

Weight and Structural strength optimization of the bumper of a vehicle using composite material

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ABSTRACT

The function of bumper in a vehicle is to protect the body of vehicle in slight collisions mainly at parking speeds. The fuel efficiency of the vehicle and strength or stiffness of the bumper depends largely on the material used in bumper design. In this paper two models of bumper were compared using two different materials i.e. ABS plastic material and CFK composite material. The main objective was to reveal the computational testing method for composite optimization using Optistrut software and to optimize the mass and compliance of the model using composite material and compare it with the mass and compliance values of the ABS plastic model. Only pressure load due to the wind when vehicle is moving at velocity of 200Km/hr was applied to the model elements. The optimization was done in two stages constraining the mass in first and compliance in the second stage and minimizing the other parameter respectively. Conclusion made was that the composite model showed a significant decrease in the mass and compliance compared to the ABS plastic model using Optistrut which can lead to increased fuel efficiency and increased stiffness of the bumper while at the same time the displacement and stress values were much below the failure limits.

Keywords

Vehicle bumper, CFK Composite, ABS plastic, Modeling in CATIA V5, FEA Analysis in Hyperworks, Hypermesh, Hyperview, Composite optimization in Optistrut, Mass and Compliance Optimization.

1. INTRODUCTION

The bumper of a vehicle is usually a bar or a beam attached to the front and rear portion of the vehicle to absorb the impact of the low velocity collisions in order to protect the hood, trunk, grill, fuel, exhaust and cooling system as well as safety equipments like parking lights, head lamps and tail lights from any damage. Previously the bumpers were made of steel or aluminum but today bumpers are generally made of plastic materials like: poly propylene, PVC, PC, ABS, Thermo plastic olefins etc. The main advantage of using plastic material is reduction in weight, improved durability, toughness, design flexibility, corrosion resistance, excellent appearance and high performance at low cost. In present work ABS plastic material was used for modeling the bumper.

The objective of present work was to reduce the weight and increase the stiffness of the bumper using composite material. The best way to increase the fuel efficiency and reduce the emissions is to reduce the weight of the vehicle. It is estimated that 10% reduction in vehicle weight can increase the fuel saving by 5 to 7% and for every kilogram of vehicle weight

reduction, there is potential to reduce carbon dioxide emissions by 20Kg. Compliance is the ability of a structure to respond to any applied force, usually expressed as the reciprocal of the material's stiffness which is the resistance offered by an elastic body to deformation. Mathematically it is defined as the deformation caused by a unit force and expressed in mm/N.

Recently composite materials are being used in the manufacturing of car panels and bumpers. Fiber reinforced composites are generally used because they are light weight, yet strong enough to take the loading conditions. They offer high specific strength and stiffness to weight ratio, good fatigue and creep resistance, resistance against corrosion and oxidation and ability to form complex shapes. In present work the composite material used was CFK composite.

The pressure applied by the wind on the bumper was calculated using the drag's equation for a vehicle travelling at the speed of 200Km/hr. The drag's equation is given below:

$$P = 0.5 * \rho * V^2 * C_d$$

ρ = Density of air i.e. 1.2 Kg/m³

V = Speed of vehicle i.e. 200Km/hr

C_d = Coefficient of discharge i.e. 0.5

2. MODELING AND MATERIAL PROPERTIES

2.1 Modeling

The modeling of bumper was done in CATIA V5 software in generative shape design module. CATIA is multi platform CAD/CAM/CAE software developed by Dassault Systems used to design, simulate, analyze and manufacture products in different industries specially aerospace and automotive.

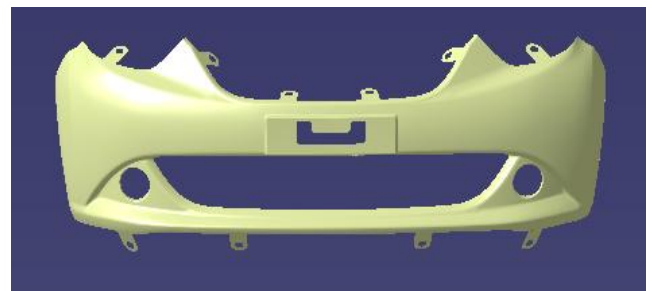


Fig1: Bumper model in CATIA V5

2.2 Material Data

2.2.1 ABS Plastic material

Table 1. Properties of ABS plastic material

Density (Kg/m ³)	1200
Poisson Ratio	0.38
Modulus of elasticity (MPa)	2400
Yield Stress (MPa)	54

