Crash Test Analysis on Automobile Bumper

R. Sampathkumar[1] Padmakumar D. S.[2]
[1]Lecturer (Senior Grade) [2]Scholar
[1,2]Department of Mechanical Engineering
[1]Nachimuthu Polytechnic College, Pollachi, India
[2]Dr. Mahalingam College of Engineering & Technology, Pollachi, India

Abstract— A good design of car bumper must have optimized weight and must provide safety to passengers. Different countries have different performance standards for bumpers. Under the International safety regulations originally developed as European standards and now adopted by most countries outside North America, a car's safety systems must still function normally after a straight-on pendulum or moving-barrier impact of 4 km/h (2.5 mph) to the front and the rear, and to the front and rear corners of 2.5 km/h (1.6 mph) at 45.5 cm (18 in) above the ground with the vehicle loaded or unloaded.. Due to increasing competency now a day's tests are carried out at some higher velocities such as 10 m/s to increase the safety level of vehicle. Increased safety of vehicle helps to claim for larger insurance amount. Automotive development cycles are getting shorter by the day. With increasing competition in the marketplace, the OEM's and suppliers main challenge is to come up with time-efficient design solutions. Researchers are trying to improve many of existing designs using novel approaches. Many times there is conflicting performance and cost requirements, this puts additional challenge with R&D units to come up with a number of alternative design solutions in less time and cost compared to existing designs. These best solutions are best achieved in a CAE environment using some of the modern CAD and FEM tools. Such tools are capable of effecting quick changes in the design within virtual environment.

Key words: Waste Foundry Sand, Ordinary Cement, Compressive Strength

I. INTRODUCTION

In modern engineering analysis it is rare to find a project that does not require some type of simulation for analyzing the behavior of the model under certain specified conditions. The advantages of simulation are numerous and important. A new design concept may be modeled to determine its real world behavior under various load environments, and may therefore be refined prior to the creation of drawings, when few dollars have been committed and changes are inexpensive. Once a detailed CAD model has been developed, simulations can analyze the design in detail, saving time and money by reducing the number of prototypes required. An existing product which is experiencing a field problem, or is simply being improved, can be analyzed to speed an engineering change and reduce its cost. In a frontal or rear crash, the bumper beam is the primary component which undergoes damage and transfers the forces to the rest of the structure. Thus the modern bumper beam systems should play a key part in the safety concept of an automobile, ensuring that minimal accelerations are transferred to the passenger. Thus we perform the crash test analysis on automobile bumpers in order to improve its crashworthiness, and by performing this analysis we gain skills in CAD modeling and finite element analysis software.

A. *Automobile Bumpers*

A bumper is a structure attached to or integrated with the front and rear ends of a motor vehicle, to absorb impact in a minor collision, ideally minimizing repair costs. Invented by Briton Frederick Simms in 1901, Bumpers ideally minimize height mismatches between vehicles and protect pedestrians from injury. Regulatory measures have been enacted to reduce vehicle repair costs, and more recently impact on pedestrians. Bumpers play an important role in preventing the impact energy from being transferred to the automobile and passengers. Saving the impact energy in the bumper to be released in the environment reduces the damages of the automobile and passengers.

1) *Construction*

Bumpers were at first just rigid metal bars. On the 1968 Pontiac GTO, General Motors brought forth an "Endura" body-colored plastic front bumper designed to absorb low-speed impact without permanent deformation. It appeared in a television commercial where John De Lorean hit the new car with a sledgehammer and no damage resulted. Similar elastomeric bumpers were available on the front and rear of the 1970-'71 Plymouth Barracuda, and in 1971, Renault introduced a plastic bumper (sheet molding compound) on the Renault 5.

Current design practice is for the bumper structure on modern automobiles to consist of a plastic cover over a reinforcement bar made of steel, aluminum, fiberglass composite, or plastic. Bumpers of most modern automobiles have been made of a combination of polycarbonate (PC) and Acrylonitrile butadiene styrene (ABS) called PC/ABS.

