Topology Analysis of Bumper to Improvise the Design for Impact Tests

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Abstract: A bumper is a protective barrier made of metal, aluminum, rubber, or plastic. For this study, a Benz automobile bumper was used. At different vehicle speeds (45, 60, and 75 km/hr), this bumper may flex and absorb impact energy during collision. Most current automotive bumpers are composed of PC/ABS, a composite of polycarbonate (PC) and acrylonitrile butadiene styrene (ABS). ABS, Polypropylene (PP), Polyurethane (PUR), Poly-Vinyl-Chloride (PVC), and Poly-Vinyl-Chloride (PVC). CATIA software was used to create the 3-D model of bumper. The deformation and tension generated in the automobile bumper were calculated using static and impact analyses. To determine the frequency and deformation for mode forms, a modal assessment was performed. Solid Works software was used to do the study of the automobile bumper. Furthermore the research focuses on improving and optimizing the mass of a car's bumper. The primary goal is to reduce the weight of the bumper in order to improve the vehicle's overall performance and economy.

KEYWORDS: PC/ABS, frequency, CATIA, weight.

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INTRODUCTION

Bumper is a part of an automotive designed to protect and support a vehicle. Bumper is comprised of an elongated support which can be attached to the front and rear of the vehicle body and which spans the width of the vehicle body as well as a shock absorber extending along the support part and extending towards the front and rear of the vehicle body in a substantially convex manner. The bumper also consists of an elastic exterior shell which can be connected to the support part and which encompasses the front and rear of the vehicle in an approximate U-shape. The exterior shell also covers the side of the support part opposite to the side facing the front and rear of the vehicle body. The support part has a mid-section that can be firmly supported on the vehicle body.

Bumper is divided in two types; they are front bumper and rear bumper. Main function for a bumper is to absorb impact energy and reduce damage caused to the car as well as bodily injury during an accident. This research work is focused on the car bumper system and it has three main components.

A. Materials used for Automobile Bumpers

Bumpers of most recent vehicles have been made of a combination of polycarbonate (PC) and Acrylonitrile butadiene styrene (ABS) called PC/ABS, Polypropylene (PP), Polyurethane (PUR) and Poly-Vinyl-Chloride (PVC). Modern bumpers are made with a combination of different elements. The first element is an impact absorbing spring device, usually gas-filled cartridges which mount the front bumper to the chassis. This allows the bumper system to absorb minor impacts without any damage.

The next part is the steel or aluminum support structure, which is a lateral beam. On top of that is a honeycomb or egg-crate shaped plastic piece made of HDPE which defines the bumper's ultimate external shape and supports the shape of the bumper cover. On the rear, these can be attached to the cars other bodywork or components. In a more serious accident, this part of the bumper structure is usually the part that is damaged, but not visible.

Finally, a polyurethane or other flexible polyethylene plastic bumper cover is placed on the outside to give the car a finished appearance. These are either charcoal or flat black and they can paint to match the car finish. They are designed to be impact resistant and can take a blow with little or no damage. Bumpers in cars are meant for absorbing shock or impact at low velocity like accidents that occur when reversing the car. Bumper material is selected in such a manner that it should have the capability to absorb the impact (i.e.) either nullify the effect or reduce the effect of the impact. Metals are not considered as excellent material for bumpers since they transfer the load applied at one end to the other with negligible loss. Plastics and polymer materials can be utilized as bumper since they have the tendency to absorb the applied impact load and thereby reduce the effect of the impact.

B. Topology Optimization of Automobile Components

The automobile industry is in a continuous struggle to reduce the weight of the cars for multiple reasons. It helps to increase the fuel efficiency and thereby reduces the emissions. The reduction in weight is caused by reducing the size or number of parts which reduces the manufacturing costs. Even the growth of emerging electric vehicles is dependent on better mileage per charge which is achievable by, among other methods, through weight reduction.

This weight reduction can be achieved mainly by two methods. The first one is using alternatives to the traditionally used materials such as steel and ductile iron. For example, the increase in use of aluminum to replace steel in manufacturing structural elements in vehicles. But there are major hurdles involved such as the high cost of manufacturing due to which it is used mostly in luxury vehicles. The use of lighter materials may even lead to negative environmental impact when their entire life cycle is considered due to their production and manufacturing processes and limitations in recycling.

