DESIGN AND DEVELOPMENT OF IMPACT ENERGY ABSORBING BUMPER

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Abstract: With the new inventions in technology, automotive sector has been growing rapidly. Also road accidents and mishaps have increased remarkably. According to the report by Ministry of Urban Development 2013, 47% of accidents in Delhi took place with pedestrian as victims and 33% in Vadodara. For the pedestrian and occupant safety, the design of bumper is one the main consideration. The objective of this work is to design and develop a shock absorbing bumper for M1 category of vehicle for better safety which is easy to manufacture, environment friendly and cost effective. The different energy absorbing materials are tried such as honeycomb, foam and compressive structures to reduce the transfer of impact force under collision. The modelling of bumper is done in CATIA and simulation is carried out by using ANSYS Explicit Dynamics Tool. After the fabrication, the testing is performed as per standard. The result shows reduction in the impact energy with energy absorber.

Keywords: Bumper, Honeycomb, foam, Impact analysis, pedestrian safety, leg form test

INTRODUCTION

Automotive industry is one of the fastest growing sectors in our country. Safety has become one of the most important criteria of the vehicle designing. With more than one death and four injuries every minute, unfortunately India has been reporting highest numbers of road fatalities in the world. The loss to the Indian economy due to fatalities and accident injuries is estimated at 3% of GDP.

A bumper system mainly consists of 3 components, namely fascia, bumper beam and mounting brackets. There is generally a gap of 70mm to 100mm between the fascia and the bumper beam which can be utilized towards improvement in safety, by inserting an energy absorbing component. This work dealt with design and development of energy absorbing bumper to absorb the impact energy under collision.

LITERATURE REVIEW

Bumper System

The Bumper of a vehicle plays an important role for the safety of the pedestrians in case of impacts at lower speeds. The design of bumper also decides the aesthetics looks of a vehicle. The main function of bumper is to sustain low speed impacts and protect various components of vehicle such as, headlamps, hood (bonnet), parking lights, trunk door, tail lamps, radiator, etc. however its contribution becomes insignificant at higher speeds.

Fascia

The fascia is that part of a bumper that is visible on the outside of the vehicle, is painted usually the same/different color as of body, and serves as a large portion of either the front or back of the vehicle. Fascia is generally made of thermoplastic olefins (TPOs), polycarbonates, Polyesters, polypropylene, polyurethanes, polyamides, or blends of these with, for instance, glass fibers, for strength and structural rigidity.

Bumper beam

Bumper beam is one of the main parts of the bumper system that protects a vehicle from front and rear collisions, located just behind the fascia. It is generally made up of steel, aluminum, plastic, or composite material.

Energy Absorber

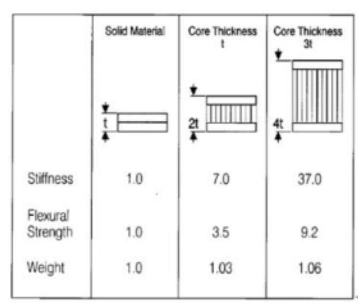

Fig 1: comparison of different parameters of honeycomb

Honeycombs are one of those very special structures which have lot of potential to be applied in the usage of the absorption of shock energy. These are continuous cellular structure consisting of array of open cells. From a safety perspective, honeycomb structures are excellent energy absorbers. Their consistency in shape and spacing efficiency makes them stand out from others in their class. Not only with the absorption energy, has honeycomb structure also excelled in providing repeatable structure which evidently repeats its crushing process. Since being similar structure throughout the body, they are simple design, cost-efficient and time-efficient in manufacturing. These honeycomb structures usually manufactured between two relatively hard faces on top and bottom which helps to force distribution to a certain extent. These structures are usually called as "Sandwich Panel Honeycomb structures". Along with pedestrian protection the bumper has to satisfy the low speed impact test of 4kmph too as per regulation. This becomes a difficult task as in order to achieve lower leg protection, a relatively soft bumper system is required while a relatively stiff system is typically needed to manage barrier and pendulum impacts. The faster the energy absorbing structure responds to the impact event, the more efficient the energy management and, therefore, the smaller the depth of space needed to absorb the energy from the event. The following impact energy balance equation used to calculate the impact efficiency of a bumper system:

$0.5\ mv^2$ * Compliance = Force * Distance * Efficiency……(1)

Where,
m = Vehicle mass
v = Impact velocity
Vehicle compliance is approximately 0.85 for barrier test

Bumper Testing

In drop test, a known quantity of the load is suspended at a certain known height through cable or rope such that the mass when released, the fall is free fall but the path is guided through auxiliary or supporting cables. The test works on the principle of conservation of energy. The energy at the surface can be calculated by the following formula:

$$0.5 * mv^2 = mgh \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (2)$$

Where,
m = suspended mass or mass of impactor
v = Velocity with which the impactor impacts the bumper facia
g = Acceleration due to gravity = 9.8 m/s^2
h = height of the impactor from bumper fascia

In lower legform test, impactor shall consist of two foam covered rigid segments, representing femur as upper leg and tibia as lower leg, joined by a deformable and simulated knee joint. The overall length of the impactor shall be 926 ± 5 mm, having a required test mass of 13.4 ± 0.2 kg.The impactor is launched at the velocity of 11.1 m/s (40 kmph) and the different reading are noted by data acquisition system.

A trolley with specific design and dimensions as per standard is made to collide with a stationary vehicle. The weight of trolley is made almost equal to the weight of vehicle. The velocity is maintained at 1.1 m/s (4 kmph). No specific readings are needed, only visual inspection is required. The systems and components such as headlights, parking lights, indicators, radiators, etc. are checked for their proper functioning.

DESIGNING OF ENERGY ABSORBER

Energy absorber is a component in the bumper system placed in between bumper fascia and bumper beam. It can be metal, non-metal or a composite. In the past, only metal bumpers were used to mitigate the crash. But these metal bumpers slowly vanished for the many reasons one being heavy weight. Thus plastic-polymer bumpers were introduced. But to further improve the efficiency of the bumper system, energy absorbers are required.

Foam

The foam used as energy absorber which is filled to occupy maximum empty space available in bumper assembly. It should be taken into consideration that filling of foam should not obstruct in any other systems, such as radiator, etc. Few researchers have used foams to manufacture sacrificial crush boxes, which is very impressive idea indeed.

Fig 2: Foam

Honeycomb

Honeycombs are better energy absorbers. The strength or energy absorbing capacity varies with its cell size and hence a variety of combinations can be tried. Also, instead of using a honeycomb of a single cell size, a sandwich of two honeycombs having different size can be used. This sandwich absorbs more energy that the individual two honeycombs.

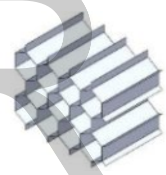

Fig 3: Honeycomb

Double cylinder model

The double cylinder model with different compression stages is used as energy absorber. The no. of stages depends on the no. of cylinders used. Due to space constraints and to make energy absorber less stiff, the two stage compression is used.

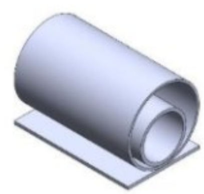

Fig 4: Double cylinder model

Double cylinder filled with foam model

In this case, the double cylinder model is filled with foam and to make energy absorber less stiff, the two stage compression is used.

Fig 5: Double cylinder filled with foam

Double half cylinder model

To increase the compression stages and energy absorbing capacity, a unique design is considered with double half cylinder model with 4 stage compression.

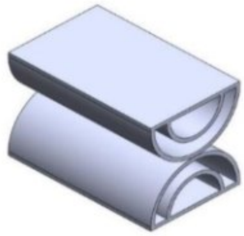

Fig 6: Double half cylinder model

MATERIAL SELECTION

For the double cylinder model and double half cylinder model, the cylinders are made up of aluminum because of its unique properties: low weight (density 2,700 kg/m3), Strength (Aluminum alloys commonly have tensile strengths of between 70 and 700 MPa.), machining, formability, joining, corrosion resistance, non-magnetic material, zero toxicity.

Based on literature it is found that Al foam is one of the best energy absorber present but it is not available yet locally. Considering for a light weight, easily available, easily compressible, and low cost, Hitlon foam is used to fill in hollow cylinders of double cylinder model.

ENERGY ABSORBER SAMPLES TESTING

The compression tests conducted on each sample using Universal Testing Machine to find out energy absorbing capacity.

