DESIGN AND ANALYSIS OF A LOW PASSENGER VEHICLE BUMPER IN AUTOMOBILES

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In the present research paper mainly focusing on the design and analysis of a low passenger vehicle bumper in automobiles. Day by day, the research on automotive design with economy, safety and aesthetics has been a great challenge to design engineers. The safety of the passengers during vehicle crashes can be ensured to a certain limit by using good bumpers. At the same time these automotive parts should not be massive in terms of weight contributing to the increase in total the weight of the vehicle. In this project impacts and collisions involving a car frame model are simulated and analysed using SOLIDWORKS and ANSYS softwares. The materials used for these analyses are Aluminium alloy, Chromium mild steel alloy and Carbon composite. During static analysis, Carbon composite showed the lowest deformation and maximum Vonmises stress value. During Modal analysis, Carbon composite showed the highest natural frequency among the three. Mild steel showed the minimum value for the frequency which is due to the high density of the material. From all these analysis, it is concluded that carbon composite is the best bumper material among all the other materials used here.

Keywords: Automotive design, Model analysis, Aluminium alloy, Carbon composite, Mild steel

INTRODUCTION

In automobile design, crash and structural analysis are the two most important engineering processes in developing a high quality vehicle. The greatest challenges faced by the automotive industry have been to provide safer vehicles with high fuel efficiency at competitive cost. The safety of the passengers during vehicle crashes can be ensured to a certain limit by using good bumpers. At the same time these automotive parts should not be massive in terms of weight contributing to the increase in total the weight of the vehicle. Computer simulation technologies have greatly enhanced the safety, reliability, and comfort, environmental and manufacturing efficiency of today’s automobiles. This significant achievement was realized with the advanced software and powerful computers that have been

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available in the last twenty years. The primary concern for drivers and passengers is safety. Governments have responded to this key concern and expectation with an increasing number of regulations. Although the details may vary slightly from country to country, the fundamental requirements are almost similar. A vehicle is expected to provide adequate protection to drivers and passengers in a not so serious accident. To protect the occupants of a car, there are many new tangible safety features such as airbags; ABS control brakes, traction control. A less tangible feature that cannot easily be seen by drivers and passengers is the crash response behaviour. In a well-designed automobile, the car body and various components act as a protective layer for the occupants of the vehicle. They serve as the crumpling zone to absorb the energy of impact. The traditional approach involves multiple iterations of design, prototype and crash tests. This process is time consuming and expensive. The availability of high performance computers and crash simulation software has revolutionized the process. Instead of relying on experimental validations, the safety design process is supplemented with computer simulation to evaluate the design. Since the inception of crash simulation, the product cycle of a new automobile has been reduced by half and the resultant vehicle is safer, better and more comfortable.

