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Crash Analysis of Car Bumper Beam in Frontal Impact

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ABSTRACT

Bumpers are structural components installed to reduce physical damage to the front and rear ends of a light/heavy motor vehicle from low-speed collisions. Damage and protection assessments are the commonly used design criteria in bumper design. For damage assessment, the relative displacements representing stiffness performance are examined and crash test will be done. The purpose of a crash analysis is to see how the car will behave in a frontal collision. In this study, impacts and collisions involving a car bumper beam model are simulated and analysed using LS-Dyna software. The bumper should support the mechanical components and the body. It must also withstand static and dynamic loads without undue deflection or distortion. The given model is tested under frontal collision conditions and the resultant deformation and von-Misses stresses are determined. The five different materials including composites are used for the bumper beam analysis. The crash analysis simulation and results can be used to assess both the crashworthiness of current bumper and to investigate ways to improve the design. Five different materials used to determine the performance of the bumper beam in crash test. The comparison of baseline material with composite material is presented in the study. This type of study methods are integral part of the design cycle and can reduce the need for costly destructive testing program.

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I. INTRODUCTION

Nowadays, in development of technology especially in engineering field make among the engineers more creative and competitive in designing or creating new product. They must be precise and showing careful attentions on what they produce. Here, we concentrate on automotive industry. The greatest demand facing the automotive industry has been to provide safer vehicles with high fuel efficiency at minimum cost. Current automotive vehicle structures have one fundamental handicap, a short crumple zone for crash energy absorption one of the options to reduce energy consumption is weight reduction. However, the designer should be aware that in order to reduce the weight, the safety of the car passenger must not be sacrificed. A new invention in technology material was introduced with polymeric based composite materials, which offer high specific stiffness, low weight, corrosion free, and ability to produce complex shapes, high specific strength, and high impact energy absorption.

Substitution of polymeric based composite material in car components was successfully implemented in the quest for fuel and weight reduction. Among the components in the automotive industry substituted by polymeric based composite materials are the bumper beam, bumper fascia, spoiler, connecting rod, pedal box system, and door inner panel. The bumper system consists of three main components, namely bumper beam, fascia and energy absorber. The automotive body is one of the critical subsystems of an automobile, and it carries out multiple functions. It should hold the parts of the vehicle together and serve to filter noise and vibration. Additionally, it should be able to protect its occupants when accidents happen. To do this, the automotive body designer should create a structure with significant levels of strength, stiffness, and energy absorption.

The rate of motor vehicle accidents globally is alarming and naturally increases as the number of vehicles on the roads increases. The trend in the rate of road accidents is the same in many countries. It is estimated that 1.2 million people are killed in road crashes and nearly 50 million are injured worldwide every year. This mission of road safety research is to reduce the incidence of road traffic accidents and to minimize their effects once an accident has happened. On contrast, the goal of this dissertation is to reduce the effect of crash impact on passengers in collision of vehicles travelling at medium speeds. This corresponds to rolling impact and it would be beneficial to improve upon this design criterion. The automotive industry has always been known to be very competitive as far as its design and material usage are concerned.

The automotive industry always faces greater market pressure to develop high quality products more quickly at lower cost, reduce weight in order to improve fuel efficiency and cost. Automotive bumper system was selected as a study of this paper. Automobile bumper is a structural component of an automotive vehicle which contributes to vehicle crashworthiness or occupant protection during front or rear collisions. The bumper system also protects the hood, trunk, fuel, exhaust and cooling system as well as safety related equipments such as parking lights, headlamps and taillights, etc.

II. PROBLEM STATEMENTS

Incorrect analysis & lower strength of bumper beam of a car may rise to damages in bumpers due to moderate impacts while driving. To strengthen the bumpers some study & correct analysis is needed in this field.

III.SCOPE OF THE WORK

The study will focus on existing design performance, advantage and limitations. Based on observations, improvements in the baseline design will be in the form of material change. The baseline design is tested in the lab for the deflection existing material. The same front bumper design will be tested using FEM software LS-Dyna for impact loads. The comparison will be done for five different materials. The best suitable material (Minimum weight and cost effective) is suggested for the manufacturing.

IV.OBJECTIVE OF THE WORK

- The objective of this work is to study front bumper of one of the existing passenger car in Indian market (TATA INDICA CAR BUMPER SYSTEM) and suggest design Improvement in front bumper of a passenger car using Impact Analysis such that the following objective will be served.
- Model and Simulate Car bumper beam for the impact at the centre of the beam.
- Use different materials in simulation to generate design parameters for better impact attenuation bumpers.
- Model and simulate impact phenomenon for composite materials in order to study crash dynamics.
- Compare the results of the conventional materials and composite materials for the crashworthiness.
- Compare Experimental & FEA results

V. EXPERIMENTAL SET UP

Purpose of the test

Impact testing machine is used to determine material behaviour at higher deformation speeds. Classical pendulum impact tester will give deflection caused to bumper after hammer impact.