A bumper valance or "valance panel" is a trim piece located in the lower part of the front or rear bumper. Bumper valances are intended to improve aerodynamic efficiency of the vehicle by directing airflow in the same way that an air dam does. Bumper valances may also include the airflow lip at the bottom. However, in many cases valance panel plays a decorative role by covering a lower part of the radiator in the front of the vehicle or concealing the gap between dual exhaust pipes in the rear.

2) *Pedestrian Safety*

Bumpers are increasingly being designed to mitigate injury to pedestrians struck by cars, such as through the use of bumper covers made of flexible materials. Front bumpers, especially, have been lowered and made of softer materials, such as foams and crushable plastics, to reduce the severity of impact on legs.

3) *Height Mismatches*

For passenger cars, the height and placement of bumpers is legally specified under both US and EU regulations. Bumpers do not protect against moderate speed collisions, because during emergency braking, suspension changes the pitch of each vehicle, so bumpers can bypass each other when the

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vehicles collide. Preventing override and under ride can be accomplished by extremely tall bumper surfaces. Active suspension is another solution to keeping the vehicle level.

Bumper height from the roadway surface is important in engaging other protective systems. Airbag deployment sensors typically do not trigger until contact with an obstruction, and it is important that front bumpers be the first parts of a vehicle to make contact in the event of a frontal collision, to leave sufficient time to inflate the protective cushions.

Energy-absorbing crush zones are completely ineffective if they are physically bypassed; an extreme example of this occurs when the elevated platform of a tractor-trailer completely misses the front bumper of a passenger car, and first contact is with the glass windshield of the passenger compartment.

B. Materials Used

The bumper is designed to have optimal mechanical properties which improve the pedestrian protection and low-speed collision as well. The bumper essentially consists of a cover, an absorber, arranged beneath to the cover and mounting elements to connect a cover and absorber to the vehicle body. The optimal mechanical properties to improve the pedestrian protection and low speed collision are achieved using general principals of stiffness, in which the stiffness of the lower portion of the bumper in its mounted position is increased relative to the upper portion of the bumper. By making the lower portion of the bumper which is directed forwardly into the direction of the driving stiffer, the impact force in case of collision with a pedestrian is concentrated at the lower portion of the bumper. Bumpers in the earlier years were made of steels or heavy metals. Nowadays, bumpers are made of rubber, plastics and other light painted and resilient materials. Some bumpers now features crumple zones which allows the material to flex upon collision in order to absorb the impact and returns to its original shape.

The majorities of modern cars are made of thermoplastic olefins (TPOs), polycarbonates, polyester, polypropylenes, polyamides, or blend of these with, for instance glass fiber for strength and structural rigidity. Other than that, there is also a rubber bumper or elastomeric bumper can be made from either natural or synthetic rubber. Bumper systems usually include a reinforcement bar plus energy-absorbing material, such as polypropylene foam. Better bumpers often have hydraulic shock absorbers instead of, or in addition to, the foam. The most widely used energy absorber construction is made from expanded polypropylene foam (EPP).

Honeycomb energy-absorber, which are made from ethylene vinyl acetate (EVA) copolymer, are also still used on some other cars. The replacement of metal in bumper to reduce the weight of the vehicle, reduce cost and improve petrol consumption has follow several stages mostly directed at the bumper fascia and improving polypropylene, polyurethane, thermoplastics, elastomers, PC/ABS and PC/PBT blends. Bumpers fascias are hardly 3 mm thick and the key physical properties are for flexibility and shock resistance. Today, the mostly used materials are polypropylenes, due to compromise between cost and mechanical properties. Other thermoplastics used for fascias have mainly been alloys-based PBT and polycarbonate, which have been used mainly in Europe by top car models of BMW and Mercedes.

