Design and Fabrication of Composite Bumper for Light Passenger Vehicles

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Abstract: *The fuel efficiency and emission gas regulation of passenger cars are two important issues in these days. The best way to increase the fuel efficiency without sacrificing safety is to employ fiber reinforced composite materials in the cars. Bumper is the one of the part having more weight. In this paper the existing steel bumper is replaced with composite bumper. In this work the design and fabrication of composite bumper made up of glass fiber reinforced polymer is carried out by which weight of the bumper can be reduced. Fabrication of composite bumper is carried out by hand layup process by using E- Glass/ Epoxy bidirectional laminates. Composite bumper is analysed and Charpy impact tests are carried out. Compared to steel bumper, the composite bumper is found to have 64% higher factor of safety and 80% less in cost. From the fabrication it was found that the weight reduction of 53.8% is achieved using composite material without sacrificing the strength.*

I. Introduction

A bumper is a shield made of steel, aluminum, rubber, or plastic that is mounted on the front and rear of a passenger car. When a low speed collision occurs, the bumper system absorbs the shock to prevent or reduce damage to the car. In existing bumper the weight is more. In the present trends the weight reduction has been the main focus of automobile manufacturers.

Less fuel consumption, less weight, effective utilization of natural resources is main focus of automobile manufacturers in the present scenario. The above can be achieved by introducing better design concept, better material and effective manufacturing process.

Steel bumper have many advantages such as good load carrying capacity. In spite of its advantages, it stays back in low strength to weight ratio. It is reported that weight reduction with adequate improvement of mechanical properties has made composites as a viable replacement material for conventional steel.

In the present work, the steel bumper used in passenger vehicles is replaced with a composite bumper made of glass/epoxy composites. The thickness of the composite bumper is calculated by bending moment equation and other dimensions for both steel and composite bumper is considered to be the same. The objective was to compare the stress, weight, and cost savings.

II. Bumper

The bumper is a safety system is used to observe the low speed collision. It is placed in car body. The car bumper is designed to prevent or reduce physical damage to the front and rear ends of passenger motor vehicles in low-speed collisions. Automobile bumpers are not typically designed to be structural components that would significantly contribute to vehicle crashworthiness or occupant protection during front or rear collisions. It is not a safety feature intended to prevent or mitigate injury severity to occupants in the passenger cars. Bumpers are designed to protect the hood, trunk, grille, fuel, exhaust and cooling system as well as safety related equipment such as parking lights, headlamps and taillights in low speed collisions.

The national highway traffic safety administration (NHTSA) produces some bumper standard to the light passenger vehicle. The bumper standard, prescribes performance requirements for passenger cars in low-speed front and rear collisions. It applies to front and rear bumpers on passenger cars to prevent the damage to the car body and safety related equipment. The bumper standards are,

- The front and rear bumpers on passenger cars should prevent the damage to the car body.
- Bumper should withstand at a speed of 2 mph across the full width and 1 mph on the corners.
- Bumper should also withstand 5 mph crash into a parked vehicle.
- Placement of the bumper is 16 to 20 inches above the road surface.

So all bumpers should satisfy the above standards.

2.1 Requirements of Bumper Material

- It should absorb more energy while collision.
- It should have good rust resistance.
- It should have high strength.
- Light in weight.
- Easy to manufacture in large quantity.
- Low cost.

III. Composite Bumper

In recent days, various materials like composites are experimented in almost all parts of the automobiles and it has also ventured into bumper. Due to reduction in weight, composite materials are preferred over conventional steel bumper. Composite bumper absorbs more collusion energy than steel bumper.

3.1 Advantages of Composite Bumper

One of the most advantageous reasons for considering their use over steel is their reduced weight.

- Absorb more collision energy.
- Excellent corrosion resistance.
- High impact strength.

- Material properties of composite bumper allow rapid response to induced or release stress.

3.2 Glass Fiber

The aim of fiber reinforced plastics is to combine the stiffness and strength of fibrous material. This material has corrosion resistance, low density and mould ability. The majority of reinforced plastics produced today are glass reinforced epoxy or polyester resins, both of which are thermosetting.

