STATIC, MODAL AND IMPACT ANALYSIS OF CAR BUMPER USING VARIED PARAMETERS

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Abstract - *Car bumpers can absorb the impact energy with deformation. A Benz car bumper was utilized for static and modal analysis. The different bumper materials used for this analysis were Polypropylene (PP), Polyurethane (PUR) and Poly-Vinyl-Chloride (PVC). 3-D modeling was carried out with the help of CATIA software. Static and impact analysis were performed to calculate the deformation and stress induced in the car bumper at different vehicle speeds (45, 60 & 75 km/hr). Modal evaluation was carried out to estimate the frequency and deformation for mode shapes. The finite element analysis of car bumper was carried out by means of SolidWorks software. It was inferred from the static analysis, that both the deformation and stresses increase with an increase in the car speed from 45 km/hr to 75 km/hr. The deformation and stress in the car bumper for all the materials were maximum at a car speed of 75 km/hr. From the static analysis, it was observed that the stress values for PP material were less when compared to PVC and PUR material at all vehicle speeds. It was concluded that PP is the optimum material for manufacturing the car bumper based on the static, modal and impact analysis.*

Keywords: PP, PVC, PUR, CATIA, SolidWorks, Static and impact analysis.

1. INTRODUCTION

Bumper is a part of an automobile designed to protect and support the 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 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 support part has a mid-section that can be firmly supported on the vehicle body.

Bumper is mainly of 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 front bumper system and it has three components.

1.1 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 car's body or other components. In a more serious accident, this part of the bumper structure usually gets damaged, but it is not visible.

Finally, a urethane or other types of flexible polyethylene plastic bumper cover is placed on the outside to give the car a finished appearance. These covers are either charcoal or flat black in colour and they can painted 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 energy at low velocity like accidents that occur while reversing the car. Bumper material is selected in such a manner that it should have the capability to absorb the impact energy (i.e.) either nullify the effect or reduce the effect of the impact. Metals are not considered as excellent materials for bumpers since they transfer the load applied at one end to the other end with negligible loss. Plastics and polymer materials can be utilized as bumper materials since they have the tendency to absorb the applied impact load and thereby reduce the effect of the impact.

1.2 Classification of high-performance plastics

The different types of high-performance plastics which are widely used as car bumper materials are PP, PUR, PVC and ABS.

(i) Polypropylene (PP)

Polypropylene is a thermoplastic polymer used in a wide variety of applications. It is a saturated addition polymer made from the monomer propylene and it is rugged and unusually resistant to many chemical solvents, bases and acids.

Applications: automotive bumpers, chemical tanks, cable insulation, gas cans and carpet fibers.

(ii) Polyurethane (PUR)

Solid Polyurethane is an elastomeric material of exceptional physical properties including toughness, flexibility and resistance to abrasion and temperature. Polyurethane has a broad hardness range, from eraser soft to bowling ball hard. Other polyurethane characteristics include extremely high flex-life, high load-bearing capacity and outstanding resistance to weather, ozone, radiation, oil, gasoline and most solvents.

Applications: flexible foam seating, foam insulation panels, elastomeric wheels and tyres, automotive suspension bushings, cushions, electrical potting compounds and hard plastic parts.

(iii) Poly-Vinyl-Chloride (PVC)

PVC has good flexibility, is flame retardant, and has good thermal stability, a high gloss, and low lead content. Polyvinyl chloride molding compounds can be extruded, injection molded, compression molded, calendared and blow molded to form a huge variety of products, either rigid or flexible depending on the amount and type of plasticizers used.

Applications: automobile instruments panels, sheathing of electrical cables, pipes and doors.

(iv) ABS

Acrylonitrile Butadiene Styrene is a copolymer made by polymerizing styrene and acrylonitrile in the presence of polybutadiene. The styrene gives the plastic a shiny and impervious surface. The butadiene, a rubbery substance, provides resilience even at low temperatures. A variety of modifications can be made to improve impact resistance, toughness and heat resistance.

2. LITERATURE REVIEW

Hosseinzadeh et al. [1] studied bumper beams in the cars that protect the passengers and the automobile from 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: aluminium, 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 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 and tested to verify formability and behaviour under load. The bumpers were clamped in a rig that allowed quasi-static impact tests to be conducted. 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 an 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.