On release, the pendulum swings down to hit the bumper beam and the deflection in beam in doing so is measured to be compared against result achieved by FEA analysis.

Following are the readings obtained from the test:

Sr. No.	Material Name	Test Results Displacement, mm
1	Actual bumper beam specimen-Steel	10.5

VI.FINITE ELEMENT ANALYSIS

The FEA study will be divided in following steps:
Baseline model analysis –
Crash analysis of car bumper beam
New model analysis
Comparison of baseline and new design models
Conclusion and remark

The main purpose of bumper is to absorb shock in case of a collision. Several materials have been used to develop these shock-absorbing capabilities, such as steel, aluminium, glass mat thermoplastics and sheet molding compound. The purpose of this project is to design a bumper which is to improve crashworthiness of the bumper beam. Crashworthiness is the ability of the bumper beam to prevent occupant injuries in the event of an accident and this is achieved by minimizing the impact force during the collision. In the next step, the composite materials like GMT, LFRT and KLFRT were used and studied to find the best impact behaviour. Here KLFRT material was chosen for its outstanding results in mechanical and thermal properties. The summarize, the objective of this research was to develop and propose a natural fiber composite bumper, which could satisfy following requirements:

Easy to manufacture by the shape. This was accomplished by removing strengthening ribs of bumper.

Being economical by utilizing low-cost composite materials.

Achieving reduced weight compared to the metallic bumper.
Achieving improved or similar impact behaviour compared to the currently used metallic structure.

Table: Mechanical properties of the bumper materials

Sr. No.	Material	Young's Modulus (GPa)	Poisson's ratio	Yield Strength (MPa)	Density (Kg/m3)
1	Steel	210	0.3	700	7850
2	Aluminium	70	0.33	480	2710
3	LFRT	9	0.45	190	1200
4	GMT	12	0.41	230	1280
5	KLFRT	8.5	0.42	220	1240

LS DYNA FOR BUMPER TESTING

LS-DYNA is an advanced general-purpose metaphysics simulation software package that is actively developed by the Livemore Software Technology Corporation (LSTC). While the package continues to contain more and more possibilities for the calculation of many complex, real world problem, its origins and core-competency lie in highly nonlinear transient dynamic Finite Element Analysis (FEA) using explicit time integration. LS-DYNA is being used by the automobile, aerospace, construction, military, manufacturing and bioengineering industries.
LS-DYNA is widely used by the automotive industry to analyze vehicle designs. LS-DYNA accurately predicts a car's behaviour in a collision and the effects of the collision upon the car's occupants. With LS-DYNA automotive companies and their suppliers can test car designs without having to tool or experimentally test a prototype, thus saving time and expense.
A crash simulation is a virtual recreation of a destructive crash test of a car using a computer simulation in order to examine the level of safety of the car and its occupants. Crash simulations are used by automakers during Computer-Aided Engineering (CAE) analysis for the crashworthiness in the Computer-Aided Design (CAD) process of modelling new cars. During a crash simulation, the kinetic energy, energy of motion, that a vehicle has before the impact is transferred into deformation energy, mostly by plastic deformation (plasticity) of the car body material (Body in White), at the end of the impact.
Data obtained from a crash simulation indicate the capacity of the car body structure to protect the occupants during a collision (and also pedestrians hit by a car) against injury. Important results are the deformations (for example, steering wheel intrusions) of the occupant space (driver, passenger) and the decelerations (for example, head acceleration) felt by them, which must fall below threshold values fixed in legal car safety regulations. To model real crash tests, today's crash simulations include virtual models of crash test dummies and passive safety devices (seat belts, airbags, shock absorbing dash boards.etc.).

Thus the basic concept of the existing bumper systems, the type of materials and the effect of different cross section used in bumper system were studied. Software required for modelling, meshing and analyzing the bumper beam such as Hypermesh and LS Dyna were utilised.

Explicit Simulations
Only explicit crash simulations were performed in this study. However, implicit dynamic simulations of the bumper beam-longitudinal system can also be performed but the convergence becomes critical due to the number of contact definitions, which requires lot of simulation time (Kokkula et al 2003). LSDYNA uses a central difference operator for time integration, requiring a limitation on the time-step size. To obtain numerical stability during the crash simulations, the time-step size is typically in the order of one microsecond. All the simulations were executed with a variable time-step. It is also possible to execute the simulations with a fixed time-step, which generally has the potential of yielding large errors in analyses including inertia effect.

