Comparison of Cross sectional Profiles for Side Impact Crash Structure in Passenger Vehicle

by

NITISH SHARMA

Presented to the Faculty of the Graduate School of
The University of Texas at Arlington in Partial Fulfillment
of the Requirements
for the Degree of

MASTER OF SCIENCE IN MECHANIAL ENGINEERING

THE UNIVERSITY OF TEXAS AT ARLINGTON
MAY 2018

Acknowledgements

I would like to express my gratitude to **Dr. Andrey Beyle** for his inspiring guidance, encouragement and for investing his valuable time in mentoring me. It has been a journey filled with learning experience.

I would also like to extend my sincere thanks and appreciation to **Dr. Kent Lawrence** , **Dr Mahdi Haghshenas-Jaryani** and **Dr Wen Shen** for serving on the thesis defense committee and providing me with several learning opportunities.

I am grateful to my parents, friends and all those who helped and supported me to achieve my goal.

.

04/26/2018

Abstract

Comparison of Cross sectional Profiles for Side Impact Crash Structure in Passenger Vehicle

Nitish Sharma, MS

The University of Texas at Arlington,2018

Supervising Professor: Andrey Beyle

Car's safety is most important structural criteria while designing an automotive chassis. To protect the occupants from a direct impact, the passenger cabin and the structure of the vehicle should have an appropriate stiffness so that the it absorbs any kind of impact and keeps the passenger safe. Design standards are set by various vehicle safety association around the world based on different crash situations i.e. front crash, side impact, roll over etc. Among these standards, side impact crash account for over all 40% crashes all around the world and is one of the most fatal crash scenarios. This research focuses on comparative study based on varying cross-sectional profiles for side impact crash structures such as B-Pillar and Anti Intrusion Beam. A detailed finite element study was performed to analyze static and dynamic behavior of different cross section profiles in side impact crash situation.

With the advent of technology, materials have advanced many folds; one such technical revelation has been Fiber-reinforced Composite Materials. Composite materials have two major advantages, among many others: improved strength and stiffness, especially compared to other materials on a unit weight basis and low density with ease of manufacturing. The study deals with redesigning and replacing existent side impact crash structures with carbon fiber (Cytec Thornell T652/35)

The objective of this study is to predict the behavior of different profiles specifically with composite material. The analogy to a side impact crash was derived from 3-point bend test and drop test to study the static and dynamic response of the geometry and the material. The finite element simulation was carried out in ANSYS 17.2 specifically using ACP, Static Structural and

Explicit Dynamic Modules. The geometries and the material were then compared for key structural parameters such as bending stiffness, effective stresses, factor of safety and overall kinetic energy absorption. At the end of the research we were able to compare and select the profiles which will be able to absorb high side impact crash energy

Table of Contents

List of Illustrations

List of Tables

Chapter 1

Introduction

Crashworthiness is the ability of a structure to protect its occupants during an impact. This is a key parameter to measure the stiffness of the structure particularly in automotive and aircraft industry. Based on the type of crash or impact, various standards have been set up to measure the chassis characteristics. Crashworthiness may be assessed based on parameter such as Frontal Crash, Side Impact Crash, Torsional, Roll Over etc. Several criteria used to measure crashworthiness include deformation, deacceleration experienced by the vehicle after the impact and the stiffness of the entire structure.

The structural safety features such as Crumple Zone is a critical measure of the beam behavior during impact crash analysis. The crumple zone is designed to absorb the energy from impact during collision by controlling deformation by crumpling[1,2].

The Critical structural components which play a crucial role in for providing passenger safety during a side impact collision are B-Pillar and Anti Intrusion Beam. The following research discusses critical behavior of various cross-sectional profiles for B-Pillar and Anti Intrusion Beam when subjected to side impact crash load

Analytical simulation of vehicle crashworthiness has evolved over time. The Finite Element Modeling are modern tool to predict structural and material behavior of such structures in a virtual environment. FEM modelling has become a primary tool to observe and measure the complex behavior of these components when subjected to various crash scenarios. These type of computational modelling tools not only save overall product development time but also enables us to perform multiple design iteration.

1.1 Pillar Trims [3]

The pillar trims are vertical or near vertical members which support car's body in white structure and are designed and named as A, B, C & D (larger cars) from front to rear of the vehicle. The A & C (some cases D) pillars are present at the wind shield section of the car and is a key structural member between the roof and front or the rear section of the vehicle. The B pillar is located between the front and rear door and is supports the chassis between the roof and floor pan of the vehicle.

1.1.1 B-Pillar

B-Pillar is one of the most structurally important components in an automobile frame. These structures are designed based on various safety regulations and specifications. The B-Pillar consist of two parts, one of them outer layer and second one is the inner layer. These two layers are generally made up of steel or aluminum and welded together. At the time of impact, the B- Pillar structure should be able to absorb most of the energy at point of impact with minimal deformation.

1.1.2 Anti Intrusion Beam

The Anti Intrusion Beam is a passive safety device placed in the door frame of ground vehicle to prevent injuries to the occupants at the time of side impact.

1.2 FMVSS [2, 4]

Federal Motor Vehicle Safety Standards 214 (FMVSS) “Side Impact Protection” were amended 1990 to insure occupant safety in dynamic test simulating several right-angle collisions. The current series i.e. FMVSS 214 are especially designed to simulate and predict the behavior of the structure during a side impact collision. Over all side impact accounts for about 35% of total number of collisions. FMVSS has developed basic methodologies: -

- A test methodology to determine the severity of interaction Collin between two vehicles moving using a Movable Deformable Barrier
- Thoracic Trauma Index
- Side Impact Dummy

1.3 Side Impact Pole Test [4]

Another Important test criteria considered is the Side Impact Pole Test. In these test procedures the vehicle is propelled sideways towards a fixed rigid pole. As these kinds of objects are very narrow and there is a major penetration into the deriver compartment affecting the occupant safety. This type of test can be modelled into a static FEA analysis to see how different materials and profiles behaved relative to each other.

Chapter 2

Motivation and Objective

Side impact crashes account for a major share of all the automotive crashes in United States. As the side of the vehicle has very little room to absorb energy and shield the occupants, there is a need to have a structure which provides substantial crumple zone. Automakers these days are providing air bags in addition to strengthening the structure. A many as six airbags are provided these days to protect the passengers at the time of incidence. The air bags are more of a fail-safe measure, the major concern is the strength of the structure of the vehicle. The aim here is to design and analyze a composite structure which would absorb a large amount of kinetic energy and prevent it from being transferred over to the passengers. According to the crashworthiness standards, there should be minimum displacement and high energy absorption. The use of composites in addition to energy absorbent material is proposed for such beam structures.

2.1 Literature Review

The studies performed earlier prove that composites when combined with efficient designs and good manufacturing practices increase the overall safety of the vehicle, reduce mass and thus increases the overall performance. The composite when designed efficiently can absorb more deformation, they can have high specific strength and high specific stiffness and good impact load absorbing and damping properties.

2.1.1 Side Impact Protection [1]

Intrusion most commonly increases the risk of chest, abdominal and pelvic injuries [4]. Door panel intrusion is still the most significant contributor in occupant injuries. Before the implementation of the side impact standard, it was likely that the lower door panel would intrude and result in pelvic fracture.

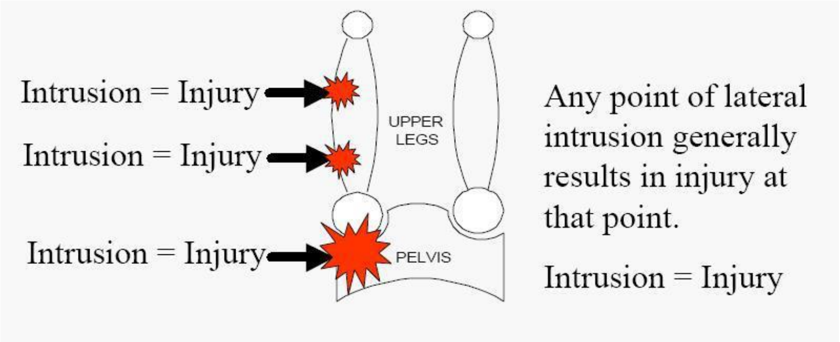


Figure 2-1: Side Impact Injury [1]

The stiffness, geometry and intrusion of door panels in side impact result in specific injury patterns. To avoid the side door intrusion into the passenger car compartment, the vehicle manufacturers generally reinforce the side he doors with intrusion beams.

2.1.2 Energy Absorption of Composite Material

The energy absorption capacity of the composites depends upon following factors

- Fiber Material – Physical properties of the fiber material affect specific energy absorption of composite material. The brittle nature of the fiber enables it to absorb more energy when compared to ductile materials
- Matrix- The matrix in composites acts as reinforcement, it plays a major role of transferring stress from one layer of fiber to another.
- Ply Sequence: The orientation of the plies are selected based on the type of load acting on the structure. A 0^o ply would resist bending, 90^o would prevent crack propagation and +/-45^o would resist torsional behavior.
- Core: The core material such as honeycomb or structural foam provide reinforcement to the structure

2.1.3 Composites in Automobile [1,2]

The application of composites in auto industry is ever increasing with time, the focus of the research is now being shifted to advance composites such as polymetric or metallic matrices reinforced along with carbon fiber, glass fiber and Kevlar. Since composites have very high strength to weight ratio i.e. high strength and low density they can replace conventional material such as steel and aluminum. There is a predicted 6-8% decrease in fuel consumption with 10% decrease in overall mass of the vehicle. Fiber reinforced plastics and composites are widely being used in body panels, bumper systems, flexible components, trims, drive shafts, rotors etc.

Chapter 3

Methodology and Design Approach

The main objective of this research is to perform computational study and draw a comparative conclusion based on different beam profiles and materials. In total 4 different profiles are analyzed out of which two are conventional profiles while the other two are relatively new profiles. All the profiles were first analyzed with conventional automotive grade aluminum followed by carbon epoxy composite. The study is conducted based on the principles of crashworthiness i.e. penetration of the striking vehicle should be minimum and energy absorption should me maximum. The comparative analysis was based on this criterion.

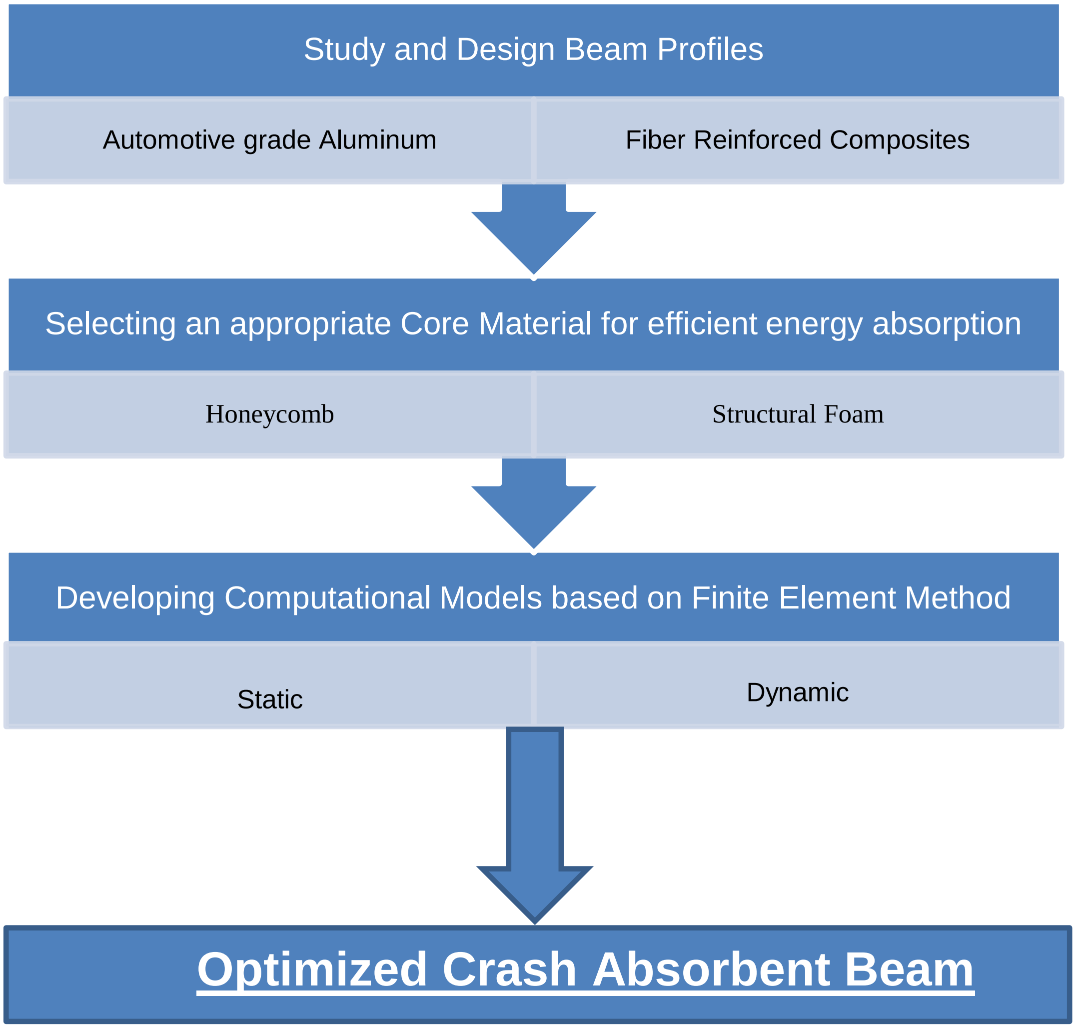
The approach and load cases were modelled based on following: -