3. MODELING OF CAR BUMPER USING CATIA

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 Systemes did not have an expertise in marketing, they had revenue sharing tie-up with IBM which proved extremely fruitful for both the companies to market CATIA.

The car bumper modeling was done using CATIA software with help of features such as pad and pocket. Pad was used for adding the material and pocket was used for removing the material. 3D model and 2D models of the car bumper are shown in Figures 1 and 2.

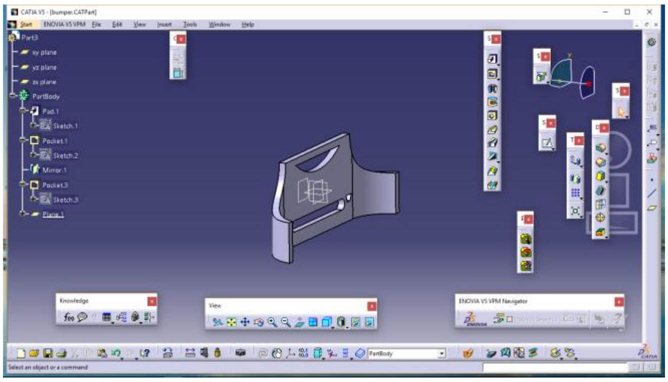

Fig –1: 3D Model of Car Bumper

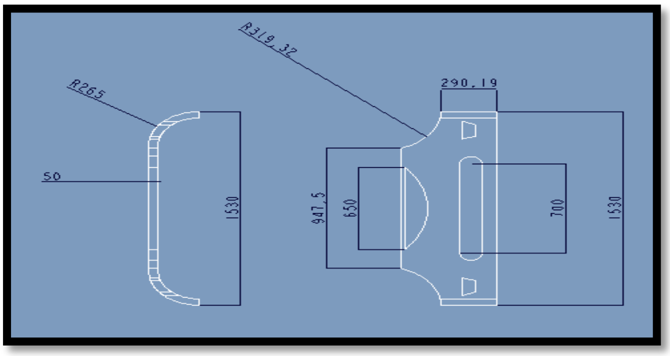

Fig – 2: 2D Model of Car Bumper

3.1 Calculation of Impact Force acting on Car Bumper during collision at various speeds

The impact force acting on the car bumper during collision at various speeds were calculated using the following procedure:

(i) Low speed car collisions at 45 km/hr
Mass of car = 1400 kg
Mass of five passengers = 350 kg
Total mass of the vehicle in motion = mass of car + mass of passengers = 1400 + 350 = 1750 kg

During collision, the work is generated in form of kinetic energy, and it was calculated from the following equation:
Kinetic Energy = ½ m v^2 (1)
where m is the mass of the car and passengers, kg
v is the velocity of the car, m/s
Velocity of car, v = 45 km/hr = 12.50 m/s

By substituting the values for velocity and mass in equation (1), the kinetic energy generated during the impact is calculated as:
Kinetic Energy = 136.72 kJ
The kinetic energy generated due to impact will be absorbed by the displacement of car components. Since it is a frontal impact, the maximum displacement is constrained to 500mm considering the safety of the passengers and major structural components of the car.
This kinetic energy generated is the work done during collision. Therefore, Kinetic Energy = Work Done (W)
Work Done (W) = 136.72 kJ
The work done can be calculated as, W = F * d (2)
Where W is work done, kJ
F is Impact Force, kN
d is maximum displacement of bumper, m
By substituting the values of work done and displacement in equation (2),
Impact Force F = 273.44 kN

(ii) Medium speed car collisions at 60 km/hr
v = 60 km/hr = 16.67 m/s
On substituting the above values for velocity and mass in equation (1), the kinetic energy generated during the impact is calculated as:
Kinetic Energy = 243.15 kJ
By following the similar procedure as in the previous case, the impact force was calculated.
Impact Force F= 486.31 kN

(iii) High speed car collisions at 75 km/hr
v = 75 km/hr = 20.83 m/s
On substituting the above values for velocity and mass in equation (1), the kinetic energy generated during the impact is calculated as:
Kinetic Energy = 379.77 kJ
By following the similar procedure as in the previous case, the impact force was calculated.
Impact Force F= 759. 55 kN

4. RESULTS AND DISCUSSIONS

4.1 Analysis of Car Bumper using COSMOSWorks

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

4.1.1 Static studies

Static studies are performed to 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 such 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.