LITERATURE REVIEW

Hosseinzadehetal. [1] Studied bumper beams in the cars that defend the passengers and the automobile form the disastrous front and rear collisions. Researchers studied the front bumper beam manufactured from glass mat thermoplastic (GMT) and analysis was performed using ANSYS LS-DYNA.

Marzbanrad et al. [2] Studied a front bumper beam made from 3 different materials: aluminum, GMT and high-strength SMC. In this research work, the most important parameters including material, thickness, shape and impact condition were studied for design and analysis of an automotive front bumper beam to improve the crashworthiness design in low-velocity impact. The study was carried out by impact modeling to calculate the deflection, impact force, stress distribution and absorption of energy-behavior. The above-mentioned characteristics were compared by the researchers to find out the most suitable fabric, form and thickness. The researchers observed that a modified SMC bumper beam can minimize the bumper beam deflection, impact force and stress distribution and maximize the elastic strain energy.

Mohapatra [3] discussed that car improvement cycles have gotten shorter and with increasing competition in the marketplace, the OEM's and supplier's essential venture is to come up with time environment friendly solutions. It was also discussed by the researchers that some bumpers use electricity absorbers or brackets, and others are made with a foam cushioning material.

Andersson et al. [4] studied the relative performance of three high strength carbon steels and two high strength stainless steel grades using intrinsic and simulative tests. The rear bumper for a Volvo Car was manufactured by the researchers using the five sheets tested to verify formability and behaviour under load. The bumpers were clamped in a rig that allowed quasi-static impact tests to be made. The energy absorbing capabilities of the bumper were evaluated by conducting the impact test.

Butler et al. [5] stated that components linked to crash safety should transmit or absorb energy and the energy absorbing capability of a specific component is a combination of its geometry and material properties. The selected material should have high yield strength and relatively high elongation to fracture and these demands have led to increasing interest in the use of high strength stainless steels.

Carley et al. [6] analyzed three bumper structural performance criteria and the objective of their study was to design efficient epoxy structural foam reinforcements to improve the energy absorption of front and rear automotive bumper beams.

Evans and Morgan [7] analyzed innovative Expanded Polypropylene (EPP) foam technologies and techniques in detail.

MODELING AND ANALYSIS

CATIA is an acronym for Computer Aided Three-dimensional Interactive Application. It is one of the leading 3D software used by organizations in multiple industries ranging from aerospace, automobile to consumer products. CATIA provides the capability to visualize designs in 3D. When it was introduced, this concept was innovative. Since Dassault Systems did not have an expertise in marketing, they had revenue sharing tie-up with IBM which proved extremely fruitful to both the companies to market CATIA.

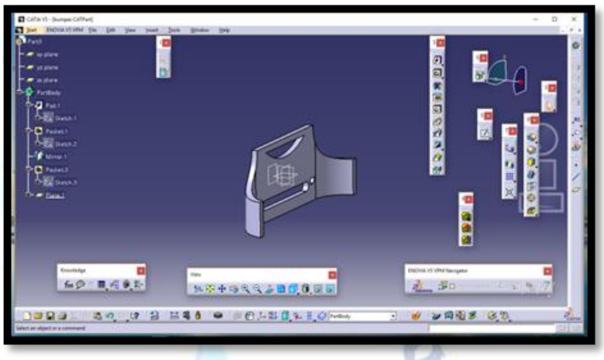


Fig –1: Car Bumper 3D Model

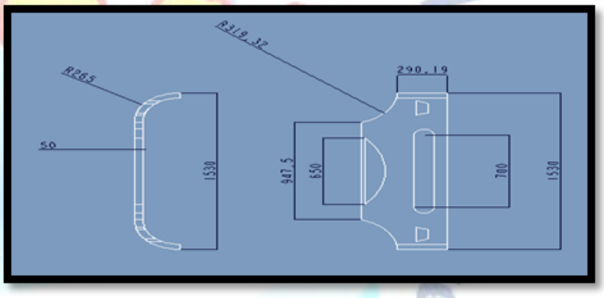


Fig – 2: Car Bumper 2D Model

A. Analysis of Car Bumper Using Cosmos Works

COSMOSWorks software uses the Finite Element Method (FEM) for analysis. FEM is a numerical technique for analyzing engineering designs. FEM is accepted as the standard analysis method due to its generality and suitability for computer implementation. FEM divides the model into many small pieces of simple shapes called elements, effectively replacing a complex problem by many simple problems that need to be solved simultaneously. The behavior of each element is well-known under all possible support and load scenarios. The finite element method uses elements with different shapes. The response at any point in an element is interpolated from the response at the element nodes.

