Design and Analysis of Front Car Bumper using Glass, Kevlar and Carbon Fiber Epoxy Composite Materials

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Abstract - *Bumper is a significant part by its function as it acts as damper for energy absorption when the kinetic energy being flow down to the vehicle body. Bumpers are protective layer required for all vehicles. In this case study, a front car bumper is designed and modelled by using the software CATIA V5 R20. The conceptual design model is analyzed using FEM package, Hyper mesh tool for FE modeling and Nastran software as Solver. In order to get fair idea on most appropriate conceptual design with composite materials, various analysis iterations are carried out with Glass, Kevlar and Carbon Fiber Epoxy composites by performing modal analysis (vibration analysis) and static analysis. The materials used for this analysis are Glass, Kevlar and carbon fiber reinforced plastic and epoxy resin having the composition 60% of CFRP and 40% of epoxy resin. The results are then compared with each other. From all these analysis and comparison, it can be concluded that the composite materials CFRP (Carbon Fiber Reinforced Plastic) and Epoxy-resin are suitable for use in the cars.*

Key Words: **Car Front bumper, Impact, Static, Nastran, Catia V5 R20.**

1. INTRODUCTION

Vehicle accidents are very prone in the busy and dynamic world. It is an engineering responsibility to avoid such troublesome incidents in every body's life. Introduction of safety features in automobiles is very much required to decrease the number of accidents and injuries on life and damage of vehicles. Automotive bumper beam is one of the safety systems in vehicles. Bumpers are designed in such a way that it absorbs the kinematic impact and avoid direct contact with external surface to prevent or reduce physical damage to the front or rear portion of the motor vehicles in collision condition. Bumper covers the trunk, hood, fuel tank, grill, exhaust, lightning systems and cooling system as well as safety related indicators such as head lamps and tail lights. Vehicle bumpers are introduced for two reasons – to accommodate the car to tolerate a low-speed impact without much damage to the vehicle's surface and safety systems and to protect the lives in the vehicle from the physical injuries. The safety of travellers during vehicle crashes can be avoided to certain limit by using good and effective bumpers. Bumpers are positioned on the front and back side of a vehicles and serve as its guard. The impact is reduced during the collisions with other cars and objects due to their excessive deformation. The bumpers are conceptualized and given shapes in order to deform and retrieve to original shape and size and absorb the kinetic force during a crash.

1.1 Composite Bumpers

As material advancement progressed over years, the automotive industry is also competing with Aerospace industries in implementing composite materials where ever metals can be replaced. Variety of composite materials have been experimented both in simulation and physical experimentation to adapt in most parts of the automobiles. Manufacturing industries are keen to implement with fiber reinforced particles in a bid to improve the toughness and stiffness of the composite materials, as a means of enhancing their fundamental properties as well as to reduce costs. The inclusive of particulate fillers can lead to few drawbacks such as brittleness or opaque nature.

1.2 Glass Fiber Reinforced Epoxy Bumper

Glass Fiber-reinforced plastics (GFRP) is a composite material consisting of a polymer matrix combined with a supporting material or fiber which serves to enhance the mechanical strength and elasticity of the plastic. Common fibers include basalt, carbon, glass or aramid although in some cases it might include asbestos, wood or paper. The core polymer matrix usually an epoxy, vinyl ester or polyester thermosetting plastic is manufactured using step-growth polymerization or addition polymerization. The matrix is hard but comparatively weak and the addition of powerful fibers and filaments serve to toughen it up and provide the desired mechanical and material properties to the resulting plastic.

1.3 Kevlar Fiber Reinforced Epoxy Bumper

Kevlar is a synthetic fiber and a familiar component of defence items such as face masks, warfare helmets and vests. Kevlar exhibits high strength, flexibility and modulus whereas little elongation, low density, corrosion impedance and non-conductivity. Kevlar is having an ability of absorbing significant amount of energy. The benefits of Kevlar fiber are its elevated impedance to impact failure; hence, it is commonly utilized in the field to reduce impact damage. Kevlar is obtainable as fabric materials. Here in our study, the Kevlar fibers are reinforced with Epoxy resin to get the desired properties for achieving required functionalities.

1.4 Carbon Fiber Reinforced Epoxy Bumper

Carbon fiber reinforced plastic is a high strength and light weight fiber-reinforced plastic which contains carbon fibers as a reinforcement. CFRPs are generally used wherever high strength-to weight ratio and rigidity is required. CFRP application can be extensively observed in the areas of aerospace, civil engineering, automotive and sports goods. There is an increase in number of other consumer and technical applications in recent developments. The binding polymer is commonly a thermoset epoxy resin, but other thermoset or thermoplastic polymers, such as vinyl ester, polyester and nylon, are also seen.

2. LITERATURE SURVEY

Literatures based on Physical Testing and Simulation on impact study are reviewed and investigated. It is clearly observed that major injury due to impact velocity affects first to the car bumpers and followed by vehicle body cover and passengers.

Vishwanath R H et al. [1] had investigated the Design and Strength validation about the use of composite materials in frontal car bumper. Materials such as Carbon fiber reinforcement composite materials. The mechanical properties of these materials are then compared with conventional car bumper material Steel. This comparison showed a reduction in weight, cost and environmental impact and concluded that the composite materials CFRP (Carbon Fiber Reinforced Plastic) and Epoxy-resin are suitable for use in the cars.

Dubem Ezekwem [2] had investigated and accessed about the use of composite materials in frontal automotive bumper. Material composition such as nylon-6 nano composite and polyethylene/palm kernel shell-iron filings are used. The mechanical characteristics of these materials are compared with conventional automotive bumper material like Aluminum and Steel. This comparison summary showed a reduction in cost, weight and environmental influence and also have some demerits such as difficulty in mass production and feasibility (quality) of the production process were also identified.

Bhavesh A. Bohra, Prof. D. B. Pawar [3] In this investigation, the front automotive bumper is conceptualized and analyzed during the impact, the materials considered are ABS (Acrylonitrile Butadiene Styrene) and PEI (Polyetherimide). ABS plastic is highly tough and resilient, has high impact capability, good chemical resistance, nontoxic and taint free. ABS plastic has less density compared to PEI. Hence, ABS material found to be best than the PEI.

S Seenuvas, N Nagendran, N Gayathri, T V B Babu, R Manjunathan [4] In this investigation they accessed about the energy absorption in front bumper of an automotive. The bumper absorbs kinetic energy and transfers against to the impact. The materials used for the assessment are carbon fiber foam composite, steel alloy, aluminum honey comb sandwich materials. Evaluation has been performed between this material and most beneficial is chosen based on the level of energy absorbed on automotive bumper. It is concluded that Carbon fiber foam composite absorbs high impact energy compared to other conventional materials. Hence, carbon fiber foam composite is identified.

Mr. Nitin S Motgi and Prof. S.B. Naik [5] They had investigated on the Impact assessment of Front automotive Bumper. In this study, the material considered for analyzing are aluminum and composite fascia, where aluminum having moderately high density than fascia. At last, it is determined that composite fascia is appropriate from impact point of assessment.

Mahesh Kumar v. Dange, Dr. Rajesh B. Buktal, Dr. Nilesh R. Raykai [6] They have projected about the design and analysis of an automotive front bumper with the material considering as M220 (Martensite 220 min tensile strength) formed from carbon steels. It can minimize the bumper deformation, impact power, stress distribution and also improves the elastic strain energy. At the same time observed some demerits such as high material cost compared to fiber glass and challenges in mass production.

Arun Basil Jacob, Arun Kumar O.N [7] They proposed about improving the crashworthiness of an automotive bumper. This investigation proposed a alternative bumper model which showed better crashworthiness than the current bumper design. They targeted at improving crashworthiness of an automotive bumpers. They identified Toyota Camry Model launched in 2012. The bumper of the current designed model had steel bumper. Two alternative designs were suggested in this study. Embedded Honeycomb inside the current bumper design being the first one and foam embedded design as the second. The alternative designed models namely foam and the honeycomb embedded bumpers show improved impact absorption capability. The absorption capability of the Honeycomb embedded model is 11.26% and of foam model has a capability is 6%. Foam is considered for crashworthiness in the automotive industries for two main reasons, to break the crash energy and to reinforce sheet metal structure.