2.2.2 CFK Composite material properties

Table 2. Properties of CFK Composite material

Property	E1 (MPa)	E2 (MPa)	Poisson Ratio	G12 (MPa)	G13 (MPa)	G23 (MPa)
Value	140000	12000	0.26	5800	5400	5400
Property	Density (Kg/m ³)	Xt (MPa)	Xc (MPa)	Yt (MPa)	Yc (MPa)	Shear Stress (MPa)
Value	1500	2000	1500	70	230	90

3. FINITE ELEMENT ANALYSIS

The Finite element analysis was done in Hyperworks 11.0 software. Hyper Works by Altair Engineering is a computer-aided engineering (CAE) simulation software platform that creates superior, market-leading products efficiently and cost effectively. It provides best-in-class modeling, analysis, visualization and data management solutions for linear, nonlinear, structural optimization, fluid-structure interaction, and multi-body dynamics applications.

3.1 Meshing and Element quality check

The 2-D meshing of the model was done in Hypermesh using automesh command.

Element size: 12.5

Mesh type: Mixed (Tria and Quad elements)

The mesh quality of all elements were maintained using Quality index and Check elements command, the elements normal were also checked to be in same direction.

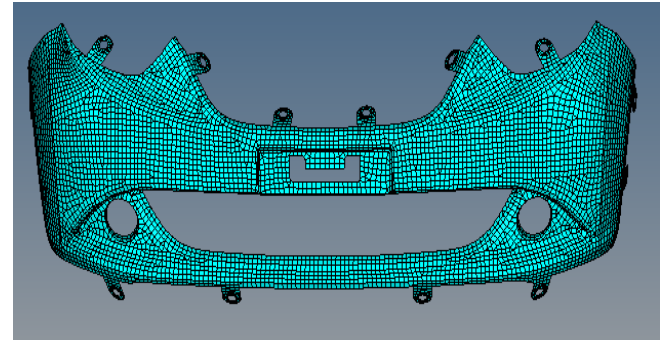


Fig 2: Meshed model in Hypermesh

3.2 Analysis using ABS Plastic material

The preprocessing steps were done in Hypermesh

Material: ABS plastic

Thickness: 5mm

Constraints: All DOF on the nodes of locking pins

Load: Pressure load of 925.74 N/mm² on all elements

The processing was done by Optistrut which showed mass value 5.098 Kg and compliance value 32.319 mm/N.

ITERATION 0	
(Scratch disk space usage for starting iteration = 15 MB)	
(Running in-core solution)	
Volume	= 4.24885E+06 Mass = 5.09862E-03
Subcase Compliance	1 3.231947E+01

Fig 3: Mass and compliance results for ABS plastic material

The displacement and stress plots were also viewed in Hyperview.

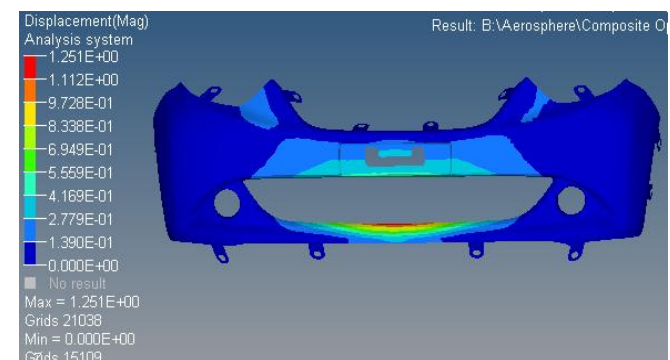


Fig 4: Displacement plot for ABS plastic model

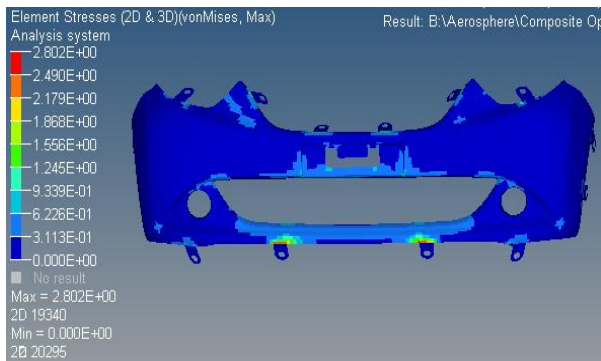


Fig 5: Stress (Von-Mises) plot for ABS plastic model

3.3 Analysis using CFK Composite material

The preprocessing steps were done in Hypermesh and the material orientation was also defined.