Glass fibers have also been used with phenolics, silicones, polystyrene and polyvinyl chloride. Glass fibers are the obvious choice as reinforcing agents, principally because of the relative ease with which high strengths can be obtained fiber a few microns in diameters.

It is possible to produce composites with a range of strength according to glass content and nature of the reinforcement. The epoxy resins have lower shrinkage than the other resins.

3.2.1 Properties

Some of the basic properties of glass fiber are,

- Specific Strength
- Low density
- Corrosion resistance
- Impact resistance
- Electrical properties

3.2.2 Different Types of Glass Fibers

Glass is the most common fiber used in polymer matrix composites. The most commonly used glass fibers are E-glass, S-glass, R-glass, C-glass and D-glass fibers. The E in the E-glass stands for electrical as it was designed for electrical applications. E-glass fiber is a high quality glass fiber used as a standard reinforcement for all the resin systems and as a well complying with mechanical property requirements.

Thus E-glass fiber was found appropriate for our applications. In S-glass S stands for higher content of silica. It retains its strength at high temperature and has higher fatigue strength. It is used mainly in aerospace applications. In C-glass C stand for corrosion, it is designed to give improved surface finish. It is available usually in the form of a surface tissue for the reinforcement of corrosive barriers in chemical plant. In D-glass D stands for dielectric used for applications requiring low electric constants.

3.2.3 Advantages of Glass Fibers

Glass fiber is most widely used as are reinforcement of all composites due to the following advantages:

- Molten glass easily drawn into high-strength fibers
- Readily available/easy to fabricate
- Relatively strong fibers produce very high strength in composite form
- Chemically insert in plastics.

These materials are limited to low temperature applications where strength is important without the need for high rigidity. Typical uses for this material are boat hulls, flooring materials and automobile bodies.

The main type of glass used is E-glass. However, it is used for many other purposes now such as decorations and structural applications.

3.3 Epoxy Resin

Epoxy resins are the most commonly used resins. They are low molecular weight organic liquids containing epoxide groups. Epoxide has three members in its ring, 1 oxygen and 2 carbon atoms. The reactions of Epichlorohydrin with phenols or aromatic amines make most epoxies. Hardeners, plasticizers and fillers are also added to produce epoxies with a wide range of properties of viscosity, impact, degradation, etc. Although epoxy is costlier than other polymer matrices, it is the most popular PMC matrix. More than two thirds of the polymer matrices used in aerospace applications is epoxy based.The main reasons for epoxy being the most used polymer matrix materials are

- Good compatibility with Glass fiber
- High strength
- Low viscosity and low flow rates, which allow good wetting of fibers and misalignment of fibers during processing
- Low shrink rates which reduce the tendency of gaining large shear stresses of the bond between epoxy and its reinforcement.
- Available in more than 20 grades to meet specific property and processing requirements.

IV. Design of Composite Bumper

For designing the composite bumper an already existing ambassador steel bumper is used as mould. Dimensions are assumed as same as that of steel bumper for fabrication.

4.1 Dimensions And Properties of Existing Steel Bumper

Effective length = 0.975m
Total length = 2.055m
Thickness = 0.002m
Effective breath = 0.078m
Total breath = 0.172m
Weight = 5.16kg
Material = mild steel (chromium coated)
Tensile strength = 460MPa (design data book)
Density = 7800 kg/m^3

The moment for steel and composite bumper is assumed to be same. Therefore the moment for steel is

$$\frac{M}{I} = \frac{\sigma}{y}$$

Where,
M = Bending moment (Nm)
I= Moment of inertia (m^4)
σ = Tensile strength (N/m^2)
y = d/2,
d = thickness of the bumper (m)
b = breadth of bumper (m)
Moment of inertia for rectangular section:
$I = bd^3/12$
There are three sections in the bumper I_1, I_2, I_3 respectively.
$I_1 = 0.058 \text{ x } 0.002^3/12 = 3.86 \text{ x } 10^{-11} \text{ m}^4$
$I_2 = 0.078 \text{ x } 0.002^3/12 = 5.2 \text{ x } 10^{-11} \text{ m}^4$
$I_3 = 0.058 \text{ x o}.002^3/12 = 3.86 \text{ x } 10^{-11} \text{ m}^4$
$I = I_1 + I_2 + I_3 = 1.2932\text{x}10^{-10} \text{ m}^4$
Tensile strength of the steel = 460 x 10^6 N/m^2 (from PSG data book)

The moment equation,

$$\frac{M}{1.2932x10^{10}} = \frac{460x10^6}{\frac{0.002}{2}}$$

M = 59.4872 Nm.

