Design and Analysis of Bumper Beam and Energy Absorbers by Using Composite Materials

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Abstract. At present the production of automobile is in increasing rate especially India which is one of the largest producer and consumer of automobile. India uses wide variety of automobile like bus, car, van, truck and heavy vehicles. But India have a poor road quality and the driving facilities are less which results in severe road accident. This results in severe collisions of vehicles and it cause damage to both vehicle and passengers. Bumper is one of the key factor which helps in avoiding damage to vehicle and passengers present inside the vehicle. Thus all vehicles will have bumper for safety purpose. The bumpers are made of different type of materials to ensure safety of the passengers and to reduce the weight of the vehicle. The production of bumper in composite material results in increased safety during collision and it is cheaper and reduces the weight of vehicle. The cross-section of beam, energy absorber and its materials is designed and analyzed, with referring to the result safe and strong bumper system is discussed. When compared to current bumper, the composite bumper with energy absorber results in greater shock absorption and increased strength which increase the overall effectiveness of the bumper and its function.

Keywords: Bumper beam, Energy Absorber, Honeycomb, Bio-Composites, S2 Glass Epoxy.

1. Introduction

Bumper is a structure, which attached to the front and rear of the vehicles. The primary purpose of the bumper is to absorb the minor impact collision, which avoid minor repair cost. But later on the development in technology, the bumper is used to reduce pedestrians injury and protect passengers. The composite material composed by the combination of two or more material sand a reinforcing element and a matrix or resin binder to obtain specific characteristics and properties. Composite materials are manmade or naturally occurring materials made from two or more constituent
materials with significantly different physical or chemical properties which remain separate and distinct within the finished structure [3-11]. The major role of resin used in composite are to give shape to obtained composite material, distribute the load to the element, protect the material from the environment, helps to fix them together and increase the strength of the composite. The purpose of reinforcing material in composites are to obtain high strength, stiffness and other mechanical properties like coefficient of thermal expansion, thermal conductivity and thermal transport. The advantages like light weight, High specific stiffness and strength , easily bondable and good dumping and good fatigue resistance [12-16].

The bio-composite materials have the ability to serve as a replacement for the glass fibre reinforced composites in various applications because of their low density, bio-degradability and ease of recyclability. A large amount of toxic and non biodegradable waste is generating due to use of synthetic fibres based composites. So bio-composites have become increasingly popular with the car manufacturers because they can reduce weight, which improves their performance and lowers CO2 emissions [1].

The palm and coir reinforced bio composites can be used for the fabrication of lightweight automobile parts. From referring these bio composites with natural fibre reinforcements have low mechanical strength than glass and carbon fibre reinforced composites. To get highest tensile, flexural, and impact strength, the hybrid composite reinforced with equal volume of pineapple leaf fibre and coconut husk fibre is used [2].

2. Materials and Modelling

2.1 Materials Used

Aluminium alloys are extensively used to form different shapes by process like extrusions and castings due to its high strength to weight ratio and low density of aluminum compared to steel. The aluminium alloys consists of composition of Al=90.6-94.5% ,Zn=5-6.5% ,Mg=.5-1% ,Fe=.35% ,Si=.3% and 0.2% of Zr, Cr, Ti, Cu. Thus in vehicles, aluminium alloys are used as the front and rear bumper beams. The use of the light weight materials helps in reducing fuel consumption which consequently lower carbon dioxide emissions obtained. While using light weight materials for automobile parts like bumper. Thin-walled tube like structures have been extensively studied as energy absorbing components. Here the aluminium alloy of grade AA7003-T1 has been taken into consideration.

Medium carbon steel consist of carbon 0.3% to 0.6% and manganese 0.6% to 1.65% normally. As the carbon percentage is high, the medium carbon steel is stronger than low carbon steel and has more ductility. It also has good wear resistance. The medium carbon steels are used for making shafts, gears and crankshafts and when carbon content ranging from 0.40%-0.60% can be used for rails and rail axles

Kenaf (Hibiscus cannabinus) is an plant that has been used since ancient times in many purpose. for example; as a rope, canvas, and sacking. Kenaf grows naturally and requires less energy to process as compared to synthetic fibres. Here, the kenaf / E-Glass bio-composite fiber was the synthesis of kenaf and glass fiber in which epoxy was used as matrices to bind the bio-composite. Due to hybridization, the mechanical property of the material increased, resulting in the expected result.

