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Comparative Analysis of Monocoque Chassis

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Abstract - *Monocoque is a single shell design for the chassis to hold all the brackets, providing external skin support for some or most of the load in static and dynamic conditions of the car. It is a part of the chassis for a formula car in motorsports. This paper gives a comparative study of monocoque chassis with composite sandwich material and general materials used to make the vehicle frame. The analysis and composite matrix formation are done on ANSYS software using different loading conditions. The monocoque is tested for the front, side and rear impacts. The torsion test is also performed on the monocoque. The study provides various comparison aspects in design, weight and material selection for a formula car.*

Key Words: *static, torsion, ANSYS Workbench 2021 R1, monocoque, epoxy carbon sandwich composite, etc.*

1.INTRODUCTION

The monocoque is one of the important parts of the chassis frame which surrounds all the components along with the driver in the vehicle. It serves as a layer on the tubular frame with the purpose of effective load transfer at static and dynamic scenarios of the vehicle. The effective design allows gaining the best performance of the vehicle with low weight and maximum acceleration for the vehicle. The mass of the chassis is a key factor in changing the inertia, centre of gravity, and many vehicle dynamic parameters. Safety and protection are also key functions to be recovered from the monocoque. The outer profile of the monocoque design depends on the frame structure considering ergonomics and driver comfort. The analysis and validation of the monocoque are done using several tests including impacts on the side, front, and rear. The torsional stiffness is also another factor influencing the design failure and strength parameters. The material is also responsible for the strength, weight, and density properties of the same. Various tests are performed to analyse the performance of the monocoque in terms of static loading on the chassis frame.

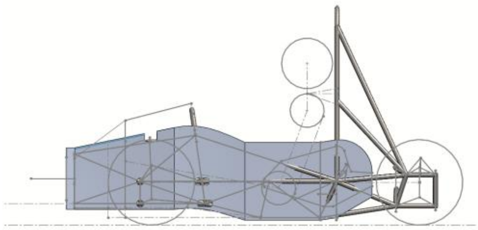


Fig-1: Ergonomics and monocoque

Fig-2: Installed monocoque with assembly

2. MODELLING

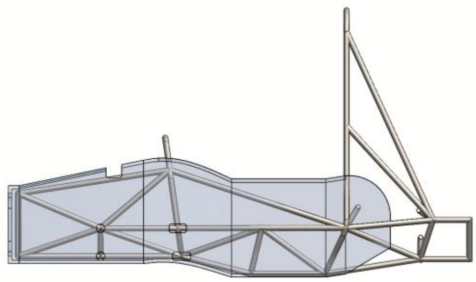


Fig-3: Monocoque on the vehicle chassis

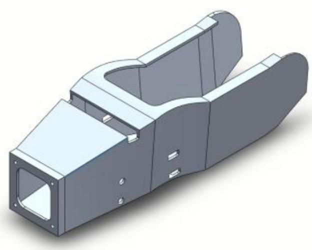


Fig-4: Monocoque Design Isometric view

3. MATERIAL SELECTION

The study includes a comparison of analysis with three materials used to manufacture the monocoque. Aluminum alloy and Unidirectional epoxy carbon are two materials used in the first study. And second part comprises a composite laminate made up of stacking layers of epoxy carbon with honeycomb. Below shown are the properties of materials used in the study.

Table-1: Material Properties

Material	Density (kg/m^3)	Tensile strength (MPa)		Young's modulus (MPa)		Poison's ratio	
Aluminum Alloy	2770	280		71000		0.33	
Epoxy Carbon UD (230 GPa)	1490	X	2231	X	121000	XY	0.27
		Y	29	Y	8600	YZ	0.4
		Z	29	Z	8600	ZX	0.27
Honeycomb	80	X	0	X	1	XY	0.49
		Y	0	Y	1	YZ	0.001
		Z	5.31	Z	225	ZX	0.001

4. FEM

As monocoque is designed with respect to the chassis frame and every edge is properly constrained at all ends. After finalizing the frame besides its material and cross-section, it is important to check the rigidity and strength of the frame beneath severe conditions. The frame ought to be able to face up to the impact, torsion, roll over conditions and supply utmost safety to the motive force while not undergoing abundant deformation. Static loading for impact test and torsion is performed using finite element methods on ANSYS Workbench 2021 R1.

5. MESH & SETUP

2D linear meshing is done with refinements at suspension mount edges and front nose mounting points. Refinements and fine mesh are adopted to increase the accuracy of results in critical areas.