Material: CFK in MAT8 Card

Plies: 0°, 45°, -45° and 90° each having 2mm thickness

Laminate Type: Symmetric

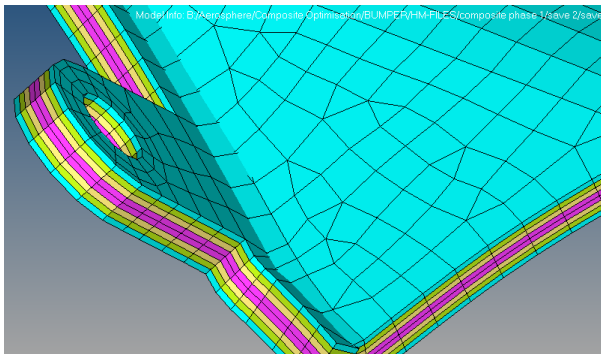


Fig 6: Laminate showing all plies for CFK composite

Property: PCOMPP Card

Constraints: All DOF on the nodes of locking pins

Load: Pressure load of 925.74 N/mm²

The processing was done by Optistrut which showed mass value 20.4Kg and compliance value 0.253mm/N.

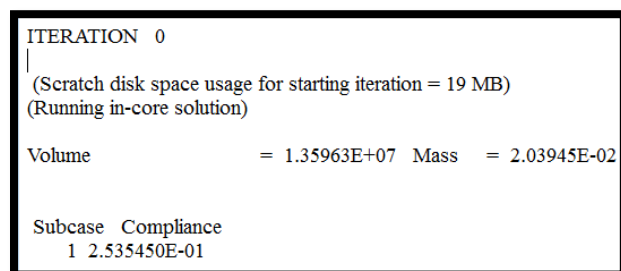


Fig 7: Mass and compliance results for CFK composite material

The displacement and stress plots were also viewed in Hyperview.

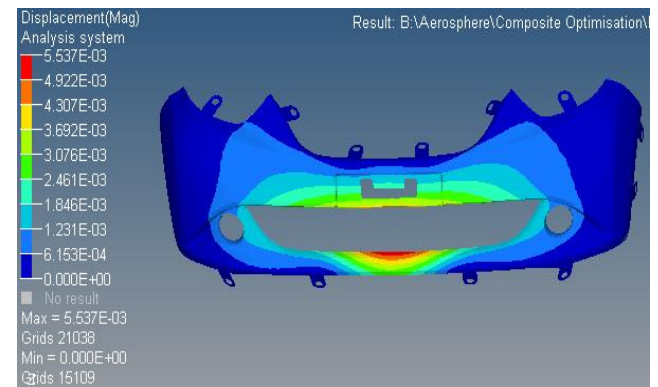


Fig 8: Displacement plot for CFK composite model

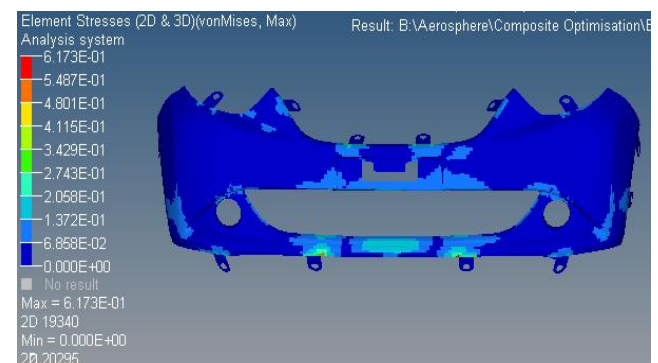


Fig 9: Stress (Von-mises) plot for CFK composite model

4. COMPOSITE OPTIMISATION

The optimization of composite structures in Optistrut is usually done in three phases: 1) Concept phase or free size optimization phase where the setting of fiber angles are done and optimal ply shapes and location of patches per ply orientation are identified. 2) Dimension or size continuous phase where optimal thickness of each ply bundle is defined and the number of plies of each shape is also defined. 3) Sequence or Composite shuffling phase where optimal stacking sequence of the plies in the laminate is defined.