Lonny Thompson et al. (2001), determined that a high sensitivity value indicates a strong influence on the torsional stiffness of the overall chassis. Results from the sensitivity analysis are used as a guide to modify the 2 base line chassis with the goal of increased torsional stiffness with minimum increase in weight and low centre of gravity placement. The torsional stiffness of the chassis with various combinations of added members in the front clip area, engine bay, roof area, front window and area behind the roll gauge was predicted using FEA. They concluded that with strategic placement of structural members to a base line chassis, torsional stiffness can be more than tripled with only a 180 N increase in weight. A method for vehicle analysis based on finite element technique has been proposed by Johansson and Gustavsson, Vehicle dynamics and durability have been taken into account in their work and in house developed pre and post processor is used to achieve effective. Kirkpatrick (2000) has provided a method for force and stress calculation using complete vehicle models in MSC.nastran, where variables such as road profile and curve radii are used as input. Accurate calculations of force histories are of at most importance for reliable fatigue life estimates. The forces are often calculated by the use of multi-body software (Mbs) and used as input for stress analysis in fine element package. A drawback is that Mbs calculations are very time consuming, especially if flexible bodies are included, and are thus not well suited for fast parameters studies. The stress analysis of truck chassis using riveted joints has been performed by Cicek Karaoglu and Sefa Kuralay (2002), in order to achieve a reduction in the magnitude of stresses near the riveted joints of the chassis frame. Side member thickness, connection plate thickness and connection plate length were varied. Numerical results showed that stress on the side member can be reduced by increasing the side member thickness locally. In order to investigate the transient response of a vehicle structure interaction system in time domain, Tso-Chien Pan (2002) developed a Dynamic Vehicle Element (DVE) method. DVE method treats vehicle as a moving part of the entire system which considers the vehicle influence at element level by
incorporating detailed interaction between multiple vehicles and structure induced by irregular road profile. In addition a simplified decoupled Dynamic Nodal Loading (DNL) method is proposed. 11 DNL method generates a time series of concentrated nodal loading which represents the vehicle reaction force on the structure. Parametric studies for the effects of road roughness, speed parameter, mass ratio, and frequency ratio on the dynamic vehicle structure interaction are then carried out using DVE and DNL methods. Arborio (1982) have developed a methodology to stimulate vehicle dynamic through ADAMS car and Mat lab co-simulation, to compare the performance obtainable considering different active systems, a mechanical model of a new car was implemented through Adams car. The model was completed with a power train specifically conceived in Mat lab environment to overcome problems due to Adams car modelling most suitable to describe every operating condition, methodology developed was applied to evaluate a control strategy developed to carry out vehicle dynamics control. Kinematics of wheeled vehicles has been studied extensively with respect to automotive systems by Alexander and Maddocks (2008) for automotive systems and robotic vehicles operation on even terrain. Costa Netoetal describes the modelling and analysis process of a medium sized truck manufacture with regard to vibration and comfort behaviour. The vehicle model includes Hotchkiss suspensions front and rear with shackle and with a double stage with bump stops at the rear. Nonlinear shock absorber curves are also represented for the vehicle and cab suspensions. The effect on vehicle comfort is changing as a design parameter, can be predicted in the model and verified experimentally.

OBJECTIVES OF THE WORK
The objective of the work is to identify the best material for bumper which will ensure passenger safety, with high strength to weight ratio through the static and modal analysis using different engineering materials like Aluminium alloy, Chromium mild steel alloy and carbon composite.

• To reduce bumper weight.
• To determine the critical point which has the highest stress.
• To find different mode shapes of Bumper for the selected materials.
• To get an optimized in terms of reducing weight and deformation of selected materials of bumper.

MODELLING AND ANALYSIS OF THE STRUCTURE
Materials Used
Most auto bodies today use stamped sheet as structural members that are spot welded together to form a unitized body. This unitized structure is called the Body-In White (BIW). BIW structural members support most of the loads designed for strength, fatigue resistance, stiffness, as well crush loads for crashworthiness.

Body materials should also possess sufficient strength and controlled deformations under load to absorb crash energy, yet maintain sufficient survivable space for adequate occupant protection should a crash occur. Further, the structure should be lightweight to reduce fuel consumption. The majority of mass-produced vehicle bodies over the last six decades were manufactured from stamped steel components. Manufacturers build only a few limited production
Crash Worthiness

In the automotive industry, crashworthiness connotes a measure of the vehicle’s structural ability to plastically deform and yet maintain a sufficient survival space for its occupants in crashes involving reasonable deceleration loads. Restraint systems and occupant packaging can provide additional protection to reduce severe injuries and fatalities. Crashworthiness evaluation is ascertained by a combination of tests and analytical methods.

Crashworthiness Goals

Vehicle crashworthiness and occupant safety remain among the most important and challenging design considerations in the automotive industry. Designers create vehicles to provide occupant protection by maintaining integrity of the passenger compartment and by simultaneously controlling the crash deceleration pulse to fall below the upper limit of human tolerance. A crash deceleration pulse with an early peak in time and a gradual decay is more beneficial for protection of a restrained occupant. Therefore, the goal of crashworthiness is an optimized vehicle structure that can absorb the crash energy by controlled vehicle deformations while maintaining adequate

and specialty vehicle bodies from composite materials or aluminum.