4.2 Thickness of the Composite Bumper

Thickness of the composite bumper can be determined by the formula,

$$\frac{M}{I} = \frac{\sigma}{y}$$

There are three individual sections, so to find them individually by using above formula,

$$\frac{59.4872}{\frac{0.058xd_1^{\ 3}}{12}} = \frac{490x10^6}{\frac{d_1}{2}}$$

$d_1 = 3.543*10^{-3}$m

$$\frac{59.4872}{\frac{0.078xd_2^{\ 3}}{12}} = \frac{490x10^6}{\frac{d_2}{2}}$$

$d_2 = 3.055*10^{-3}$m

$$\frac{59.4872}{\frac{0.058xd_1^{\ 3}}{12}} = \frac{490x10^6}{\frac{d_1}{2}}$$

$d_3 = 3.543*10^{-3}$m

Average thickness (d) = $d_1+d_2+d_3/3$ = 3.38mm

A layer of E-glass mat thickness is 0.2mm, so 17 layers are required for fabricating composite bumper.

4.3 Force Acting On the Bumper (F)

Force (F) = m*a

Where,

m = mass of the vehicle crashed on the bumper (1554kg)

a = acceleration due to gravity (m /sec^2)

a = (u -v) / t

Where,

v = Final velocity after collapsing (m/sec)

u = Initial velocity before collapsing (m/sec)

u = 8km/hr = 2.22 m/s (taken from NHTSA)

t = time taken for collapsing (sec)

a= (2.22-0) / 0.1= 22.22 m/sec2

Force (F) = 1554 x 22.222 = 34529.88 N

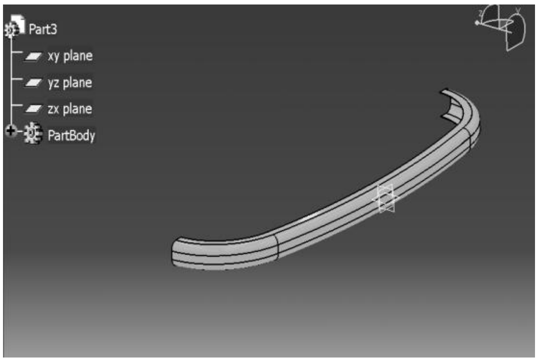

Fig 4.1 Model of the Bumper

4.4 Model of the Bumper

The load applied on the bumper is not a point load; it is a uniformly distributed load (pressure load). So calculation pressure load is given below.

Pressure (P) = F/A

F = force acting on the bumper = 34529.88 N

A = front area cross section = 2055 x 78 = 160290 mm^2

P = 34529.88 /160290 = 0.13 N/mm^2

4.5 Drafted Model of the Bumper

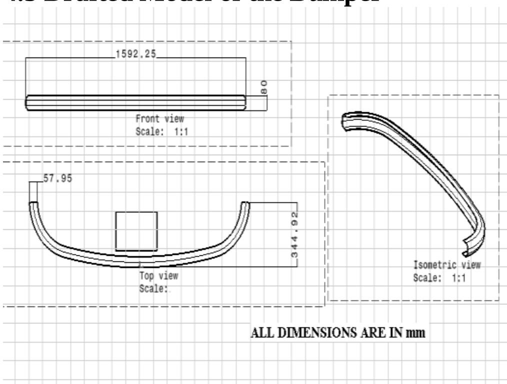

Fig 4.2 Drafted Model of the Bumper

V. Fabrication of Composite Bumper

In Hand lay-up, liquid resin is applied to the mould and then fiber glass is placed on the top. A roller is used to impregnate the fiber with resin. Another resin and reinforcement layer is applied until a suitable thickness builds up. It is very flexible process that allows the user to optimize the part by placing different types of fabric and mat materials. Because the reinforcement is placed manually, it is also called the hand lay-up process. Though this process requires little capital, it is labor intensive.