- Evaluate and compare specific energy based on 3 Point Bend Test Simulations.
- Evaluate and compare dynamic behavior of different profiles, material and core material based on standards set by FMVSS 214.
- To measure and compare net deacceleration of the impacting body.
- To measure the effectiveness of the beam profiles in terms of stiffness and factor of safety.

3.1 Design Approach

This thesis begins with studying the conventional profiles and the materials for the b- pillar and anti- intrusion beam. The profiles are analyzed in different combinations of material namely Hollow Aluminum, Aluminum with Core , Hollow Composites and Composite with Core. The material orientation was decided based on three key parameters

- Resistance to bending.
- Resistance to crack propagation.
- Resistance to torsion.


Study and Design Beam Profiles
Automotive grade Aluminum
Fiber Reinforced Composites
Selecting an appropriate Core Material for efficient energy absorption
Honeycomb
Structural Foam
Developing Computational Models based on Finite Element Method
Static
Dynamic
Optimized Crash Absorbent Beam

3.2 Computer Aided Engineering Tools

CAE tools are being increasingly used in auto industry for dynamic crash simulations. It reduces the product development cost and predicts the real time behavior of the structure during the impact. These tools also help the auto industry to perform product validation and in turn improve product quality, comfort, durability etc.

3.2.1 Ansys 17.2 [5]

Ansys develops and markets finite element analysis software used to simulate engineering problems. The software creates simulated computer models of structures, electronics, or machine components to simulate strength, toughness, elasticity, temperature distribution, electromagnetism, fluid flow, and other attributes. Ansys is used to determine how a product will function with different specifications, without building test products or conducting crash tests. For example, Ansys software may simulate how a bridge will hold up after years of traffic, how to best process salmon in a cannery to reduce waste, or how to design a slide that uses less material without sacrificing safety.

Most Ansys simulations are performed using the Ansys Workbench software, which is one of the company's main products. Typically Ansys users break down larger structures into small components that are each modeled and tested individually. A user may start by defining the dimensions of an object, and then adding weight, pressure, temperature and other physical properties. Finally, the Ansys software simulates and analyzes movement, fatigue, fractures, fluid flow, temperature distribution, electromagnetic efficiency and other effects over time.

Ansys also develops software for data management and backup, academic research and teaching. Ansys software is sold on an annual subscription basis.

3.2.2 MATLAB [6]

MATLAB in a programming language developed by Math Works. It is mainly used for complex analytical calculations and computation. It uses predefined functions and plotting tools. It is a high-level computation tools with relatively easier user interface when compared to another programming languages.

Chapter 4

Materials

There are many materials used in automobile industry for key structural components. Various grades of steel and aluminum alloy. The recent trend shows that the auto manufactures are shifting from such conventional materials to more advanced materials such as Fiber Reinforced Composites namely Carbon Fiber, Glass Fiber, Kevlar etc.

The materials used in this research were

- Aluminum 6061-T6
- Carbon Epoxy
- Honeycomb core
- Structural Foam

4.1 Aluminum 6061 T6 [7]

High grade aluminum is used in key structural components as it not only provides high strength and but also saves weight.

Physical Properties:

Ultimate Tensile Strength	310 MPa
Tensile Yield Strength	276 MPa
Modulus of Elasticity	68.9 GPa
Passion’s Ratio	0.33
Shear Modulus	26 GPa
Density	2.7g/cc

Table 4.1 : Aluminum Properties

4.2 Composites

Unidirectional Epoxy Carbon with 0.6 volume fraction is used. Carbon fiber composites are 3-5 times stronger than conventional material. These fibers are manufactured using advanced manufacturing techniques such as Pultrusion. The fibers are then combined and formed into thin sheets i.e. prepreg. Carbon fiber have high stress carrying capacity when compared to other fibers

The fibers used in this analysis had following properties.

Cytec Thornel T650/35 [8]:

Properties	Symbol	Units	T650/35
Young Modulus in 0	E1	GPa	175
Young Modulus in 90	E2	GPa	8
In Plane Shear Modulus	G12	GPa	5
Major Possion Ratio	V12		0.3
Ult Tensile Strength 0	Xt	MPa	1000
Ult Comp. Strength 0	Xc	MPa	850
Ult Tensile Strength 0	Yt	MPa	40
Ult Comp. Strength 0	Yc	MPa	200
Ult In Plane Strength	S	MPa	60

Table 4.2 : Composite Properties

4.3 Honeycomb

Honeycomb are light weight structures with high impact strength, excellent crush strength, structural intracity and high fatigue resistance. The core material is made up of Nomex/korex. The honeycomb material provides good strength to weight ratio.

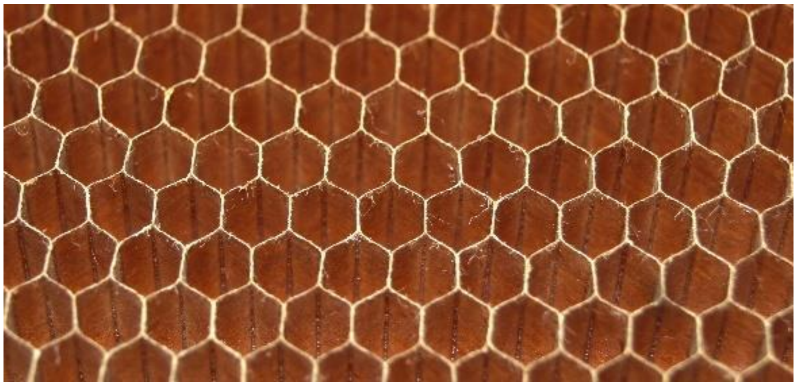


Figure 4-3: Nomex Honeycomb [7]

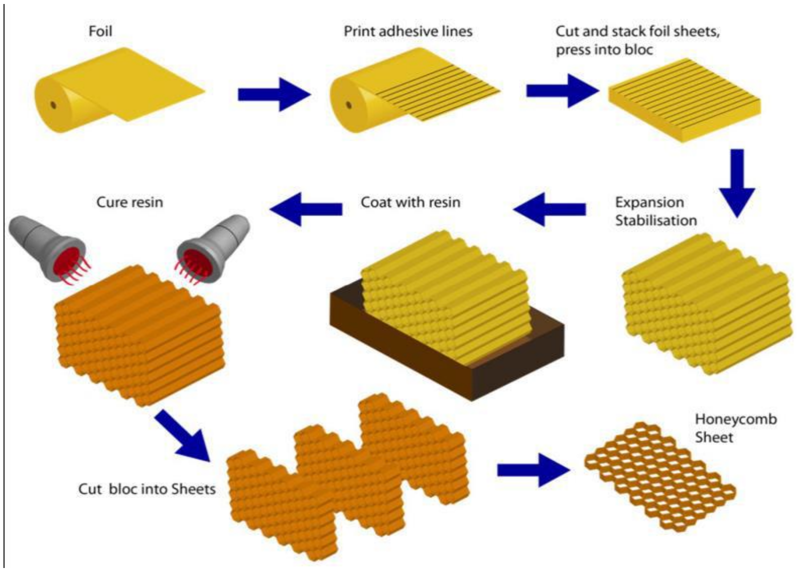


Figure 4-3.0-1: Honeycomb Manufacturing Process [7]

4.4 Epoxy Resin

Epoxy Resin or matrix are organic compounds which plays the role of adhesive in fiber reinforced composites. The matrix acts as a reinforcement and transfers stress from one layer to another. They are basically reinforcement in FRP. They have high strength modulus and good reinforcement properties.

Chapter 5

Geometry and Boundary Conditions

5.1 CAD Models

The B- Pillar and the anti-intrusion beam are complex geometries and its difficult to model such geometries for varying parameters. To limit the complexity of computational these geometries were converted to their representative profiles with a span of 1000 mm. Studying the profiles not only help us understand a general behavior of the geometry but also limit the complexity of the models.

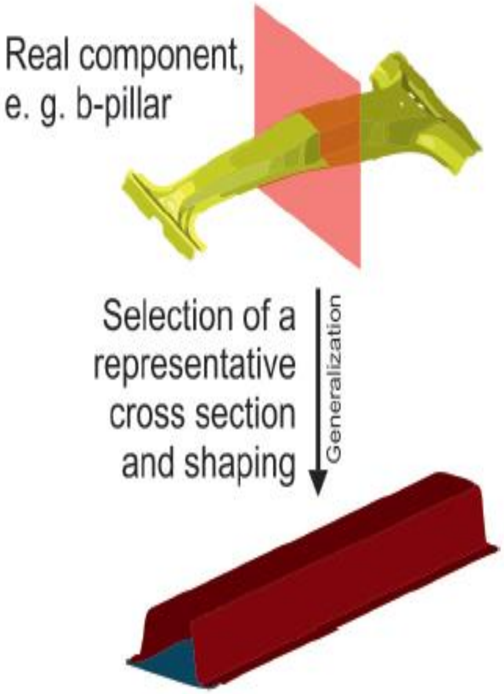


Figure 5-1 Geometry Conversion [2]

