamy et al. 2021) and epoxy resin (Yang et al. 2020; Horta Muñoz et al. 2019)

Property	Jute Fibre	Epoxy Resin	Unit
Density	1460	1100	Kg m^{-3}
Isotropic Elasticity			
Young's Modulus	55	3.42	GPa
Poisson's Ratio	0.152	0.35	
Bulk Modulus	1.27	3.81	GPa
Shear Modules	1.15	5.86	GPa
Bilinear Isotropic Hardening			
Yield Strength	373	110	MPa
Tangent Modulus	3.75	3.1	GPa

Table 2 Mechanical properties of polyethylene plastic (Kaseem et al. 2015)

Property	Value	Unit
Density	950	Kg m^{-3}
Isotropic elasticity		
Young's modulus	1100	GPa
Poisson's ratio	0.42	
Bulk modulus	291	MPa
Shear modules	387	MPa
Bilinear isotropic hardening		
Yield strength	37	MPa
Tangent modulus	80	GPa
Tensile yield strength	25	MPa
Tensile ultimate strength	33	GPa

The bulk modulus is the measure of resistance to compression. In this case, the bulk modulus of jute is the infinitesimal increase in pressure to the relative decrease of volume which is measured in Pa. Shear modulus is used to measure elastic shear or stiffness of the material. Shear modulus can also be understood as the ratio of shear stress to shear strain.

Characteristic of yield strength will determine if the material is brittle or ductile. For instance, the upper yield strength is that jute is not elastic and is changed to plastic. The upper and lower yield strength points will determine the suitable material for the construction of the product. Based on the measurements in Table 1 and properties for the bumper, the thickness needed for the jute bumper is given by the relation:

$$M/I = \sigma/y \tag{2}$$

In Eq. (2), M is the bending moment; I is the moment of inertia of the area of a cross-section of jute; σ is the bending stress; y is the distance of fibre endpoints from the neutral axis. The measure of one layer of jute fibre is 0.5 mm, and hence to achieve a required level of thickness of jute fibre, multiple layers of jute fibre is needed in the car bumper design.

The polyethylene material in the plastic car bumper design is used to compare with the jute composite bumper. The mechanical properties of polyethylene material are provided in Table 2.

Bumper design

Figure 2 represents an engineering drawing of the bumper design with its overall geometric dimensions. For FEA analysis in equivalent stress and deformation of plastic and jute materials, the bumper design is divided into three layers, namely layers 1, 2 and 3 as shown in Fig. 2. The choice of the three layers represents the locations where the impact force would critically distribute along the car bumper (Sonawane and Shelar 2018).

Meshing is performed to define the physical shape of the object. The number of details in each mesh will provide more accuracy in the design. The mesh of the bumper design is shown in Fig. 3. The mesh type in this FEA implementation uses quadrilateral and hexahedron elements because they are more robust compared with triangle or pyramid types (Durand et al. 2019). FEA is a software tool in ANSYS which can be used to perform analysis of 3D designs. Furthermore, FEA is used to create geometry, mesh, boundary condition and has multiple features for analysing physical properties of materials. FEA is made up of three parts:

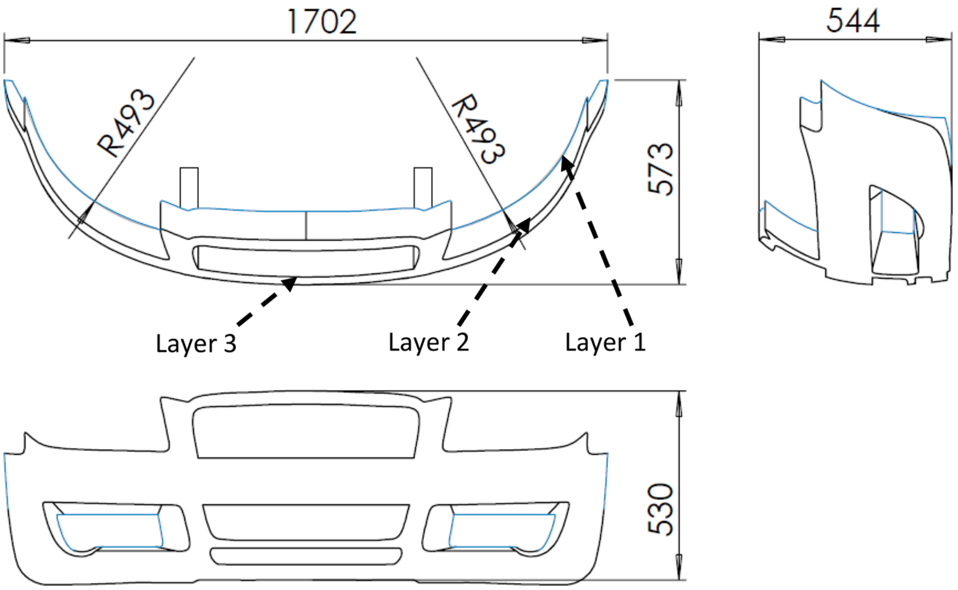


Fig. 2 An engineering drawing of the bumper design

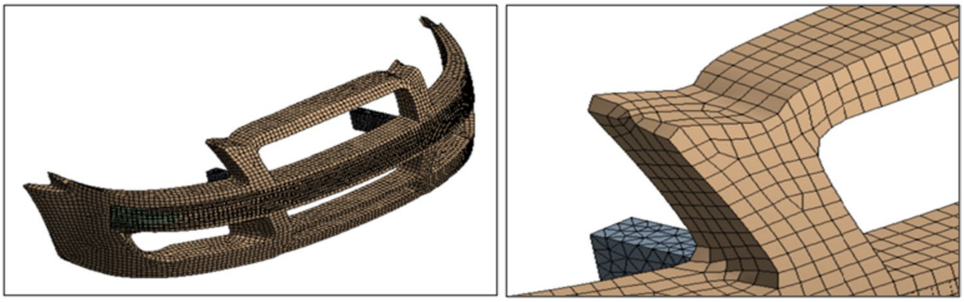


Fig. 3 Mesh elements and nodes of the bumper design

i. Pre-processing or modelling
ii. Analysis of mechanical behaviours
iii. Post-processing or optimising the bumper

Table 3 ANSYS element specification of the bumper body

ANSYS element specification	
Scope	
Scope method	Geometry selection
Geometry	4 Bodies
Definition	
Suppressed	No
Type	Element size (15 mm)
Advanced	
Defeature size	0.107 mm
Behaviour	Soft
Growth rate	1.2
Capture curvature	No
Capture proximity	No

In the pre-processing stage, the design material, attributing the model, material properties, meshing, defining structural and boundary conditions with applied loads for thermal or mechanical loads are defined. The analysis is used to study the mechanical properties. The post-processing stage of FEA will provide the results when the product is subject to thermal, impact, static and fatigue before a product's final development. The FEA method in this research will be used to compare the bumper made of polyethylene and jute for their mechanical behaviours, namely stress, deformation and physical characteristics in order to understand the performances during impacts.

Details of ANSYS elements for the bumper are provided in Table 3. From the geometry of the mesh, the nodes are 30,730, and the elements are 13,004. Since many nodes and elements are involved in the design, the impact energy is further distributed perpendicularly in the bumper to minimise the impact on the car or passengers.

Impact force calculation of bumper

Impact is usually a high force applied suddenly for a very short time when the car collides with another body. Impact force must be measured for the designed bumper because such force will have a greater effect than a lower force applied to a body over a longer period. The impact force on a car bumper is measured at different speeds to understand its stiffness and absorbing capacity.

- Suppose the mass of the car, m = 1400 kg
- Mass of 5 passengers (average weight of each person is 70 kg = 350 kg

The vehicle's total mass during motion is the sum of the car's mass and the mass of all passengers, hence, the total mass of car during motion (m) is 1750 kg.

- Assuming the collision speed (velocity of car *v*) is 45 km/hr, and this is equivalent to 12.5 m/s

The kinetic energy is the energy generated during motion and given by:

$$KE = 1/2mv^2 \quad (3)$$

Substituting the values of *m* and *v*, KE is equal to 136.72 kJ.

The displacement of car components will absorb the kinetic energy generated due to impact. Since it is a frontal impact, the maximum displacement is constrained to 1000 mm, considering the safety of the passengers and major structural components of the car. This kinetic energy generated will represent the work done by the bumper during the collision. In other words, Work Done (W) = 136.72 kJ.