Polyurethane is also used in bumpers where flexibility has the advantage of avoiding deformation. For example, a bumper which is made of polyurethane will roll back into its initial shape after small shock or collision where the speed is usually less than 5 km/h. It is very convenient and avoids costly repair. For Nissan, they developed an integrated lightweight bumper system for their vehicle using higher modulus polypropylene. The usage of this material precluded the need for the steel reinforcement that up until then was necessary for the polypropylene bumper. In order to obtain the required material properties which are high in modulus and impact strength, an advanced compounding technology was applied to improve the existing mineral filled polypropylene bumper material. The higher modulus was achieved by advanced in compounding technologies which minimized the filler function and achieved in higher dispersion level for higher loading for fine particulate filler. Impact strength was increased by improving the interfacial strength between the polypropylene and elastomers particles by developing an alloy at the surface. Basically, the most important mechanical properties of a car bumper are strength and toughness as well. Toughness is a mechanical term that is used in several contexts. Loosely speaking, it is a measure of the ability of materials to absorb energy before it tends to fracture. Fracture toughness is a property indicative of a material's resistance to fracture when a crack is present. For a material to be tough, it must display both high strength and ductility. In conclusion, good bumper performance requires not only engagement with the test barrier but also strength sufficient to absorb the energy of a low speed collision.

C. Manufacturing Process

A car bumper is made by a process called reaction injection molding (RIM), which basically consists of making a special polyurethane compound and introducing it into a large bumper moulding. RIM is a process that conserves raw materials and reduces costs. It is similar to injection molding except thermosetting polymers are used, which requires a curing reaction to occur within the mold. Common items made via RIM include automotive bumpers, air spoilers, and fenders.

As to automobile's bumper, it is the front-most or rear-most part, ostensibly designed to allow the car to sustain an impact without damage to the vehicle's safety systems. They are not capable of reducing injury to vehicle occupants in high-speed impacts, but are increasingly being designed to mitigate injury to pedestrians struck by cars.

In the process of making car bumper, there are two steps. The first step is making a Polymer. Liquid plastic precursors are mixed with a catalyst that causes them to combine and polymerize rapidly. The materials then are poured or injected into a large mold, where they combine rapidly. And the next step is using the car bumper mould. The result is a polymer of polyurethane. With the help of gas, the polyurethane expands to fill the bumper mold. The lightweight product then is removed.

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D. Crash Test

A crash test is a form of destructive testing usually performed in order to ensure safe design standards in crashworthiness and crash compatibility for various modes of transportation or related systems and components.

II. PROJECT METHODOLOGY

The general requirement of the crash test analysis includes a finite element model of the bumper and the barrier. First the CAD model of the bumper is created using the modeling software SOLIDWORKS. The next step includes the conversion of the CAD model into the finite element model and it is done with the help of the FEA software HYPERMESH. The finite element model is then imported to a solver for conducting the crash test analysis. The solver used is ANSYS-Explicit Dynamics, in which the material properties of the bumper beam are specified .Once the material properties is specified the crash test parameters are specified. The crash test parameters include the speed at which collision occurs, the degrees of freedom of the bumper and the barrier that are to be arrested and the time taken for the crash to occur are specified. The properties that are to be measured are specified in the solver at the last which includes the displacement and stress included on the bumper beam due to the collision. For the given conditions the crash test is simulated and the results which include the displacement and stress can be view in the solvers result reader- ANSYS result reader.

A. Objective of the Project

– To investigate optimum and effective bumper material based on their geometry and other parameters that influence the compatibility of car bumper with Finite Element Analysis.
– To perform analysis for various thicknesses and find the optimum thickness.
– To perform and compare the results (displacements) for various speed conditions.

As the first objective indicates the analysis is done for various materials that include carbon fiber Composite, E-Glass Epoxy, S2 Glass Epoxy and ABS Plastic and the optimum material is selected. The analysis is the performed for the same set of materials at different thickness that include 4.5mm,5mm and 5.5mm and the optimum thickness is selected. The next analysis includes performing the analysis at different speed that includes 65 km/hr, 125 km/hr and 316 km/hr for the same set of material and the stress and displacement at different speeds are compared and the optimum material is selected.