The following profiles were studied and modeled for this research

- Single Hat

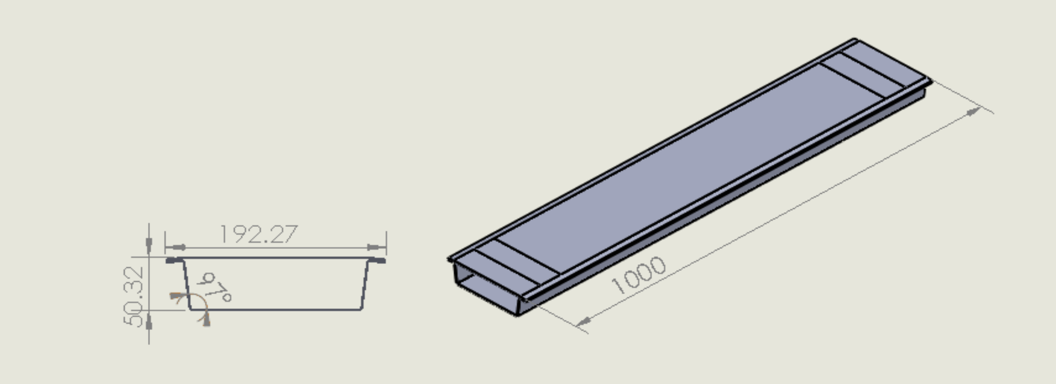


Figure 5-2 CAD Model Single Hat

- Double Hat

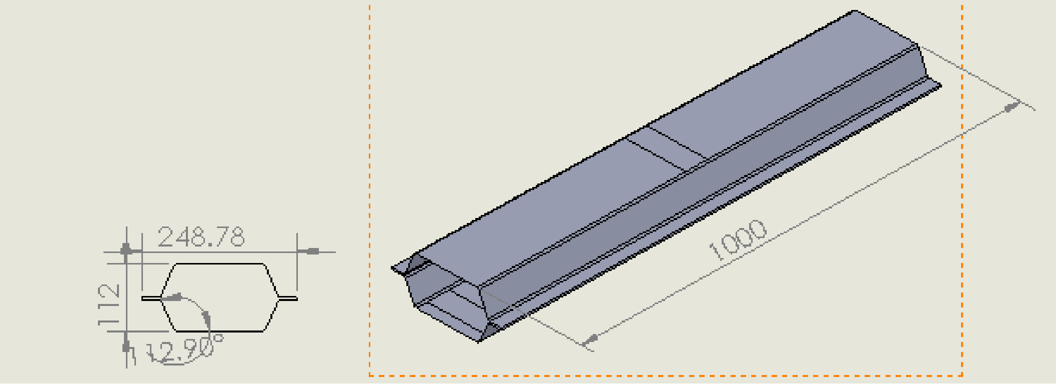


Figure 5-3 CAD Model Double Hat

- Double Z

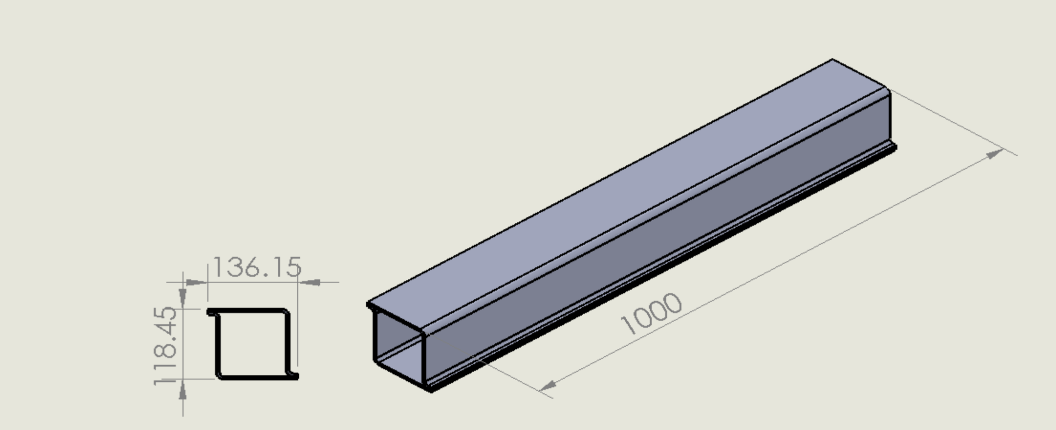


Figure 5-0-4 CAD Model Double Z

- Beads

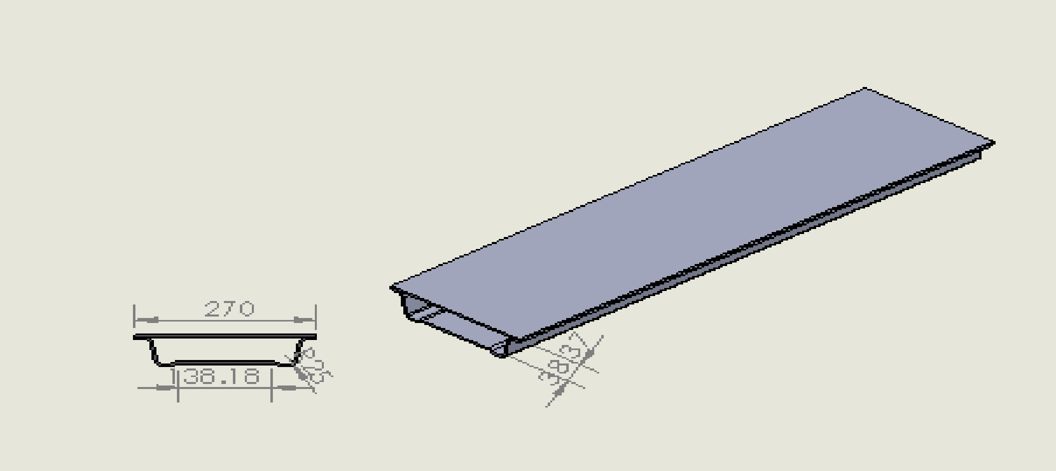


Figure 5-0-5 CAD Model Beads

5.2 Meshing

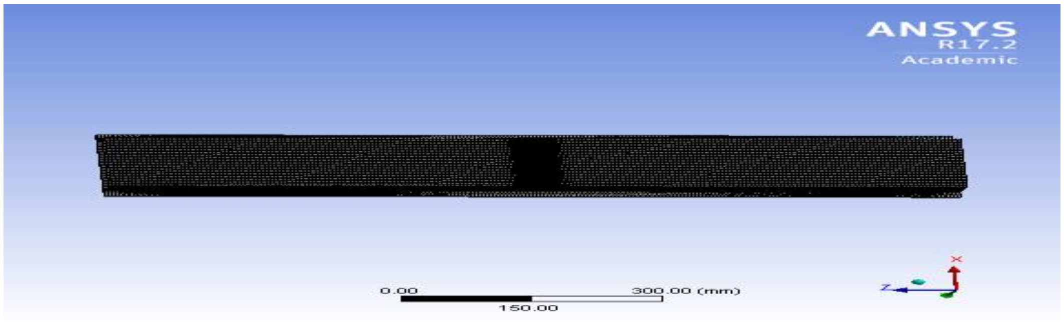


Figure 5-0-6 Meshing

The Meshing was done using the Shell 281 [8] elements. Shell 281 are 8 node quad elements with 6 DOF/node i.e. X, Y, Z translation and X, Y, Z rotation. These elements are used to analyze thin to moderately thick structures. The Shell 281 are well suited for linear, large rotation and large strain non-linear problems. Layered structures such as composites can be well presented using these elements.

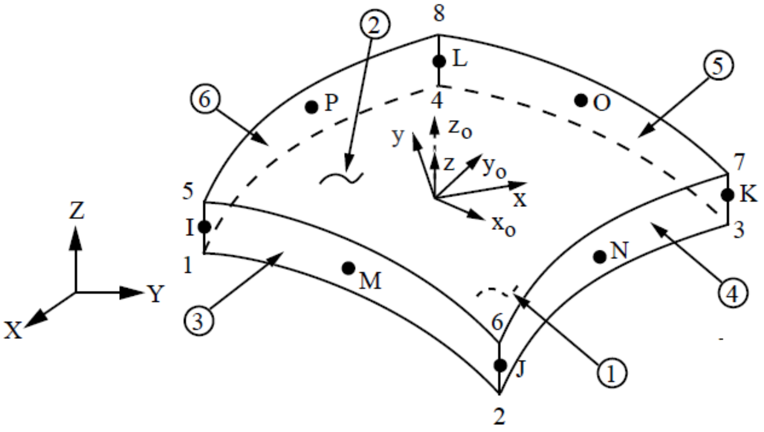


Figure 5-0-7 Shell 281[9]

The order of element considered is quadratic as mid side nodes are included in the analysis. The midside nodes enable the mesh solver to capture the geometry of the structure in a more realistic way and yield better results at less expense then linear material.

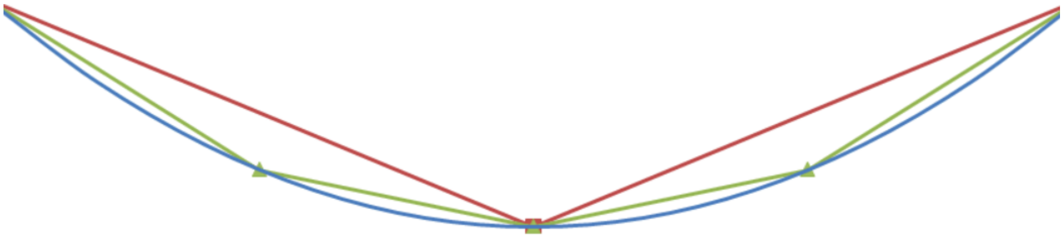
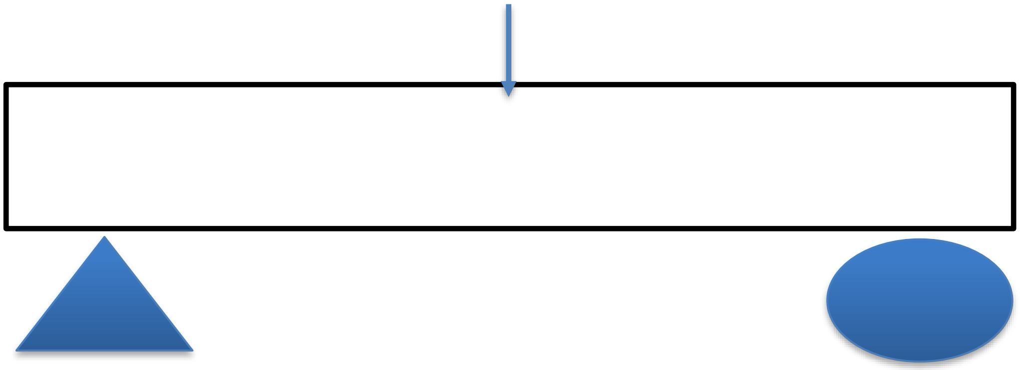


Figure 5-0-8 Mid Side Nodes [9]

To consider the non-linearities in the analysis and capture more realistic behavior, large deflection was considered i.e. stiffness matrices were updated at each iteration.

5.3 Boundary Condition

The simulations were performed in two parts i.e. static and dynamic. The static simulations were modelled based on 3 pt. bend test formulations. Load was applied at the central section of the beam, while lower sections were constrained with all DOF at one end and roller support at another end i.e. only translation DOF allowed at another end



Force Calculations:

- **Force = 20,000 N** (at the center of the beam)
    - Total Weight of the Car = 1200 Kg = 1200 X 9.81 = **11,772 N**
    - As per FMVSS impact test = total weight (N) x 1.5(g's)
      = 11,772 X 1.5 = **17,658 N**
    - Based on the above calculation a generalized value of **20,000 N** was selected

The load was assumed based on FMVSS [2,4] regulations for static test. Simulation a collision at 1.5g’s.

For the dynamic simulations we have considered to model and impact test. The weight of the impactor is half the weight of the car i.e. 600kg’s and travelling at 15m/s. The fixed boundary conditions remain same as the static test. The dynamic simulations were used to estimate total energy absorption and deacceleration of impactor body.