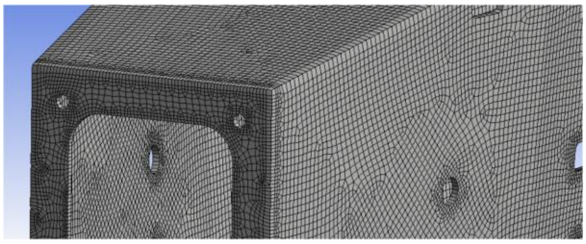


Fig-5: Mesh refinement at critical edges

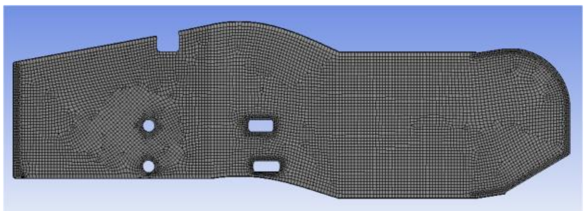


Fig-6: Side view of mesh

Table-2: Mesh Statistics

Nodes	34196
Elements	33724

6. ACP SETUP

The monocoque model is imported in ANSYS ACP modeler. Three plies are designed with epoxy carbon and honeycomb sandwich layered plies. The epoxy carbon is two-layered plies with 0-degree and 45-degree fabric angles. Honey comb is the layer in the middle and epoxy fabrics at both ends.

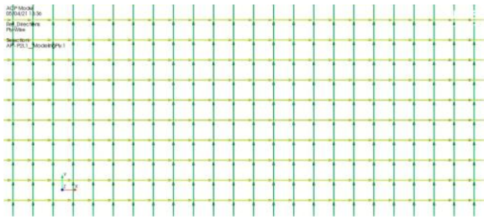


Fig-7: Outer epoxy carbon ply

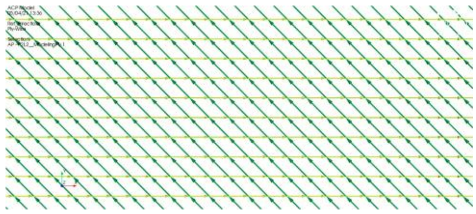


Fig-8: Inner epoxy carbon ply

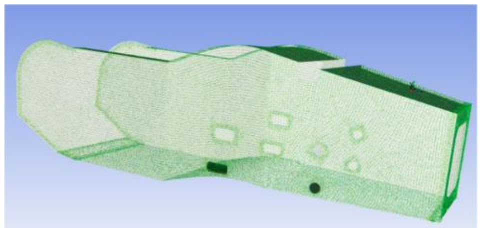


Fig-9: Composite layered monocoque

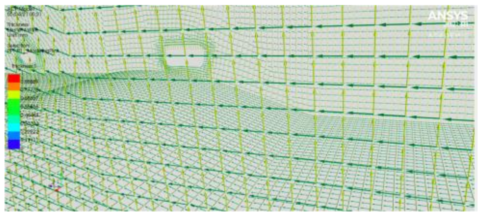


Fig-10: ply orientations on monocoque

The stackup and polar properties are shown below from the ACP set up

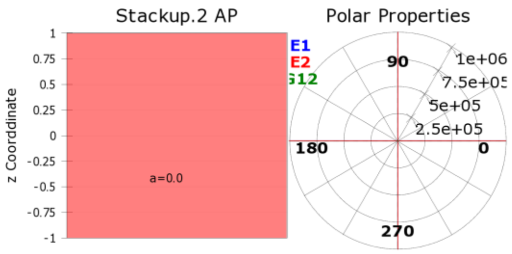


Fig-11: Honeycomb properties

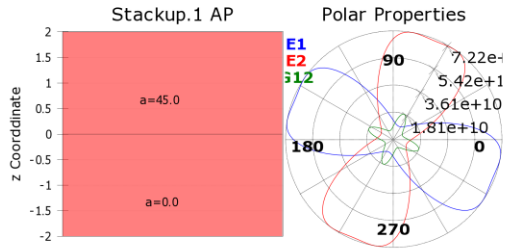


Fig-12: Two layered epoxy carbom ply properties

7. CALCULATIONS

The calculations are based on the work-energy principle which says the work done is equal to the change in kinetic energy of the system. And below shown are MATLAB calculations for impact forces acting on the monocoque.