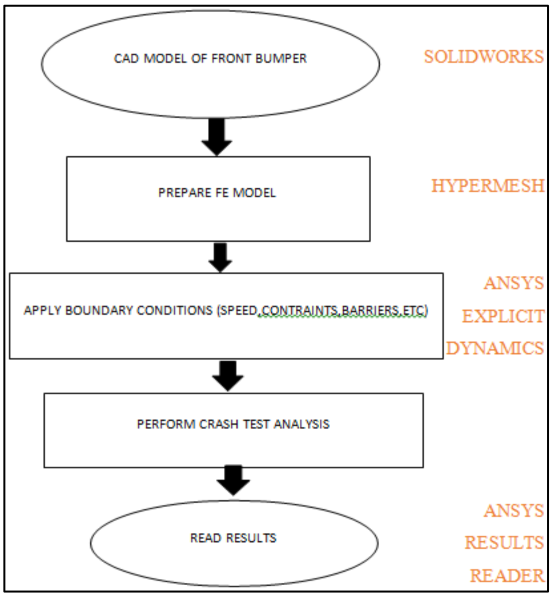

Fig. 1: Project Methodology

III. MODELLING & ANALYSIS

A. CAD Model of the Bumper

The cad modeling is done in the modeling software solidworks2017 with the help of surface modeling technique. Fig. 2 shows the CAD model of the bumper which was modeled through surface modeling technique. Surface modeling is a technique of creating a planar or non-planar geometry of zero thickness. This zero thickness geometry is known as surface. The surfaces are generally used to create models of complex shapes. We can convert surface models in solid models. We can also extract a surface from a solid model using the tools available for surface modeling .Most of the real world components are created using solid modeling. But sometimes, we may need to create some complex features that can only be created by surface manipulation. This manipulation of surfaces is done using surface modeling. After creating the required complex surface, we can convert it into a solid model. The reasons why we need to convert a surface model into solid model are because a surface is a zero thickness geometry, and so it has no mass and no mass properties. In Solid Works, the surface modeling is done in the Part mode and the tools used for surface modeling are available in the Surfaces toolbar. This toolbar is not available by default in the Part mode. Therefore, you need to invoke it by choosing View >Toolbars >Surfaces from the menu bar. The tools used for surface modeling are also available in the menu bar. Choose Insert >Surface from the menu bar to invoke the surface options. You will notice that some of the tools available in the Surfaces toolbar are the same as those discussed in solid modeling. These tools are extruded, revolve, sweep, and loft.

Fig. 2: CAD Model of Bumper

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B. Mesh Model of Bumper

We have meshed the bumper in hyper mesh software (Hyper Mesh is a multi-disciplinary finite element pre-processor which manages the generation of the largest, most complex models, starting with the import of a CAD geometry to exporting ready-to-run solver file), in which we have meshed it in 2D shell meshing and the thickness and material properties are added in the analysis software ANSYS explicit dynamics. Fig 3 shows the meshed bumper model.

Fig. 3: Mesh Model of Bumper

C. Crash Test Performed on a Simple Bumper Beam

We first performed a mock crash test analysis in a simple bumper beam in Hyper Crash. This included the following steps:

- Geometry meshing with Hyper Mesh. The beam was meshed in 2D shell meshing.
- Mesh preparations and modifications with Hyper Crash Creation of new assemblies and sorting the parts.
- Material creation and assignment. The material of the bumper was assigned as steel.
- Property creation and assignment. The bumper thickness was assigned as 5mm.
- Load case creation. Gravity load was assigned and initial velocity was defined as 18km/hr. A rigid wall was constructed as a barrier.
- Model check. The model was checked was any errors in order to export to the solver.
- Start of simulation

In the control cards the required options for the solver are made clear and it is exported to the solver.

The results of the mock analysis is descried below,

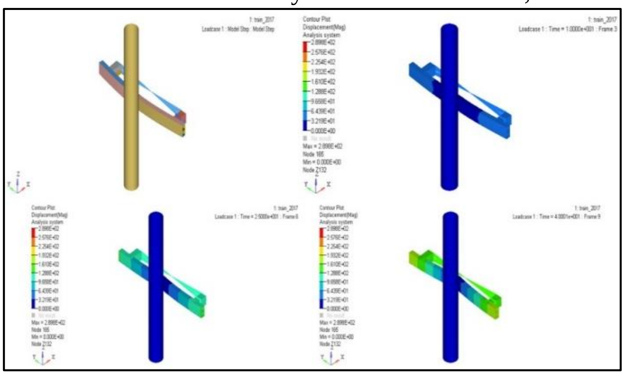

Fig. 4: Crash Test Performed on Simple bumper Beam

IV. RESULTS & DISCUSSION

Now the analysis has been done for material such as ABS Plastic, S2 glass epoxy, Carbon fiber composite and E glass epoxy.