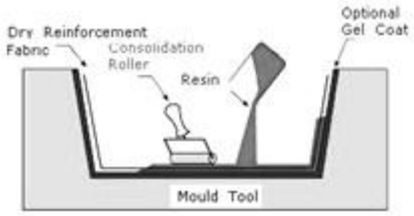

Fig 5.1 Hand Layup Process

5.1 Basic Raw Material

- E-Glass fibers
- Epoxy resin
- Hardener
- Wax

5.2 Tools Required

The mould design for the hand lay-up process is very simple as compared to other manufacturing process because the process requires room temperature to cure with low pressures. In this project existing bumper is used as mould.

5.3 Fabrication of Bumper

In the hand lay-up process the thickness of the composite part is built up by applying a serious of fiber glass layers and liquid resin layers. A roller is used to squeeze out the excess resign and create uniform distribution of the resign throughout the surfaces. By the squeezing action of the roller, homogeneous fiber wetting is obtained, the part is then cured at room temperature for about one week and once solidified it is removed from mould. The cost making one composite bumper is around Rs.820.

5.4 Advantages of Hand Lay-up Process

Very low capital investment is required for this process because there is negligible equipment cost as compared to other processes.

- The process is very simple and versatile. Any fiber type material can be selected with any fiber orientation.
- The cost of making a prototype part is very low because a simple mold can be used to make the part. In addition, the raw material used for this process is liquid resin, mat and fabric, material, which are less expensive than preparing material.

5.5 Limitations of Hand Lay-Up Process

- The process is labor incentive.
- The process is mostly is suitable for prototype as well as for making large structures.
- Because of its open mold nature,
- Styrene emission is major concern.
- The quality of the part produced is consistent form part to part. High fiber volume fraction cannot be manufactured using this process.

VI. Charpy Impact Test

The purpose of impact testing is to measure a material's ability to resist high rate reading a material's ability to resist impact often is one the determining factor in the service life of the material. Impact testing commonly consists of charpy and izod specimen configuration.

6.1 Chapy Impact Test Machine

The charpy impact test, also known as the charpy v-notch test, is a standardized high strain rate test which determines the amount of energy absorbed by a material during fracture. This absorbed energy is a measure of a given material's toughness and acts as a tool to study temperature-dependent brittle-ductile transition. It is widely applied in industry, it is easy to prepare and conduct and result can be obtained quickly and cheaply. But major disadvantage is that all results are only comparative.

Fig 6.1 Charpy Impact Test Machine

6.2 Charpy Test Specimens

Charpy test specimens normally measure 55*10*6mm and have a notch machined across one of the larger faces. The notch dimensions are v-shaped notch, 2mm deep, with 45^0angle and 0.25mm radius along the base.

6.3 Experimental Result

DESCRIPTION	COMPOSITE	STEEL
Cross sectional area, A (mm ^{2})	40	40
Impact value ,I (J)	294	163
Impact energy (J/mm^2) (I/A)	7.35	4.07

Table 6.1 Experimental Result

VII. Analysis of Composite Bumper

The Ansys computer program is a large scale multipurpose finite element program, which may be used for solving several classes of engineering analyses. The analysis capabilities of Ansys include the ability to solve static and dynamic structural analyses, steady state and transient heat transfer problems, mode frequency and buckling eigen value problems, static or time varying magnetic analyses and various steps of field and coupled-field applications. In this project Ansys 10.0 has been used as a tool to achieve the project target. The static-nonlinear analysis is carried out to find out the deformation, stress distribution over the structure.

7.1 Description for Steel and Composite Bumper

DESCRIPTION	STEEL	COMPOSITE
Element type	Solid186	Solid191
Pressure Load (N/mm2)	0.13	0.13
Young's modulus(N/mm2)	$2x10^5$	$78x10^3$
Poisson ratio	0.3	0.27

Table 7.1 Description for Steel and Composite Bumper

7.2 Boundary Condition

Two ends of the bumper are fixed for supporting purpose. It is common for both steel and composite bumper. Bumper is arrested at 547.88mm from center to both the ends.