4.1.2 Frequency Studies

Frequency studies are performed to calculate resonant frequencies and the associated mode shapes. When a body is subject to a vibrating environment, frequency studies can help one to 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.

4.2 Static Analysis - Deformation, Stress and Strain distribution in the Car Bumper at various Speeds

The material considered for the static analysis of car bumper were PP, PVC and PUR and analysis was carried out at different car speeds like 45 km/hr, 60 km/hr and 75 km/hr. 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 into COSMOSWorks and further analysis was carried out.

The restraints were specified and structural studies were carried out by defining how the model was supported. The impact forces acting on Car Bumper during collision at various speeds 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. 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 the model into a number of nodes and elements as shown in the Figure 4.

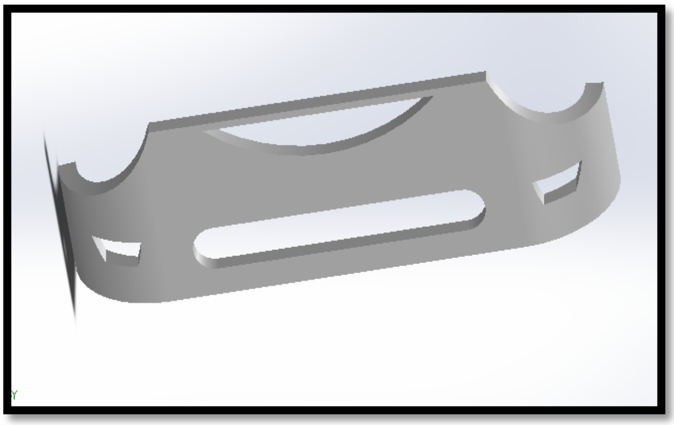

Fig - 3: Imported model of bumper

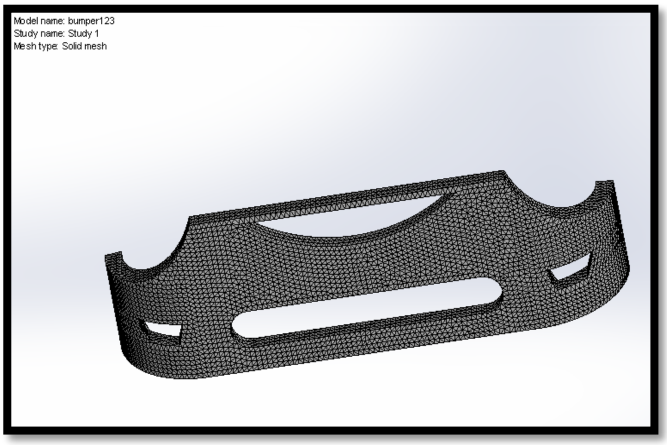

Fig - 4: Meshed model for bumper

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 figure that the maximum deformation region 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 the mid-section of the 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 stress was calculated in the model. The minimum stress occurred at the outer ends of the bumper and the maximum stress was generated at mid portion of the bumper.