The formula for work done is $W = F * d$ (4)

W is the work done in kJ and d is the maximum displacement of the bumper. The unit of displacement (d) in meter, and F is the impact force having is measured is in kilo-Newton (kN). By substituting the values for work done and displacement, the force of impact is equal to F = W/d = 136.72/1 = 136.72 kN, hence the impact force on the bumper = 136.72 kN. Therefore, theoretically, at an assumed car velocity at 45 km/hr (12.5 m/s), the impact force on the bumper is obtained. The same method can be applied for obtaining impact force at different speeds. To study the impact analysis, the FEA method is deployed.

Results

This section presents the overall results in mechanical behaviours analysis on both plastic and jute materials in car bumper design.

Analysis of mechanical properties

The impact tests for polyethylene plastic bumper design are performed and presented. The boundary conditions for the designed bumper are shown in Fig. 4a for the fixed support and applied force, and (Fig. 4b) force applied on the bumper.

The force applied is 136.7 kN (see Sect. "Impact force calculation of bumper") for a time of 1 s in all cases. The speed or velocity is 45 km/hr. The equivalent stress and total deformation are observed at boundary layers are recorded in FEA.

Analysis of plastic bumper

The equivalent stress for the plastic bumper rear view is shown in Fig. 5a, b. It is noted that 293.68 MPa is the equivalent stress observed from the geometry. The total deformation is the sum of all displacements in the bumper. The