COSMOS Works is a design analysis automation application fully integrated with SolidWorks. This software uses the Finite Element Method (FEM) to simulate the working conditions of your designs and predict their behavior.

B. Static studies

Static studies calculate displacements, reaction forces, strains, stresses and factor of safety distribution. Materials usually fail at locations where stresses exceed a certain threshold level. Factor of safety calculations are based on a failure criterion. COSMOSWorks offers four failure criteria. Static studies can help one to avoid failure due to high stresses. A factor of safety less than unity indicates material failure. Large factors of safety in a contiguous region indicate low stresses and therefore some material can be removed from this region.

C. Frequency Studies

Frequency studies calculate resonant frequencies and the associated mode shapes. When a body is subject to a vibrating environment, frequency studies can help you avoid failure due to excessive stresses caused by resonance. A body disturbed from its rest position tends to vibrate at certain frequencies called natural or resonant frequencies. The lowest natural frequency is called the fundamental frequency. For each natural frequency, the body takes a certain shape called mode shape.

D. Static Analysis - Deformation, Stress and Strain in Car Bumper at various Speeds

The material considered for the analysis was polypropylene and a car speed of 40km/hr was used. COSMOSWorks formulates the equations governing the behavior of each element taking into consideration its connectivity to other elements. These equations relate the response to known material properties, restraints, and loads. Next, the program organizes the equations into a large set of simultaneous algebraic equations and solves for the unknowns. In stress analysis, for example, the solver finds the displacements at each node and then the program calculates strains and finally stresses.

The car bumper model as depicted in Figure 3 was developed using CATIA software and then it was saved in IGES format. Later on, the model was imported in COSMOSWorks and further analysis was carried out.

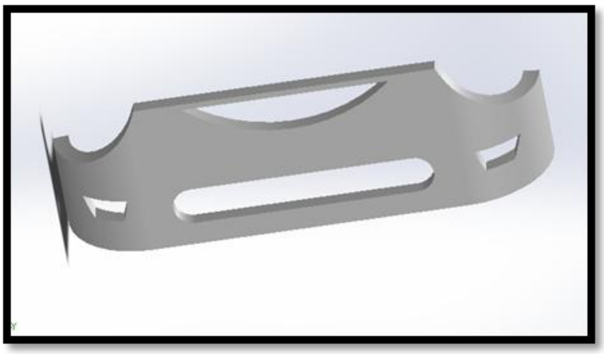


Fig - 3: Imported model of bumper

The restraints were specified and structural studies were carried out by defining how the model was supported. The loads were specified and static analysis was carried out. Elements share common points called nodes. The process of dividing the model into small pieces is called meshing. The behavior of each element is well-known under all possible support and load scenarios. The finite element method uses elements with different shapes. The response at any point in an element is interpolated from the response at the element nodes. Each node is fully described by several parameters depending on the analysis type and element used. After importing the design file, the meshing was performed using tetra hydro fine mesh by dividing into number of nodes and number of elements as shown in the Figure 4.

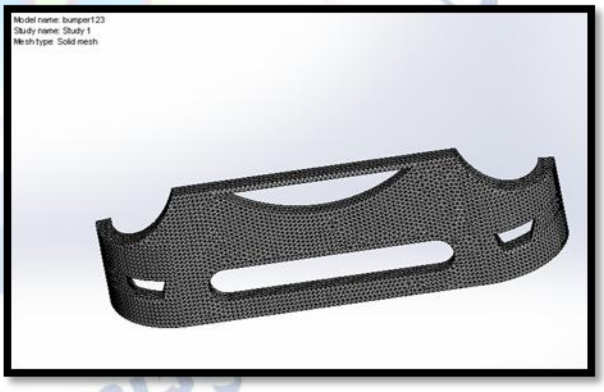


Fig - 4: Meshed model for bumper

Static analysis was carried out on the car bumper by applying the boundary conditions. The total deformation of car bumper is shown in the Figure 5. It can be observed from the above figure that the maximum deformation is indicated in red color, whereas the minimum deformation is indicated in blue color. The minimum deformation occurred at the fixed ends of the bumper and the maximum deformation occurred at mid-section of the bumper.