Table 1: Sample Testing Results

Sr. No.	Sample	Energy Absorbed (J)
1	Hitlon foam	4.8
2	Honeycomb	93.05
3	Double cylinder model filled with foam	257.22
4	Double cylinder model	326.5
5	Double half cylinder model	396.89

The result shows that Hitlon foam is easily compressible, and absorbs very less energy, hence it's not effective to be used. Although, the honeycombs are good energy absorbers but the best results are achieved at larger lengths. Hence it's proven that it's not effective for such a small space to be filled between beam and fascia.

Foam absorbs less energy whereas aluminium pipes absorb more energy. But, the energy absorbed by combining these two is not equal to the sum of energy absorbed by each component individually. The result shows that the energy absorbed by double cylinder model with foam is less than hollow cylinder. This is because; foam absorbs less energy but occupies more space, and does not allow cylinders to get compressed to their limit, reducing overall performance. The double cylinder model is giving good energy absorption due to two stage compression.

Finally unique design of tangentially joined two double half cylinder with 4 stage compression, leading to better energy absorption results than the other designs. This is found to be more effective than other designs. Hence it is selected as energy absorber to be used in the bumper system.

MODELLING OF BUMPER SYSTEM

A bumper of M1 category vehicle is considered as test sample. The modelling of bumper system is done in CATIA. It consists of following bumper beam and facial.

Bumper Beam

Bumper beam is one of the main parts of the bumper system that protects a vehicle from front and rear collisions, located just behind the fascia. It is made up of steel (Density = 7850 kg/m3, Young's modulus 200 GPa and Poisson's ratio = 0.3). Generally there is no energy absorber in front of the beam and hence in case of a collision both fascia and beam get affected.

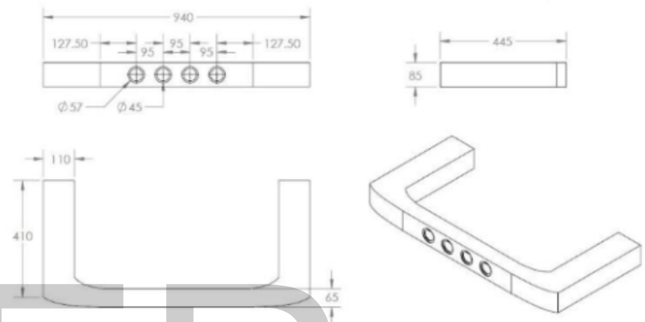

Fig 7: Design of Bumper Beam

Fascia

The fascia is a part of a bumper that is visible on the outside of the vehicle and serves as a large portion of either the front or back of the vehicle. Fascia is generally made up of polyurethane (Density = 1265 kg/m3, Bulk modulus = 2 GPa and Shear modulus= 5 MPa). The fascia deforms in case of a collision but since it is made of a highly elastic material which regains its shape with little or no repair.

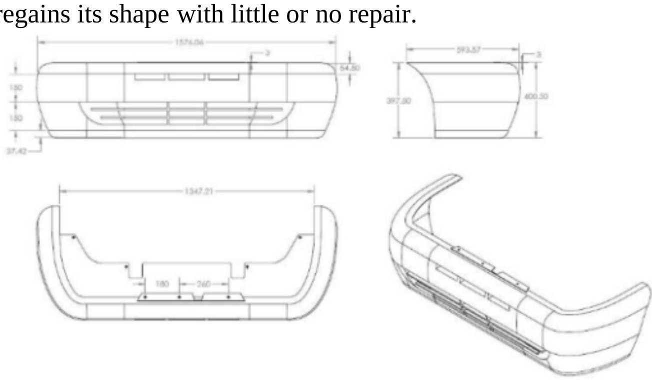

Fig 8: Design of Fascia

Assembly (bumper system)

A bumper system mainly consists of 3 components, namely Fascia, Bumper beam and mounting brackets. The energy absorber is fixed to the beam on the front side facing the fascia so that it can absorb the impact energy in case of a frontal collision. In case of a frontal impact, first the fascia will deform and absorb little energy upto energy absorber, then energy absorber will start compressing and absorb high amount of energy which reducing the transfer of impact energy to the bumper beam.

