ISSN(Online): 2584-1025

MIT UNIVERSITY'S – ABHIVRUDDHI JOURNAL
VOL.1 (01) , JUNE , 2021 pp – 24 -29

Analysis & Structural Optimization of Bumper as Shock Absorber in Frontal collision of cars

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***Abstract*—The occupant's safety from a direct impact during a frontal collision is become very important aspect in today's fast-moving world. Also, the passenger compartment and the structure of a vehicle should be such that in crash scenario their shape shouldn't change drastically so that passenger can face minimum of the damage. Number of ideas, Research & development is going on to improve safety & material selection are now more popular, standards are set to avoid different crash scenario.**

In many vehicles crash scenario most of the time we have observed that frontal collision of the cars. In that case if speed of the both vehicle is greater than 60 kmph then eitherwe hear news of death of driver or heavily injury of the same person, so to minimise these scenarios it is very important that we should focus on Design & Development of Bumper who absorbs maximum of frontal impact so that driver should face minimum of injury as possible. Although that we are concentrating on it, but additionally have to be mindful of the consumption of fuel, which poses a significant challenge that must be taken into account. Taking into account these limits allows for the adoption of an element that is both thinner and more durable than steel, specifically aluminium or a composite material. If this material were used, it would contribute to a reduction in fuel efficiency while maintaining the security ofthe passengers in the car and causing less harm to the vehicle overall.

In this research we will study the design of Bumper as a shock/energy absorbing structure and its behaviour while frontal impact (Using FEA). The injuries sustained by the occupant are predicted from previous researcher's data. Occupant injuries like chest and head injuries are studied & ways to avoid chances of different injuries.

Keywords*—*Collision, Direct Impact, Material, Efficiency, Shock Absorbing.

I. INTRODUCTION

To sustain impact loading the development of automotive structures in varied crash situations like frontal angular, perpendicular and side collisions is necessity of the current time. Some of other non-crash functional requirements like vibration, long lasting characteristics and fatigue life are also one of the prominent portions of vehicle design. But in today's world as there is growing focus on safety it is need of the hour that vehicles must be well tested and more & more focus would be on crash scenario that means vehicle-to-vehicle 30° oblique offset impact test as per National Highway Traffic Safety Administration (NHTSA).

The Throughout the span of the past few years, there has been a meteoric rise in the overall level of protection offered by today's automobiles in the event of a collision. A car that was thought to be the safest when it was first introduced ten years ago is no longer believed to be safe. . If the requirements are never altered, there are also certain benefits to improve the level of security. Even though they were rated safe and received high ratings, certain vehicles were still engaged in tragic accidents. It is very evident that current safety standards need to be revised if the percentage of people killed in automobile accidents continues to declinedown. [1].

II. NHTSA ANALYSIS OVER CRASH

According to the NHTSA study it has been observed that Rollover is one of largely occurred crash scenario in vehicle crash. Also, in the study Sport Utility Vehicles (SUV) with rollover accidents made death to the people in one out of every four people in crashes. Nearly 25% of new automobiles sold in the USA are SUVs.

In the year 2002, over 10,000 people's death occurred due to rollover crash, while in 1998 crash involvement of rollovers is about 10,280. This is characteristically qualified to a high CG (centre of gravity) comparative to vehicle's wheelbase. In number of scenarios, it has been seen that rollover is very critical incident which is also having complex fatality rate compared to other crash. There are almost 1.1 crores passenger Sedans, pickup and van crashes in the year of 2002 and out of those only 3% are having a rollover. Still, rollovers are accounted approximately 33% of the all deaths of peoples in vehicle crash [2].

The persistence of the report is to explore an efficacy of the front metallic bumper in frontal collision and to improve the structural design of the Bumper so that it should minimize people's injury which are inside vehicle.