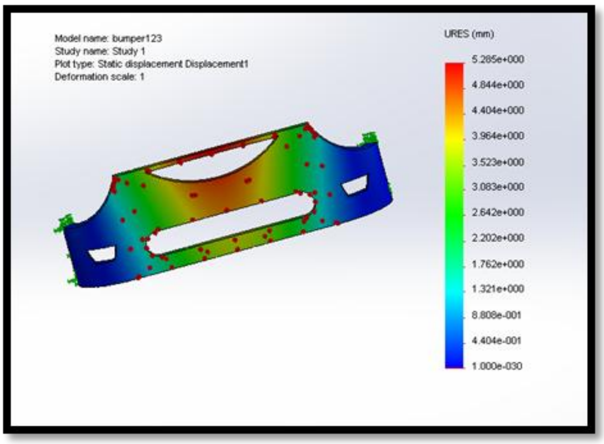


Fig - 5: Total deformation of bumper

As observed in the Figure 6, the maximum stress regions are indicated by red color and minimum stress regions are indicated by blue color. The boundary conditions were applied and the minimum stress occurred at the outer ends of the bumper and the maximum stress was generated at mid portion of the bumper.

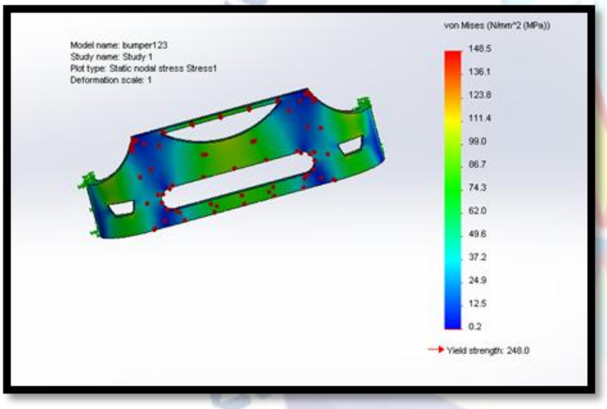


Fig - 6: Stress distribution in bumper

As indicated in the Figure 7, the maximum strain regions are indicated by red color and minimum strain regions are indicated by blue color. It can be observed form the Figure 7 that the minimum strain occurred at the outer ends of the bumper, whereas the maximum stress was generated at mid portion of the bumper.

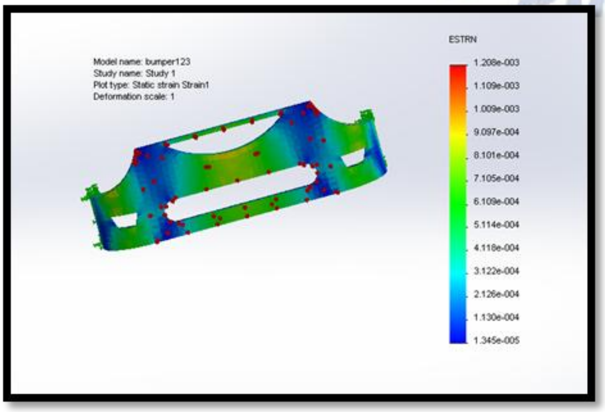


Fig - 7: Strain distribution in bumper

The Table 1 shows the results obtained from the static analysis of the car bumper at different speeds for different materials. It is observed from the results that when the speed of the car is at 45 km/hr, the values of deformation and strain values for Polyurethane (PUR) are low when compared to the other two materials Polypropylene (PP) and Poly-Vinyl-Chloride (PVC). Stress value of Poly-Vinyl-Chloride (PVC) is also low when compared to the other materials.