Alen John, Nidhi M B [8] In this investigation, the materials considered in this analysis are aluminum 390 alloy, chromium coated steel and carbon composites. The assessment under dynamic loading shows that the carbon composite has the maximum Stress and it is having the high strength to weight ratio and producing deflection. From all these assessments it is concluded that carbon composite is the better material.

Lingam Jayashree, D Venkataramaniah, G Naveen Kumar [9] In this investigation the material considered is long fiber reinforced thermoplastics. It is then compared with conventional material steel. The purpose of this activity is to design a bumper to improve the crashworthiness of automotive bumpers. From the assessment it is concluded that long fiber reinforced thermoplastic is good and also in comparison with other materials it is found that natural fibers have good energy absorption capability.

Pradeep Kumar Uddandapu [10] In this investigation the material considered is ABS plastic and PEI. The aim of this review is to analyze and to assess the structure as well as materials. In this research, the assessment is performed for speed according to certification requirements and also by varying speed in the analysis. The density of ABS plastic and PEI is less than that of steel therefore the overall weight of automotive bumper is decreased. In this summary, comparing the outcome of ABS plastic and PEI with steel, the stress values are low for ABS plastic and for the other alternative materials considered, therefore ABS plastic is best for utilization.

Prashanth S and Suresh T [11] They conceptualized and assessed composite truck bumper using FEM. In this investigation the material considered is mild steel and composite material (glass epoxy). The composite material designed gives low stress compared to steel, also composite material weight found to be less in comparison with mild steel.

2.1 Summary from Literature Survey

From the literature review and survey, we understood that weight saving, economical and high impact absorption are the three major aspects to be accounted in designing of a automotive bumpers. Various researchers had investigated with different materials and assessed their results with conclusions. In keeping view of all the observations from the detailed literature reviews, we have conceptualized the front automotive bumper and performed the modal analysis (vibration analysis) and static analysis. And the materials considered for this assessment are Glass, Kevlar and Carbon fiber reinforced plastic with epoxy resin (composite material). And it is then compared with the each other materials. The tabulated results determined from the strength analysis for all three materials are then compared. And concluded, from the results that the design is safe and the Carbon fiber reinforced plastic with epoxy resin is better option among considered three different materials.

3. PROBLEM IDENTIFICATION

The current issue of the automobile industries is in reduction of weight and safety, as well as to overcome the difficulty in mass Production which includes high cost and in maintaining its quality. The fundamental goal of our activity is to overcome the disadvantage of weight and the quality of the component. In this assessment, determination of stress and deflection of various composite materials such as Glass, Kevlar and Carbon epoxy composition by static and modal analysis. And identify the most appropriate material for further investigation.

3.1 Objective

The main objective of our task and activity is to overcome the disadvantage of weight and the quality of the product. Determination of stress and deflection of various composite composition such as Glass, Kevlar and Carbon epoxy materials, by static and modal analysis. And to assess most appropriate material to satisfy the functionality of the product. Modal analysis performed to find the various modes and their fundamental frequencies in vibrational environment. Finally, comparative analysis is performed among each other composite materials.

Table -1: Material Properties

Property	Units	E-Glass/ Epoxy	Kevlar/ Epoxy	HM Carbon/ Epoxy
E_{11}	GPa	50.0	76.0	190.0
E_{22}	GPa	12.0	5.5	7.7
G_{12}	GPa	5.6	2.3	4.2
ν_{12}		0.3	0.34	0.3
$\sigma^T_1=\sigma^C_1$	MPa	800.0	870.0	1400.0
$\sigma^T_2=\sigma^C_2$	MPa	40.0	53.0	54.0
τ_{12}	MPa	72.0	34.0	30.0
ρ	Kg/m^3	2000.0	1500.0	1600.0
V_f		0.6	0.6	0.6
t_k	mm	0.4	0.4	0.12

4. METHODOLOGY

We have conceptualized the automotive front bumper making use of CATIA V5 R20 tool. To carry out analysis, the CAD part is discretised and provided loads and boundary conditions using Finite element tool Hyper mesh and the prepared input decks are solved using Nastran Solver. Post processing is performed by making use of Hyper mesh tool to extract static and modal analysis results for three different materials namely, Glass, Kevlar and Carbon Epoxy composites and with three different layup sequence as mentioned below.

Table -2: Laminate Stacking Sequence

Layup No.	No. of Plies	E-Glass/Epoxy	Hm Carbo/ Epoxy	Kevlar/Epoxy
1	16 Plies	$[\pm45]_{4s}$	[±45]4s	[±45]4s
2	16 Plies	$[90/45/-45/90]_4$	$[90/45/-45/90]_4$	$[90/45/-45/90]_4$
3	17 Plies	$[(90/-45/90/45)_4/90]$	$[(90/-45/90/45)_4/90]$	$[(90/-45/90/45)_4/90]$

4.1 Model Description

The graphical view of the conceptualized model is shown below with the dimensions specified. The data required for design and analyzing the model are:

THICKNESS : 60 mm

TOTAL LENGTH: 1498.45 mm

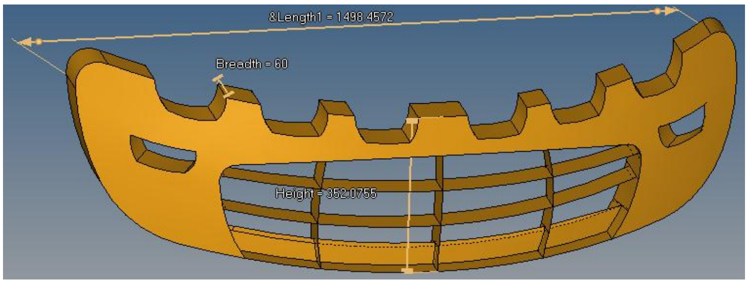


Figure -1: Graphical view of Draft Model

4.2 Geometry

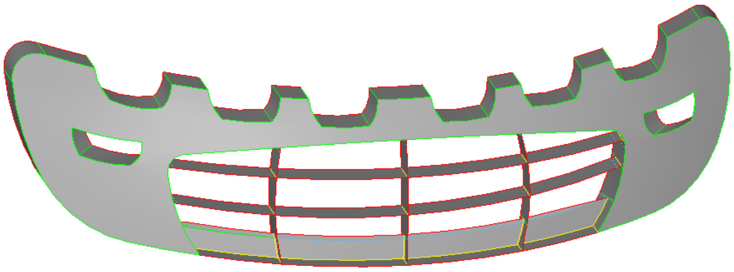


Figure-2: Isometric Bumper Model

4.3 Meshed Model

Loads (100Kg Load - 981N) applied at the center of the bumper.

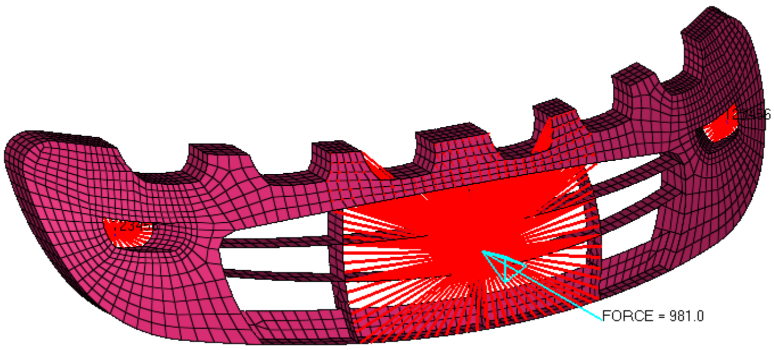


Figure-3: Finite Elements model with Loads and Boundary Conditions

FINITE ELEMENT MODEL DATA INFORMATION:

Total # of Grids (Structural) : 6455

Total # of Elements : 6094

Total # of Degrees of Freedom: 38292

Element Type Information:

CQUAD4 Elements : 5785

CTRIA3 Elements : 324

4.4 BOUNDARY CONDITIONS

Post finite element model preparation, model is constrained to at the two lamp positions as shown in figure.