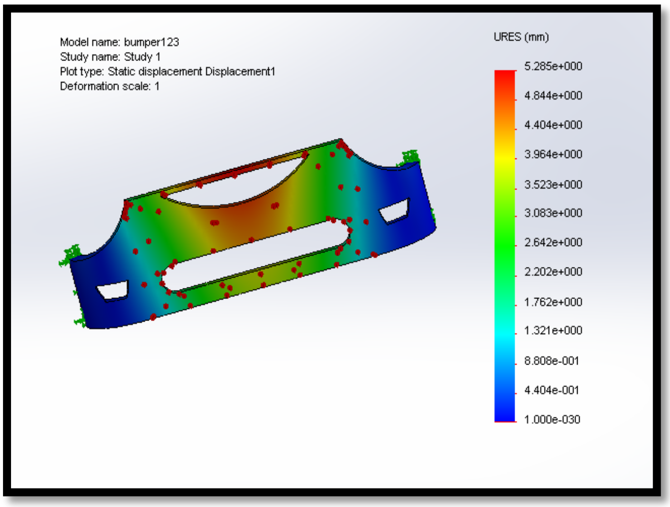

Fig - 5: Total deformation of bumper

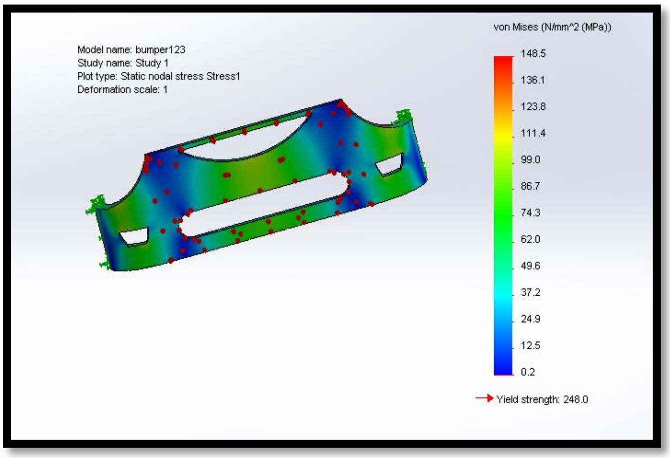

Fig - 6: Stress distribution in bumper

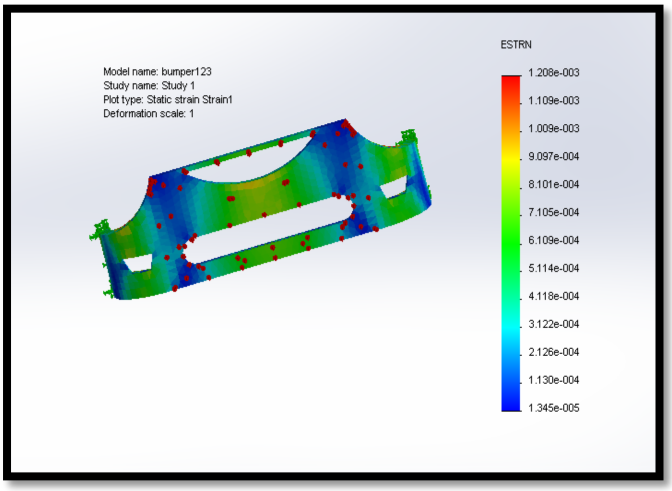

Fig - 7: Strain distribution in bumper

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 from the figure that the minimum strain occurred at the outer ends of the bumper, whereas the maximum strain was generated at mid portion of the bumper.

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 PUR are low when compared to the other two materials PP and PVC. Stress value of PVC is also low when compared to the other two materials.

Table - 1: Results for Static Analysis

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 was 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).

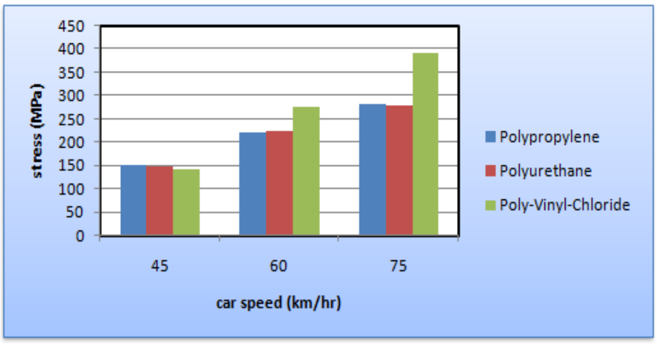

Chart – 1: Variation of stress in bumper for different materials and car speeds

4.3 Modal Analysis of 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 form 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 utilizing 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.