A. Analysis for Different Speed Conditions

The analysis has been conducted for three speeds namely 65km/hr, 125km/hr, 316 km/hr.

1) Material Properties of Abs Plastic

Tensile strength N/m2	Elastic modulus, N/m2	Poisson's ratio	Mass density, kg/m3	Shear modulus , N/m2
3e+007	2e+009	.39	1020	3.189e+008

Table 1: Material Properties of ABS Plastic

2) Material Properties of S2 Glass Epoxy

Tensile strength N/m2	Elastic modulus, N/m2	Poisson's ratio	Mass density , kg/m3	Shear modulus , N/m2
4.89e+009	8.69e+010	.23	2460	3.189e+008

Table 2: Material Properties of S2Glass Epoxy

3) Crash Test Results

Material	Speed km/hr	Stress N/mm2	Displacement mm
ABS Plastic	65	38.71	.0022348
	125	53.576	.012061
	316	239.89	34.256
S2 Glass Epoxy	65	42.693	.0024395
	125	102.34	.015651
	316	274.21	23.111
E- Glass Epoxy	65	50	.0032413
	125	114.65	.010005
	316	302.73	16.79
Carbon Fiber	65	42.823	.0026264
	125	88.42	.0089552
	316	286.37	14.9

Table 3: Crash Test Result of ABS Plastic and S2 Glass Epoxy, E Glass Epoxy and Carbon Fiber for Different Speed

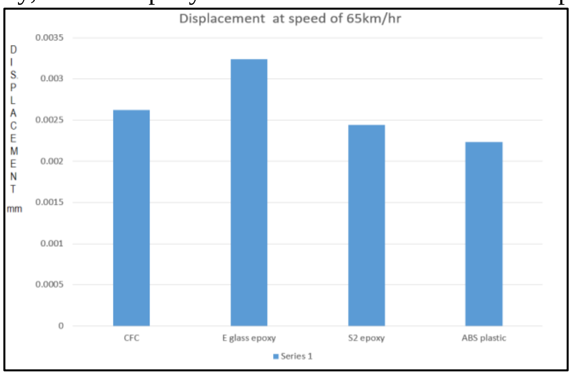

Fig. 5: Displacement at the Speed of 65 km/hr.