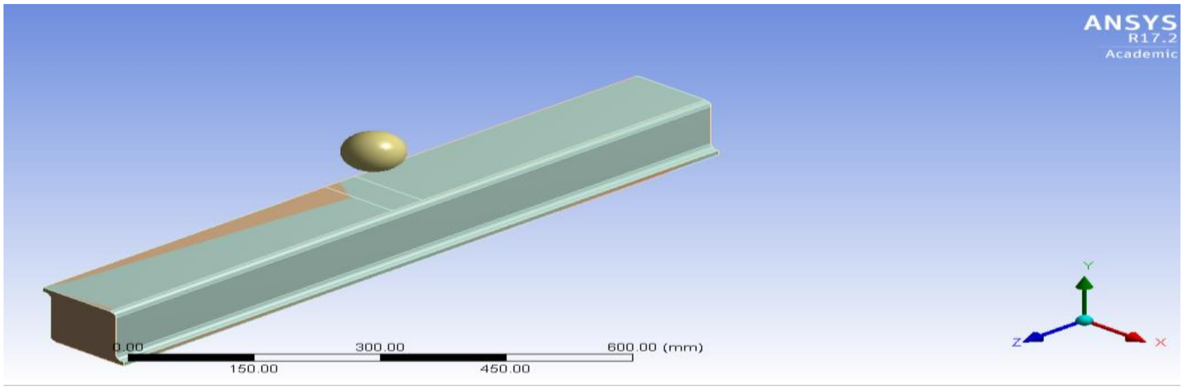


Figure 5-9 Explicit Dynamic Model

The above analysis was performed varying cross-sectional profiles and material, in addition to this the core material was also varies i.e. hollow, honeycomb core and structural foam.

A comparative study was performed, and conclusion was derived based on beam stiffness, FOS, overall mass, energy absorption and deacceleration.

Chapter 6

Simulations

6.1 Static

Static and Dynamic simulations were carried out using ANSYS 17.2. The geometry was modelled in SOLIDWORKS 2018 and imported in ANSYS as a Parasolid file. The material properties were modelled in ANSYS. Modelling of composites were done in ANSYS PrePost. It performs a layer by layer section of composites based on layer material and thickness

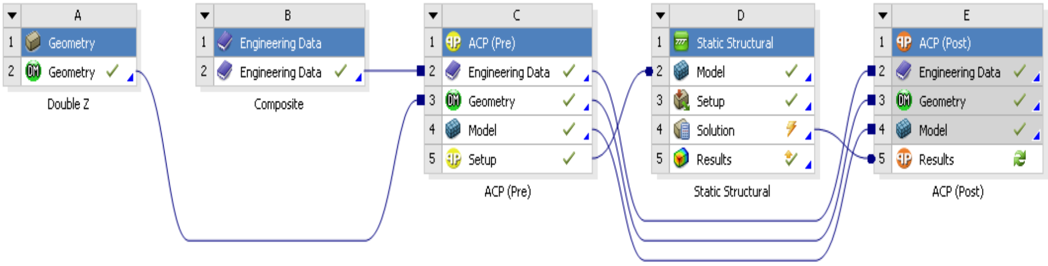


Figure 6-0-1 ANSYS ACP Module

The material used to model composites is Carbon Fiber : Cytec Thornell T650/35. Honeycomb is being used as the core material. Three different types of cases were developed for core section namely hollow, honeycomb core, structural foam core. The ply stacking sequence was decided based on performance of fibers in 0^{o}, 90^{o} and $+45^{o}$, -45^{o}

The significance of the angles are as follows: -

- 0^{o}- Resistance against bending
- 90^{o}- Resistance against crack propagation
- +/- 45^{o} - Resistance against torsional

The stacking sequence in unbalanced and quasi isotropic. Each ply of carbon fiber is 0.15mm thick with 0.2 mm core thickness. The stacking sequence of the laminate is as follows

$0^{o}/0^{o}/90^{o}/0^{o}/0^{o}/45^{o}$/Honeycomb/$-45^{o}/0^{o}/0^{o}/90^{o}/0^{o}/0^{o}$

The ply direction is kept normal to the surface and orientation is kept along the length of the beam.

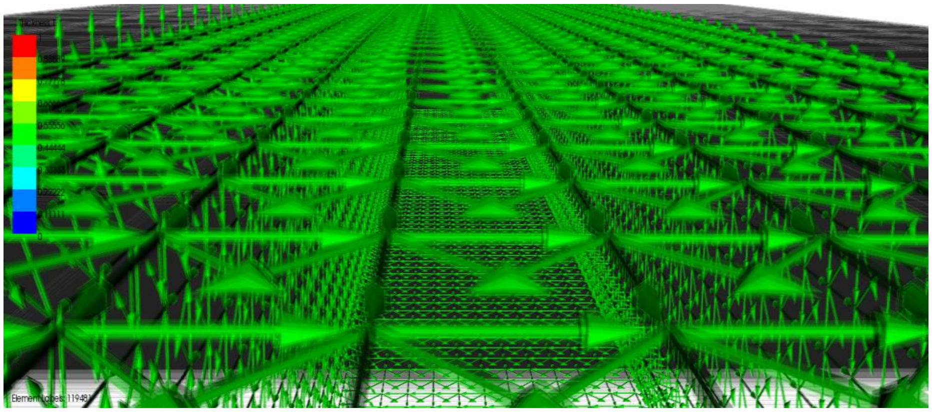


Figure 6-0-2 Fiber Direction

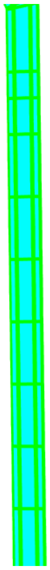


Figure 6-0-3 Laminate Direction

Loading and Boundary conditions are applied in static structural. Post analysis is done using ANSYS post module. The results are calculated for

- Bending Stiffness
- Deformation
- Normal Stresses
- FOS

6.2 Dynamic Simulations

The explicit dynamic module is used to carry out dynamic analysis. The explicit dynamics enables us to effectively model impact simulations. The interpolation functions are calculated based on time interaction. In addition to these features we can also calculate results based on very small-time steps. This allows us to model and understand the behavior of the structure more effectively.

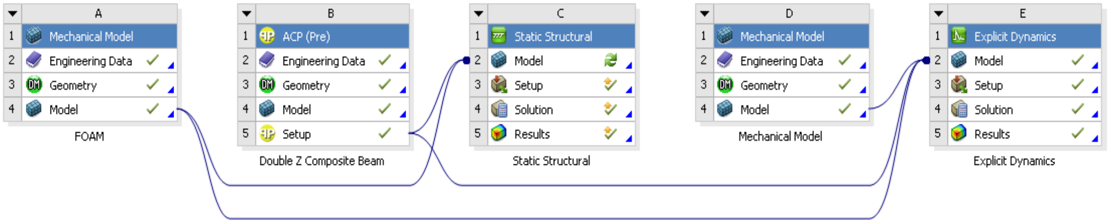


Figure 6-4 Explicit Dynamic Module

Chapter 7

Results

The results obtained for different cases with varying material and fixed boundary conditions are as follows