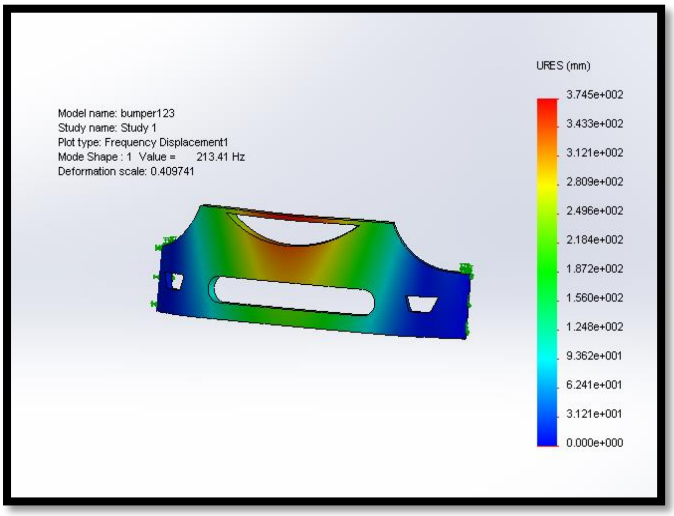

Fig – 8: Frequency displacement plot 1 for bumper

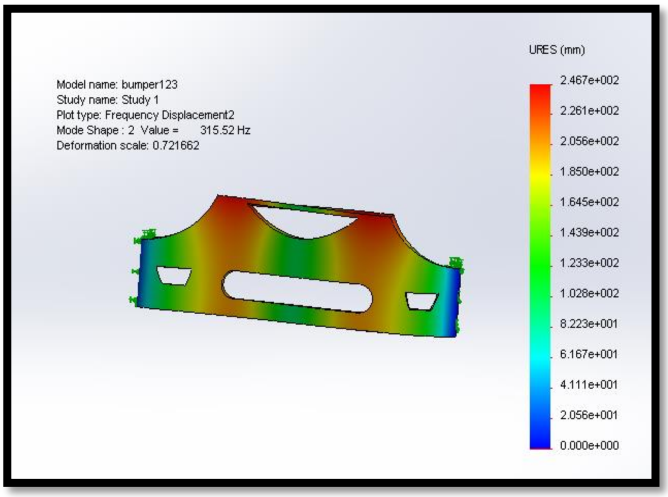

Fig – 9: Frequency displacement plot 2 for bumper

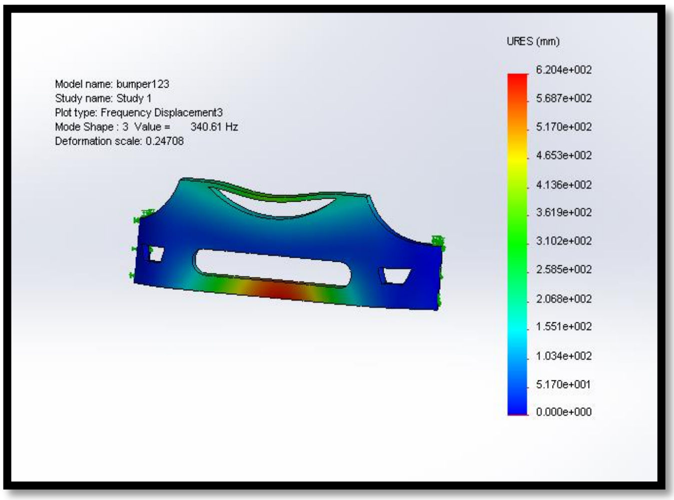

Fig – 10: Frequency displacement plot 3 for bumper

Table 2 shows the values of frequency at different modes, for different materials of the bumper. In the table, it can be observed that the frequency of the Polyurethane (PUR) material at mode5 is maximum when compared to the other materials. The maximum deformation occurred for PVC material at mode4. The minimum deformation occurred for PP material at mode4. Hence, based on modal analysis of car bumper, it was concluded that PP material is the optimum one for manufacturing a car bumper.

Table 2: Results for Modal Analysis

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

4.4 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.