4.1 Stage 1

The objective function and design constraints were given similar in all three stages as defined below

Objective: Minimize the compliance

Design Constraint: Maximum value of mass i.e 5.098 Kg.

4.1.1 Free Size optimization

Design Variable: Free size

Constraints: Minimum laminate thickness of 2mm and balancing number of 45 and -45 degree plies

Responses: Mass and Compliance

Control Card: FSTOSZ

The processing was done by Optistrut which showed mass value 5.098 Kg and compliance value 0.708 mm/N.

ITERATION 13			
the 2nd satisfied convergence ratio = 3.2724E-03			
Objective Function (Minimize WCOMP) = 7.08867E-01 % change = -0.33			
Maximum Constraint Violation % = 0.18045E-05			
Design Volume Fraction = 2.49970E-01 Mass = 5.09800E-03			
Subcase	Weight	Compliance	Weight*Comp.
1	1.000E+00	7.088665E-01	7.088665E-01
Sum of Weight*Compliance			
			7.088665E-01

Fig 10: Mass and compliance results of Free size optimization of CFK composite for stage 1

4.1.2 Size Continuous optimization

The sizing.fem file was imported, there were 16 ply bundles (4 ply bundle per fiber orientation) formed and each ply was having its own design variable.

Design Variable Constraint: Upper value of 1.5mm

Manufacturing constraint: 0.5mm

Control Card: SZTOSH

The processing was done by Optistrut which showed mass value 4.376Kg and compliance value 1.404 mm/N.

ITERATION 5			
Soft convergence criterion satisfied; the design did not change during the last iteration.			
Objective Function (Minimize WCOMP) = 1.40400E+00 % change = 0.00			
Maximum Constraint Violation % = 0.00000E+00			
Volume = 2.91768E+06 Mass = 4.37652E-03			
Subcase	Weight	Compliance	Weight*Comp.
1	1.000E+00	1.403997E+00	1.403997E+00
Sum of Weight*Compliance			
			1.403997E+00

Fig 11: Mass and compliance results of Size continuous optimization of CFK composite for stage 1

4.1.3 Composite Shuffling

The shuffling.fem file was imported, there were 10 plies now in the laminate.

Manufacturing constraints: Pairing 45 and -45 degree plies and maximum number of successive plies to be 2 only.

The processing was done by Optistrut which showed mass value 4.376Kg and compliance value 1.249 mm/N.

ITERATION 6			
Objective Function (Minimize WCOMP) = 1.24977E+00 % change = -3.15			
Maximum Constraint Violation % = 0.00000E+00			
Volume = 2.91768E+06 Mass = 4.37652E-03			
Subcase	Weight	Compliance	Weight*Comp.
1	1.000E+00	1.249768E+00	1.249768E+00
Sum of Weight*Compliance			
			1.249768E+00

Fig 12: Mass and compliance results of Composite shuffle optimization of CFK composite material for stage 1

The final optimized sequencing of plies was obtained in shuf.html file as shown

Iteration 0	Iteration 1	Iteration 2	Iteration 3	Iteration 4	Iteration 5	Iteration 6	Legend
11101	12401	14301	12401	14401	12401	14401	90.0 degrees
11102	13401	14401	13401	14402	13401	12401	45.0 degrees
11301	11101	14402	11402	14301	11402	13401	0.0 degrees
14301	14301	12401	11401	12401	11401	11401	-45.0 degrees
11401	11102	13401	11301	13401	14401	11301	
11402	14401	11301	14402	11101	11301	14402	
12401	11301	11102	14301	11102	11101	11101	
13401	14402	11101	11102	11301	14301	14301	
14401	11401	11401	11101	11401	11102	11102	
14402	11402	11402	14401	11402	14402	11402	

Fig 13: Optimized plies sequence of CFK composite for stage 1

4.1.4 Analysis of optimized model

The optimized model was now analyzed in Optistrut to find the displacement and stress values in the final model