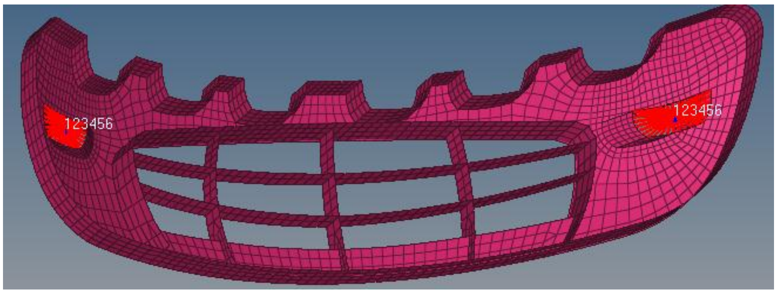


Figure-4: Constrained at two lamp positions

5. MODAL ANALYSIS

This analysis is performed on the designed front automotive bumper model of all three various materials with different layups to have a data for concluding the results, when the bumper is in static position. In this modal analysis, the maximum first fundamental mode is captured among three different layup sequence, in order to ensure there is no resonance with natural frequency of Automobile.

5.1 Glass Fiber Reinforced Epoxy Bumper

Mode:1 Freq: 62.56 Hz, Layup Sequence No. 1

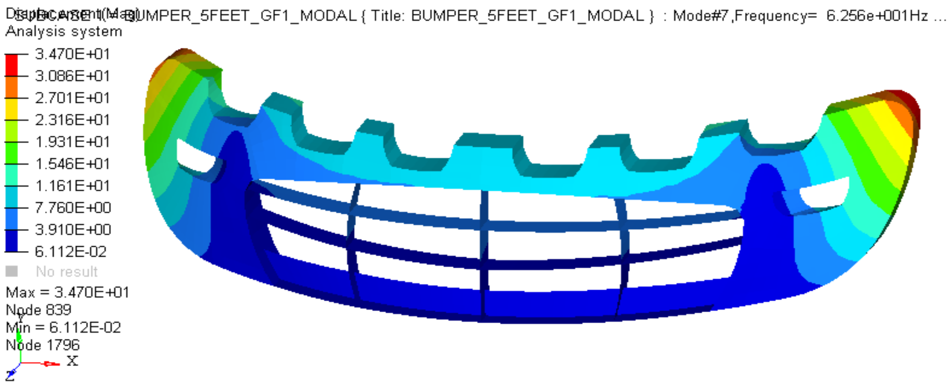


Figure-5: Displacement for Mode 1 Modal Analysis

Mode:1 Freq: 59.17 Hz, Layup Sequence No. 2

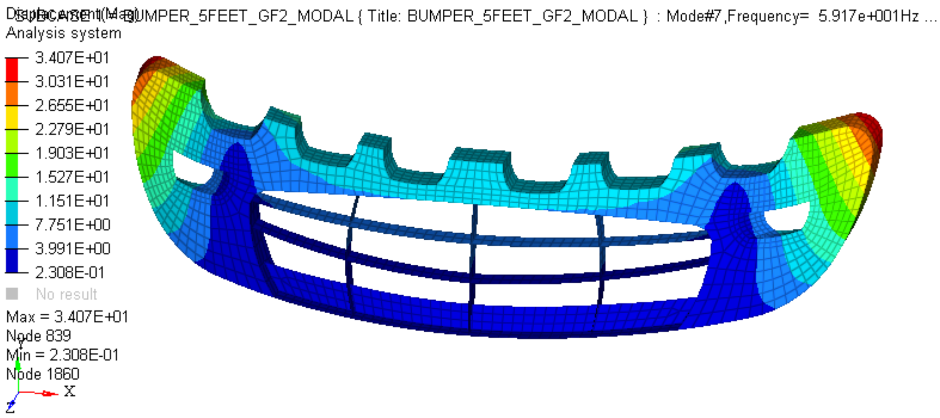


Figure-6: Displacement for Mode 1 Modal Analysis

Mode:1 Freq: 60.77 Hz, Layup Sequence No. 3

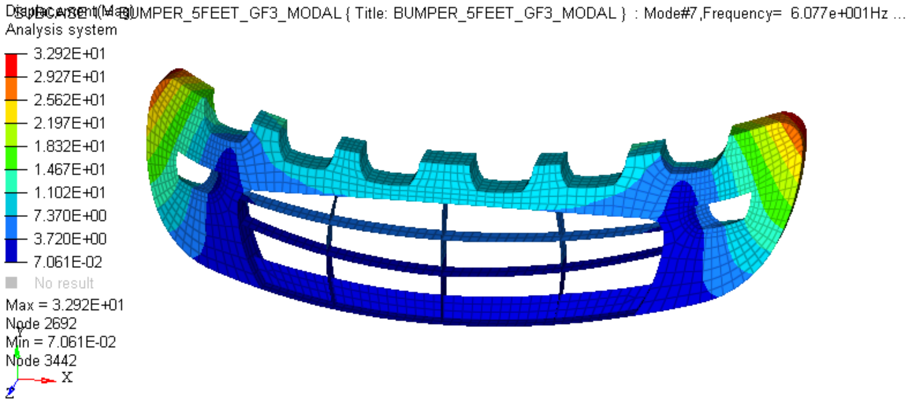


Figure-7: Displacement for Mode 1 Modal Analysis

5.2 Kevlar Fiber Reinforced Epoxy Bumper

Mode:1 Freq: 77.35 Hz, Layup Sequence No. 1

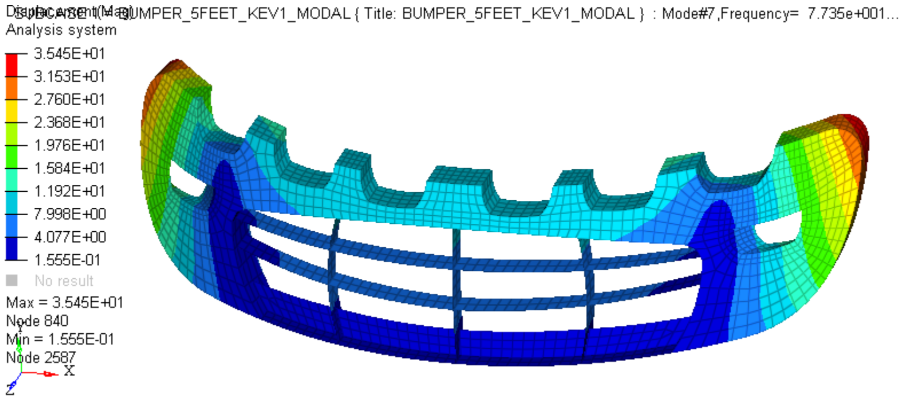


Figure-8: Displacement for Mode 1 Modal Analysis

Mode:1 Freq: 96.21 Hz, Layup Sequence No. 2

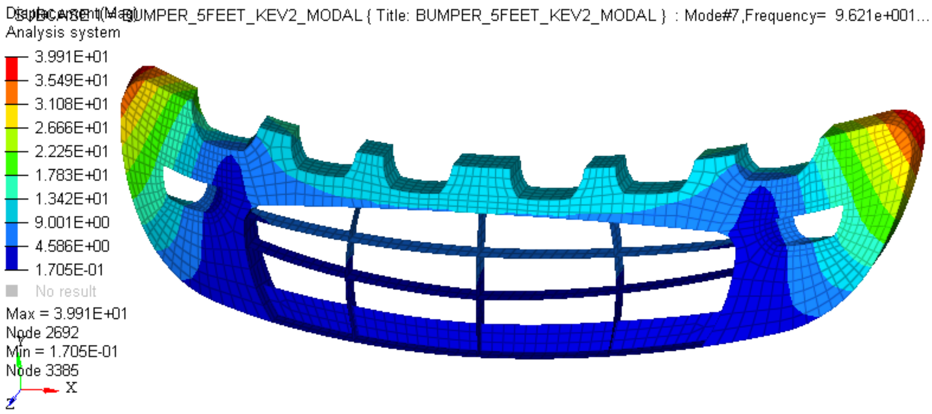


Figure-9: Displacement for Mode 1 Modal Analysis