DEVELOPMENT OF BUMPER BEAM FOR THE FEA SIMULATIONS
Specification of the bumper
As initially a chosen passenger car – TATA INDICA bumper beam in analysis.
Baseline Material used in bumper beam - steel

S. No.	***Parameter Description***	***Value***
1	*L Length of bumper*	*1020 mm*
2	*X Width of bumper*	*80 mm*
3	*Ө_ Angle of bumper*	*26 degree*
4	*Thickness*	*2 mm*

Meshing

The conventional model which was developed in CATIA software has to be meshed for analysis of crash. For this HYPERMESH software is used. Altair Hypermesh is a high-performance finite element pre-processor that provides a highly interactive and visual environment to analyze product design performance. With the broadest set of direct interfaces to commercial CAD and CAE systems, Hypermesh provides a proven, consistent analysis platform.

- Number of nodes = 1587
- Number of elements = 1426
- Mesh element size -10 mm
- Element Type = Single order shell elements
- Element formulations = ELFORM 16
- Number of integration points = 5
- The gap between the Rigid wall and bumper beam is 10 mm

Material models used in the LS-Dyna

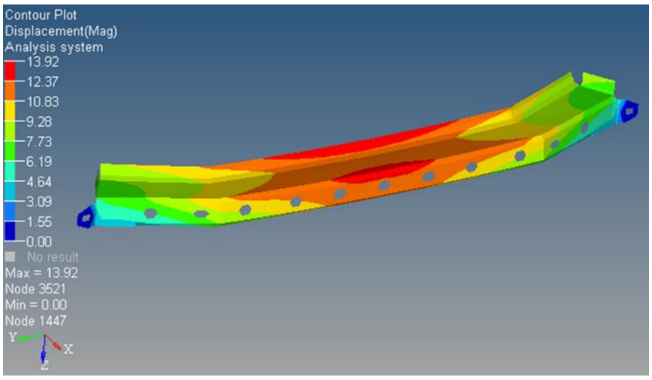
Bumper beam - MAT24

PIECEWISE_LINEAR_PLASTICITY

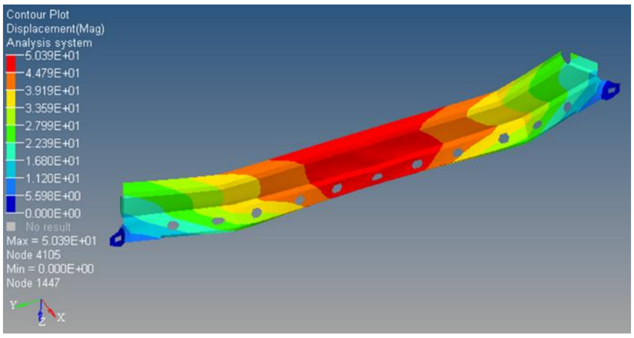
VII. RESULT AND DISCUSSIONS

DISPLACEMENT RESULTS

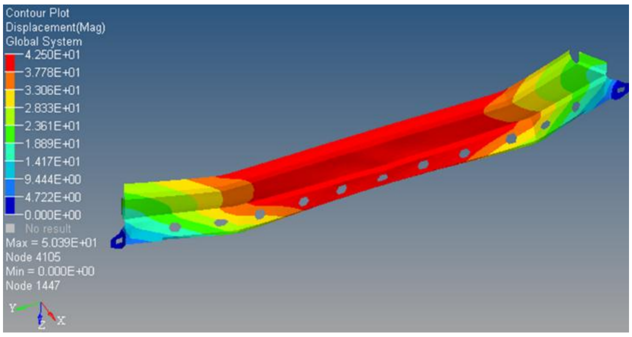
The effect of impact loading on bumper beam system is investigated by comparing the displacement between five different materials within model. The deflection contour plots are shown in the following pictures.