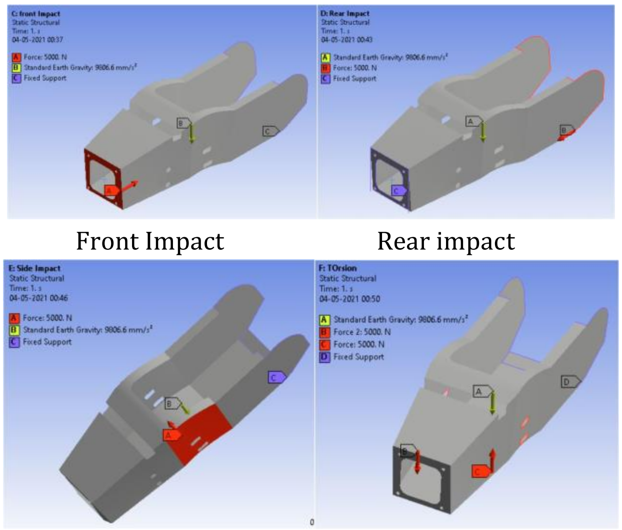
```
%%
% calculation parameters
m = 280; % laden Weight (kg)
g = 9.81; % Gravitational constant (m/s^2)
vi = 33.34; % initial velocity(m/s)
vf = 0; % final velocity (m/s)
vmax = vi; % (maximum velocity)
t1 = 1.5; % impact time
t2 = 1.2; % side impact time

W = 0.5*m*(vi^2 -vf^2); % workdone
s = t1*vmax; % displacement
Fi = W/s; % Front Impact Force

display(Fi);
%%
W2 = 0.5*m*(vi^2 -vf^2); % workdone
s2 = t1*vmax; % displacement
Fr = W/s; % Rear Impact Force

display(Fr);
%%
W3 = 0.5*m*(vi^2 -vf^2); % workdone
s3 = t2*vmax; % displacement
Fs = W/s; % Rear Impact Force

display(Fs);
```

Fig-13: MATLAB calculation code

8. ANALYSIS

The analysis in three parts to conduct static tests on the monocoque. The model analysis is performed to check any non-continuous bodies in the monocoque design with 6 model frequency outputs. Furthermore, the monocoque design is undergone front impact, rear impact, side-impact, and torsion test under a static structural Ansys analysis system.