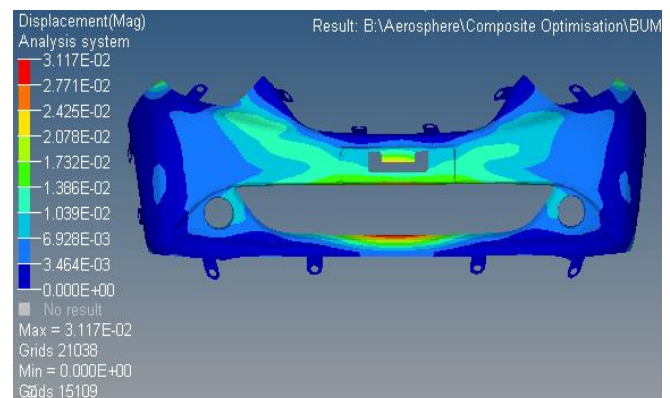


Fig 14: Displacement plot for Optimized CFK composite model for stage 1

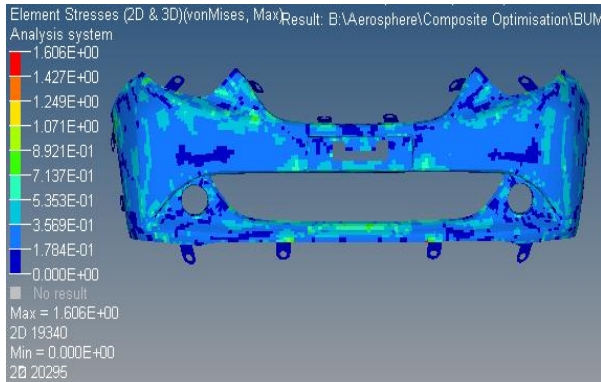


Fig 15: Stress (Von mises) plot for Optimized CFK composite model for stage 1

4.2 Stage 2

The objective function and design constraints were given similar in all three stages as defined below

Objective: Minimize the mass

Design Constraint: Maximum value of compliance i.e 32.319mm/N.

4.2.1 Free Size optimization

Design Variable: Free size

Constraints: Minimum laminate thickness of 0.5mm and balancing number of 45 and -45 degree plies

Responses: Mass and Compliance

Control Card: FSTOSZ

The processing was done by Optistrut which showed mass value 0.69Kg and compliance value 32.09mm/N.

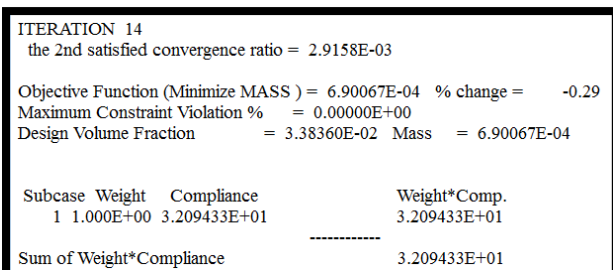


Fig 16: Mass and compliance results of Composite shuffle optimization of CFK composite material for stage 2

4.2.2 Size Continuous optimization

The sizing.fem file was imported, there were 16 ply bundles (4 ply bundle per fiber orientation) formed and each ply was having its own design variable.

Design Variable Constraint: Upper value of 1.5mm

Manufacturing constraint: 0.1mm

Control Card: SZTOSH

The processing was done by Optistrut which showed mass value 1.088Kg and compliance value 20.549mm/N.

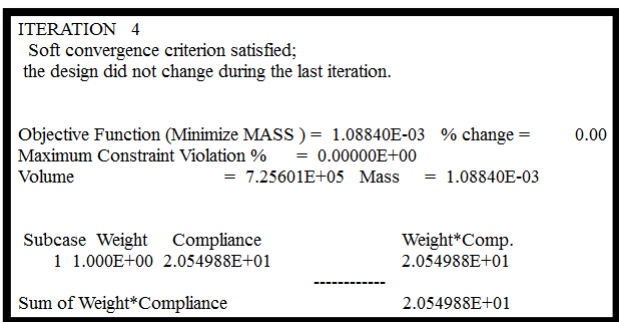


Fig 17: Mass and compliance results of Composite shuffle optimization of CFK composite material for stage 2

4.2.3 Composite Shuffling

The shuffling.fem file was imported, there were 12 plies now in the laminate.

