Design Optimization and Analysis of Car Bumper with the Implementation of Hybrid Biocomposite Material

Vipul Jain*, Mohit Mittal and Rajiv Chaudhary

*1, 2, 3 Department of Mechanical, Production, and Industrial Engineering, Delhi Technological University, Delhi, 110042, India
E-mail address: vipuljain1502@gmail.com

Abstract. The components of an automobile are usually made up of steel and its alloy which leads to an increase in consumption of fuel. Moreover, a large amount of non-recyclable waste is being produced by the automotive sector. Therefore, it becomes necessary to move towards the lightweight, environment-friendly, and sustainable material which can replace the existing ones. In this regard, the current research work is focused on the pineapple leaf and glass fiber reinforced hybrid epoxy composite to be used for automotive car bumper. The bumper of Ambassador Car was designed in CATIA V5R18 and analyzed in ANSYS18.1. It was found that the geometrical optimization is an important parameter in structural strength improvement. The strength of automotive bumper was increased significantly after providing the strengthening ribs, changing the cross-section, and increasing the thickness. For static and impact analysis, the biocomposite bumper exhibits a lower value of deformation and higher value of strength than the steel and aluminium ones. The results of analysis and reduction in the mass of bumper have proved that the hybrid biocomposite material has significant potential for automotive structural components.

1. Introduction

Steel and its alloys are commonly used for the manufacturing of vehicle bodies, engine, wheel, chassis, and many other components. Inspite of their large number of advantageous properties, it makes the parts heavy which leads to an addition in the weight of automobile body. Therefore, the engineers have put their attention towards the aluminium material as a replacement for steel components because of its lightweight property. With further advancement in the automotive sector, the researchers are showing their interest towards the composite materials. The application areas of composite materials have grown rapidly and found a new market in the world of automobiles. The synthetic fiber reinforced composites have showed good mechanical and thermal properties and are widely used in different applications of the automotive and construction sector. However, the biodegradation of these composites is not a simple task and require a lot of efforts which leads to the formation of toxic non-biodegradable waste. To solve this problem, the researchers and technologists are focusing more on the biocomposite materials. Yan Cao et al. [1] have reported that the biocomposite materials can serve as a replacement for the glass fiber reinforced composites (GFRCs) in various applications and it was due to their low density, biodegradability, and ease of recyclability. The popularity of biocomposites is continuously increasing in the automotive sector which results in the improvement of car performance and lowers CO₂ emission. Moreover, the environmental awareness and sustainability concept have attracted the researchers towards the utilization of natural fiber reinforced composites (NFRCs) in wide varieties of engineering applications.

NFRCs exhibit a lot of advantageous properties such as lightweight, high strength to weight ratio, renewability, wide availability, lower energy requirements for processing, biodegradability, and non-
abrasiveness. These properties make them suitable to be used in the automotive sector. However, they possess low mechanical strength than the glass and carbon fiber-reinforced composites. This limitation can be overcome by employing the hybridization concept. Mittal et al. [2] reported that the hybrid epoxy based composite reinforced with equal volume content (50:50) of PALF and COIR fiber possess higher value of tensile, flexural, and impact strength than the other compositions. Hybrid composites exhibit the enhanced toughness, longer fatigue life, and very good impact resistance as compared to the composites made from single reinforcement. M. Jawaid et al. [3] found that the hybrid composites have improved mechanical and thermal properties which prove them as a potential material for medium load-bearing applications in automobile parts.

European car manufacturers explored the potential of NFRC for aesthetic components of an automobile. However, their application is very limited in structural components. Car bumper is a structural component usually made up of steel, aluminium, and GFRC. Very less research has been done on the application of NFRC in automotive car bumpers. Therefore, this research work focussed on the use of PALF and Glass fiber reinforced epoxy based composite for the automotive application. The use of biocomposite material for the bumper structure will lead to a weight loss of vehicle, lower fuel consumption and pollutant emissions of greenhouse gases, and higher resistance to impact and corrosion.