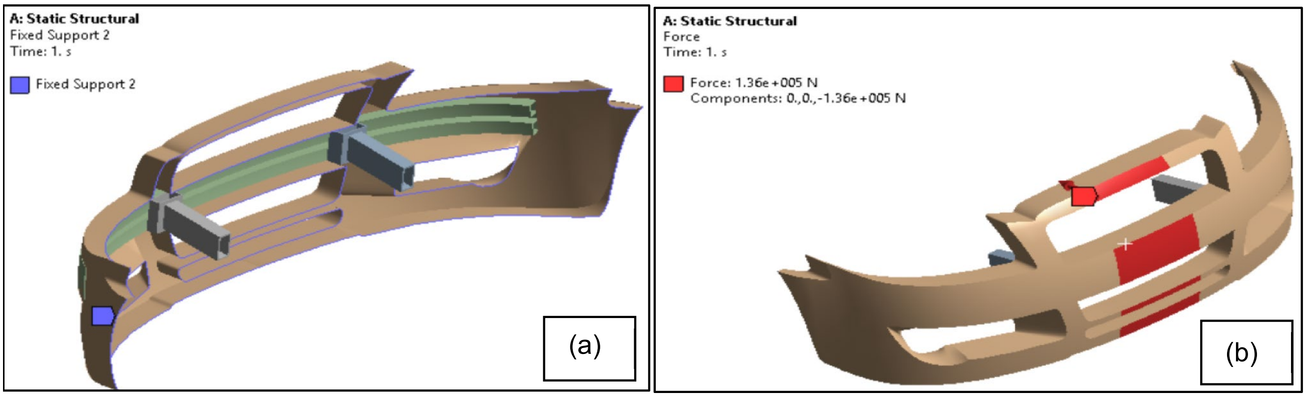


Fig. 4 Boundary conditions for the designed bumper

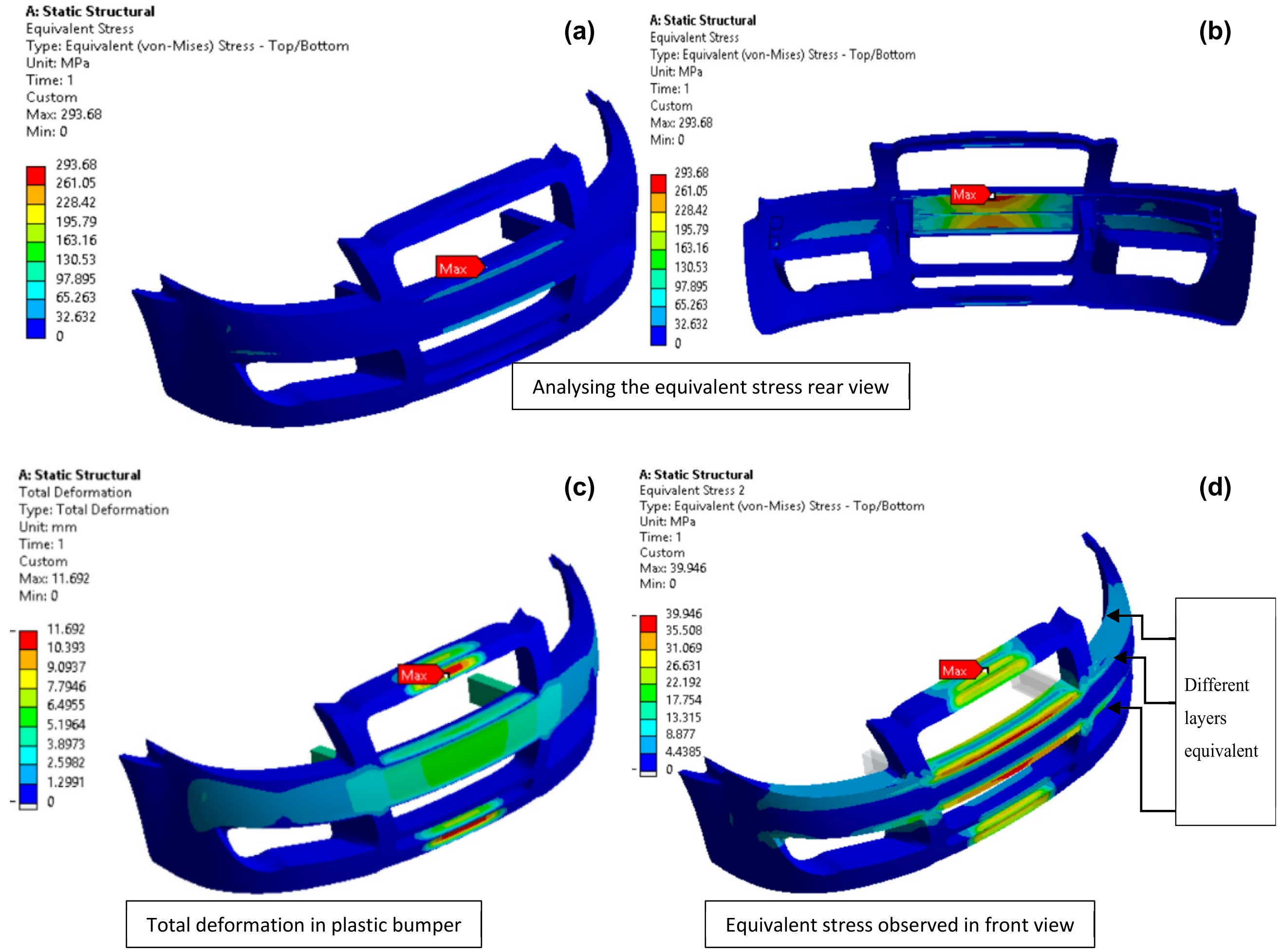


Fig. 5 Simulation results of the plastic bumper

impact energy can travel in three directions as in coordinates x, y and z. The total deformation of the static structure is illustrated in Fig. 5c. The value recorded from the analysis for total deformation is 11.692 mm. The equivalent stress on different layers is the normal stress in the x and y components and the shear stress in “xy”. The equivalent stress for the bumper on different layers is 39.94 MPa as shown in Fig. 5d.

Analysis of jute bumper

The layered orientation of the geometry is shown in Fig. 6. Layer 3 is at the bottom of the geometry. The thickness is maintained at 1 mm in all the layers. Layers 1 and 2 are at an angle of 45° on either end of the geometry.