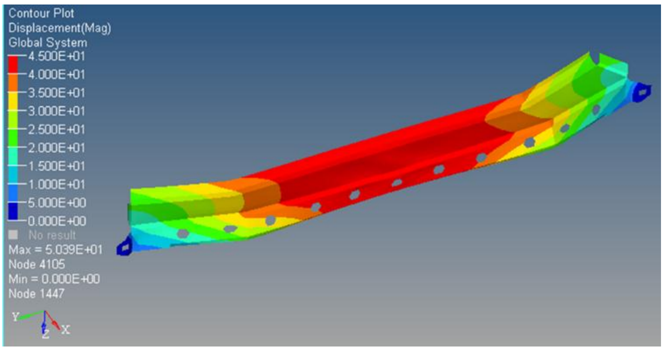
Displacement contour plot: Steel Bumper System



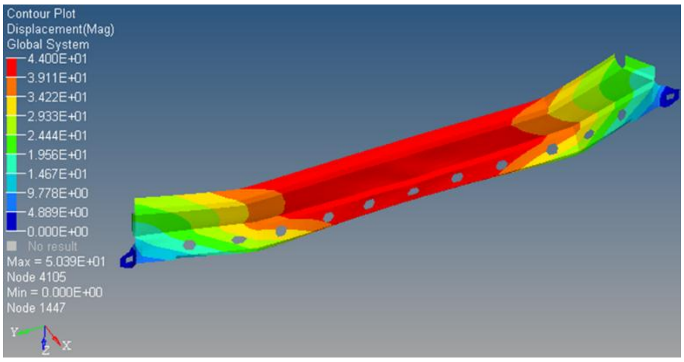
Displacement contour plot: Aluminium Bumper System



Displacement contour plot: LFRT Bumper System



Displacement contour plot: GMT Bumper System



Displacement contour plot: KLFRT Bumper System

Following Table shows the Displacement of different bumper beam during the frontal collision. KLFRT material bumper beam shows more displacement compared to other material bumper beams during the collision.

Table Displacement Results of the bumper materials

Sr. No.	Material Name	Displacement, mm
1	Steel	13.92
2	Aluminium	50.3
3	LFRT	42.5
4	GMT	45
5	KLFRT	44

VON-MISES STRESS RESULTS

The equivalent stress (von-Mises stress) is considered as failure criteria for steel material since, the tensile strength and compressive strength of the steel material remain same. Therefore, the distortion energy theory (von-Mises theory) will become the ultimate failure criteria for the steel material. There are four different materials apart from steel material used for the bumper system. The same failure criterion is used for the all listed materials. Following contour plots shows the von-Mises stress.

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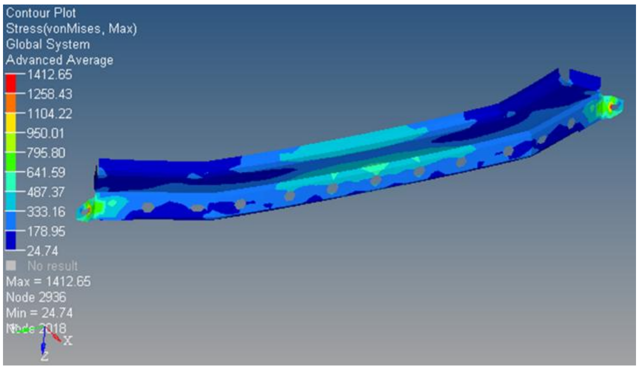
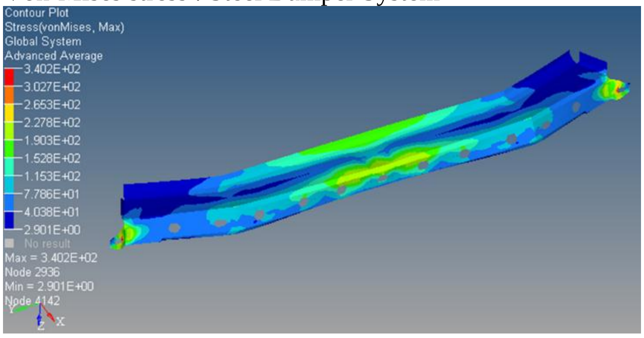
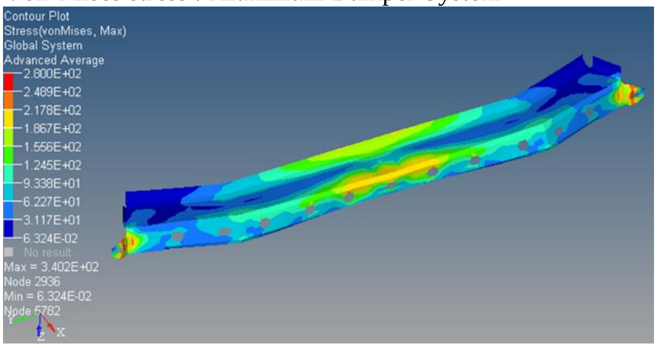