Table - 1: Static Analysis Result Table

Material	Car speed(km/hr)	Deformation (mm)	Stress (MPa)	Strain
Polypropylene (PP)	45	$5.285e^{+000}$	148.5	$1.208e^{-003}$
	60	$8.068e^{+000}$	224.4	$1.31e^{-003}$
	75	$1.021e^{+001}$	282.5	$2.304e^{-003}$
Polyurethane (PUR)	45	$2.012e^{+000}$	150.3	$4.551e^{-004}$
	60	$3.042e^{+000}$	224.7	$6.851e^{-004}$
	75	$3.820e^{+000}$	279.4	$8.615e^{-004}$
Poly-Vinyl-Chloride (PVC)	45	$3.44e^{+001}$	141.9	$8.368e^{-003}$
	60	$8.203e^{+001}$	276.1	$1.638e^{-002}$
	75	$1.282e^{+002}$	393.5	$2.450e^{-002}$

From the static analysis, it was inferred that the deformation and stresses increase with an increase in the car speed from 45 km/hr to 75km/hr. The deformation and stress in the car bumper for all the materials were maximum at a car speed of 75km/hr. From the static analysis it was observed that the stress values for Polypropylene were less when compared to Poly-Vinyl-Chloride material and Polyurethane at all vehicle speeds.

The Chart 1 shows the variation of the stress induced in the bumper made up of different materials at various vehicle speeds. It is observed that the stress values of the materials Polypropylene (PP) and Polyurethane (PUR) are low when compared to the Poly-Vinyl-Chloride (PVC).

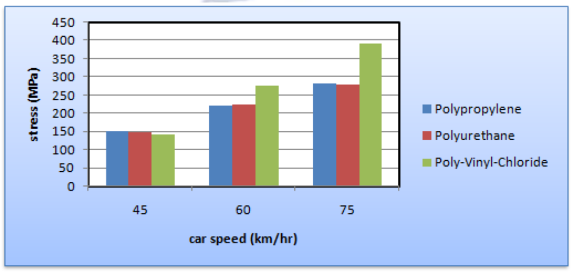


Chart – 1: Variation of Stress in bumper for different materials and car speeds

E. MODAL ANALYSIS OF THE CAR BUMPER

Modal analysis is the study of the dynamic properties of systems in the frequency domain. Modal analysis is the process of determining the inherent dynamic characteristics of a system in forms of natural frequencies, damping factors and mode shapes and using them to formulate a mathematical model for its dynamic behaviour. Modal analysis of car bumper was conducted using COSMOSWorks software using appropriate boundary conditions and meshing.

A continuous model has an infinite number of natural frequencies. However, a finite element model has a finite number of natural frequencies that is equal to the number of degrees of freedom considered in the model. Meshing was done and modal analysis of car bumper was carried out. The Frequency displacement plots for bumper are depicted in Figures 8, 9 and 10.