Mode:1 Freq: 99.62 Hz, Layup Sequence No. 3

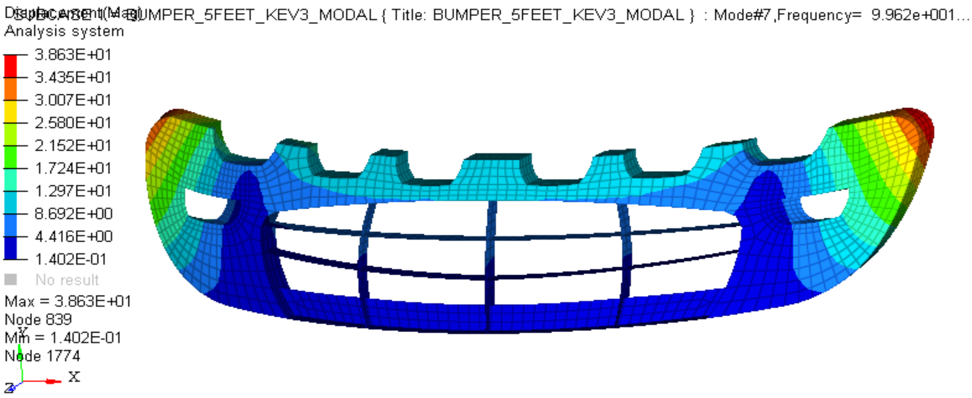


Figure-10: Displacement for Mode 1 Modal Analysis

5.3 Carbon Fiber Reinforced Epoxy Bumper

Mode:1 Freq: 46.01 Hz, Layup Sequence No. 1

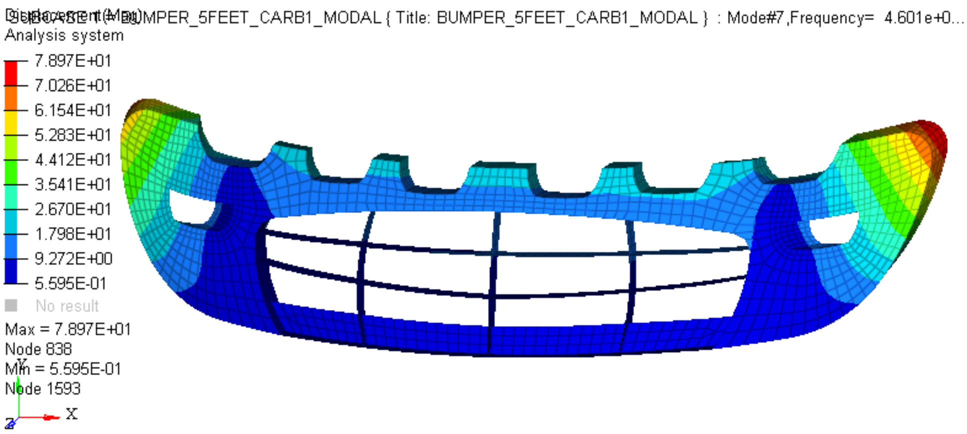


Figure-11: Displacement for Mode 1 Modal Analysis

Mode:1 Freq: 45.33 Hz, Layup Sequence No. 2

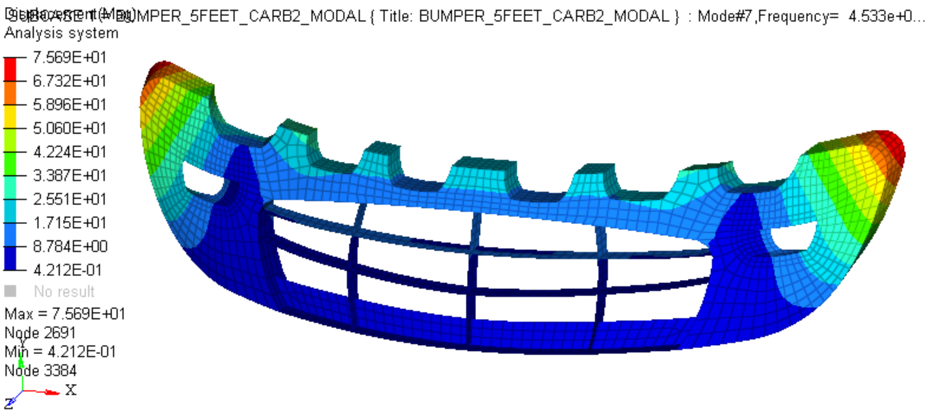


Figure-12: Displacement for Mode 1 Modal Analysis

Mode:1 Freq: 45.96 Hz, Layup Sequence No. 3

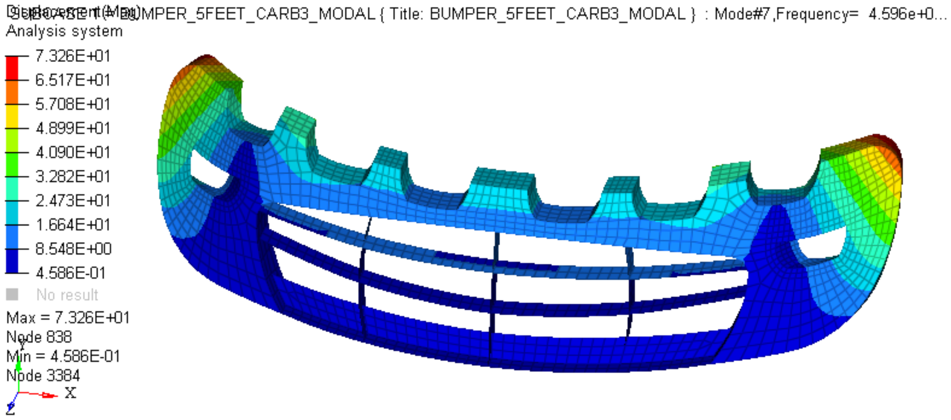


Figure-13: Displacement for Mode 1 Modal Analysis

6. STRENGTH ANALYSIS

Strength analysis is performed for the designed front automotive bumper model of different composite materials i.e. Glass, Kevlar and Carbon Epoxy composites

Carbon Fiber Reinforced Plastic Numerical method:

Factor of Safety (FOS) =

Ultimate Strength/Working Stress FOS =

$X_T + Y_T$ / STRESS

FOS= 1440/104.3 = 13.4

Where,

XT = ultimate tensile strength in fiber direction.

XC = ultimate compression strength in fiber direction.

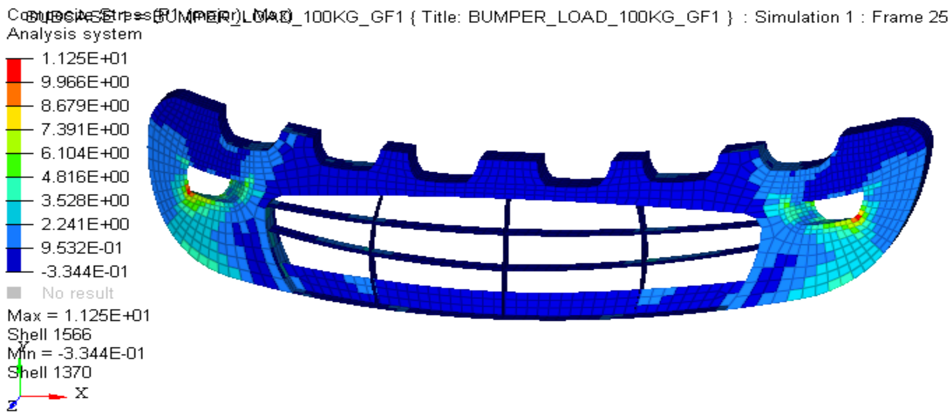
YT = ultimate compression strength perpendicular in fiber direction.

YC = ultimate compression strength perpendicular in fiber direction.

Therefore, from the results obtained we can say that, the design is safe.