7.3 Stress Distribution for Steel Bumper

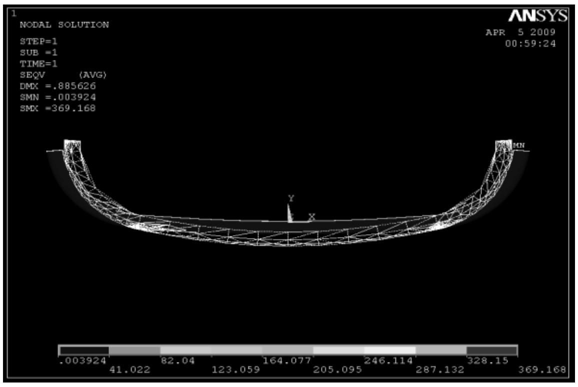

Fig 7.1 Stress Distribution for Steel Bumper

Maximum stress = 369.168 N/mm^2
Minimum stress = 0.003924 N/mm^2
Ultimate stress for steel = 460MPa (PSG design data book)
Factor of safety = Ultimate sress/Working stress
= 460/369.16 = 1.2

7.4 Stress Distribution of Composite Bumper

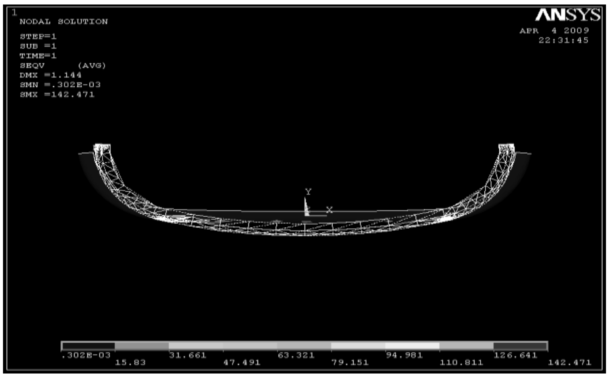

Fig 7.2 Stress Distribution of Composite Bumper

Maximum stress = 142.471 N/mm^2
Minimum stress = 0.302x 10^{-3} N/mm^2
Ultimate stress for composite = 490MPa (composite hand book)
Factor of safety =ultimate stress/Working stress
= 490/142.471= 3.4

7.5 Results of FEA

DESCRIPTION	STEEL BUMPER	COMPOSITE BUMPER
Max. stress (N/mm^2)	369.168	142.471
Min. stress (N/mm^2)	0.003924	0.302x 10^{-3}
FOS	1.2	3.4

Table 7.2 Results of FEA

VIII. Comparison

DESCRIPTION	STEEL BUMPER	COMPOSITE BUMPER	% OF REDUCTION
Weight	5.15	2.38	53.78%
Cost	3600	820	77.22%
Impact strength	3.25	7.35	-
Max.stress(N/mm^2)	369.168	142.471	-
F.O.S	1.2	3.4	-

Table 7.3 Comparison

IX. Conclusion

Design, fabrication and testing of steel and composite bumper (using glass fiber material) are completed and also composite bumper is analyzed and compared with steel bumper. The steel bumper weighs about 5.15Kg where the weight of composite bumper is 2.38kg. Which is 53.8% lesser than steel bumper. It is proved that fuel economy of the vehicle is improved as the composite bumper weighs less when compared with steel bumper. Cost of composite bumper is Rs. 820/- which is 80% less than steel bumper. Impact strength of composite bumper is 7.35 J/mm^2 where steel bumper is 3.25 J/mm^2. The existing and composite bumper are analysed in ANSYS10.0 and the Maximum stress induced in the composite bumper is 159.36 N/mm^2 where steel is 292.669 N/mm^2. Factor of safety for composite bumper is increased by 64%. From the study, it is concluded that fiber reinforced plastic material is a suitable material for manufacturing the bumper.

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