2. Experimental work

2.1 Materials used

In this research work, an alkaline-treated PALF/Glass hybrid epoxy composite is used as a material for car bumper which is developed and characterized by one of the author of this research work. The properties of a hybrid composite are reported in Table 1. In comparison to the other natural fibers, the PALF is better one because it contains high cellulose content (70-85%) which results in the better tensile and flexural properties. Moreover, PALF possess low density, favorable aspect ratio, and low microfibrillar angle. The hybridization of PALF with synthetic glass fiber lead to an increase in mechanical strength of resulting composite which can be used for the development of a car bumper.

| Properties                  | Values  |
|-----------------------------|---------|
| Density (g/cm3)             | 1.142   |
| Tensile strength (MPa)      | 49.28   |
| Young’s modulus (GPa)       | 1.57    |
| Flexural strength (MPa)     | 152.21  |
| Flexural modulus (GPa)      | 6.86    |
| Poisson ratio               | 0.31    |

2.2 Design of Car Bumper

In this research work, the rear bumper of the ambassador car has been designed. The dimensions of a car bumper have been taken from reference [5] with some modifications in the geometry. CATIA V5R20 software is used for the design of an automotive car bumper. The basic design of car bumper with different views is shown in figure 1-2.
2.3 Finite Element Analysis

ANSYS computer program is employed for analyzing the various problems of industrial models using the concept of finite element analysis (FEA). The different problems can be of static and dynamic structural analysis; steady-state; static or time-varying magnetic analysis; and transient heat transfer. FEA of the model was done in the workbench of ANSYS 18.1 software.
2.3.1 Static Analysis of a car bumper

Static analysis is carried out to find out the deformation and stress distribution over the structure. The boundary conditions play an important role in the static analysis of the model. The load applied can be calculated as shown below:

- Mass of an Ambassador car = 1600 kg
- Mass of 4 persons can be taken as = 300 kg
- Sum of both the masses = 1900 kg
- Assume velocity of the car = 36 km/hr = 10 m/s.

Let another car is hitting the same ambassador car and assume the stopping time as 0.1 sec.

- Deceleration of the car = \( \frac{(v-u)}{t} \)
  - = \( \frac{(10-0)}{0.1} \)
  - = 100 m/s\(^2\)

- Force on the front face of bumper = \( ma \)
  - = 190 KN

The front face of the bumper has area = l*b

Here l and b are length and width of the front face of the bumper

- Pressure acted on the bumper = \( \frac{F}{A} \)
  - = 2.61*10^6 N/m\(^2\)

![Figure 3. Meshing of the model](image)
2.3.2 Impact analysis of a car bumper

Dynamic-explicit type of analysis is used for completion of impact analysis in the workbench of ANSYS. Again the CAD model is imported in the software, the material is applied to the bumper and meshing is done. Now the boundary conditions are applied to the model for impact analysis. In this type of analysis, the important parameters are velocity and the surface at which this bumper is hitting.

Figure 4. Boundary condition and load applied

Figure 5. Wall is fixed for impact analysis
3. Results and Discussion

3.1 Results of Analysis

The FEA results show that the deformation value for static and impact analysis is 1584.1 mm and 465.65 mm respectively as shown in Figure 6 and Figure 7. These deformation values are large so we should require optimizing the design of a bumper by employing some structural changes.

![Figure 6. Deformation obtained for static analysis](image_url)

![Figure 7. Deformation obtained for impact analysis](image_url)
3.2 Design Optimization of Basic Car Bumper

To replace the traditional materials of car bumper with the biocomposite material, some design modifications need to be performed. Optimization in geometry will lead to an increase in mechanical strength of car bumper.

There are various parameters which affects the performance of a car bumper is listed below:

*Strengthening ribs*: Strengthening ribs raise the distortion resistance, improves rigidity, and provides structural stability. So three strengthening ribs are provided in front and rear portion of the basic design of car bumper. One rib is provided in the center of the bumper and the remaining two at a distance of 21 mm from the center rib.

*Cross-section*: Giving a better cross-section to structure will magnify the strength, structural stiffness, and damping capability. In this work, the cross-sections of the bumper is changed to I section to increase its strength and reduce deformation.

*Thickness*: Increasing the thickness of the front of a car bumper improves strength and energy absorption. The value of deformation is large at the front face of a car bumper so the thickness is increased at this face. However, it increases the weight of bumper which can be compensated with the low density of resulting bio-composite material.

We have performed the above mentioned geometrical changes in the basic design of a car bumper in CATIA and make our final design which can be seen in Figure 8-9.