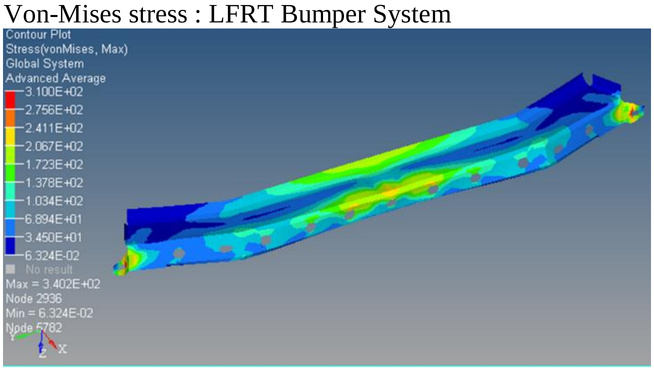
Von-Mises stress : Steel Bumper System



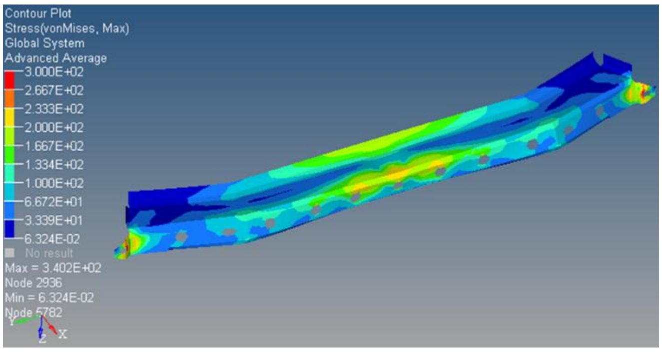
Von-Mises stress : Aluminum Bumper System



Von-Mises stress : LFRT Bumper System



Von-Mises stress : GMT Bumper System



Von-Mises stress: KLFRT Bumper System

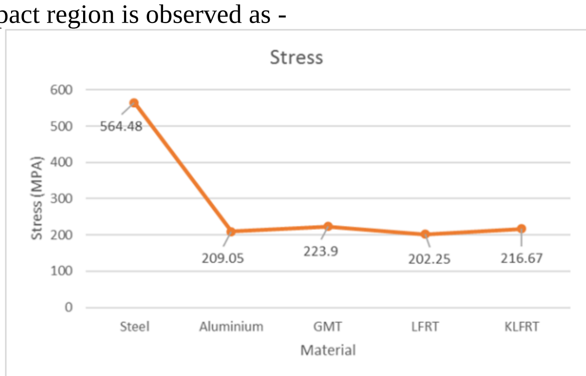
Table: von-Mises stress results of the bumper materials

Sr. No.	**Material Name**	**Average von-Mises stress at impact region, MPa**	**Maximum von-Mises stress observed, MPa**	**Yield Strength MPa**	**Factor of Safety**
1	Steel	564.48	1412.65	700	1.24
2	Aluminium	209.05	340.2	480	2.29
3	LFRT	202.25	280	190	0.93
4	GMT	223.9	310	230	1.03
5	KLFRT	216.67	300	220	1.01

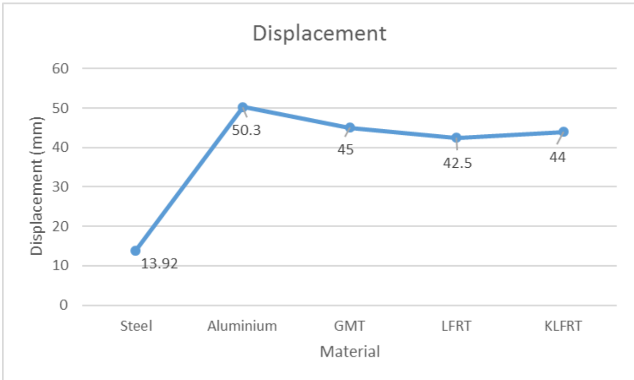
VIII. CONCLUSION

Impact testing leads to improvement of the safety systems. These systems again have to be tested for their workability during a crash. Hence crash testing plays a vital role in continuous improvement of the safety systems. Design changes in vehicles and the location of engine block have been the results of evolution of crash testing.

During the analysis test the average Von-Mises stress at impact region is observed as -



During the analysis test the displacement at impact region is observed as –



From the impact test, it is concluded that, the GMT & Aluminium are more suitable for the bumper beam system. GMT is already has a wide usage amongst Automobile sector. So availability is not an issue. For weight reduction purpose GMT can replace steel bumper beams. Aluminium lowers the weight of the system than steel but, is still more than compared to GMT.

Also from Table 4.8.2 it is observed that there is a failure at end holder region. They found to be weak. Therefore, in future further studies could suggest design changes in shape or size in addition to material change, which could further increase the design quality & will reduce the probability of damage during a crash.

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