Manufacturing constraints: Pairing 45 and -45 degree plies and maximum number of successive plies to be 2 only

The processing was done by Optistrut which showed mass value 1.088Kg and compliance value 18.93mm/N.

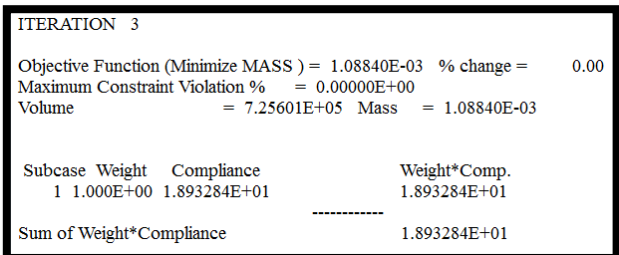


Fig 18: Mass and compliance results of Composite shuffle optimization of CFK composite material for stage 2

The final optimized sequencing of plies was obtained in shuf.html file as shown

Iteration 0	Iteration 1	Iteration 2	Iteration 3	Legend
11101	12101	11401	11401	90.0 degrees
12101	13101	14403	14403	45.0 degrees
13101	14101	14101	14101	0.0 degrees
14101	14401	12101	12101	-45.0 degrees
11401	14402	13101	13101	
12401	11101	14401	14401	
13401	12401	14402	14402	
14401	13401	11101	11101	
14402	14403	14405	14405	
14403	14404	14404	14404	
14404	14405	12401	12401	
14405	11401	13401	13401	

Fig 19: Optimized plies sequence of CFK composite for stage 2

4.2.4 Analysis of optimized model

The optimized model was now analyzed in Optistrut to find the displacement and stress values in the final model.

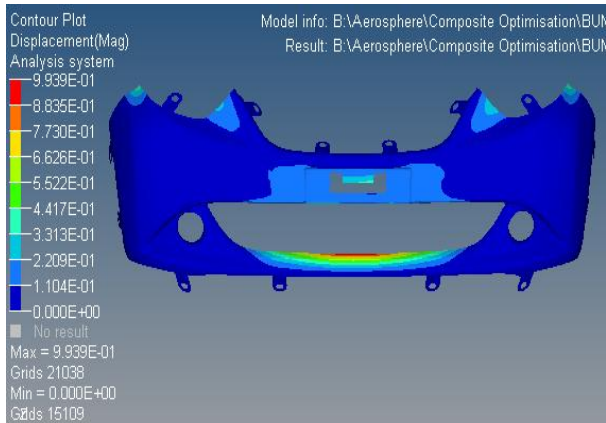


Fig 20: Displacement plot for Optimized CFK composite model for stage 2

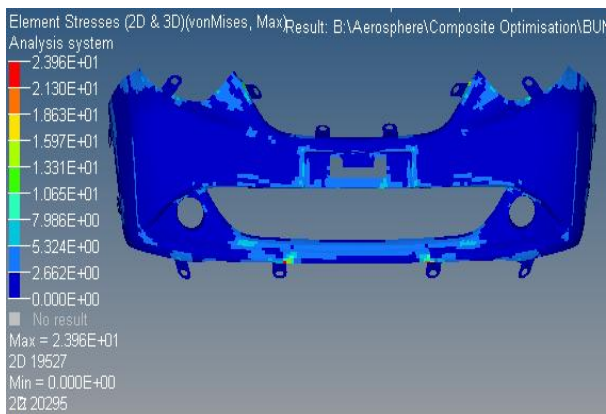


Fig 21: Stress (Von mises) plot for Optimized CFK composite model for stage 2

5. COMPARISONS AND CONCLUSIONS

5.1 Comparisons

The mass and compliance results of both the models were compared using graphs as shown