![Figure 8. Isometric view of bumper after design optimization](image-url)
3.2.1 Results for static analysis of car bumper after design optimization

Figure 10 depicts the deformation obtained during the static analysis of car bumper. It observed that the value of deformation in car bumper is reduced significantly from 1584.1mm to 149.54 mm after the design optimization. The maximum Von Misses stress value is 1696 MPa as shown in figure 11. The Von Misses stress gives the information about the load-bearing capacity of a structure.
3.2.2 Results for impact analysis of car bumper after design optimization

Figure 12 shows the value of deformation during the impact analysis of modified car bumper. This value is decreased from the initial value of 465.65 mm to 92.49 mm after the design optimization. The impact analysis was done on a car bumper of hybrid biocomposite material with velocity of 36 km/hr against a wall. Figure 13 shows the Von Misses stress distribution during the impact analysis. The maximum Von Misses stress value is 1696 MPa.

Figure 12. Deformation obtained for impact analysis
Figure 13. Von Misses stress distribution

The FEA of car bumper made up of steel and aluminium during static and impact analysis under similar loading condition can be obtained from the reference [5] and shown in Table 2 and 3. We can compare these values of deformation and stresses with the results of car bumper made of hybrid biocomposite material having geometrical changes in design.

Table 2. Various stresses and deformation obtained during static analysis

| Material                                | Max. Von mises stress (MPa) | Deformation (mm) |
|-----------------------------------------|----------------------------|-----------------|
| Chromium coated Mild Steel              | 971                        | 151             |
| Aluminium B390 alloy                    | 846                        | 196             |
| PALF/glass fibers hybrid biocomposite   | 1374.8                     | 92.49           |

Table 3. Various stresses and deformation obtained during impact analysis

| Material                                | Max. Von mises stress (MPa) | Deformation (mm) |
|-----------------------------------------|----------------------------|-----------------|
| Chromium coated Mild Steel              | 958.7                      | 273.2           |
| Aluminium B390 alloy                    | 843.2                      | 422.4           |
| PALF/Glass fibers hybrid biocomposite   | 1696                       | 149.54          |

It can be observed from Table 2-3 that the value of deformation is lowest for both the static and impact analysis in case of hybrid biocomposite material. As compared with the other materials, the hybrid composite exhibits the maximum value of stress, since it is the strongest among all these. The mass of bumper made from different materials can be obtained using ANSYS Workbench. The material properties of Chromium coated mild steel, Aluminium B390 alloy, and the biocomposite material are
entered into the software and the mass values of bumper are shown in Table 4. It was observed that the bumper of hybrid composite possess lower mass value than the other two materials.

Table 4. Mass of different bumper

| Material                                      | Density (kg/m$^3$) | Mass of bumper (kg) |
|-----------------------------------------------|--------------------|---------------------|
| Chromium coated mild steel                    | 7800               | 12.94               |
| Aluminium B390 alloy                          | 2710               | 4.49                |
| PALF/glass fibres hybrid biocomposite         | 1142               | 4.46                |

4. Conclusions

Biocomposite materials have potential to replace steel and aluminium in various applications and it was due to their low density, biodegradability, and ease of recyclability. The PALF and glass fiber reinforced hybrid epoxy composite possess good mechanical properties which make them suitable for use in structural applications of automobile. The use of biocomposite in automobile can reduce weight and lower CO$_2$ emission.

The hybrid biocomposite has a potential to be used in automotive car bumper after the structural optimization. The results of FEA proved that the hybrid biocomposite can replace steel and aluminium as a car bumper material and this was due to its least value of deformation and large reduction in mass. The value of deformation in static and impact analysis is significantly reduced from 1584.1 mm to 149.54 mm and 465.65 mm to 92.49 mm respectively after the design optimization. The mass of bumper made up of hybrid biocomposite is 65.53% lower than the mass of traditional steel bumper.

In future work, a numerical analysis can be done for validation of the result. The use of fully biodegradable material in structural components of an automobile is yet to be seen.

5. References

1. Cao Y. et al. 2013 Applications of mechanical models to Flax fiber/wood fiber/plastic composites *Bioresources* 8 3276-88 2013.

2. Mittal M. et al. 2018 Experimental investigation on the mechanical properties and water absorption behavior of randomly oriented short pineapple/coir fiber-reinforced hybrid epoxy composites *Mater. Res. Express* 6 1-14

3. Jawaid M. et al. 2012 Woven hybrid biocomposites: dynamic mechanical and thermal properties *Composites: Part A* 43 288–293

4. Mittal M. et al. 2018 Development of PALF/glass and coir/glass fiber reinforced hybrid epoxy composites *J. Mater. Sci. Surf. Eng.* 6 851-861

5. John A. et al. 2014 Modelling and analysis of an automotive bumper used for a low passenger vehicle *Int. J. Eng. Trend. Tech.* 15 344-353