6.1 Glass Fiber Reinforced Epoxy Bumper

Layup Sequence 1: Max Stress = 11.2 Mpa



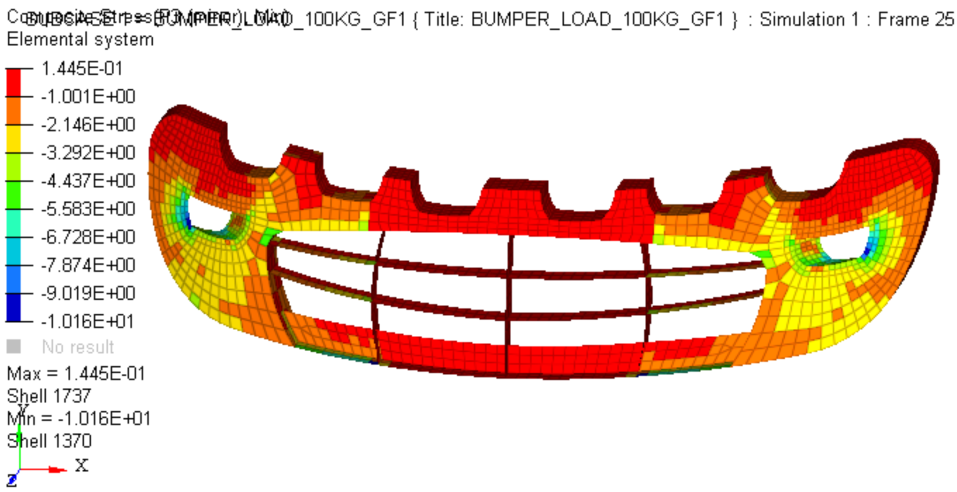


Figure-14: Maximum & Minimum Principal Stress region

Layup Sequence 2: Max Stress = 13.5 Mpa

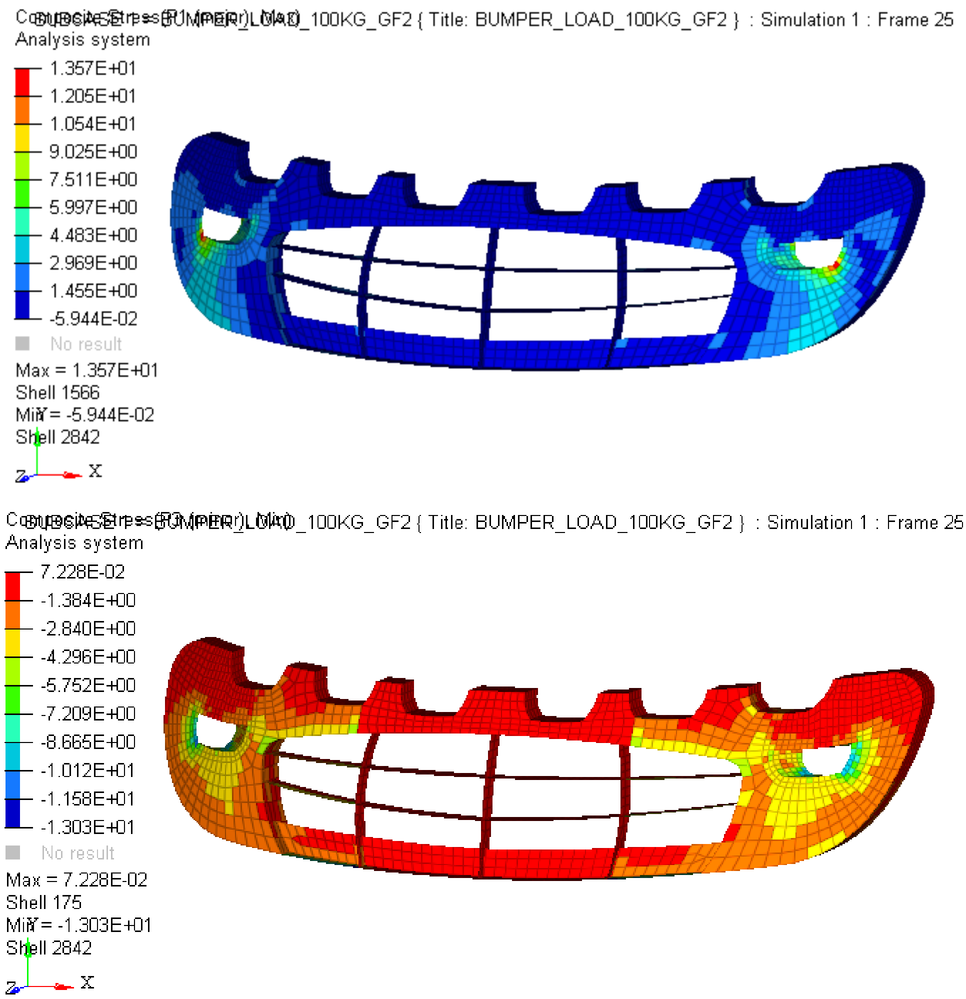


Figure-15: Maximum & Minimum Principal Stress region

Layup Sequence 3: Max Stress = 12.9 Mpa

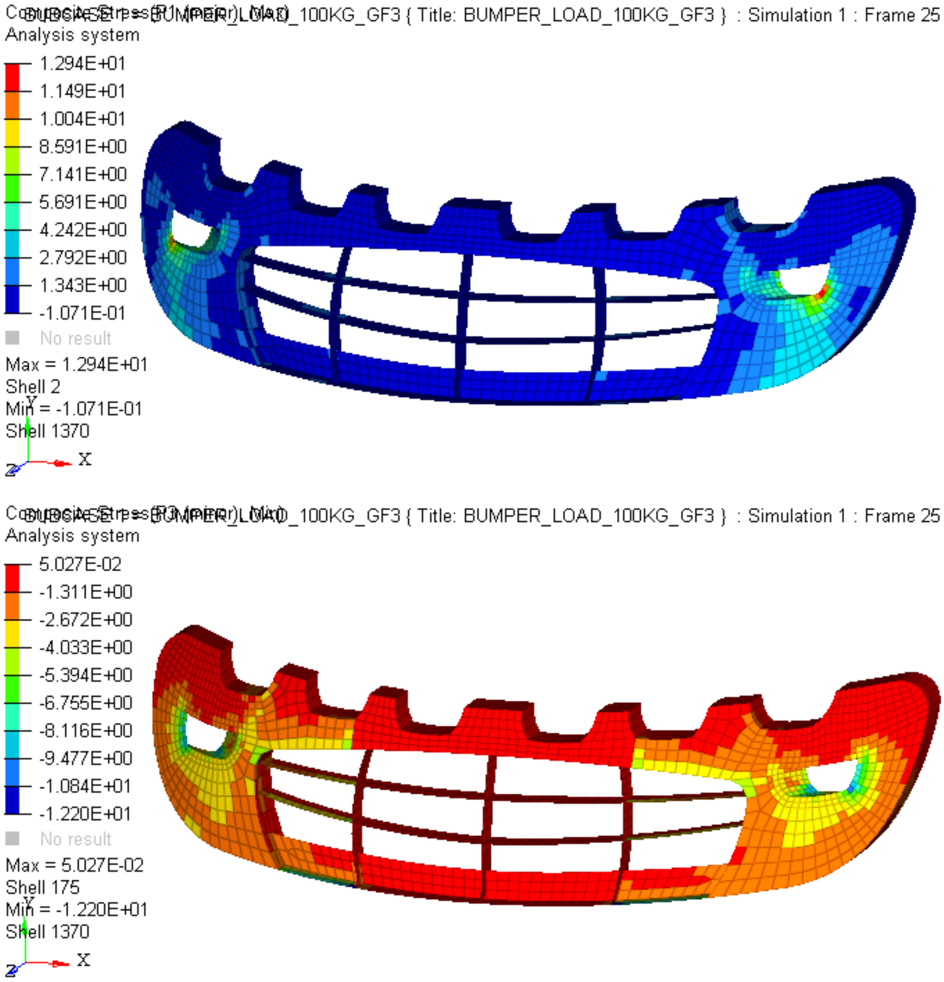
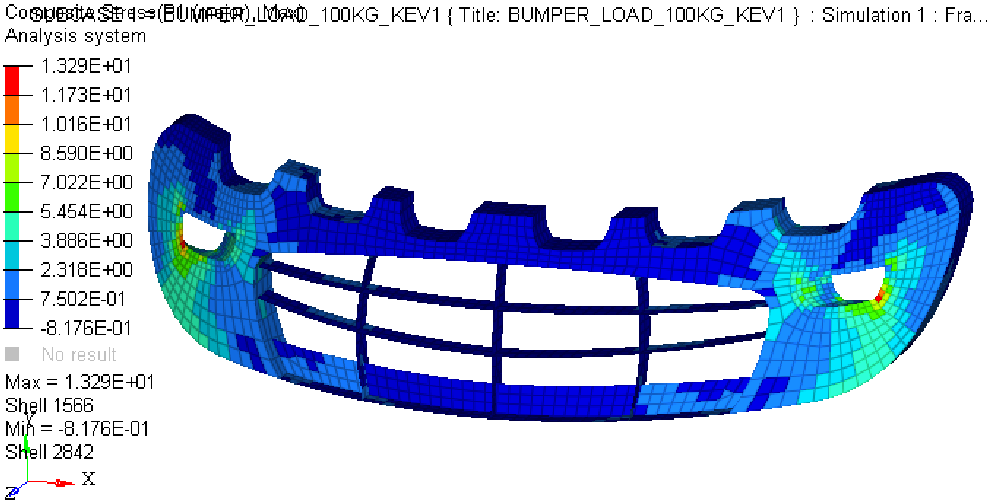