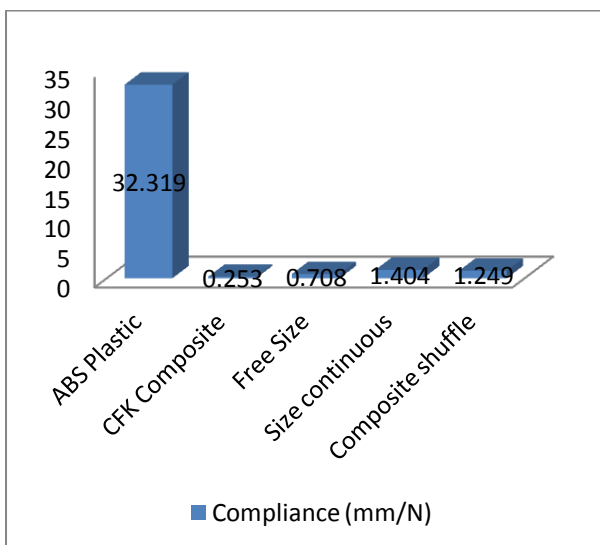


Fig 22: Graph showing compliance values for ABS and CFK material for stage 1

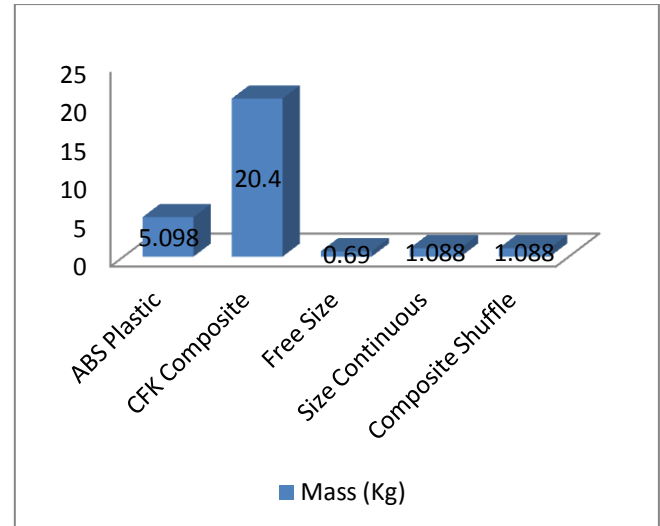


Fig 23: Graph showing compliance values for ABS and CFK material for stage 2

The summarized table showing the values of mass, compliance, displacement and stress on the model at all stages of analysis and optimization is shown in table 3.

5.2 Conclusions

- Using the composite optimization module in Optistrut the mass and compliance values were decreased significantly
- Optistrut provides optimized sequence of plies in a laminate satisfying all design and manufacturing constraints
- Compared to ABS Plastic model, CFK Composite model reduced mass from 5.098 Kg to 1.088 Kg and compliance values from 32.319 mm/N to 1.249mm/N
- Composites are a good choice as a automotive body panels material and can increase the fuel efficiency and strength of the body panels
- The displacement and stress values were also noted in all the stages of analysis and found to be much below the failure limits.

6. FUTURE SCOPE

- Study of other body panels or different shapes can be done for optimization
- Study of other materials and different loading conditions can also be done for optimization
- The responses variables, design constraints and objective function can also be changed
- More manufacturing constraints can be added during the optimization process

7. ACKNOWLEDGEMENT

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Table 3. Summary of results of all stages of analysis and optimization

Material →	ABS Plastic				Composite (Stage 1)				Composite (Stage 2)			
Stages ↓	Mass (Kg)	Compliance (mm/N)	Displacement (mm)	Stress (N/mm ²)	Mass (Kg)	Compliance (mm/N)	Displacement (mm)	Stress (N/mm ²)	Mass (Kg)	Compliance (mm/N)	Displacement (mm)	Stress (N/mm ²)
Analysis of initial model	5.098	32.319	1.25	2.802	20.4	0.253	5.53 * 10 ⁻³	0.617	20.4	0.253	5.53 * 10 ⁻³	0.617
Free Size Optimization					5.098	0.708	1.262 * 10 ⁻²	0.702	0.69	32.09	1.336	14.13
Size Continuous Optimization					4.376	1.404	3.117 * 10 ⁻²	1.606	1.088	20.549	0.365	9.123
Composite Shuffling Optimization					4.376	1.249	2.52 * 10 ⁻²	1.21	1.088	18.93	0.837	30.29
Analysis of Optimized Model							3.117* 10 ⁻²	1.606			0.993	23.96

8. REFERENCES

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