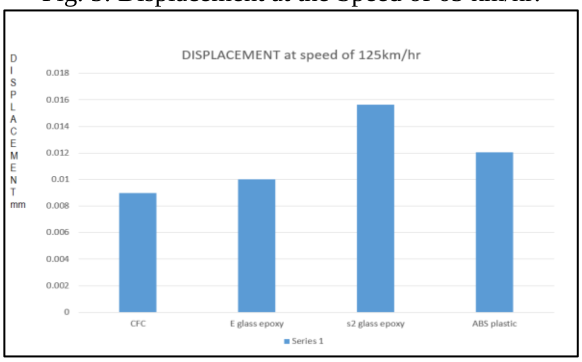

Fig. 6: Displacement at the Speed of 125 km/hr

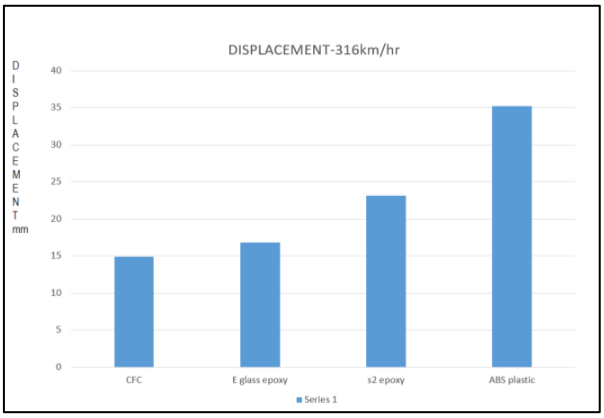

Fig. 7: Displacement at the Speed of 316 km/hr

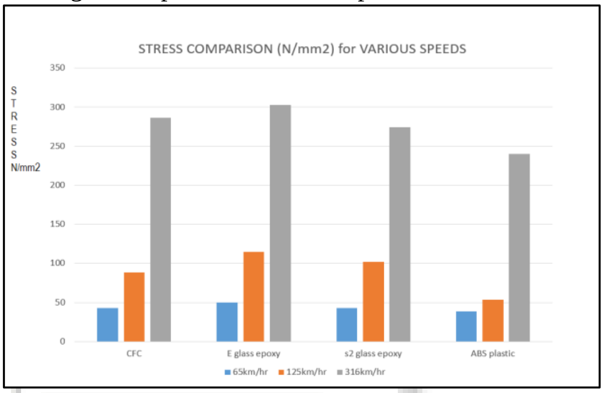

Fig. 8: Stress Comparison at Various Speeds

B. Analysis for Different Bumper Thickness

1) Crash Test Result

Material	Thickness mm	Stress N/mm2	Displacement mm
ABS Plastic	4.5	338.21	37.2
	5	239.89	34.256
	5.5	348.23	38.46
S2 Glass Epoxy	4.5	264.68	21.95
	5	274.21	23.111
	5.5	405.6	23.347
E- Glass Epoxy	4.5	294.6	14.98
	5	302.73	16.79
	5.5	310.19	18.29
Carbon Fiber	4.5	283.49	13.86
	5	286.37	14.9
	5.5	293.46	15.3

Table 3: Crash Test Result of ABS Plastic and S2 Glass Epoxy, E Glass Epoxy and Carbon Fiber for different Bumper thickness