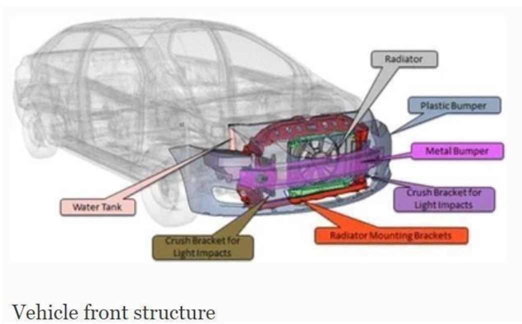

Fig. 1. Front support structure & Bumper mounting of a typical Sedan

In Fig. 1 shows relative positioning of the metallic as well as plastic bumper which is surrounded by the peripheral parts in a typical sedan car. As I explained that there are two bumpers Plastic and Metallic bumper. Plastic bumper is placed at exterior side of the vehicle whose

ISSN(Online): 2584-1025

function is to act as casing for metallic bumper as well as not to show inside components, also who faces maximum of contact with the surrounding, whereas Metallic bumper which is mounted inside of the car whose primary function is to absorb maximum of frontal impact in the crash scenario and to protect from severity of the injuries to the humans as well as damage to the components [3].

III. CRASHWORTHINESS

A. Definition

In simple terms Crashworthiness is refers to capability of the vehicle to absorb maximum of the impact energy in the crash scenario and to prevent occupants from any type of injury. So, the design of the vehicle should be such that even if at higher speed of the vehicle its occupants should not experience a net deceleration. For simplicity the Crashworthiness is categorizing into 3 basic domains, 1st one engineering material and its design, 2nd is combustion or fire, and 3rd would be biomechanics.

In Crashworthiness we can include accessories like airbags, seat belts. Sometimes zone or areas like crumple zones and protection from side impact, padding.

The calculate crashworthiness of any material it should be expressed in terms of its energy absorption, and formula for this is Es= F/D, in which D is denoted by the Density of that composite material and F is envaulted from crush stress.

For passenger's protection during the crash impact the structure should be based on its overall strength as well as its stiffness so that it should be far from being optimal [2].

B. Composite Materials for Crashworthiness

In this competitive automotive world, all customers are demanding for higher fuel efficiency and emission from the vehicle should be as low as possible. As the days passes, we can observe that day the price of the crude oils and the demand for fuels is increasing rapidly and eventually, the emission that are by products of chemicals as well as from the vehicle exhaust which are getting to pollutes the environment and leads to increase in the global warming effects biomechanics.

One of the main advantages of composite as a material is that it has capability to absorb maximum of energy to obtain unique combination of reduction in structural weight as well as enhanced passenger's safety as a result. With the help of composite materials, we can reduce the weight of structure thus it helps to bringing the down use of the fuel so likewise we can achieve its optimum quantity. Composite materials are such engineered materials that they are designed and developed mainly to provide pointedly greater specific stiffness along with specific strength (which can get it by stiffness/density of material).

Composite materials have very great potential for its tailored designs so as advantage of it is it can have wider variety of matrices as well as fibres. Also, there are various performs, and they have few laminates architecture i.e., fibre orientation and stacking sequence of single laminate.

Composite If we study the cost required to conduct the test on crash-worthy structure then we can have higher development program cost and the reason for the same is that FEA Analysis for simulating which requires more costing [4].

IV. CRASH STATISTICS SURVEY

In resent day, the number of accidents is happening in every single minute in the world and which are included with very hazardous consequences. If we analysed in many of the reports that the side-Impact crash is 2nd most happening crash after frontal-impact. In Fig. 1.2 we can observed comparison between different crash and its count/frequency.As per that study frontal impact is greater than the of side impact. If we compared the criticality of the occupant'sinjuries in the side-impact crash is very greater than that of frontal crash. Also, we can get the data for other crashes as well like rollover and rear side impact.