7.1 Static Results

7.1.1 Profile 1: Double Hat

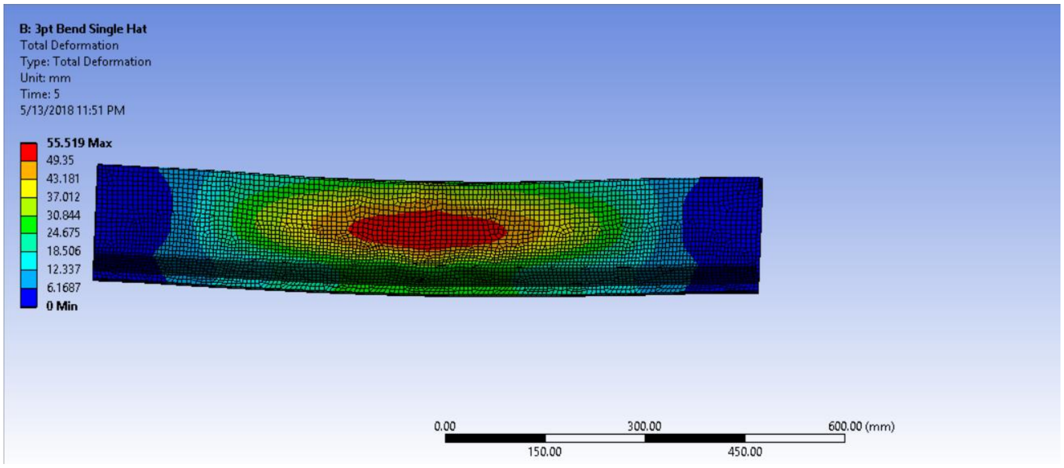


Figure 7-1: Hollow Aluminium

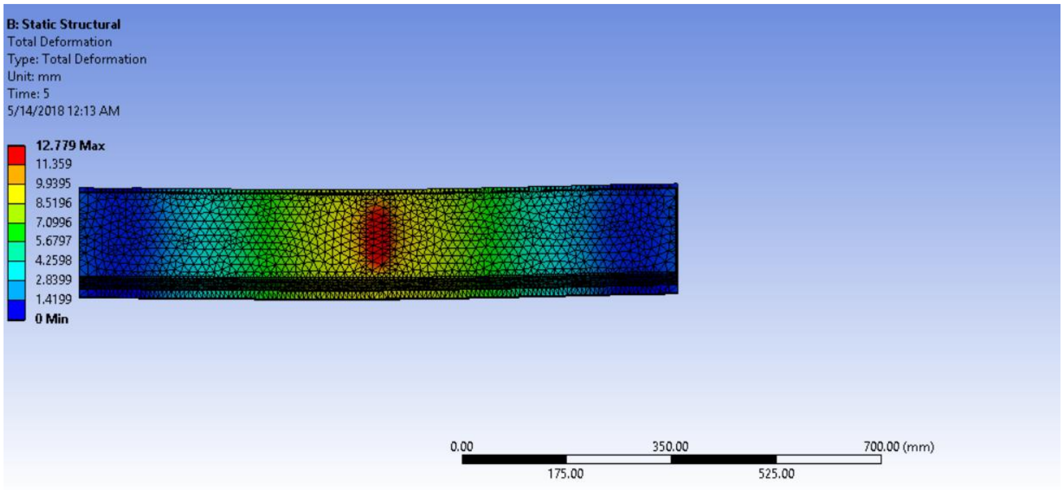


Figure 7-2: Foam Core

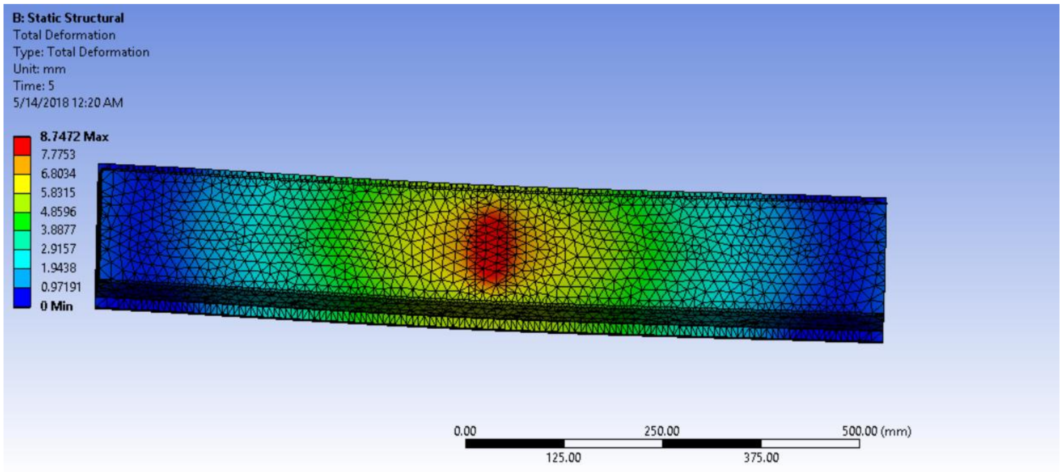


Figure 7-3: Aluminum Honeycomb Core

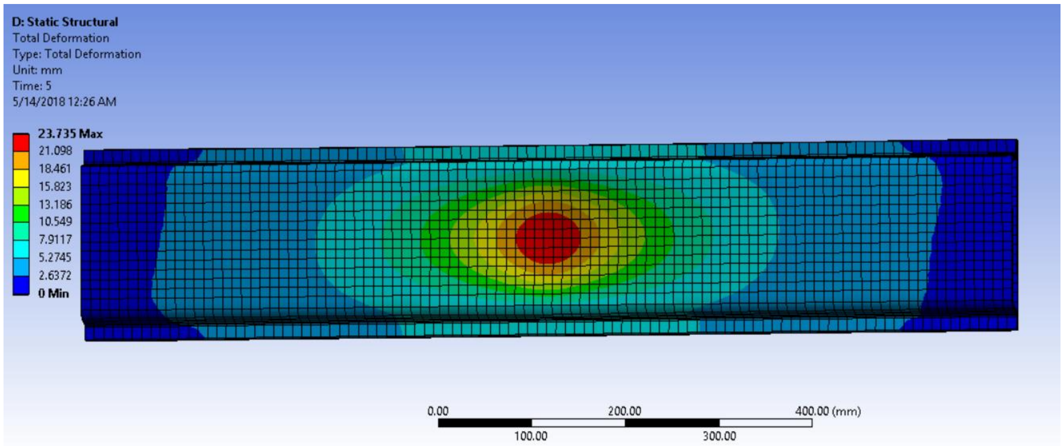


Figure 7-3: Composite Hollow

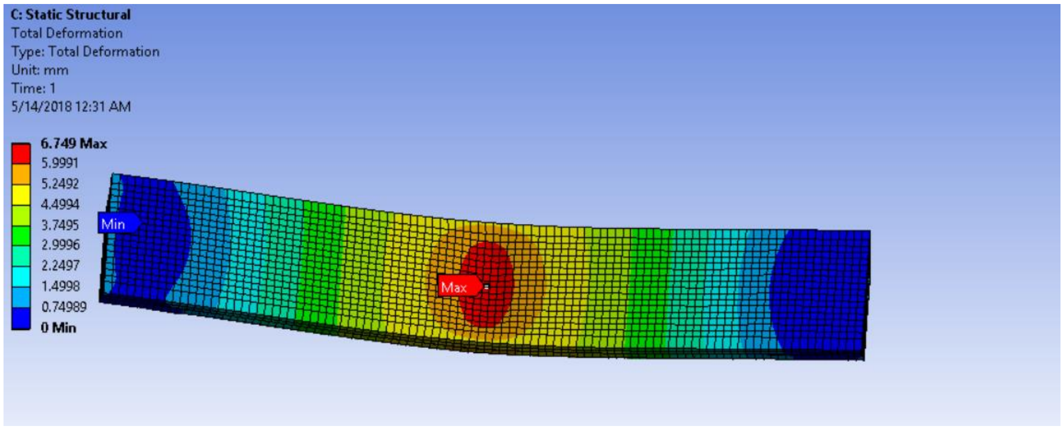


Figure 7-4: Composite Foam Core

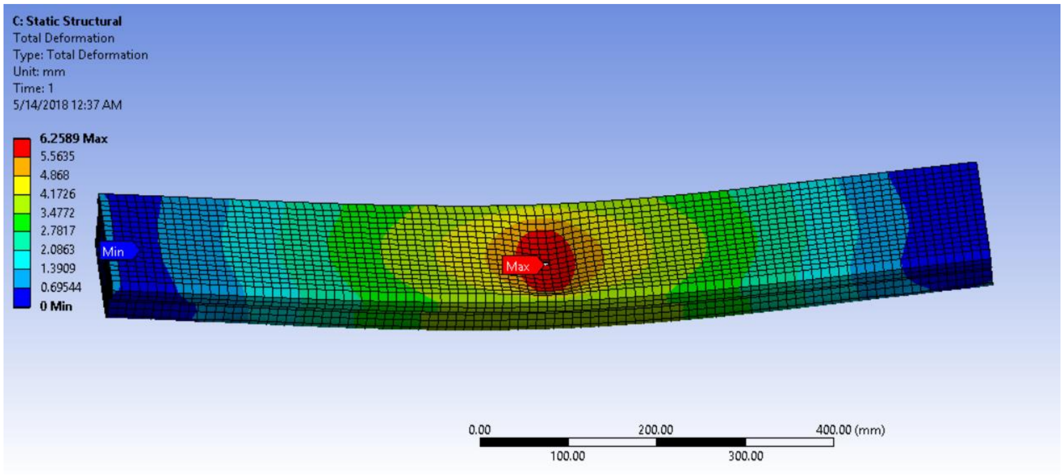
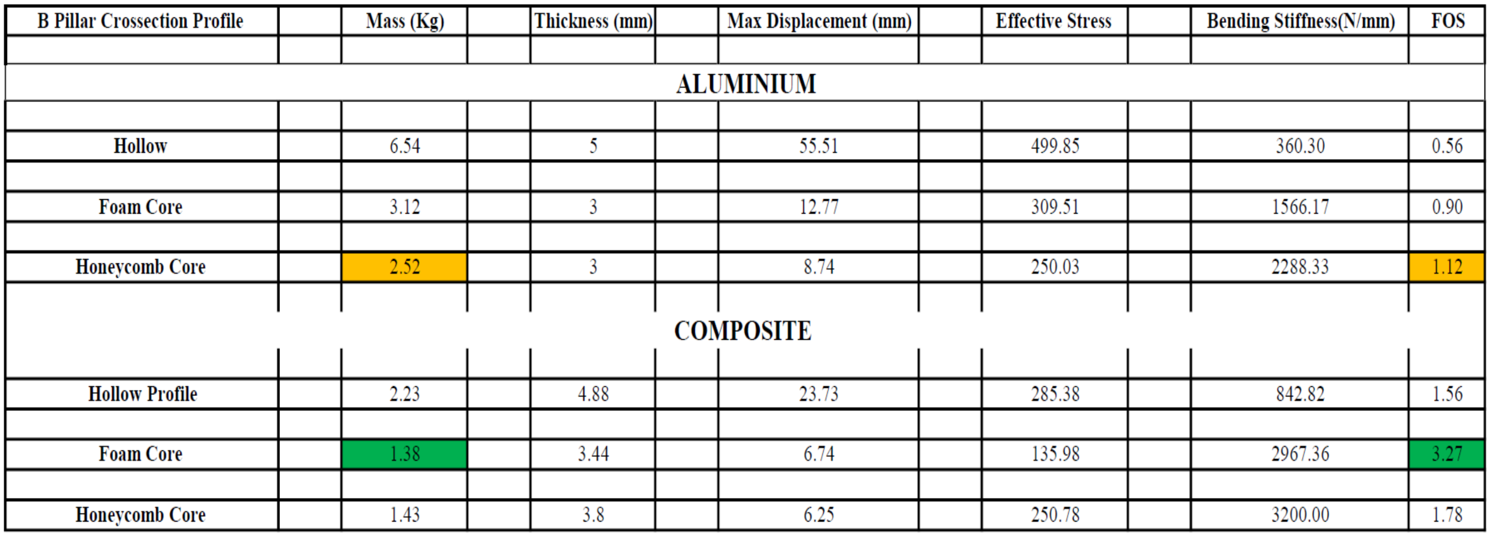


Figure 7-5: Composite Honeycomb Core



B Pillar Crossection Profile	Mass (Kg)	Thickness (mm)	Max Displacement (mm)	Effective Stress	Bending Stiffness(N/mm)	FOS
ALUMINIUM						
Hollow	6.54	5	55.51	499.85	360.30	0.56
Foam Core	3.12	3	12.77	309.51	1566.17	0.90
Honeycomb Core	2.52	3	8.74	250.03	2288.33	1.12
COMPOSITE						
Hollow Profile	2.23	4.88	23.73	285.38	842.82	1.56
Foam Core	1.38	3.44	6.74	135.98	2967.36	3.27
Honeycomb Core	1.43	3.8	6.25	250.78	3200.00	1.78

Table 7-1: Tabulated Results

7.1.2 Profile 2: Double Hat

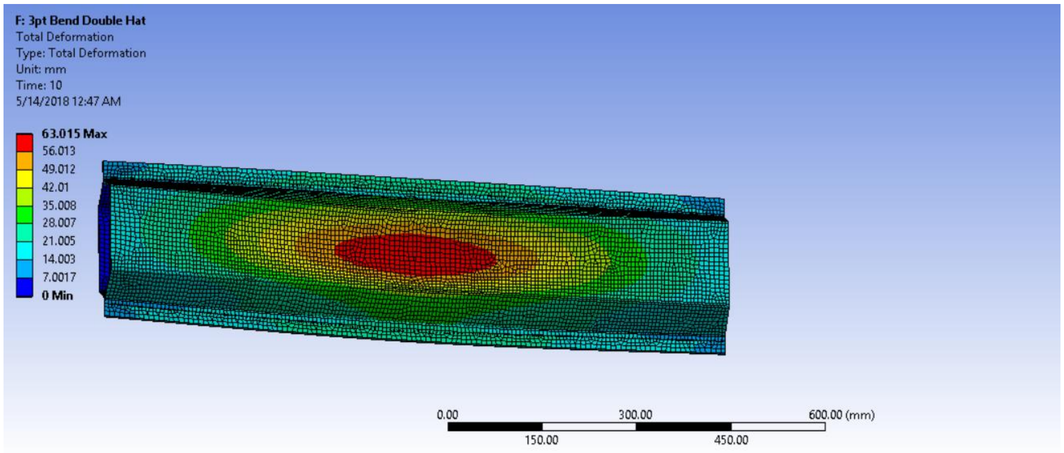


Figure 7-9: Aluminum Hollow

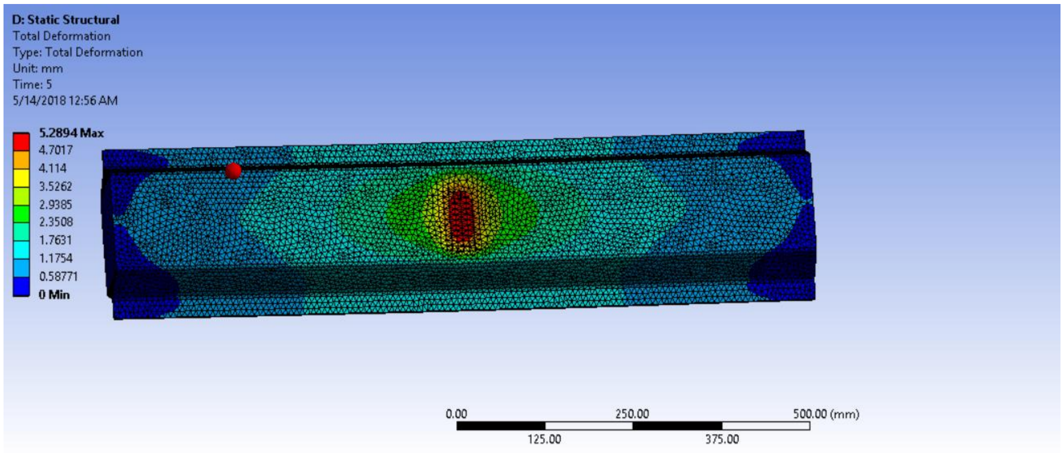
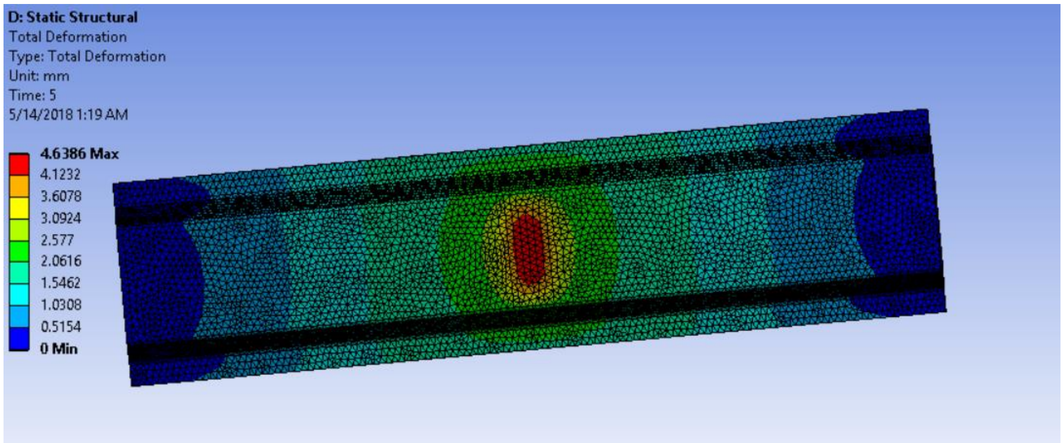
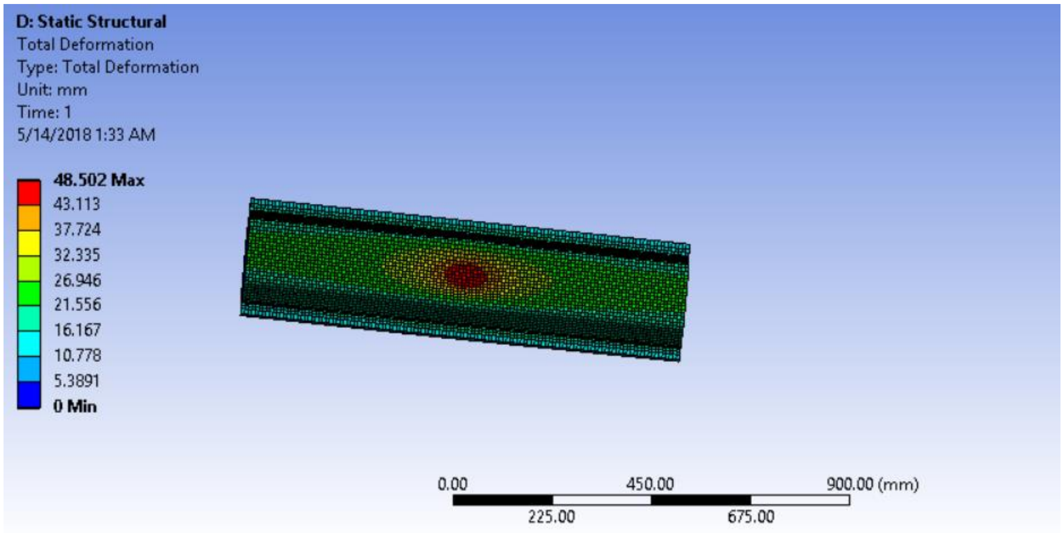