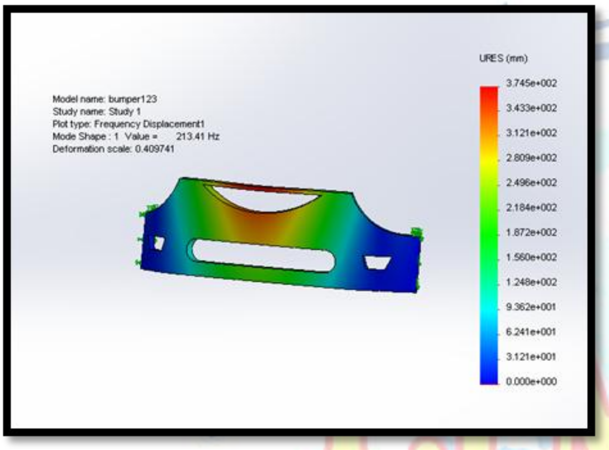


Fig – 8: Frequency displacement plot 1 for bumper

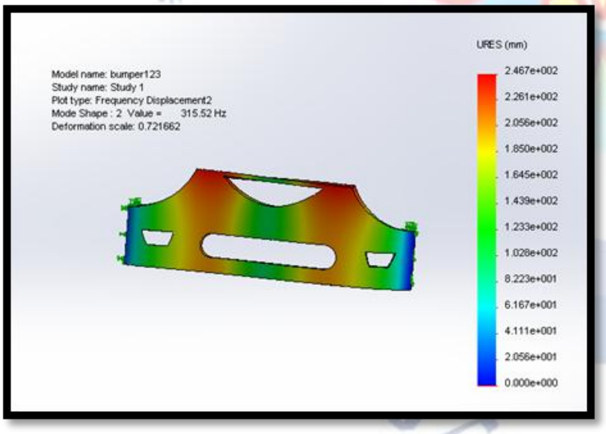


Fig – 9Frequency displacement plot 2 for bumper

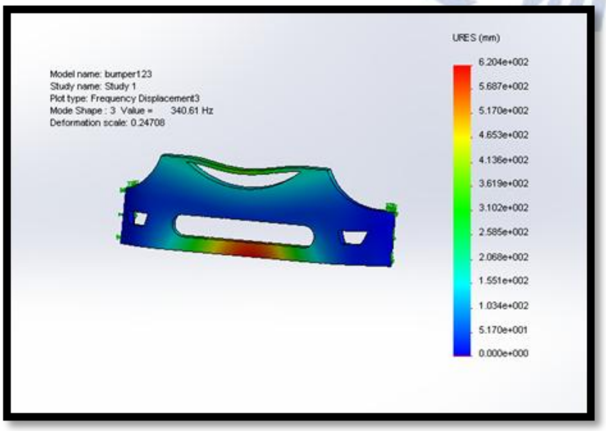


Fig – 10: Frequency displacement plot 3 for bumper

The Table 2 shows the values of frequency at different modes, for different materials of the bumper. In the below table, it is observed that the values frequency of the Polyurethane (PUR) material at five modes are high when compared to the other materials.

Table 2: Modal Analysis Result Table

Material	Mode shapes	Deformation (mm)	Frequency (Hz)
Polypropylene (PP)	Mode1	$3.745e^{+002}$	231.41
	Mode2	$2.467e^{+002}$	315.52
	Mode3	$6.204e^{+002}$	340.611
	Mode4	$1.703e^{+002}$	366.37
	Mode5	$4.252e^{+002}$	572.43
Polyurethane (PUR)	Mode1	$3.73e^{+002}$	342.44
	Mode2	$2.441e^{+002}$	505.59
	Mode3	$6.198e^{+002}$	549.53
	Mode4	$1.701e^{+003}$	588.09
	Mode5	$4.153e^{+002}$	922.91
Poly-Vinyl-Chloride (PVC)	Mode1	$3.770e^{+002}$	82.449
	Mode2	$2.543e^{+002}$	122.58
	Mode3	$6.219e^{+002}$	129.66
	Mode4	$1.708e^{+003}$	141.47
	Mode5	$4.520e^{+002}$	218.28

F. Impact analysis of Car Bumper at different speeds

The impact analysis of car bumper was carried at different speeds like 45km/hr, 60 km/hr and 75 km/hr. The deformation plot, stress plot and strain plot obtained from the impact analysis are depicted in Figures 11,12 and 13.