Fig. 6 The layered orientation of bumper made using jute material

The equivalent stress measured for jute fibre is shown in Fig. 7a. The equivalent stress for the same force applied in plastic and for the same time is computed as 177.1 MPa. The total deformation observed in the bumper (layer 2) is 2.123 mm as shown in Fig. 7b. The equivalent stress on the bumper at layer 3 is computed for jute fibre as shown in Fig. 7c. The computed value for equivalent stress is 65.332 MPa observed for layer 3. Hence, the equivalent stress is 65.332 MPa for the jute bumper. The recorded

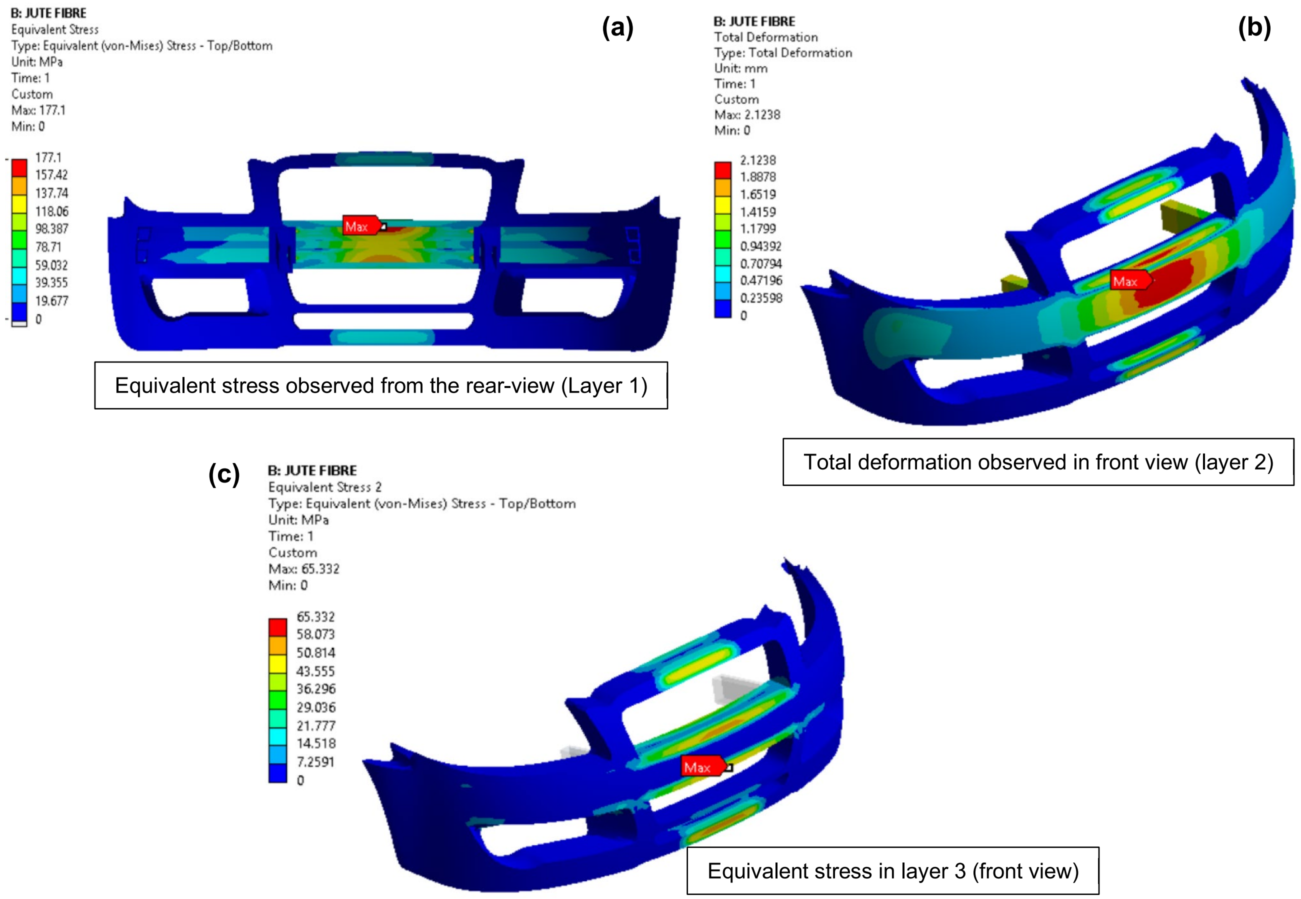


Fig. 7 Simulation results of the jute bumper

Table 4 Observation of mechanical behaviours for plastic and jute materials

Mechanical behaviours	Design 1 (plastic)	Design 2 (jute)
Force applied	136.72 kN	136.72 kN
Time (seconds)	1	1
Total deformation in Layer 2	11.692 mm	2.123 mm
Equivalent stress in layer 1	293.68 MPa	177.1 MPa
Equivalent stress in layer 3	39.94 MPa	65.332 MPa