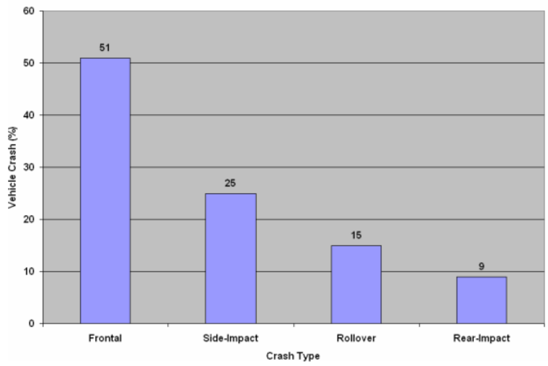

Fig. 2. Crash type Vs Vehicle Crash

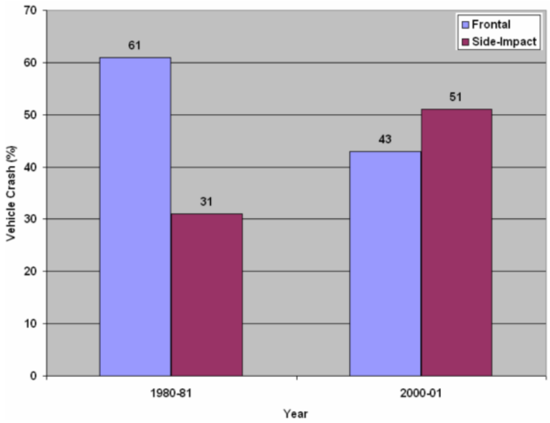

Fig. 3. Comparison of frontal and side impact crash

C. R. Sonawane & A. L. Shelar studied the current advanced world requires greater safety to the passengers with minimum fuel efficiency and cost. In the current automobile have one disadvantage that they have short front crumple zone to absorb frontal impact. So, the safety of the vehicle as well as of the passengers is certainly depending upon the design of the Bumper. Since the Bumper is the strongest structure which absorbs maximum of the frontal impact force

ISSN(Online): 2584-1025

in the crash scenario. As a result of the closeness of the passenger's head and neck to the crumpled bumper, the latter poses a significant threat to the individual's health in the event that the bumper sustains any damage as a result of the crash. The bumper is the component of the vehicle's crush zone that has the most responsibility because the vast majority of fatal accidents are caused by frontal and rollovercollisions.

The blind spots which are developed due to obstacle between occupants' eye and vehicle parts on side during motion, it is more than 70% of accidents occurred due to that fault on road. It has been observed that most of the times driver do one common mistake is that while changing lane on road and it leads to greater exposure to the blind spot andthis is the main reason for causing the accidents. As per the results for Russia in 2017 it has been confirmed that lots of accidents are happened only due to the driver's fault [5].

In this paper researchers observed that frontal bumper structure is made up by combination of 3 different material which are named Aluminium, GMT Thermoplastic and HSS Sheet Mould Compound. On these three materials FEA studies is carried out to get the data of Stress distribution, Impact force, Deflection, Total deformation of the component. As per the results it is observed that HSS Sheet Moulding Compound bumper structure would minimize the its deflection, stress applied on it as well as the impact force. Also, it will increase Elastic strain energy. For Glass Mat Thermoplastic it is observed that it has very excellent impact behaviour when it is compared with the steel & aluminium.

In the study conducted by Charis Phan and Yong Seok, the A-pillar cross-sectional shape of the Volvo XC60 was utilised as a benchmark to evaluate a potential upgrade for the 2015 Toyota Camry. This evaluation was done in relationto the previous paragraph. Steel (HSS) with yield strengths ranging from 210 to 550 MPa and tensile strengths ranging from 270 to 700 MPa is the material that is generally utilised for the construction of modern bumper beam structures. The use of advanced high strength steel (AHSS), which also includes ultra-high strength steel (UHSS) with a yield strength that is greater than or equal to 550 MPa and a tensile strength that is greater than or equal to 700 MPa, has become commonplace in many modern models of automobiles. [6].

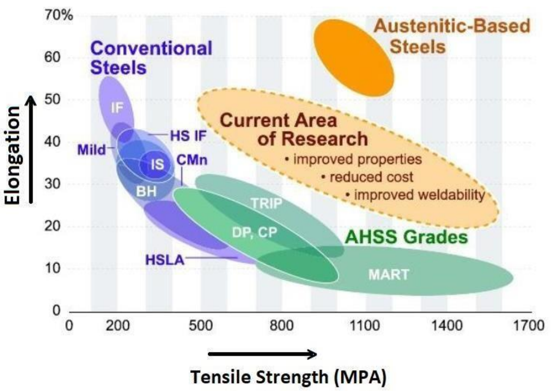

Fig. 4. Advanced HSS Elongation vs Total Tensile Strength of Materials

For traditional materials, the increase in strength may leads towards decrease in ductility or reverse of the same can happen. Although, newly evolved materials such as TRIP provides a combined advantage of high strength as well as ductility which we can observed in Fig. 4.