Figure 7-10: Aluminum Honeycomb Core



D: Static Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 5
5/14/2018 1:19 AM

Figure 7-11: Aluminum Foam Core



D: Static Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
5/14/2018 1:33 AM

Figure 7-12: Composite Hollow

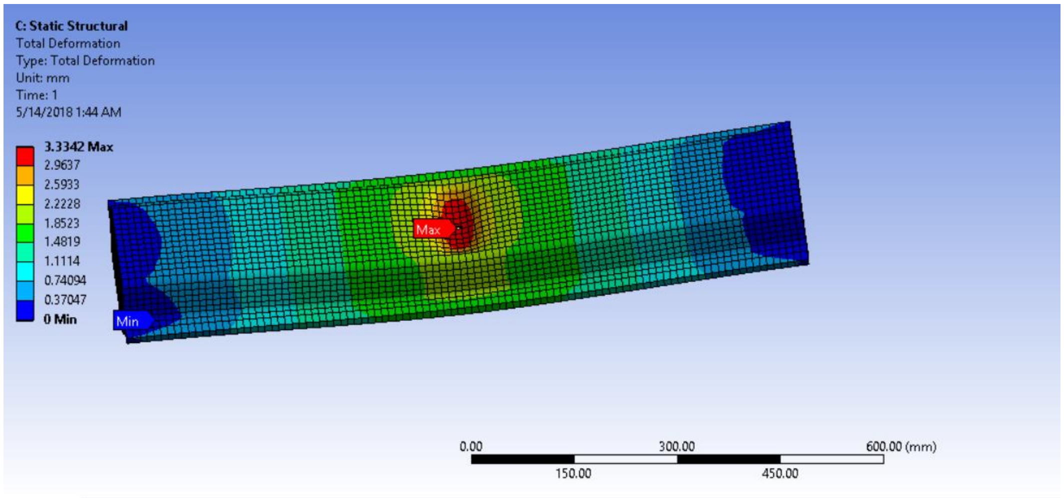


Figure 7-13: Composite Foam Core

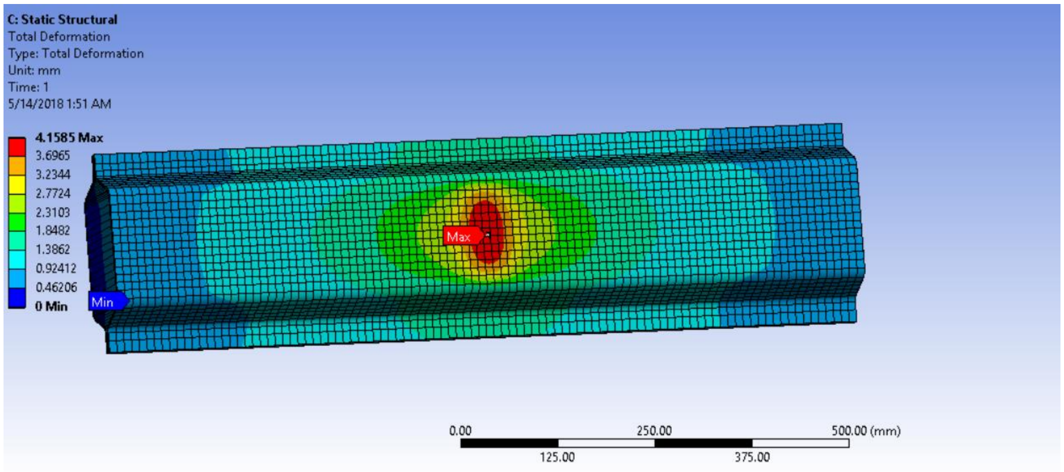


Figure 7-14: Composite Honeycomb Core

B Pillar Crossection Profile	Mass (Kg)	Thickness (mm)	Max Displacement (mm)	Effective Stress	Bending Stiffness(N/mm)	FOS
			ALUMINIUM			
Hollow	8.91	5.00	63.02	360.46	317.38	0.78
Foam Core	6.12	3.00	4.64	78.59	4314.44	3.56
Honeycomb Core	4.10	1.50	5.29	108.53	3781.15	2.58
			COMPOSITE			
Hollow Profile	1.14	5.12	48.50	299.16	412.35	1.49
Foam Core	1.92	3.33	3.33	134.00	5998.44	3.33
Honeycomb Core	1.90	4.16	4.16	166.70	4809.43	2.67