Figure-16: Maximum & Minimum Principal Stress region

6.2 Kevlar Fiber Reinforced Epoxy Bumper

Layup Sequence 1: Max Stress = 13.2 Mpa



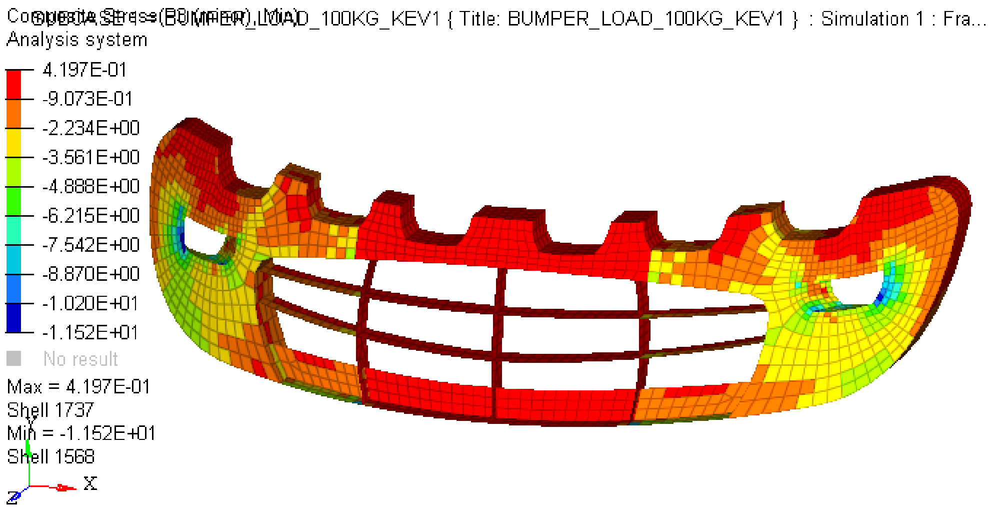


Figure-17: Maximum & Minimum Principal Stress region

Layup Sequence 2: Max Stress = 9.97 Mpa

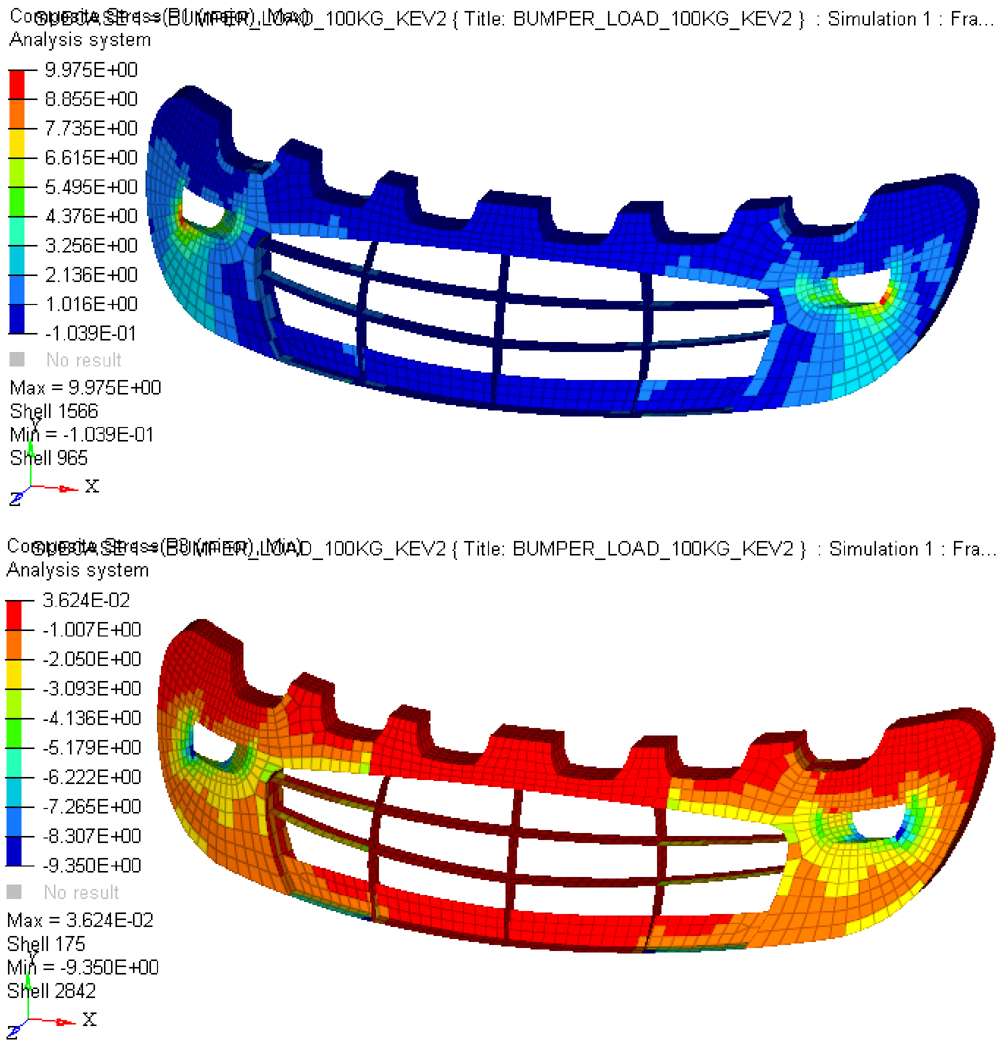
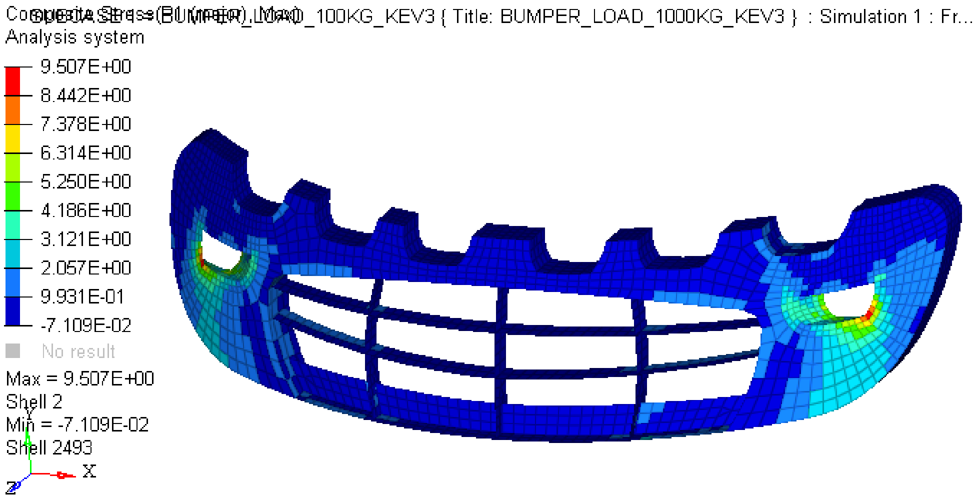