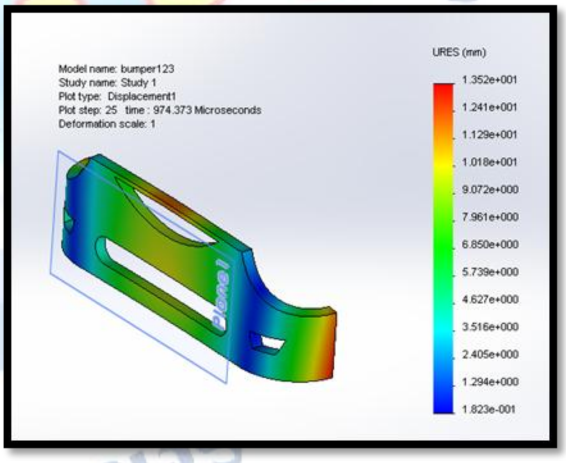


Fig – 11: Total deformation in bumper

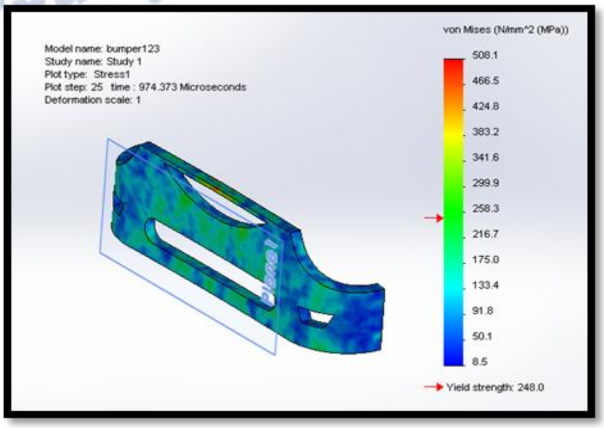


Fig – 12: Stress distribution in bumper

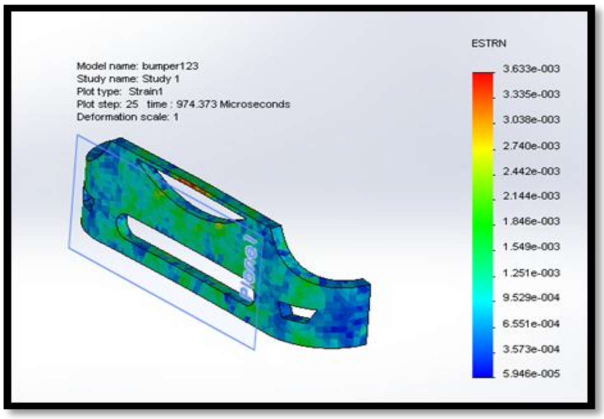


Fig – 13: Strain distribution in bumper

The results of the impact analysis of the bumper at different speeds like 45km/hr, 60 km/hr and 75 km/hr are shown Table 3. It is observed that, bumper at 45 km/hr, the values of deformation, strain values of the material are Polyurethane (PUR) are low compared to the Polypropylene (PP) and Poly-Vinyl-Chloride (PVC). Stress value of Polypropylene (PP) is also low when compared to the other materials.

Table - 3: Impact Analysis Result

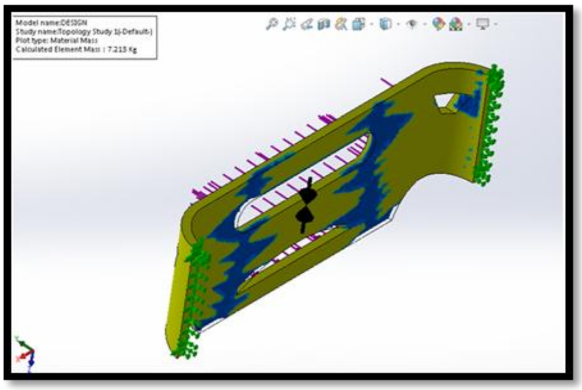
Material	Car speed(km/hr)	Deformation (mm)	Stress (MPa)	Strain
Polypropylene (PP)	45	$1.385e^{+001}$	91.7	$5.075e^{-003}$
	60	$2.088e^{+001}$	133.3	$7.273e^{-003}$
	75	$2.617e^{+001}$	163.3	$9.352e^{-003}$
Polyurethane (PUR)	45	$1.040e^{+001}$	776.5	$2.528e^{-003}$
	60	$1.561e^{+001}$	1150.2	$3.743e^{-003}$
	75	$1.952e^{+001}$	1434.2	$4.662e^{-003}$
Poly-Vinyl-Chloride (PVC)	45	$1.352e^{+001}$	508.1	$3.633e^{-003}$
	60	$2.021e^{+001}$	753.9	$5.591e^{-003}$
	75	$2.521e^{+001}$	1022.9	$7.658e^{-003}$

Table

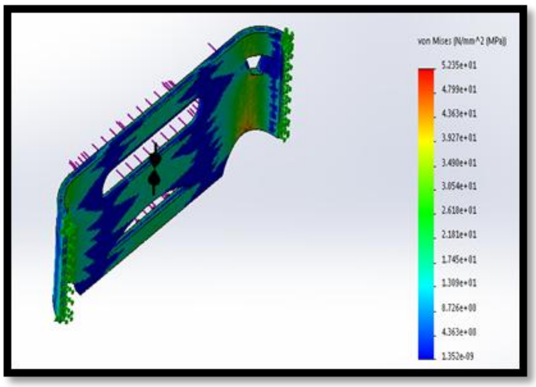
The Chart -2 depicts the values of the stress of the bumper made up of different materials at various vehicle speeds. It is observed that the stress values of the materials Polypropylene (PP) and Polyurethane (PUR) are low when compared to the Poly-Vinyl-Chloride (PVC).