Table 7.2 : Double Hat Tabulated Results

7.1.3 Profile 3: Double Z

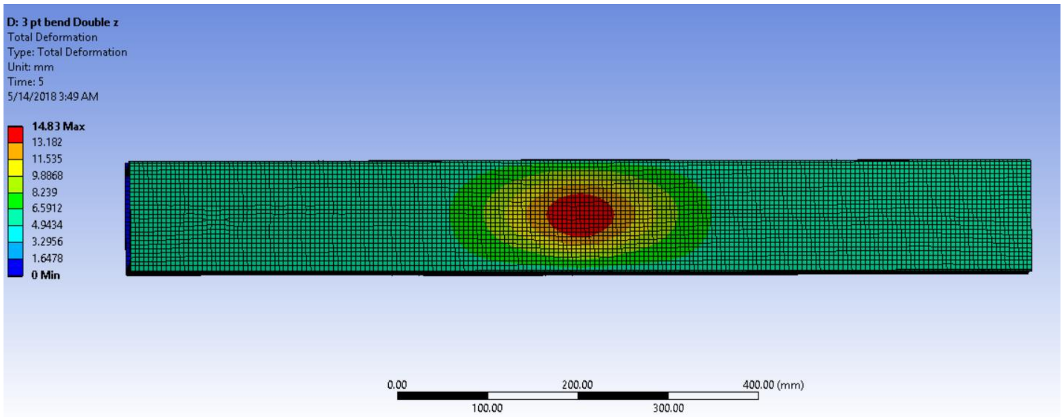


Figure 7-15: Aluminum Hollow

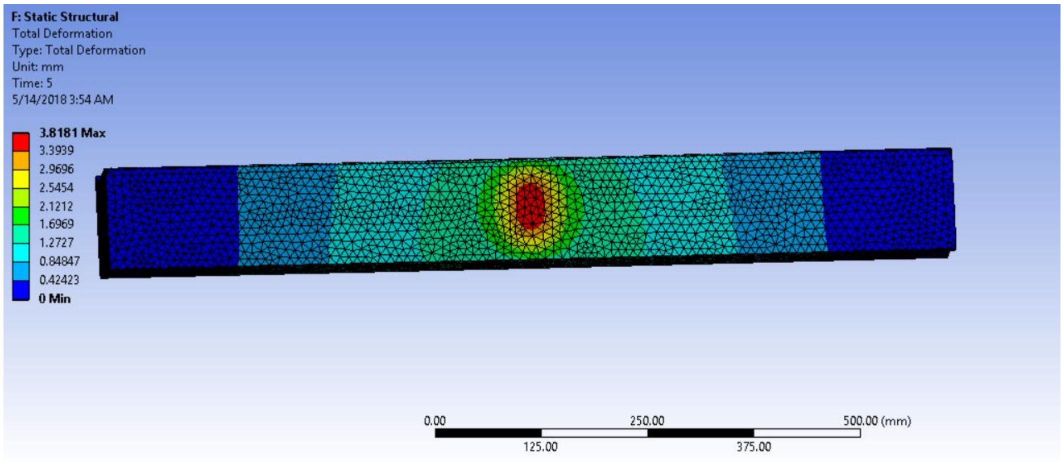


Figure 7-16: Aluminum Honeycomb

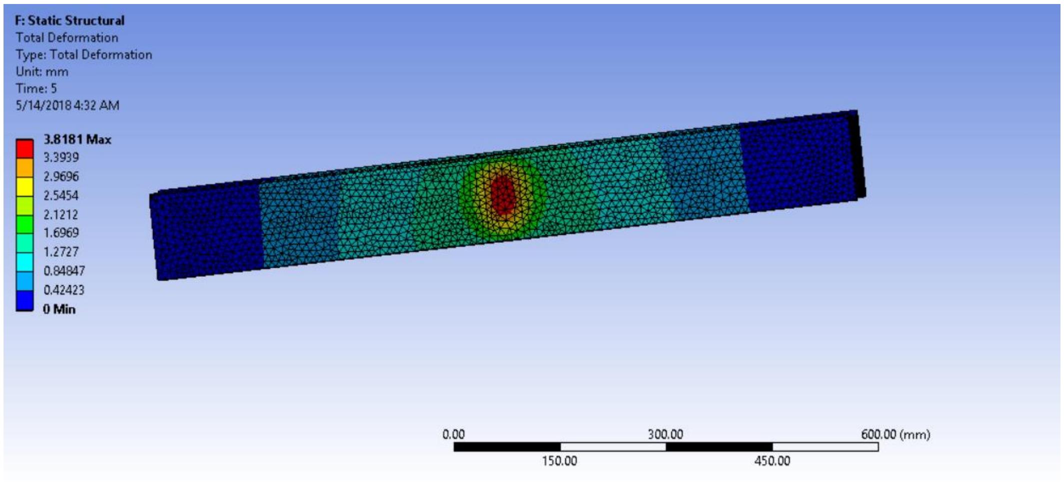


Figure 7-17: Aluminum Foam Core

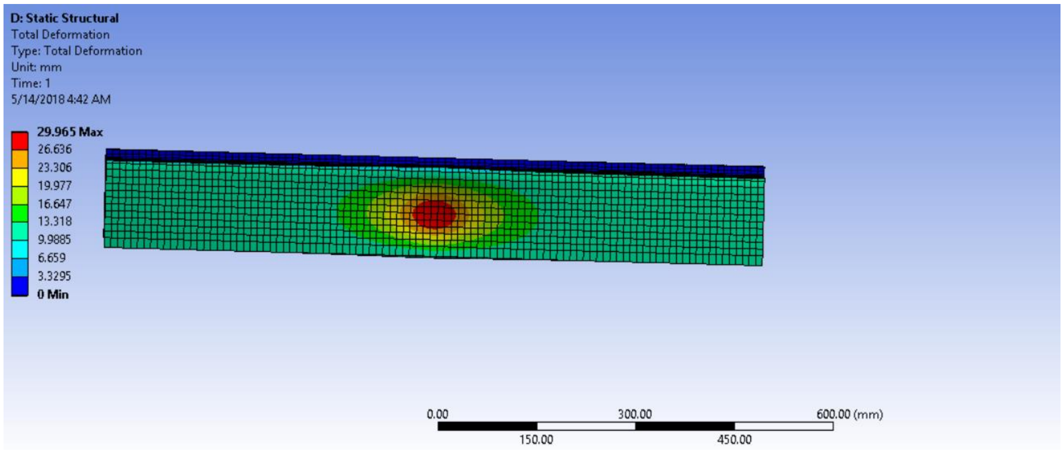


Figure 7-17: Composite Hollow

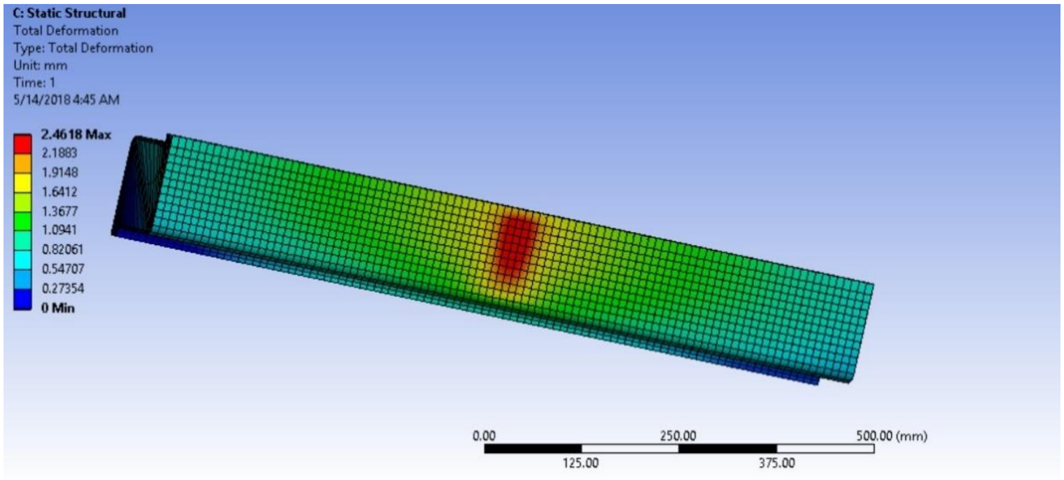


Figure 7-18: Composite Honeycomb Core

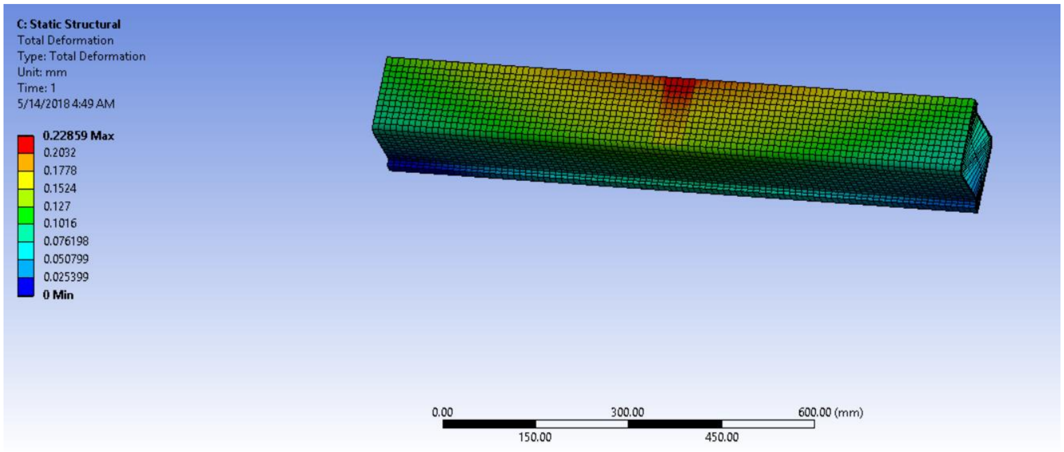
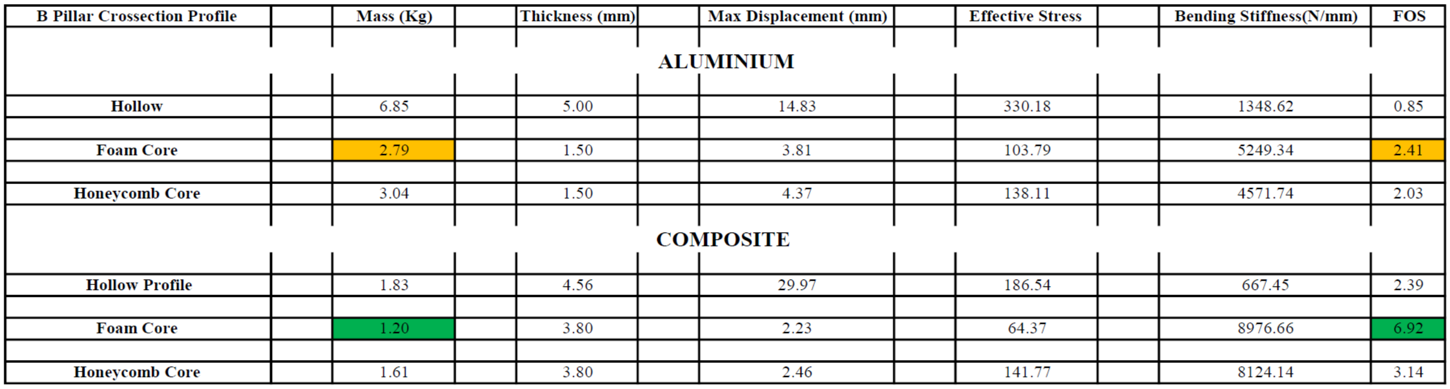


Figure 7-19: Composite Foam Core



B Pillar Crossection Profile	Mass (Kg)	Thickness (mm)	Max Displacement (mm)	Effective Stress	Bending Stiffness(N/mm)	FOS
ALUMINIUM						
Hollow	6.85	5.00	14.83	330.18	1348.62	0.85
Foam Core	2.79	1.50	3.81	103.79	5249.34	2.41
Honeycomb Core	3.04	1.50	4.37	138.11	4571.74	2.03
COMPOSITE						
Hollow Profile	1.83	4.56	29.97	186.54	667.45	2.39
Foam Core	1.20	3.80	2.23	64.37	8976.66	6.92
Honeycomb Core	1.61	3.80	2.46	141.77	8124.14	3.14