Table 1: Material Properties of Steel

<table>
<thead>
<tr>
<th>S. No</th>
<th>Material</th>
<th>Density (kg/m³)</th>
<th>Young Modulus (GPa)</th>
<th>Poisson ratio</th>
<th>Yield Stress (MPa)</th>
<th>Fracture strain</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mild steel (chromium coated)</td>
<td>7800</td>
<td>210</td>
<td>0.3</td>
<td>300</td>
<td>16.6</td>
</tr>
<tr>
<td>2</td>
<td>Aluminium B390 alloy</td>
<td>2710</td>
<td>81.3</td>
<td>0.33</td>
<td>250</td>
<td>28.7</td>
</tr>
<tr>
<td>3</td>
<td>Carbon fiber composite</td>
<td>1600</td>
<td>85</td>
<td>0.15</td>
<td>150</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 2: Composition of Aluminum Alloy

<table>
<thead>
<tr>
<th>Element</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALUMINIUM</td>
<td>72.5-79.6%</td>
</tr>
<tr>
<td>COPPER</td>
<td>4-5%</td>
</tr>
<tr>
<td>IRON</td>
<td>&lt; 1.3%</td>
</tr>
<tr>
<td>Mg</td>
<td>0.45-0.65%</td>
</tr>
<tr>
<td>Mn</td>
<td>&lt; 0.5%</td>
</tr>
<tr>
<td>Ni</td>
<td>&lt; 0.1%</td>
</tr>
<tr>
<td>Si</td>
<td>16-18%</td>
</tr>
<tr>
<td>Ti</td>
<td>&lt; 0.2%</td>
</tr>
<tr>
<td>Zn</td>
<td>&lt;1.5%</td>
</tr>
</tbody>
</table>

Table 3: Composition of Mild Steel Chromium Alloy

<table>
<thead>
<tr>
<th>Element</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>0.17-0.33%</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.70-0.90%</td>
</tr>
<tr>
<td>Nickel</td>
<td>Nill</td>
</tr>
<tr>
<td>Chromium</td>
<td>0.7-1.15%</td>
</tr>
<tr>
<td>Iron</td>
<td>Remaining %</td>
</tr>
</tbody>
</table>

Table 4: Composition of Epoxy-Carbon Fiber Composite

<table>
<thead>
<tr>
<th>Component</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiber</td>
<td>carbon</td>
</tr>
<tr>
<td>matrix</td>
<td>Epoxy polymer</td>
</tr>
</tbody>
</table>
space so that the residual crash energy can be managed by the restraint systems to minimize crash loads transfer to the vehicle occupants.

Real world vehicle collisions are unique dynamic events where the vehicle may collide with another vehicle of similar or different shape, stiffness and mass or it may collide with another stationary object such as a tree, utility pole or bridge abutment. Generally, for the purpose of body development, safety experts classify vehicle collisions as frontal, side, rear or rollover crashes.

Further, the vehicle may experience a single impact or multiple impacts. Moreover, vehicle crashes occur over a wide range of speeds, persisting for a fraction of a second, such as when a vehicle hits a tree, or for few seconds as in rollover events. These factors illustrate some of the complex tasks involved in the design of vehicle structures to satisfy crashworthiness constraints for all collision scenarios.

Currently vehicle crashworthiness is evaluated in four distinct modes: 1) Frontal, 2) Side, 3) Rear and 4) Rollover crashes

**Crashworthiness Tests**

There are three categories of tests:

**Component Tests:** The component test determines the dynamic and/or quasi-static response to loading of an isolated component. These component tests are crucial in identifying the crush mode and energy absorption capacity.

**Sled Tests:** In a sled test, engineers use a vehicle buck representing the passenger compartment with all or some of its interior components. Dummies or cadaver subjects are seated in the buck to simulate a driver and/or passenger and subjected to dynamic loads, similar to a vehicle deceleration-time pulse, to evaluate the occupant response in a frontal impact or side impact. The primary objective of a sled test is evaluation of the restraints.

**Full Scale Barrier Impact Tests:** It involves collision of a guided vehicle, propelled into a barrier at a predetermined initial velocity and angle. Typically a barrier test uses a complete vehicle. Safety engineers run this barrier test to ensure vehicle structural integrity and compliance with government-mandated regulations.