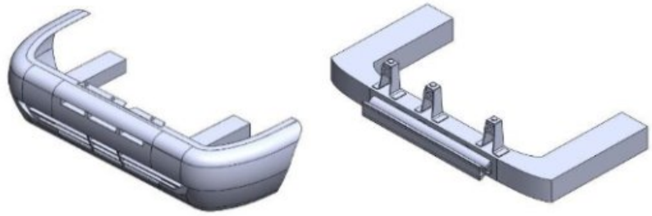

Fig 9: Assembly: The Bumper System

Simulation of Bumper System

The simulations of bumper system are performed by using ANSYS Explicit dynamics tool as per AIS 100 and ECE R-42 regulations.

Simulation as per AIS 100

The lower leg form impactor shall consist of two foam covered rigid segments, representing femur as upper leg and tibia as lower leg, joined by a deformable, simulated knee joint. The overall length of the impactor shall be 926 ± 5 mm, having a required test mass of 13.4 ± 0.2 kg.

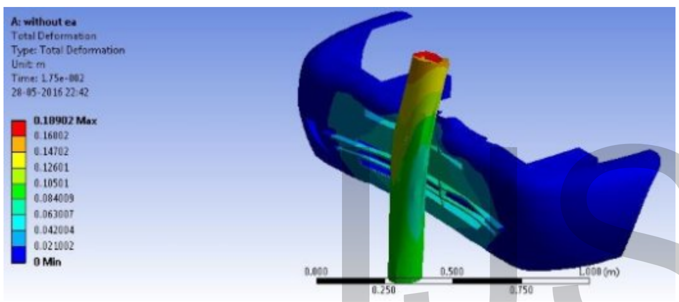

Fig 10: Simulation graphic of Lower Legform Test

Table 2: Simulations according to AIS 100

Sr. No.	Component	Parameter	without Energy Absorber	With Energy Absorber
1	Impactor	Total energy	798.19 J	792.93 J
2	Fascia	Internal energy	148.89 J	75.63 J
3	Energy Absorber	Internal energy	-	107.13
4	Beam	Total energy	73.073 J	24.31 J
5	Beam	Deformation	1.52 mm	1.12 mm

Simulation result shows that when the energy absorber is attached to the beam, the energy absorbed by the fascia is less compared to the without energy absorber. As the space available for fascia to deform freely has reduced, because of the introduction of energy absorber. The energy absorbed by energy absorber is 107.13 J which leads to the reduction in energy transfer to the beam. Only 24.31 J of energy is transferred to the beam causing a maximum deformation of 1.12mm of the beam.

Simulations as Per ECE R-42

The impactor has a particular design as mentioned in ECE R-42 standard. The impactor is part of a trolley. The weight of trolley is made almost equal to the weight of the vehicle to be tested.

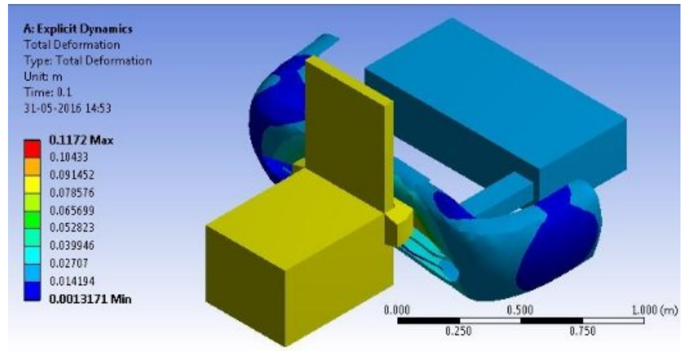

Fig 11: Simulation graphic of Low Speed Impact Test

Table 3: Simulations according to ECE R-42

Sr. No.	Component	Parameter	without Energy Absorber	With Energy Absorber
1	Impactor	Total energy	615.13 J	615 J
2	Fascia	Internal energy	116.22 J	10.96 J
3	EA	Internal energy	-	428.83 J
4	Beam	Total energy	178.66 J	145.28 J
5	Beam	Deformation	22.8 mm	10.4 mm

Here also result shows that the introduction of energy absorber leads to reduction of energy transfer to the beam and hence also a reduction in deformation of the beam.