8.1 Constraints and Boundary Conditions



Front Impact Rear impact

Side Impact Torsion

Fig-14: Constraints and boundary conditions

8.2 Stress and deformation contours for various tests

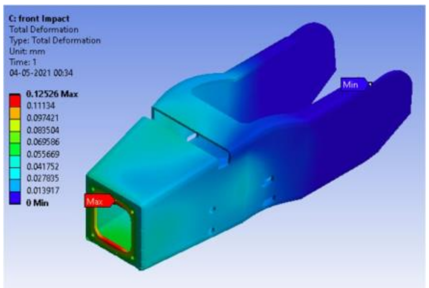


Fig-15: Front Impact deformation

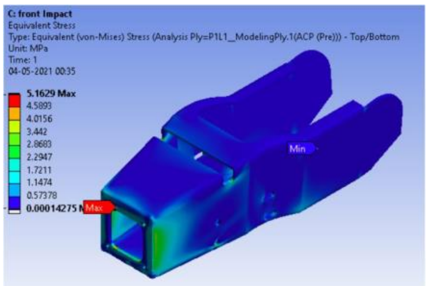


Fig-16: Front Impact von mises stress

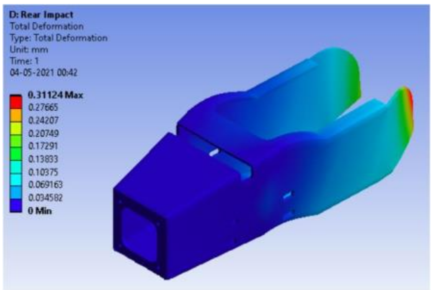


Fig-17: Front Impact deformation

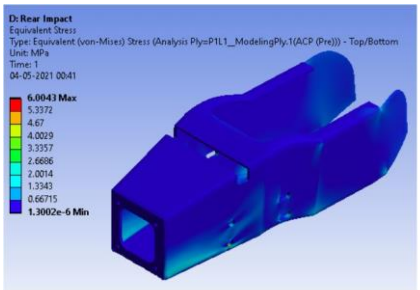


Fig-18: Front Impact von mises stress

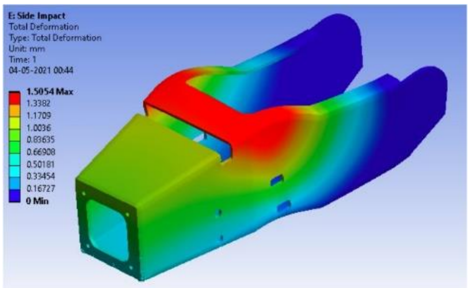


Fig-19: Front Impact deformation

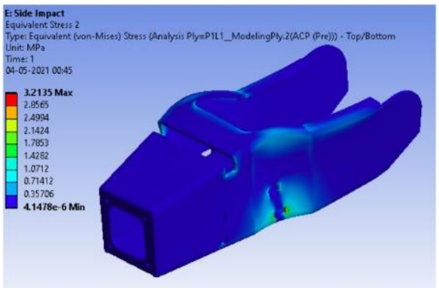


Fig-20: Front Impact von mises stress

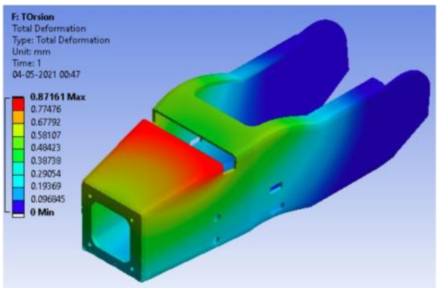


Fig-21: Front Impact deformation

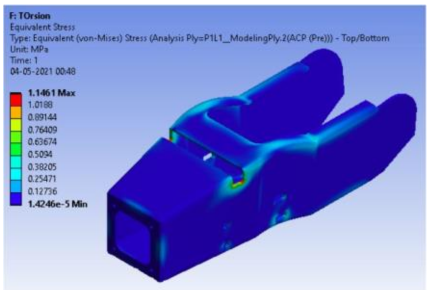


Fig-22: Front Impact von mises stress

The above shown are deformation and stress contours for epoxy-carbon and honeycomb sandwich composite. Similar tests are performed with a material variation of Aluminum alloy and epoxy carbon unidirectional layer.

9. RESULTS

Table-3: Post processing data

	Aluminium Alloy	
Test	Deformation (mm)	Von Mises Stress (MPa)
Front Impact	0.04498	5.1959
Side Impact	0.8831	41.66
Rear impact	0.047931	2.9121
Torsion	0.2267	7.4976
	Carbon Epoxy	
Test	Deformation (mm)	Von Mises Stress (MPa)
Front Impact	0.1523	11.008
Side Impact	2.0758	0.36644
Rear impact	0.11334	6.0175
Torsion	0.55477	17.702
	Epoxy carbon honeycomb sandwich	
Test	Deformation (mm)	Von Mises Stress (MPa)
Front Impact	0.085	3.3176
Side Impact	1.2038	29.296
Rear impact	0.20355	4.2284
Torsion	0.44035	0.57015

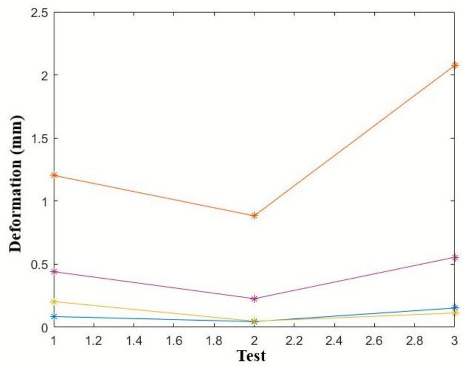


Chart-1: Deformation vs Material

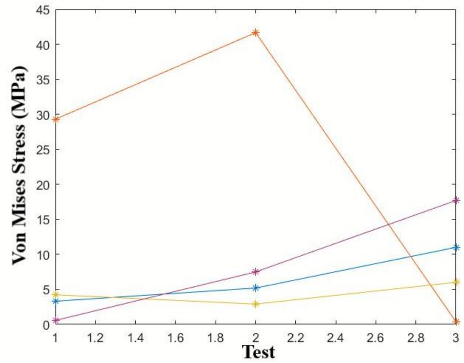


Chart-2: Von Mises Stress vs Material

Results show Test 1, Test 2, and Test 3 for carbon epoxy and honeycomb sandwich, aluminum, and Unidirectional carbon epoxy FRP. The data is plotted using the MATLAB plotting function with legend as mentioned below.

Table-4: Legend

Front impact test	
Side impact test	
Rear Impact test	
Torsion	

10. CONCLUSION

The comparative study shows that deformation strain can be retained with minimum values by aluminum alloy and deformation is maximum if epoxy carbon layer is given as material for the monocoque. The composite sandwich can also take up low values of deformation. The stress concentration magnitude is minimum in the case of sandwich composite for all the tests and increased with aluminum and epoxy carbon as materials. The maximum stress developed is bearable by the monocoque design and best suited for sandwich of epoxy carbon and honeycomb material. The study shows the sandwich composite can be used as an alternative material for sheet metals to be used in the design of monocoque for chassis.

11. SCOPE & FUTURE WORK

The design of sandwich composite can be altered by varying thickness and angles of fiber alignments to get the best-suited material in terms of strength and weight optimization. Also, along with varying thickness and layers, the materials to be used for stacking can be altered. The reduction of weight along with keeping material properties intact in terms of strength and torsional stability would be a key in future designs of the monocoque.

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BIOGRAPHIES

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