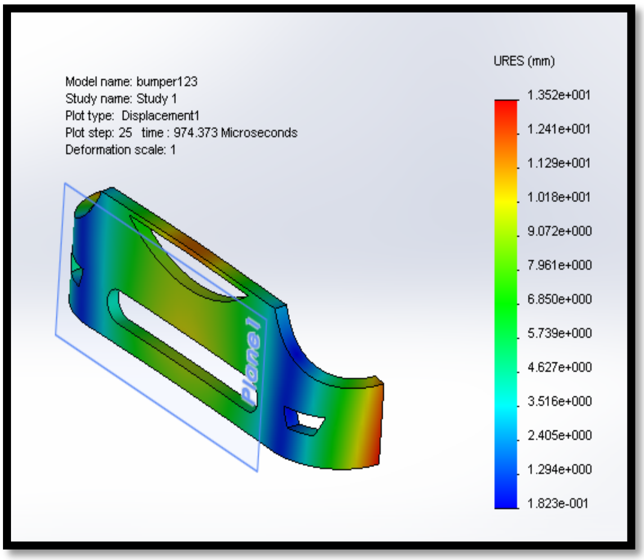

Fig – 11: Total deformation in bumper

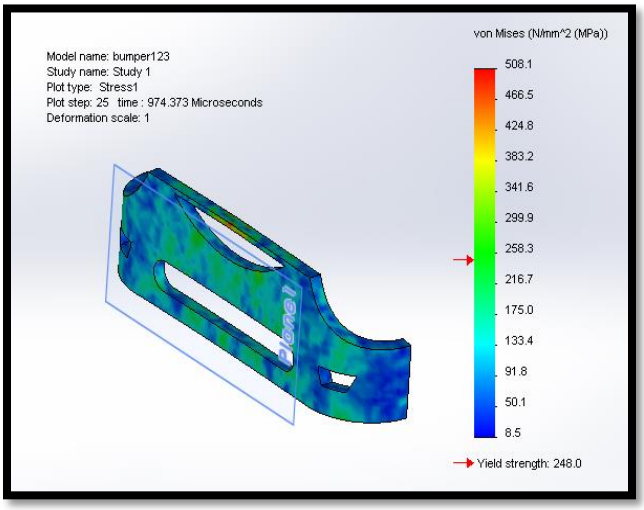

Fig – 12: Stress distribution in bumper

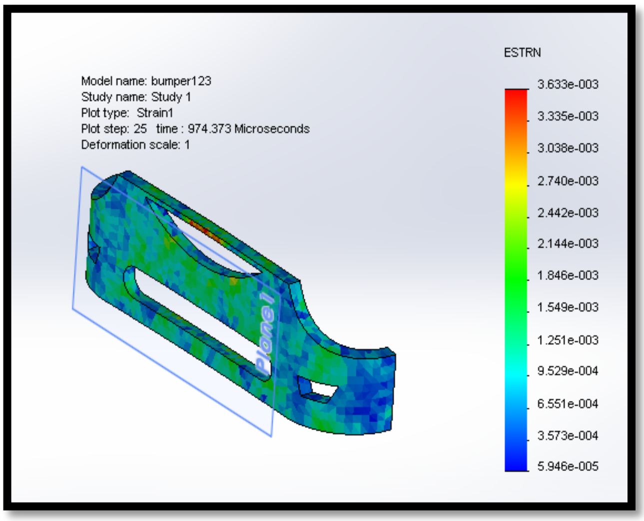

Fig – 13: Strain distribution in bumper

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 from the table that the values of deformation and strain for PUR are low when compared to Polypropylene (PP) and Poly-Vinyl-Chloride (PVC) at all car speeds. Stress value of Polypropylene (PP) is low when compared to the other materials and it can be chosen as bumper material.

Table - 3: Impact Analysis Result Table

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

Chart - 2 depicts the values 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).

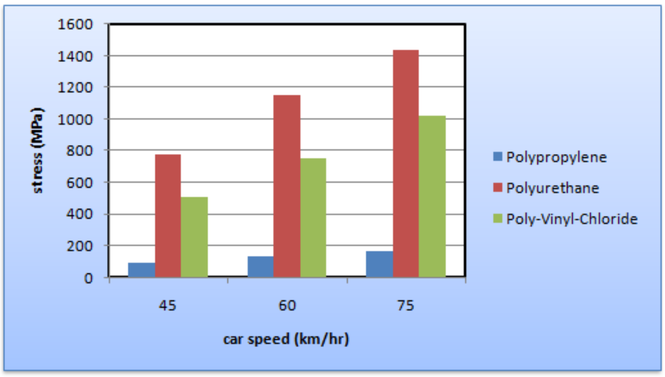

Chart - 2: Variation of stress in bumper for different materials and car speeds

5. CONCLUSION

In this research work, a Benz car bumper was used for analysis. The static, modal and impact analysis were conducted at different speeds (45, 60 & 75 km/hr) and the materials used for the analysis were Polypropylene (PP), Polyurethane (PUR) and Poly-Vinyl-Chloride (PVC).

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 75 km/hr. The deformation and stress induced in the car bumper for all the materials were maximum at a car speed of 75 km/hr. It was also observed that the stress values for Polypropylene were less when compared to Poly-Vinyl-Chloride and Polyurethane at all vehicle speeds.

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

It was observed from the impact analysis that the deformation was increased with an increase in the car speed for all the materials. The stress induced for Polypropylene car bumper was the least when compared to Polyurethane and Poly-Vinyl-Chloride. Hence, it was concluded that the Polypropylene is the optimum material for manufacturing car bumper based on the static, modal and impact analysis.

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