Simulation of Drop Test

The impactor of weight 94.5 kg used. The impactor was made up of 6 plates combined. One with weight 37 kg and other 5 with weight of 11.5 kg each. The applied weight can be varied from 37kg to 94.5 kg. The velocity of impact is 4.2 m/s.

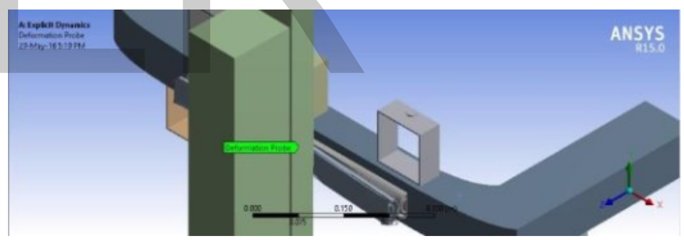

Fig 12: Simulation graphic of Drop Test

Table 4: Simulations of Drop Test

Sr. No.	Component	Parameter	without Energy Absorber	With Energy Absorber
1	Impactor	Total energy	832.92 J	832.92 J
2	Fascia	Internal energy	191.56 J	72.95 J
3	EA	Internal energy	-	692.19 J
4	Beam	Total energy	533.18 J	95.39 J
5	Beam	Deformation	0.18 mm	0.04 mm
6	EA	Deformation	-	5.27 mm

The result shows the energy absorber has absorbed a high amount of energy i.e. 692.19 J leading to transfer of only 95.39 J of energy to the beam causing a maximum deformation of 0.04 mm of the beam.

Table 5: Summary of Simulations

Sr. No.	Test	Energy transfer to beam Without EA (J)	Energy transfer to beam With EA (J)	% Reduction in energy transfer
1	Low speed impact test (ECE R-42)	178.66	145.28	**18.68**
2	Lower leg-form test (AIS 100)	73.07	24.31	**66.73**
3	Drop test	533.18	95.39	**82.1**

The results vary because of different materials, weights and speeds of impactor. It is shows that when area of impact is smaller, energy absorbed is higher. In all cases, effectiveness of energy absorber is seen.

EXPERIMENTAL DROP TEST

The fabricated energy absorber fitted to the bumper beam with fascia. The weights rose over a height of 0.9 m from the topmost point of fascia using inbuilt pulley mechanism of the setup. The drop test performed using a release mechanism at 4.2 m/s velocity of impact and energy of impact is calculated.

$m = 94.5\ kg,\ h = 0.9\ m,\ g = 9.81\ m/s^2$
where, 'm' is mass, 'v' is velocity and 'h' is height of impactor

$$mgh = 0.5 * mv^2$$
$$94.5 * 9.81 * 0.9 = 0.5 * 94.5 * v^2$$
$$v = 4.2\ m/s$$

$$E = 0.5 * mv^2$$
$$= 0.5 * 94.5 * 4.2 * 4.2 = 833.49\ J$$

Fig 13: Experimental setup of Drop Test

Table 6: Drop test observation

Height of EA before impact (mm)	Minimum height of EA after impact (mm)	Maximum deformation (mm)	Energy of Impactor (J)
46	40.25	5.75	833.49

The result shows that after impact the thickness of energy absorber reduced from 46mm to 40.25 mm which shows deformation of 5.75 mm and the energy of impactor is found to be 833.49 J.

Table 7: Comparison of simulation results with experimentation results

	Simulation	Experimentation
Energy of Impactor (J)	832.92	833.49
Deformation of Energy Absorber (mm)	5.27	5.75

The simulation result shows reduction in deformation of the bumper beam 26.31% in case of lower legform test with energy absorber. Whereas In case of low speed impact test, this reduction is 54.38% and 77.77% in drop test. The reduction in transfer of impact energy is found to be 66.73%, 18.68%, and 82.1%, respectively in the cases mentioned above.

The correlation difference in the energy of impactor is may be due to the size of mesh in simulation and in deformation of beam, is maybe due to mesh size in simulation, friction between plates and cables, pulley and cables and/or quality of welding in energy absorber.

CONCLUSIONS

The result shows that the objective of this work is fulfilled by reducing the transfer of impact energy through energy absorbing bumper under collision. It also reduced the deformation of beam as well. So, it is conclude that energy absorber not only reduce the transfer of impact force but also promises the reduction in damage cost, in case of collision of a vehicle.

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