S2-glass epoxy is one of the most important glasses compared with other forms of glass fiber. It has highest strength, stiffness, and softening point of any commercial reinforcement glass fiber. This glass is used in defense products such as FRP lightweight armor. S-glass is of alumino silicate glass without CaO but with high MgO content which increase the high tensile strength. S-glass known as R-glass in Europe is based on this SiO2-Al2O3- MgO and this fiber has higher stiffness and strength than E-Glass fiber and also its improved properties to higher temperatures.
2.2 Design of Bumper Beam

Concept 1

In first concept the bumper beam of rectangle cross section was used which was so basic cross section in bumper beams. Here the rectangle cross section of length 120 mm and breadth 60 mm were used and the thickness of beam was 5 mm. The overall length of bumper beam was 1400 mm. The bumper beam was three dimensionally modelled using CATIA.

![Fig. 1. (a) CATIA model of concept 1](image)

Concept 2

In this concept the cross section was in optimized I form when compared to normal I section and in this concept the length of the bumper beam was same as that when compared to previous two concept. Here the length was 120 mm and breadth was 60 mm and thickness was 5 mm and the angle 100 degree was used where the vertical height of I was 35 mm and the horizontal height of 45 mm were used. The bumper beam was modelled using CATIA.

![Fig. 1. (b) CATIA model of concept 2](image)

Concept 3

The cross section was entirely different from the above mentioned cross section. Here the cross section of length 120 mm and width 60 mm and the thickness of 5 mm and angle of 85 degree were used. The overall length of beam remains same when compared to the previous model and only the cross section dimensions only varied and the beam was 3-dimensionally modelled using CATIA.
2.3 Design of Energy Absorber

Bumper absorber is another major component which is used to absorb the impact energy and helps to redistribute the energy in the vehicle chassis so the bumper will work efficiently when there is impact or collision occurs. The absorber of many types can be designed and here honeycomb structures were used for designing the absorber and two different channels were taken for designing the absorber for testing.

Honeycomb Structure

Honeycomb structure was considered to be one of the best absorber design when compared to other like double cylinder and double half cylinder model. In honeycomb structure the strength or energy absorbing capacity varies depend on their cell structures and cell size and variety of combinations can be used of which cell structure of Hexagon and triangle were used for designing honeycomb absorber.
3. **Analysis of Bumper Beam**

3.1 **Force Calculation:**

Weight of passenger car (sedan) = 1040kg
Weight of four passengers occupied = 400kg
Thus, Total weight of vehicle = weight of car + weight of passengers

During collision the energy (work) is generated in form of kinetic energy, which is given by

\[ \text{Kinetic Energy} = \frac{1}{2}mv^2 \]

\[ v = 15 \times \left( \frac{5}{18} \right) \]
\[ v = 4.17 \text{ m/s} \]
\[ \text{Kinetic Energy} = \left( \frac{1}{2} \right) \times 1440 \times (4.17)^2 \]
\[ = 12500.2 \text{ Joules} \]

\[ \text{Work Done (W)} = 12500.2 \text{ Joules} \]

During frontal impact, to oppose the kinetic energy produced the car components will be moved or displaced. Let us consider the maximum displacement to 500 mm for passenger and other major component’s safety.

We know that work done can also be calculated as, \( W = F \times d \)

\[ 12500.2 = F \times 0.500 \]
\[ F = 25000.4 \text{ N} \]
\[ F = 25 \text{ kN} \]

Therefore, during the frontal collision the car experiences the force of 25 kN at the speed of 15 km/h.

Similarly, The force produced in 30 km/h and 60 km/h is 100kN and 400kN respectively.

3.2 **Selection of Bumper Beam Cross-section**

Concept 1 - Deformation under Varied Speed

![Fig. 3. (a) Deformation at 60 km/h](image-url)
The above figure shows the deformation of rectangle cross section bumper beam under various speed where at 15 km/h, the maximum deformation was 0.32 mm and at 60 km/h the maximum deformation was 5.39 mm.

(b) Von Mises stress at 60 km/h

The above figure shows the von mises stress of B cross section bumper beam under various speed where at 15 km/h, the maximum stress acted on bumper beam was 141.44 M Pa and at 60 Km/h the maximum stress acted on bumper beam was 1873.8 M Pa.

Concept 2 - Deformation under Varied Speed

The above figure shows the deformation of optimized I cross section bumper beam under various speed where at 15 km/h, the maximum deformation was 0.36 and at 60 km/h the deformation was 5.83 mm.

(c) Deformation at 60 km/h

(d) Von Mises stress at 60 km/h
The above figure shows the von mises stress of optimized I cross section bumper beam under various speed where at 15 km/h, the maximum stress acted on bumper beam was 104.83 M Pa and at 60 km/h the maximum stress acted on bumper beam was 1677.3 M Pa.

**Concept 3 - Deformation Under Varied Speed**

The above three figure shows the deformation of B cross section bumper beam under various speed where at 15 km/h, the maximum deformation was 0.28 mm and at 60 km/h the deformation was 4.43 mm.