**Types of Crash Tests:** All cars undergo front-and side-impact testing, which includes:

- 64 kph (40 mph) Front impact test: to assess car’s performance in severe accident.
- 50 kph (30 mph) Side impact test.
- 29 kph (18 mph) optional Pole impact test: to driver’s head.
- 40 kph (25 mph) child and adult pedestrian impact tests.

**Crash Tests-Regulatory Rules**

The following are the requirements for the consumer rash tests conducted by

- Federal Motor Vehicle Safety Standard (FMVSS)
- Insurance Institute for Highway Safety (IIHS)

FMVSS Frontal impact requirements:

- 30 mph (48 kph) into a fixed barrier
- Hybrid III in front driver and passenger seats
- Uses dummy injury measures for regulation
  - chest G’s $\leq 60$
  - HIC $\leq 1000$
  - Femur loads $\leq 10$KN
- Protection must be automatic
- Purpose of this test is to examine the performance of the occupant restraint systems
  - (seatbelts, airbags, etc.)

**IIHS Frontal impact requirements:**
40% offset, 40 mph (64 kph) into a deformable barrier
- Male Hybrid III dummy in front driver seat
- Good, Acceptable, Marginal and poor ratings to assess vehicle’s overall crashworthiness
- Rating based on:
  - Dummy injury measures
  - Structural performance
  - Restraint/dummy kinematics
- Evaluates the structural performance of the vehicle
- FMVSS Side impact requirements:
  - 33.5 mph (54 kph) crabbed impact
  - Impactor mass 1367.6 kg (3015 lb)

Use SID dummy in front and rear seats
Uses dummy injury measures for regulation
TTI(d) $\leq 85$ g for 4 door passenger cars
TTI(d) $\leq 90$ g for 2 door passenger cars
Pelvic acceleration $\leq 130$ g
Where $TTI(d) = 0.5 \times (Gr + Gs)$
  - $Gr =$ Max. Rib acceleration
  - $Gs =$ Lower spine acceleration

IIHS Side impact requirements:
- Impactor mass $= 1500$ Kg
- Impactor shape derived from Ford F150 front profile
- 30 mph perpendicular impact
- Driver and rear passenger dummies
- Purpose is to represent crash type that poses greatest risk to occupants (pickups/SUV as striking vehicle)
- Promote head protection

**Modeling**
The model of the chassis frame has been created using the primitives approach using SOLIDWORKS software.

1. Model is a uni-body structure
2. The figures shown in the literature review were the basis of our model
3. A work plane is established (xy plane)
4. By using different geometrical primitives basic geometry is obtained
5. By using different modeling options of SOLIDWORKS for several times model is created according to dimensions as shown in Figure 3.
Meshing of Model

- By saving the file in igs format we can open that in ANSYS WORKBENCH for doing analysis
- In ANSYS WORKBENCH igs file is imported
- Now meshing is done using solid element 187
- Element division is taken as 10
- After meshing material is assigned for solid element, the element solid187 (ANSYS library) is taken.
- Refined mesh is shown in Figure 5.

ANALYSIS OF CAR CHASSIS FRAME-BUMPER

Types of Analysis Used

The following analysis has been carried out

- Static Analysis
- Modal Analysis
- The meshed model is initiated for analysis

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The boundary conditions are imposed on all the end support edges in all DOF.

The final car frame with imposed boundary conditions is shown in Figure 6.

**Static Analysis**

A static analysis calculates the effects of steady loading conditions on a structure, while ignoring inertia and damping effects, such as those caused by time-varying loads. A static analysis can, however, include steady inertia loads (such as gravity and rotational velocity), and time-varying loads that can be approximated as static equivalent loads (such as the static equivalent wind and seismic loads commonly defined in many building codes).

**Loads in a Static Analysis:** Static analysis is used to determine the displacements, stresses, strains and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed; that is, the loads and the structure’s response are assumed to vary slowly with respect to time. The kinds of loading that can be applied in a static analysis include:

- Externally applied forces and pressures
- Steady-state inertial forces (such as gravity or rational velocity)
- Imposed (non-zero) displacements
- Temperatures (for thermal strain)
- Fluencies (for nuclear swelling)

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**Linear vs. Nonlinear Static Analysis:** A static analysis can be either linear or non linear. All types of nonlinearities are allowed-large deformations, plasticity, creep, stress stiffening, contact (gap) elements, hyper elastic elements, etc.