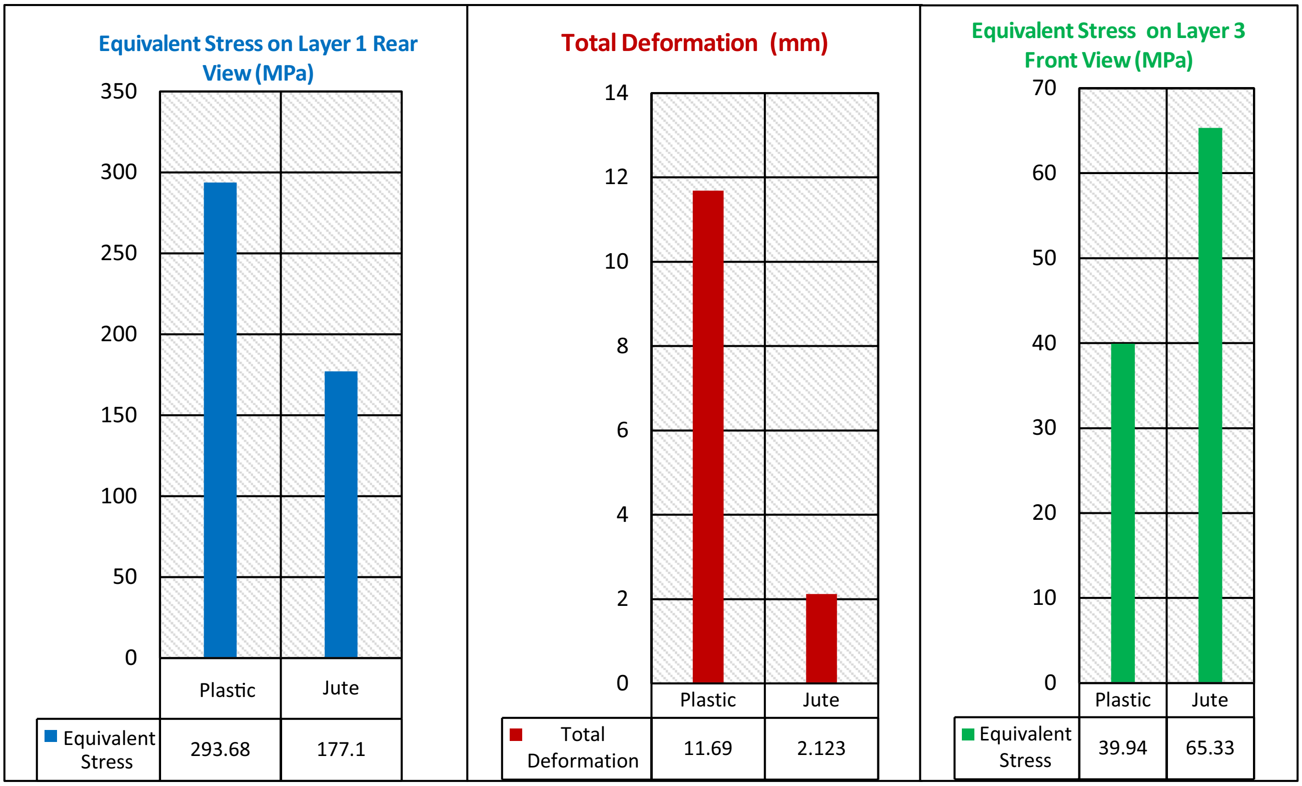
values obtained for the material analysed using FEA are compiled in Table 4.

NFCs have potential properties similar to metal or plastic in terms of stiffness and absorbing impact energy during a collision. The natural phenomena and processes are analysed, and the results are summarised in Table 4. Based on the different characteristics of the material chosen for comparison, three main parameters, namely stress, deformation and physical characteristics at different layers in the design are computed in the analysis.