The above figure shows the von mises stress of B cross section bumper beam under various speed where at 15 km/h, the maximum stress acted on bumper beam was 130.1 M Pa and at 60 km/h the maximum stress acted on bumper beam was 2081.8 M Pa.
3.3 Selection of Bumper Beam material

The material which is used for the analysis is listed below in the table:

| Materials types          | Density (g/cm³) | Tensile strength (MPa) | Young’s modulus (GPa) | Poisson ratio |
|--------------------------|----------------|------------------------|-----------------------|---------------|
| Aluminium Alloys         | 2.9            | 150                    | 70                    | 0.29          |
| Medium Carbon Steel      | 7.8            | 220                    | 200                   | 0.3           |
| Kenaf/E-Glass fibre      | 1.41           | 160                    | 75                    | 0.28          |
| S2-Glass Epoxy           | 2.46           | 489                    | 86.9                  | 0.23          |
For further analysis, the selected cross-section bumper beam is attached with the energy absorber. The dimensions of the energy absorber is discussed above which has hexagonal honeycomb structure is used. The bumper beam and energy absorber is assembled with the CATIA V5 software. The material for energy absorber is aluminium alloy 3000 which is constant for all, only bumper beam material is changing.

**Aluminium Alloy - Deformation Under Varied Speed**

![Deformation at 60 km/h (Al alloy)](image)

The deformation of aluminium alloy bumper beam under various speed where at 15 km/h, the maximum deformation was 0.38 mm, at 30 km/h the maximum deformation was 1.53 mm and at 60 km/h the maximum deformation was 6.12 mm.

**Medium Carbon Steel Alloy- Deformation under Varied Speed**

![Deformation at 60 km/h (Steel alloy)](image)

The deformation of Medium Carbon Steel Alloy bumper beam under various speed where at 15 km/h, the maximum deformation was 0.24 mm, at 30 km/h the maximum deformation was 0.98 mm and at 60 km/h the maximum deformation was 3.91 mm.
S2-Glass Epoxy Composite - Deformation under Varied Speed

(c) Deformation at 60 km/h (S2 glass epoxy composite)

The deformation of S2-glass epoxy composite bumper beam under various speed where at 15 km/h, the maximum deformation was 0.34 mm, at 30 km/h the maximum deformation was 1.38 mm and at 60 km/h the maximum deformation was 5.53 mm.

Kenaf-Glass/Epoxy Hybrid Bio-Composite - Deformation under Varied Speed

(d) Deformation at 60 km/h (Kenaf-Glass/Epoxy Hybrid Bio-Composite)

The deformation of kenaf-glass/epoxy hybrid bio-composite bumper under various speed where at 15 km/h, the maximum deformation was 35.02 mm, at 30 km/h the maximum deformation was 140.08 mm and at 60 km/h the maximum deformation was 560.33 mm.
The deformation and von mises stress of kenaf-glass hybrid composite is not used in the graph as the value is deviated very high than other material. Hence kenaf-glass hybrid composite cannot be used for bumper beam.

4. Conclusion

From the above graphs and the results obtained from analysis, it was found that bumper with steel and concept 3 (B section) has better mechanical properties and shows less deformation under various speeds. But when compared to S2-Glass epoxy composite, steel was of more weight and high cost which results in increased fuel efficiency and affect the environment. So, bumper and its components made S2-Glass epoxy with B-cross section was considered to be better when compared to other materials and cross sections. This paper is mainly focused on designing and analyzing of bumper and its components using various materials and identifying which will be suitable for the automobile. With increasing rate of automobile production accident has been occurring daily in our day to day life and leads to lots of injuries and even deaths. Even though there were many safety features available in automobile to prevent accidents it happens daily and bumper is one of the safety feature which was implemented in automobile to prevent passengers inside the vehicle while accident occurs in form of
collision or impact with other vehicles. But the bumper used in vehicle was of high cost and increases weight of vehicle which results in increased fuel consumption and results in high pollutant gas emission which affects environment.

So bumper which made of composite will results in greater impact as it will reduce the cost and also reduce the weight of vehicle even though the mechanical properties varies lightly when compared to metal bumpers. But using composite bumper results in pollution reduction which helps in protecting environment. Here composite materials like S2-glass/epoxy fibre was used in bumper and its components. Where S2-glass/epoxy fibre composite was strong and its currently paving its way inside the automotive field as the composite materials were being used recently. Though there are some works present in developing composite bumper as manufacturing of composite was complex and enhancing the mechanical properties need some additional hybridization work. Mostly composite which were eco-friendly available abundantly which makes it more comfortable as metal resources were scarce in nature and obtaining composite were very easy when compared to extracting metal from earth surface. So, the usage of composite in bumper will play an vital role as it has more advantages and also increase the performance of vehicle by increasing the vehicle mileage.

5. References

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