**RESULTS AND DISCUSSION**

The simulation results are shows the analysis related to the bumper of the vehicle in static and model analysis while using the different types of the composites.

**Static Analysis**

The below results related to the static structural analysis with three different types, i.e., total deformation, equivalent stress and maximum principal elastic strain. It can be observed that in Figure 8a shows the maximum deformation of the bumper when using the Al alloy is 45.871 mm. In Figure 8b related to the maximum von-misses
Figure 8: Schematic Diagram Showing the Static Analysis on Al Alloy Bumper (a) Total Deformation, (b) Equivalent Stress (c) Elastic Strain

(a) Total Deformation
(b) Equivalent Stress
(c) Elastic Strain

Figure 9: Schematic Diagram Showing the Static Analysis on Carbon Fiber Composite Bumper (a) Total Deformation, (b) Equivalent Stress (c) Elastic Strain

(a) Total Deformation
(b) Equivalent Stress
(c) Elastic Strain
stress of the said material is 1792.3 Mpa and the Figure 8c represent the maximum principal elastic strain of the Al alloy is 0.015131.

In Figure 9 shows the simulations related to the static analysis of the carbon fibre composite material using on bumper. It can be observed that the deformation of the material is 42.847 mm, the stress of the material is 1905.1 Mpa and the strain of the material is 0.016052.

In Figure 10 shows the results related to the static analysis mild steel chromium coated bumper. It can be observed that the deformation of the material is 17.697 mm, the stress of the material is 1811.4 Mpa and the strain of the material is 0.0059326.

Model Analysis

The simulation result shows the modal analysis of three different materials is discussed in this section. The natural frequency of the different materials is determined in this section. It is a frequency at which the system tends to oscillate in the absence of driving and damping force. The free vibrations are developed on any elastic body is called natural vibration of the body. The natural frequency of the material is depends on the mass and stiffness of the material. The mass of the material is varied always depends on the density of material. Similarly, the stiffness of the material is always depends on the force and deflection of the geometry of the material. Since all the geometries taken in these analysis are identical, the chances for the variation of the frequencies are only due to the change in the density of the materials.

The natural frequency of the three different material models is given in Table 5. From these results it can be observed that the carbon fibre composite material has more natural frequency compared to other two materials.
Figure 11: Schematic Diagram Showing the Natural Frequency of Aluminum Alloy (a) Mode 1, (b) Mode 2, (c) Mode 3, (d) Mode 4, (e) Mode 5, (f) Mode 6, (g) Mode 7, (h) Mode 8, (i) Mode 9 and (j) Mode 10
Figure 12: Schematic Diagram Showing the Natural Frequency of Carbon Fiber Composite
(a) Mode 1, (b) Mode 2, (c) Mode 3, (d) Mode 4, (e) Mode 5, (f) Mode 6, (g) Mode 7,
(h) Mode 8, (i) Mode 9 and (j) Mode 10
Figure 13: Schematic Diagram Showing the Natural Frequency of Mild Steel Chromium Alloy (a) Mode 1, (b) Mode 2, (c) Mode 3, (d) Mode 4, (e) Mode 5, (f) Mode 6, (g) Mode 7, (h) Mode 8, (i) Mode 9 and (j) Mode 10
In the present research work the authors discussed the design and analysis of a low passenger vehicle of ambassador car bumper in automobiles. Initially, the author modelled by using solid works and it is analysed by statically. In static analysis they compare the deformation, von-mises stress and strain of the three different materials, i.e., Al alloy, Carbon fibre and mild steel materials. The carbon fibre composite obtained highest von-mises stress value and the lowest deformation of the other two materials. In addition to, the model analysis due to low density and the natural frequency is analysed of the three different materials. Finally, the carbon fibre composite material is giving more natural frequency compare to other materials.

**REFERENCES**