Figure-18: Maximum & Minimum Principal Stress region

Layup Sequence 3: Max Stress = 9.5 Mpa



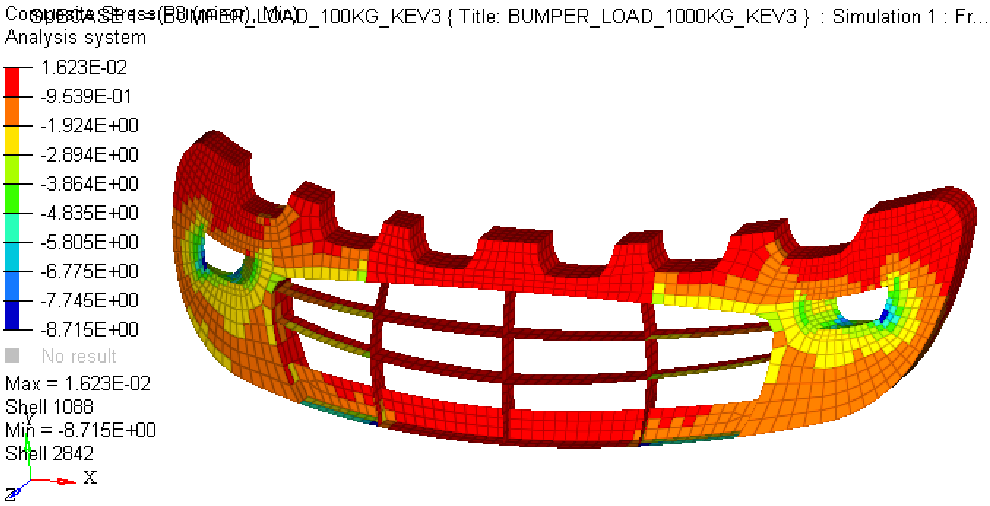
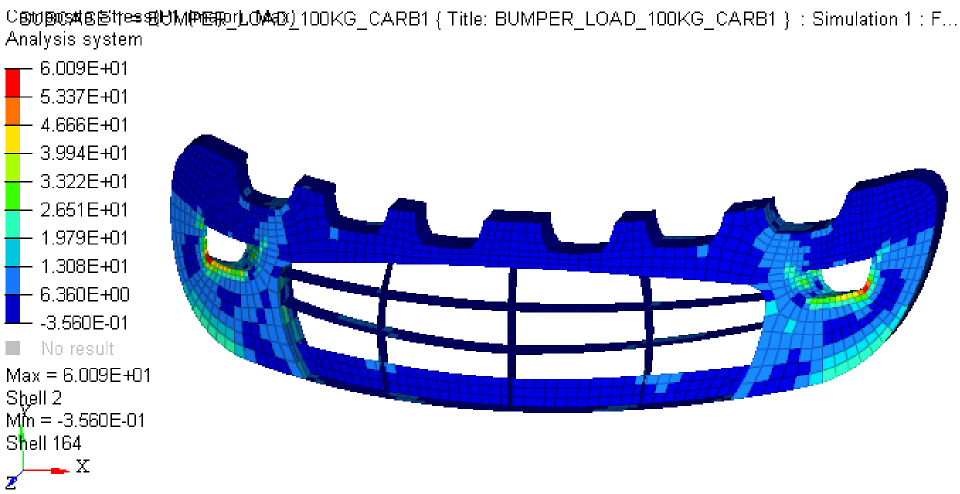