By the use of LS DYNA software, it is shown that the results are improved when GMT is used as a material in the design of commercial bumper beam in impact test. This test is conducted as per ECE United National Agreement. In the design there are three main constituents namely shape, material and study of impact. The results of the study are compared with steel and aluminium. It has been observed that in terms of impact behaviour when we use GMT as material in design of beam structure then the impact resistance is improved.

In this study the BEM sub-model is used for frontal bumper fascia. This process is further resulted into the more accurate one as well as improved the optimization of the sampling data. The objective is to conduct slow speed impact test and the test is carried out with IIHS standards and guidelines in the three different locations of vehicles, which are at Central, Right-hand (RH) and Left-hand (LH) corner [7].

- Insurance Institute for Highway Safety Test Protocol:

IIHS is nothing but one of the top educational independent organizations as well as scientific study conducting industry which is established to reduce deaths, injuries and damage to the property in the crash of vehicle. In this low impact test series frontal and rear both are studied in that addition two localised impact test also carried out. In this test the results show how various components will helps to absorb energy during impact. Following Fig. 5 shown how the Frontal and Corner impact test is going to be conducted.

Fig. 5. Snaps during frontal and corner impact test

Guideline per IIHS for the configuration is shown below:
Configuration For Full Frontal Test,

(a) Barrier Height (from ground) :- 457 mm
(b) Vehicle speed :- 10 km/h

Configuration For Front Corner Test,

(a) Barrier Height (from ground) :- 406 mm

ISSN(Online): 2584-1025

(b) Vehicle speed :- 5 km/h

(c) Overlap location :- 15 % to the width of the vehicle at frontal axle. (except accessories of vehicles)

Model Information :

To conduct this test the model is generated with the baseline of Toyota Yaris 2010. These models are developed for research purpose only and it is documented over this paper study. In the following figure the solid modelling has been generated as well as to conduct finite element analysis study meshing view is also shown. As per snaps we can observed that there are total 771 number of parts or components in the model, they are having 9,98,218 number of nodes with 9,74,383 hybrid elements.

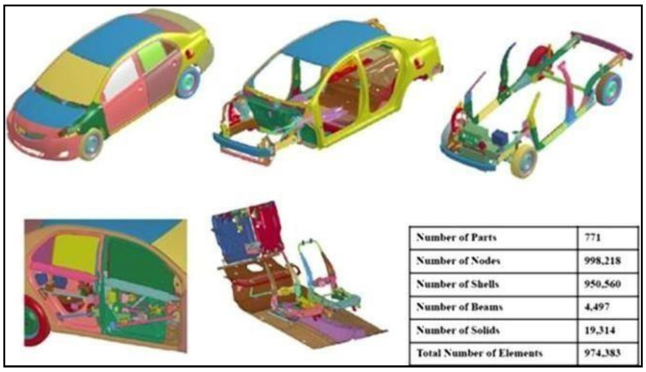

Fig. 6. Generated 3D Solid model information

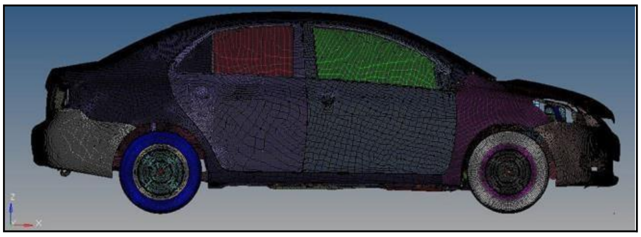

Fig. 7. Meshing of Generated 3D Solid model

In the following Table I is shown with detailed information of the meshing model, elements used and the utilized connections for analysis of FE model. As prominence is put down to analysis of the slow speed impact to the bumper with Mat24 (as a material) and the characteristics of the material is shown in the Table II.

While generating 3D CAD of metal bumper the meshing is made fine whenever possible to get more accurate results. In the previous researcher's data, the list of parts, it's materials, properties, testing details, etc. can be found.