G. Topology Optimization of Car Bumper

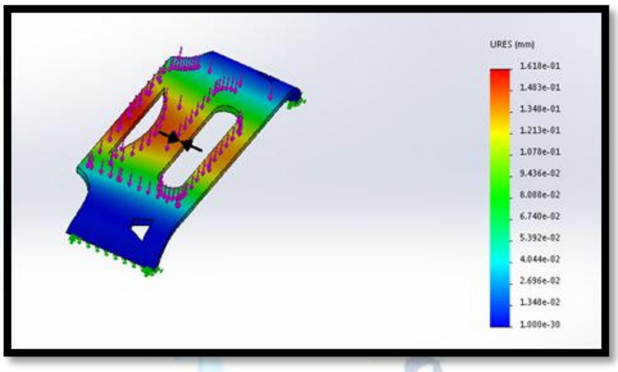
Mass



Topology Variable Stress



Topology Variable Displacement



Topology Variable Strain

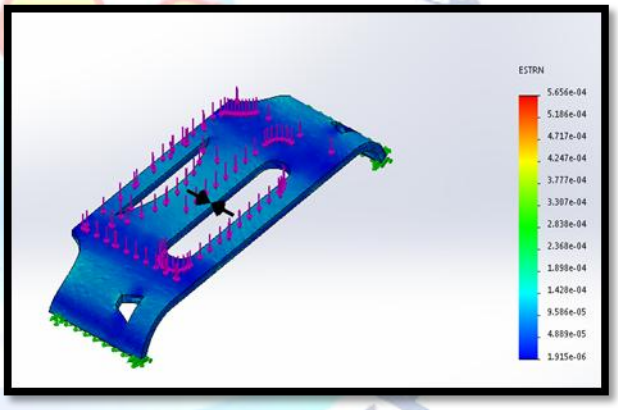


Table - 4: Topology Analysis Result Table

Materials	Displacement (mm)	Stress (N/mm^2)	Strain	Mass (kg)
Polypropylene (PP)	5.65e-04	5.235e+01	1.618e-01	7.213
Polyurethane (PUR)	6.948e-04	6.282e+01	1.941e-01	7.566
Poly-Vinyl-Chloride (PVC)	5.7064e-04	5.865e+01	1.812e-01	7.414

Chart-2 Materials Vs mass

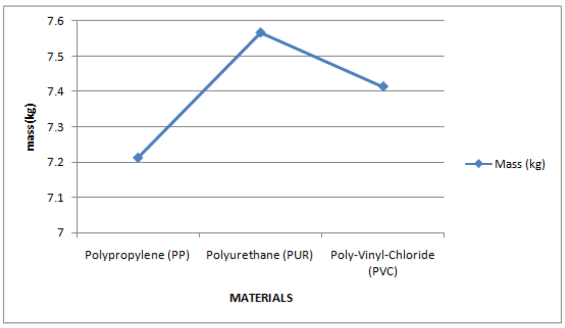


Chart-3 Materials Vs mass Comparison graph

CONCLUSION

From the static analysis, it was inferred that the deformation and stresses increase with an increase in the car speed from 45 km/hr to 75km/hr. The deformation and stress in the car bumper for all the materials were maximum at a car speed of 75km/hr. From the static analysis it was observed that the stress values for Polypropylene were less when compared to Poly-Vinyl-Chloride material and Polyurethane at all vehicle speeds.

From modal analysis, the frequency for Polyurethane was the greatest when compared to Poly-Vinyl-Chloride and Polypropylene. From modal analysis; it was also observed that the deformation for Polypropylene material was the least when compared to both Poly-Vinyl-Chloride and Polyurethane.

From the impact analysis, it can be observed that the deformation was increased with an increase in the car speed for all the materials. The stress for Polypropylene was the least when compared to Polyurethane and Poly-Vinyl-Chloride. The deformation for Polyurethane was the least when compared to Poly-Vinyl-Chloride and Polypropylene.

Hence, it was concluded that the Polypropylene is the optimum materials for car bumper based on the static, impact and modal analysis.

Conclusions traced out during the optimization and evaluating the strength of the bumper are as follows:

•The weight of car bumper is optimized from 10.0 Kg to 7.2 Kg using topology method.

•The shape of the arm's cross section is made easier to manufacture and to distribute the stress induced in the bumper.

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