Discussion

The bumper made of plastic is compared with natural fibre composite material, jute in order to study the performances of their mechanical behaviours. Both designs with their geometry were analysed, and the computed values were obtained mainly for Equivalent stress (Von Mises stress) on two different layers, total deformation. The computations were measured using standard physical quantities and units to understand the performance of plastic and jute. The results obtained are based on the conditions of the physical properties of materials in automotive industry applications (Fentahun and Savas 2018).

As mentioned earlier, jute can absorb high kinetic energy during impact and the main factors for studying impact energy are the momentum and velocity of the vehicle. Based on the result obtained for both the plastic and jute, the comparison is shown in Fig. 8a. The equivalent stress for plastic is higher than the stress obtained on jute. This implies that jute with 177.1 MPa has a greater yield limit and is more resilient to fracture or break. Plastic with a value



(a) (b) (c)

Fig. 8 Mechanical behaviours comparison of plastic and jute

of 293.68 MPa has a lesser yield limit. Therefore, the jute material can withstand more impact force.

In the case of plastic and jute, the total deformation point is chosen as the centre of the bumper. Deformation is usually indicated the changes in shape and size of the bumper after impact. The total deformation comparison for plastic and jute is shown in Fig. 8b. The total deformation after impact in the case of jute is 2.123 mm, which is significantly less than deformation in plastic with a value of 11.69 mm for the same amount of force applied. This implies jute is less likely to become deformed and can easily regain its original shape with minimal damage.

The equivalent stress is compared for both plastic and jute material. The values obtained are compared as shown in Fig. 8c. The equivalent stress is the stress of the bumper structure. It is a scalar to determine material failure. The layers equivalent stress for plastic is 39.94 MPa, which suggests that the plastic material will yield soon when the force is higher. On the other hand, the equivalent stress for jute is 65.55 MPa, indicating the material has higher strength and would need a much higher force to yield. The same value of 65.55 MPa was computed at different central points in the bumper structure, indicating jute fibre provides consistency in absorbing the impact energy. Also, the material is not likely to fracture easily due to the jute's internal bonding and mesh structure. This demonstrates that jute has more stiffness and higher impact force absorbing capacity than plastic bumpers.

Conclusions and further recommendations

This paper presented a simulation study of natural fibre composite as a potential material for the automotive industry. It is observed that metal, plastic, hybrid composites and natural fibre composites are used widely in the automotive industry. The literature review provided a good understanding of the use of different materials for front bumpers in automobiles.

Based on the findings, it is noted that for a given speed, mass and time, the bumper designed with jute fibre provides promising results on equivalent stress of different layers of the bumper design and the total deformation. The results reveal that jute fibre composite exhibits a lower equivalent stress on the rear view (layer 1) with 177.1 MPa compare with a higher equivalent stress of the plastic material with a value of 293.18 MPa. This finding indicates that jute fibre has greater yield limit, and it is more resilient to fracture, or break compare with plastic material which has a lesser yield limit. The simulation result also shows that jute fibre has a higher equivalent stress of 65.55 MPa on the front bumper (layer 3) compare with plastic which has a lower equivalent stress of 39.94 MPa. This suggests that plastic material will yield soon when an impact force is higher. Furthermore, the total deformation after impact in jute fibre is 2.123 mm, which is significantly less than deformation in plastic with a value of 11.69 mm for the same amount of force applied. This implies jute is less likely to become deformed and can easily regain its original shape with minimal damage. The overall results are consistent with Murugu Nachippan et al., (2021) and Qi et al. (2020)'s findings in numerical analysis of natural fibre reinforced composite bumpers and hybrid materials bumper design.

It can be concluded that jute fibre can be considered as a potential replacement for plastic in car bumpers (Khalid et al. 2021a). In addition, jute fibre is environmentally safe with less cost, and hence it is highly recommended by other researchers such as De Queiroz et al., (2021); Kim and Chalivendra. (2020). Further work in this research will include:

- Performing an experiment with higher speeds and determining the stress breaking point, along with increasing jute fibre meshing to withstand high impacts.
- A cost modelling approach to determine the amount of cost could be saved by adding jute fibre in car bumper design.

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Author contributions WMC supervised SKS in this research work. SKS conducted the literature review, data collection and implementation. PSL provided background study and support on Ansys. All authors have prepared and approved this manuscript.

Data and materials availability All related data and materials are within the manuscript.

Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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