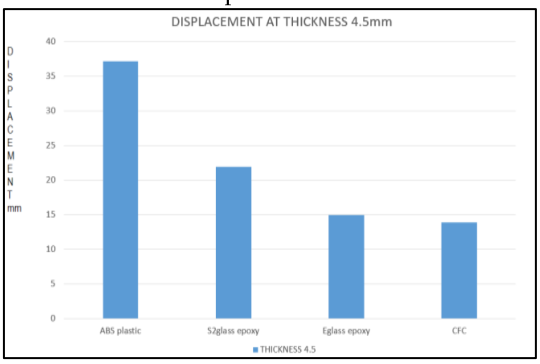

Fig. 9: Displacement at the Thickness 4.5mm

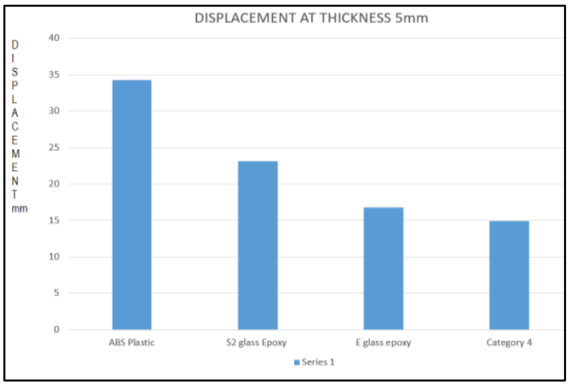

Fig. 10: Displacement at the Thickness 5mm

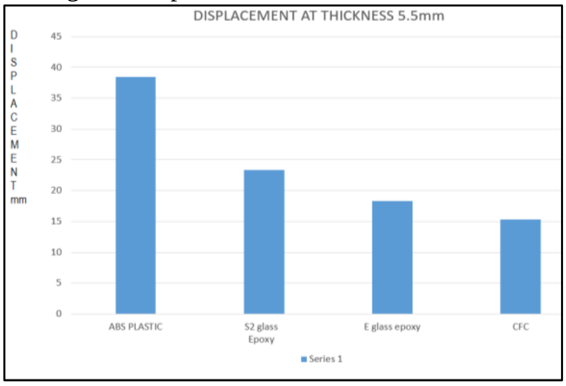

Fig. 11: Displacement at the Thickness 5.5mm

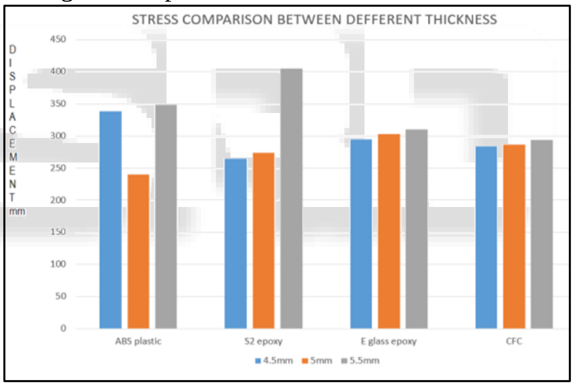

Fig. 12: Stress Comparison for Various Thickness

C. Discussion

From the results of the analysis conducted for the different speeds of 65,125 and 316 km/hr, It is found that at 65km/hr E-glass epoxy to have the poorest performance with the displacement of about .0032 mm whereas all the other material have the displacement values bellow .003 mm. At the speed of 125 km/hr it is found that S2 Glass epoxy to have the worst performance with the displacement value of 0.015mm followed by the ABS plastic with the displacement value of 0.012mm.at the highest speed level of 316 km/hr it is found that carbon fiber composite having the lowest displacement of 15 mm and the stress values of 320 N/mm2.So therefore the carbon fiber composite bumper is to have high crashworthiness when compared to other materials. While conducting the analysis for different thickness of the bumper beam that include 4.5mm, 5mm, 5.5mm, it is found that the displacement values are to be higher at the thickness of 4.5mm than at the thickness of 5 mm. Since the configuration with lowest displacement is considered to be worthier, the bumper with 5 mm thickness configuration has

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lower displacement and the stress values are on the safer side when compared to the stress values at 4.5 mm and 5.5 mm. So the bumper beam with 5mm thickness is considered to have higher crashworthiness.

V. CONCLUSION

In the project "crash test analysis of automobile bumpers" in this phase II of the project work we have reviewed literatures on crash test and have modeled the bumper successfully and meshed it in the FEA software and conducted the crash test analysis in the solver Ansys explicit dynamics for different material that include carbon fiber composite, E-Glass Epoxy, S2 Glass Epoxy and ABS Plastic and the analysis have been performed at various speed and thickness. By performing the above tasks knowledge on various parameters involved in the crash test analysis like material library, applying constraints, specifying the speed, time frame and other important parameters for the crash test analysis are gained. The analysis for various material of the bumper beam, various speeds at which the impact occurs and at various thickness of the bumper beam is conducted and the results of all the analysis done are consolidated. From the results of the analysis conducted for the different speeds of 65,125 and 316 km/hr, It is found that at 65km/hr E-glass epoxy to have the poorest performance with the displacement of about .0032 mm whereas all the other material have the displacement values bellow .003 mm. At the speed of 125 km/hr it is found that S2 Glass epoxy to have the worst performance with the displacement value of 0.015mm followed by the ABS plastic with the displacement value of 0.012mm.at the highest speed level of 316 km/hr it is found that carbon fiber composite having the lowest displacement of 15 mm and the stress values of 320 N/mm2.So therefore the carbon fiber composite bumper is to have high crashworthiness when compared to other materials. While conducting the analysis for different thickness of the bumper beam that include 4.5mm, 5mm, 5.5mm, it is found that the displacement values are to be higher at the thickness of 4.5mm than at the thickness of 5 mm. Since the configuration with lowest displacement is considered to be worthier, the bumper with 5 mm thickness configuration has lower displacement and the stress values are on the safer side when compared to the stress values at 4.5 mm and 5.5 mm. So the bumper beam with 5mm thickness is considered to have higher crashworthiness.

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