TABLE I. DETAILS OF FE MODEL GENERATED FOR MESHING

Mesh element summery	Connections used
Number of parts: 771 Number of nodes: 998,218 Number of shells: 950,560 Number of beams: 4497 Number of solids: 19,314 Total number of elements: 974,383 Weight, kg: 1078 (actual vehicle)	Beam connections: 4324 Nodal rigid body: 423 Extra nodes set: 16 Joints: 14 Rigid bodies: 2 Spot weld: 2862

TABLE II. MATERIAL PROPERTIES OF METAL BUMPER

Material	Mat24
Density, kg/m^3	7890
Youngs Modulus (E), GPA	200
Poissons ratio	0.3
Yield Strength, GPA	800

In full overlap impact test, speed of the vehicle is maintained at 10 km/h. The mounting position of the crash barrier is placed such that front extreme end area of (bottom edge) the barrier at 457 mm from ground.

Fig. 8, 9 shows condition taken while doing test on front overlap impact test FE (finite element) modelling and their boundary condition. During an impact the centreline of the vehicle and barrier is aligned in straight manner. The impact of the vehicle on the barrier is takes place at 10 km/h as mentioned earlier and the analysis is done on it when vehicle comes to the rest.

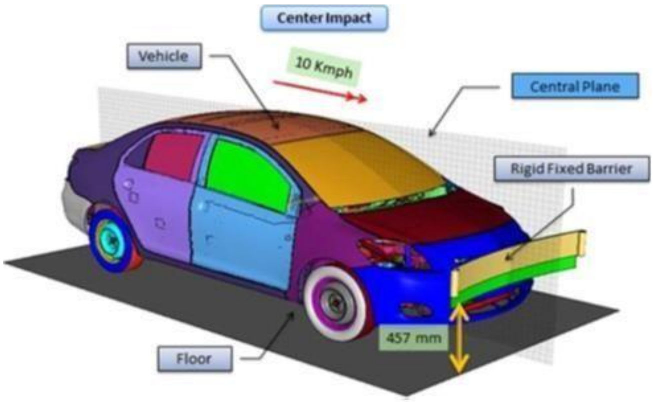

Fig. 8. FE model in Frontal full overlap impact test

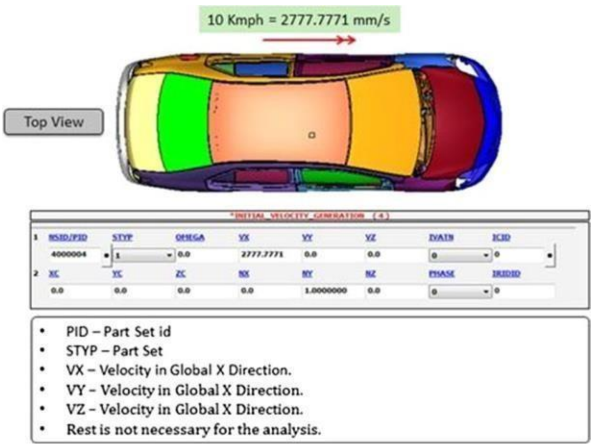

Fig. 9. Boundary conditions setup during frontal overlap impact test

When the frontal overlap impact test is conducted in the results it is came out that the metallic bumper is not having enough strength in the protection of the radiator and all its nearby parts. We can observe in Fig. 9 the simulation instances that has been captured during overlap impact test. Also, the damage happened to the radiator can also been seen.

In the following Fig. 10 the baseline geometry of the metallic bumper is shown as well as plastic strain's contour plot are shown. The highest value for plastic strain during immediate buckle (at t = 0.15 s) is observed which is 0.2284.

To get optimization in the results and more protections to the interior parts of the vehicle it is needed that the some of the Iterations, that is by doing modification in the geometry, material, thickness, etc.