Figure-19: Maximum & Minimum Principal Stress region

6.3 Carbon Fiber Reinforced Epoxy Bumper

Layup Sequence 1: Max Stress = 65.6 Mpa



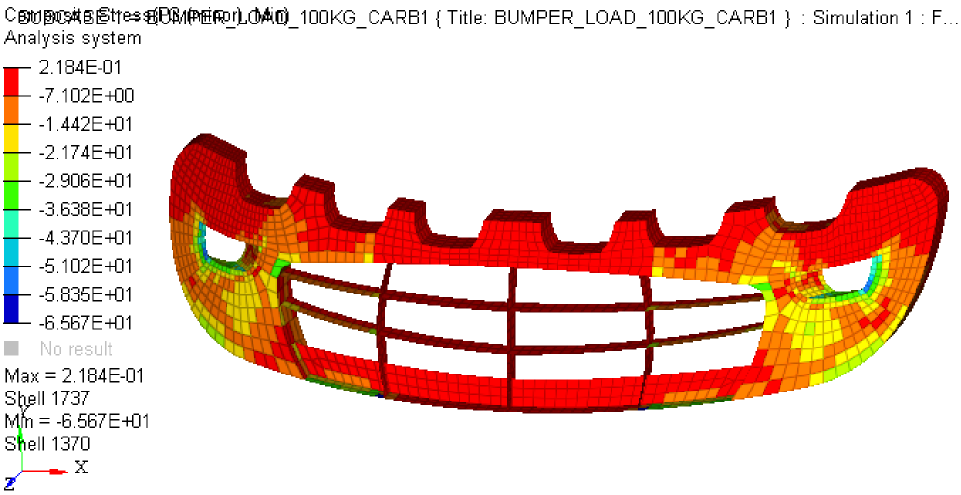


Figure-20: Maximum & Minimum Principal Stress region

Layup Sequence 2: Max Stress = 104.3 Mpa

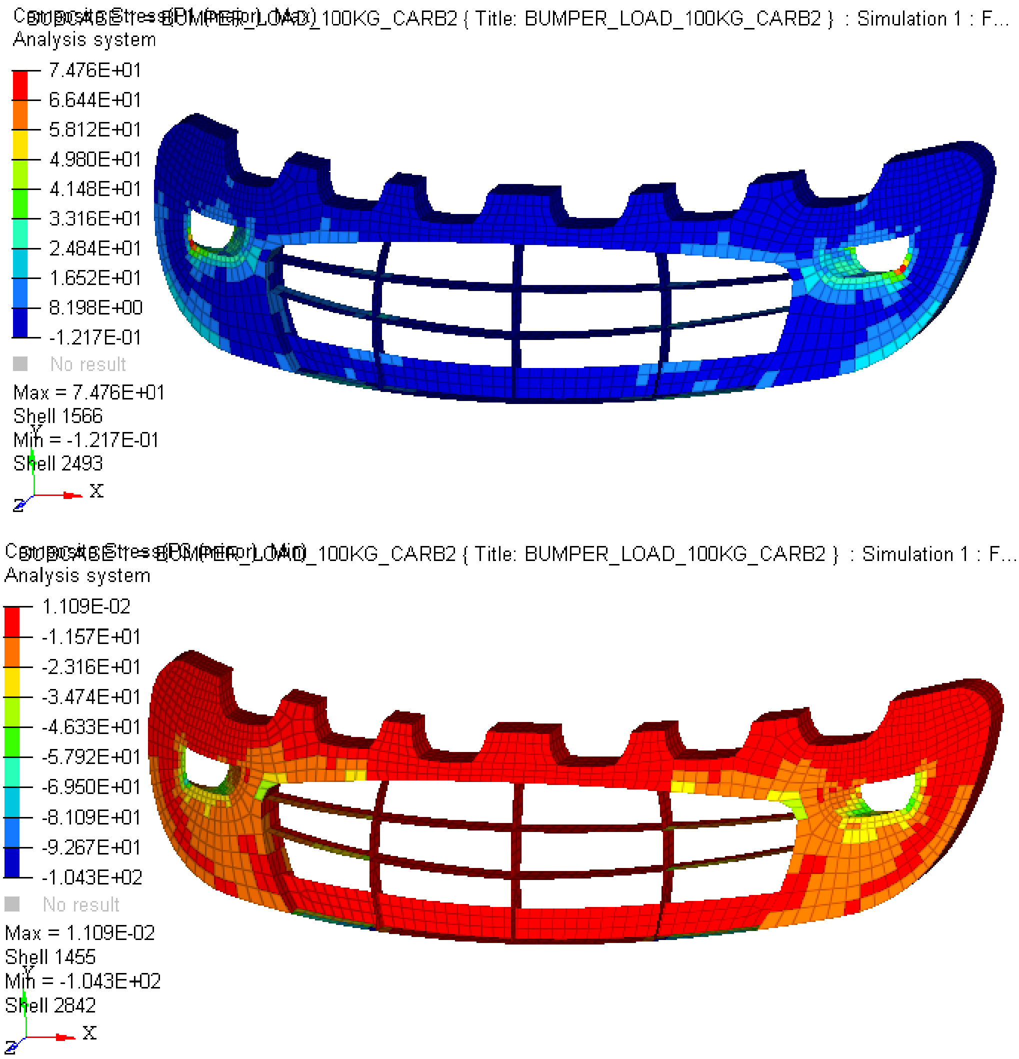


Figure-21: Maximum & Minimum Principal Stress region

Layup Sequence 3: Max Stress = 101.2 Mpa

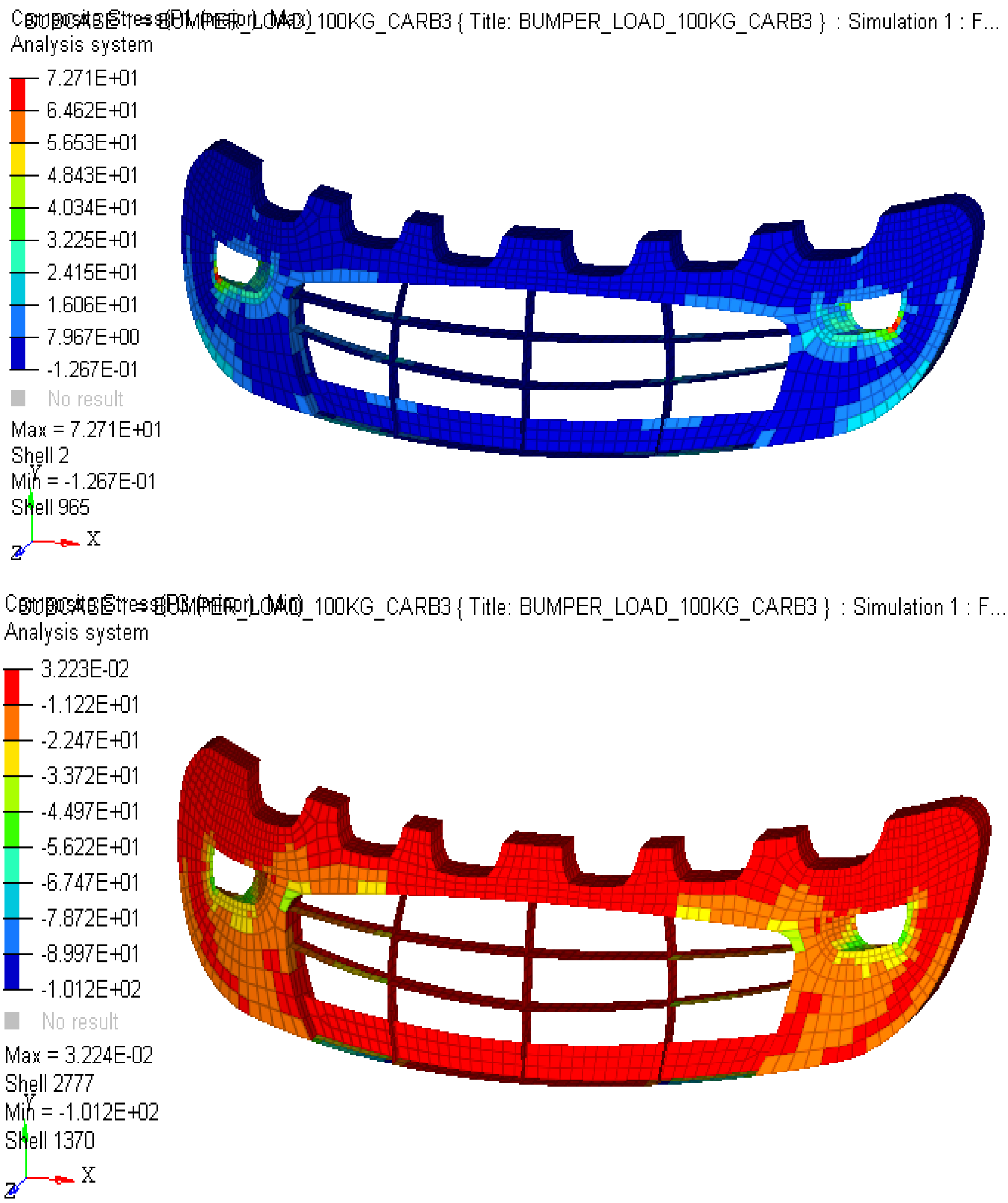


Figure-22: Maximum & Minimum Principal Stress region

7. COMPARATIVE ANALYSIS

For the automotive front Bumper, Modal and Static analysis performed using Glass, Kevlar and Carbon fiber epoxy composite materials with three different ply sequences, data collected based on the analysis outcome and tabulated. Post carefully analyzing data and comparison graphs.

Table-4: Comparison between Various Composite Compositions

Composite Material	Iterations	No of Plies	Laminate Thickness	Allowable	Reserve Factor	Normal Modes	Stress	
						Mode1	MAX P	MIN P
Glass Fiber Epoxy Layups	GF1	16	6.4	800	71.43	62	11.2	10.16
	GF2	16	6.4	800	58.95	59	13.57	1.03
	GF3	17	6.8	800	61.82	61	12.94	12.2
Kevlar Fiber Epoxy Layups	KEV1	16	6.4	870	65.91	77	13.2	11.5
	KEV2	16	6.4	870	87.44	96	9.95	9.35
	KEV3	17	6.8	870	91.58	99	9.5	8.71
Carbon Fiber Epoxy Layups	CARB1	16	1.92	1400	**21.34**	46	60.1	65.6
	CARB2	16	1.92	1400	**13.42**	45	74.7	104.3
	CARB3	17	2.04	1400	**13.83**	46	72.7	101.2

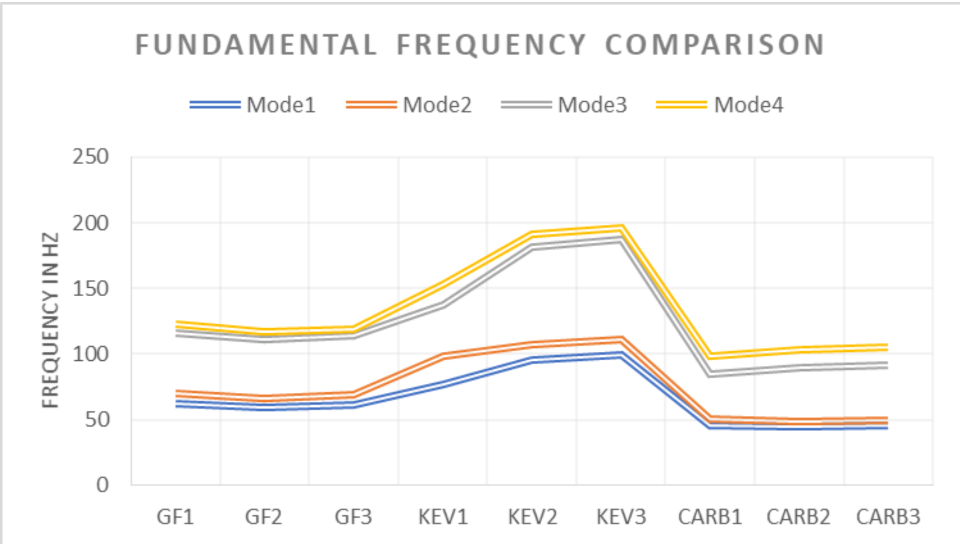


Figure-21: Fundamental Frequency Comparison Graph

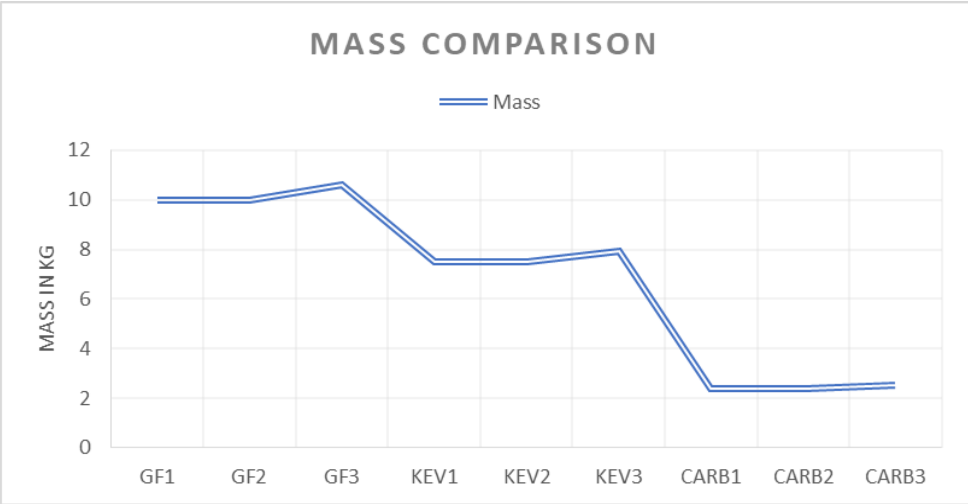


Figure-22: Mass Comparison Graph

8. CONCLUSIONS

It is evident that Carbon fiber Epoxy is most suitable among Glass and Kevlar Fiber composite as the fundamental frequency is much below the natural frequency of automobile and weight of the material required is low due to high strength.

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