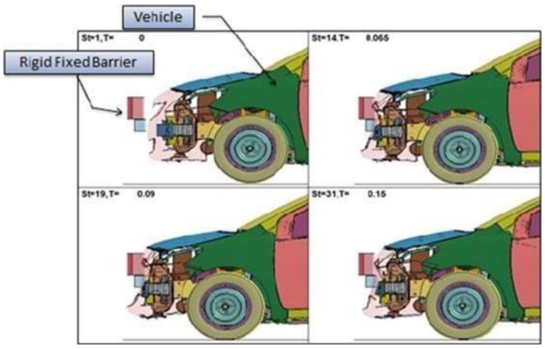

Fig. 10. Frontal overlap impact test Analysis instance

In Table III and IV will give us comparative study of all the Iterations for the energy absorption done by metallic bumper while both impact test. From that table it is also confirms that there is significant growth in the stiffness of the bumper whenever we modify it. This development is in terms of the increase in thickness of material and upgradation in bumper profile.

TABLE III. FULL FRONTAL OVERLAP IMPACT TEST RESULTS

Iteration	***Design changes***	Energy absorbed ***by metal bumper, J***	Energy absorbed ***by LH bracket, J***	Energy absorbed ***by RH bracket, J***
Baseline	Thickness 1.5 mm	2857.5	90.64	94.756
Iteration 1	Geometry extended in corners	2830.4	90.7	92.693
Iteration 2	Thickness change (1.5–2 mm)	3453.8	76.09	67.63
Iteration 3	Shape changes (double C profile)	3597	85.4	89.68
Iteration 4	Thickness change (1.5–2.5 mm)	3735.4	98.14	95.7

TABLE IV. SIDE IMPACT TEST RESULTS

Iteration	***Design changes***	Energy absorbed ***by metal bumper, J***	Energy absorbed ***by LH bracket, J***	Energy absorbed ***by RH bracket, J***
Baseline	Thickness 1.5 mm	1.54	0.17	0.87
Iteration 1	Geometry extended in corners	116.46	0.37	2.43
Iteration 2	Thickness change (1.5–2 mm)	184.81	0.51	2.61
Iteration 3	Shape changes (double C profile)	182.98	0.48	2.98
Iteration 4	Thickness change (1.5–2.5 mm)	186.69	0.45	3.08

This upgradation will impact the results to fewer deflection in the bumper beam which relates bumper would have greater impact to deflection to absorb more impact energy.

This change will result in lesser deflection of the bumper metallic beam which relates to the bumper would have better impact to deflection to absorb more impact energy.

In Fig. 11 we can get graphical representation of energy absorption for all iterations for comparative analysis.

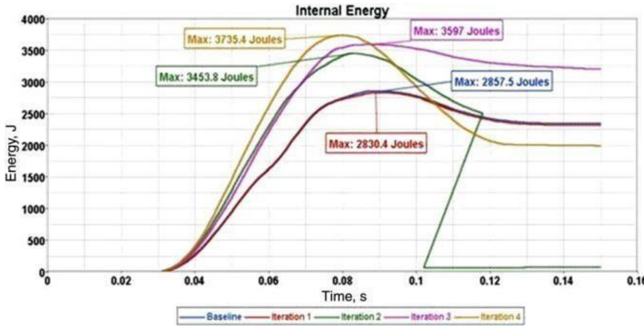

Fig. 11. Energy absorption at frontal full overlap test for different iterations

V. CONCLUSION

During study of above topic, we understood that composites can be used as an alternative in design of Bumper beam and hence it helps in the reduction of risk of injury to the passenger. Bumper which is made of composite was being tested on diverse fields to find out characteristics like highest energy absorption, toughness as well as thickness.

Use of GFRP as will gives better specific energy absorption and more importantly reductions in the load ratio. To use PET foam filled tubes gives advantage in the production cost because of the material price is lower than GFRP in the market. Use of the CFRP is having better corrosion resistance as well as it has excellent lower thermalconductivity. But it has only disadvantage over the higher costing.

After all the above studies I wish to conclude this topic by following statements,

1) We should use of combination CFRP and GFRP as a material in the bumper beam profile so that we can achieve optimum strength and cost for design.
2) To develop profile of the metallic front bumper in Double C shaped which gives higher impact energy absorption capacity.
3) Optimum materical thickness for optimum stiffness.
4) Use of sensors and alert system so that driver will notified before crash scenario.

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