Table 7.3 : Double Z Tabulated Results

7.1.4 Profile4: Beads

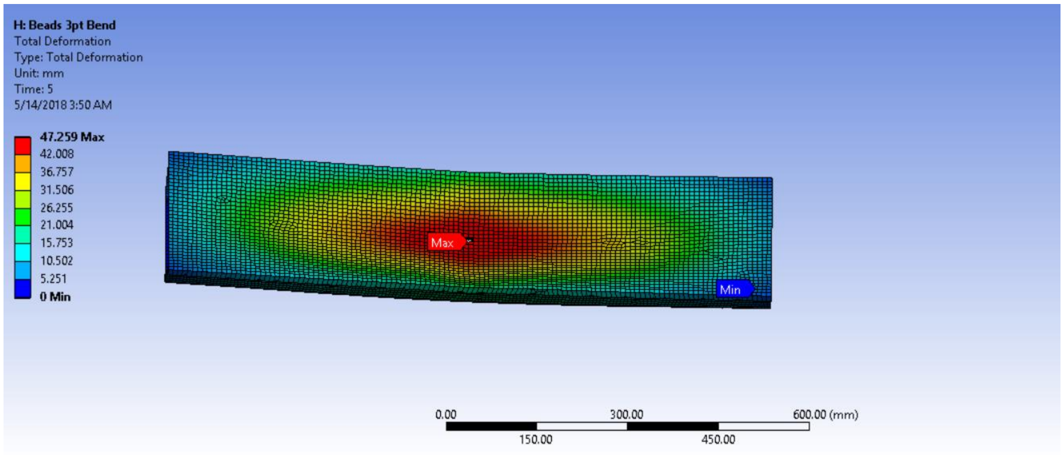


Figure 7-20: Aluminum Hollow

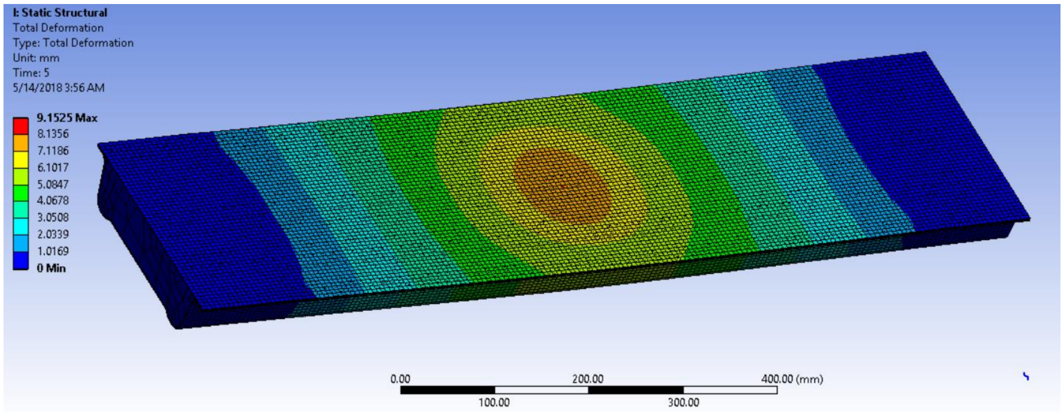


Figure 7-21: Aluminum Honeycomb Core

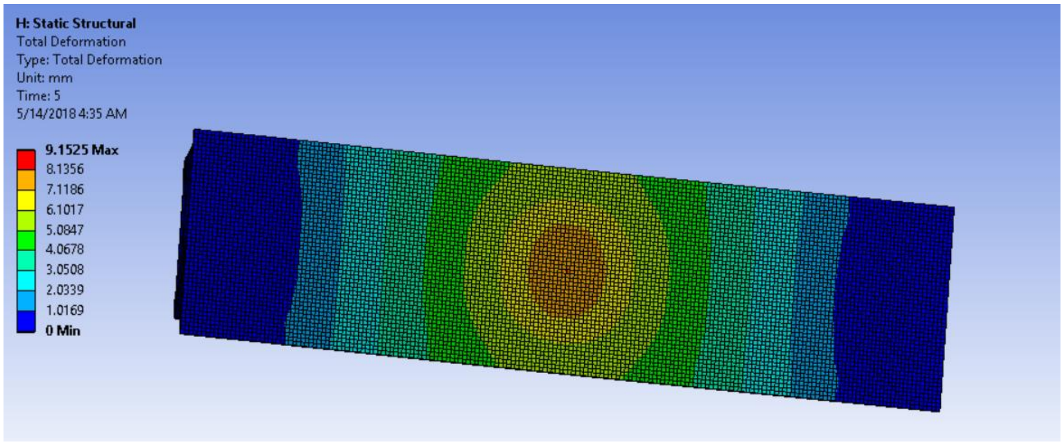


Figure 7-22: Aluminum Foam Core

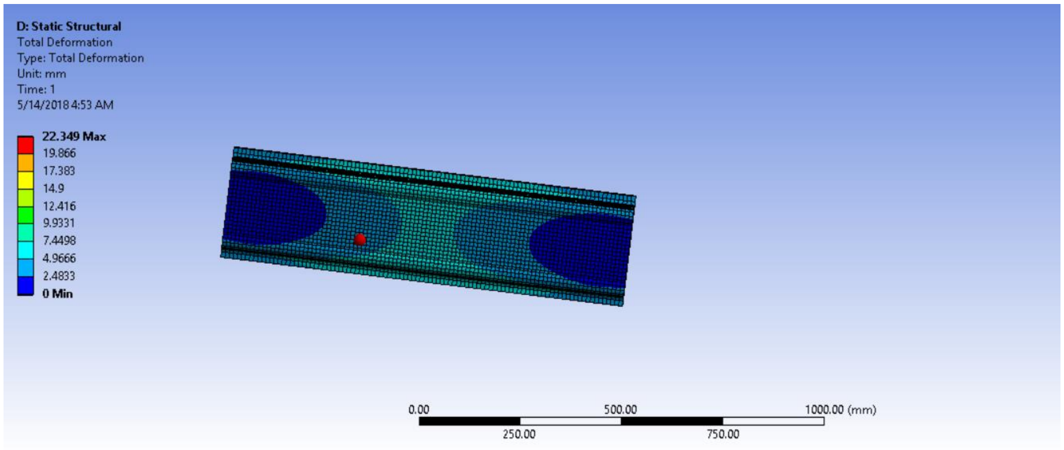
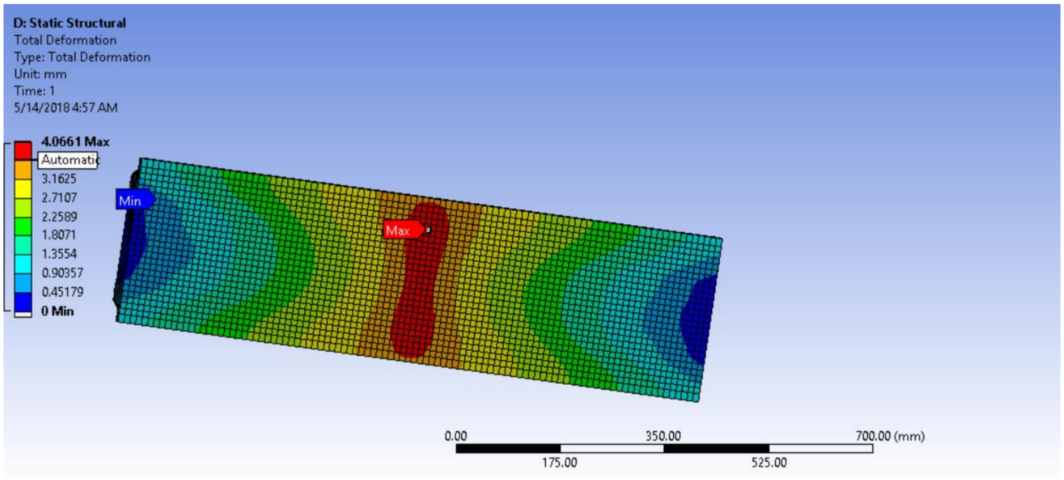
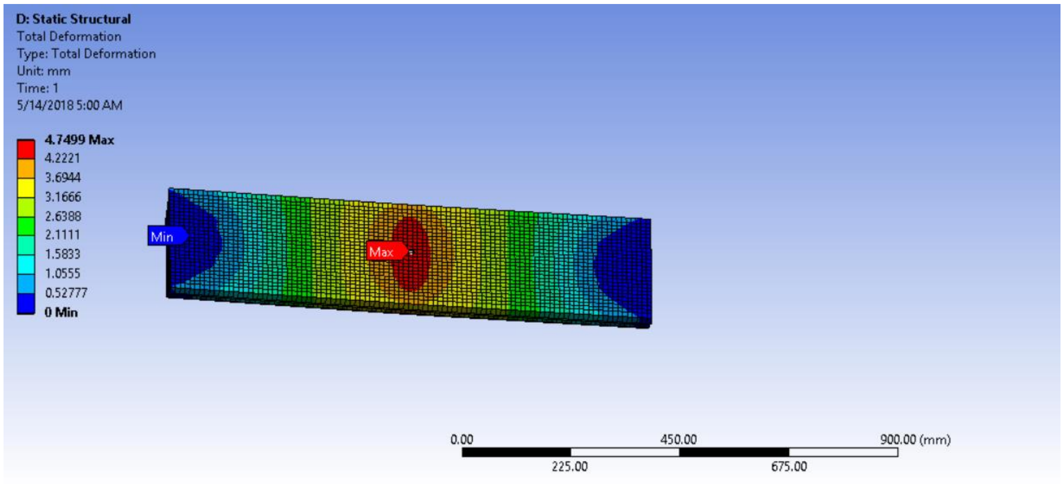


Figure 7-26: Composite Hollow



D: Static Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
5/14/2018 4:57 AM

Figure 7-27: Composite Honeycomb Core

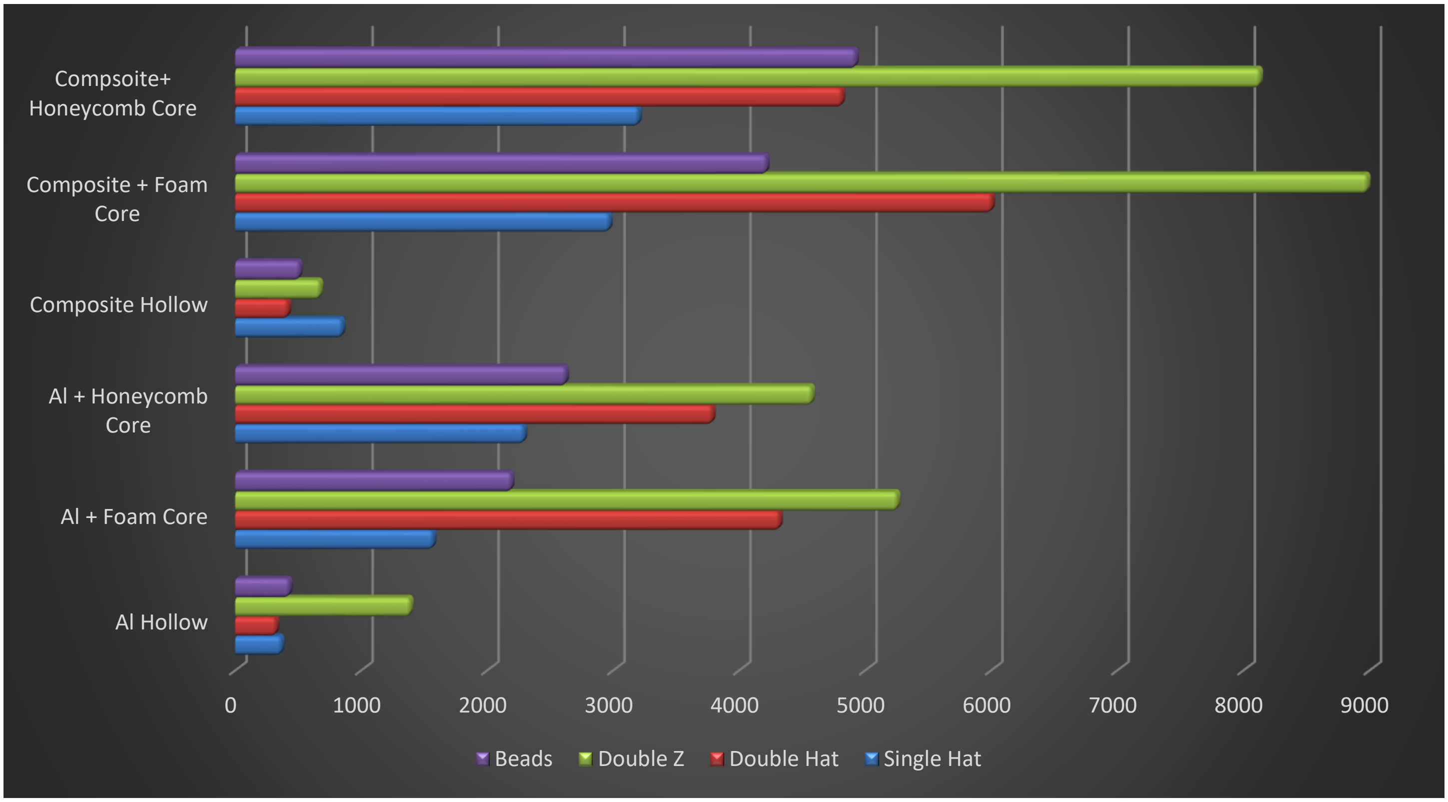


D: Static Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
5/14/2018 5:00 AM

Figure 7-24: Composite Foam Core

B Pillar Crossection Profile	**Mass (Kg)**	**Thickness (mm)**	**Max Displacement (mm)**	**Effective Stress**	**Bending Stiffness(N/mm)**	**FOS**
ALUMINIUM						
Hollow	8.89	5.00	47.26	259.50	423.20	1.08
Foam Core	2.90	1.50	9.15	144.04	2185.20	1.94
Honeycomb Core	3.13	1.50	7.64	140.01	2616.64	2.00
COMPOSITE						
Hollow Profile	1.31	5.00	39.70	82.30	503.78	5.42
Foam Core	1.70	3.80	4.75	67.29	4210.61	6.62
Honeycomb Core	1.75	3.80	4.07	75.43	4918.72	5.91

Table 7.4: Beads Profile Tabulated Results



7.2 Dynamic Analysis

The dynamic behavior of the structure was calculated based on net energy change at the point of impact of the ball with the beam.

- Velocity at Impact, V_i = 15 m/s
- Energy absorbed = change in Kinetic Energy of ball

$$= 0.5 * m * (V_i^2 - V_f^2)$$

	Energy Absorbed (J)
Al + Foam	35,152
Al + Honeycomb	38,793
Composite + Honeycomb	54,648
Composite +Foam	58,097

Chapter 8

Conclusion

- **Crashworthiness** i.e. able to absorb energy during impact. Composite show **40 %** crashworthiness than conventional material .
- Double Z profile geometry proves to be most structurally stable with an FOS of 6
- Double Z composite with foam can sustain much higher loads
- Use of core material such **Structural Foam** and **Honeycomb** acts as good impact absorbents during crash
- Composite along with core material have much higher safety factor as per standards.
- Simplified geometrical profiles which are easy to manufacture
- Lighter structural components with good stiffness to weight ratio, would achieve high power to weight ratio.

Chapter 9

Future Works

- Manufacturing of beam profiles and physical testing
- Implementing AL –Composite hybrid beams
- Implementing these profiles in Frontal and Rear crash scenarios
- Modelling entire structure and performing static and dynamic test

References

[1] Viquar Hasan Mohammad, Evaluation of New Steel and Composite Beam For Side Impact Protection of a Sedan as per FMVSS 214 , IIIHS and Side Pole Test Requirements, Osmania University, India,2010

[2] Advanced Composite Material for Automotive Application, Ahmed Elmarakbi, Wiley, 2014

[3] https://en.wikipedia.org/wiki/Pillar_(car)

[4] https://www.nhtsa.gov/fmvss/side-impact-protection

[5] https://en.wikipedia.org/wiki/Ansys

[6] https://www.mathworks.com/products/matlab.html

[7] Aniket Chandu Thosar, Comparison of Mechanical Behavior of Metallic and Composite Front Door of a Standard Automobile Car by FEA, The University of Texas at Arlington, 2017

[8]http://www.matweb.com/search/datasheettext.aspx?matguid=7e9aca60a2e84538a4e8038784f2b629

[9] Ansys Professional, Shell 281, https://www.sharcnet.ca/Software/Ansys/16.2.3/en-us/help/ans_elem/Hlp_E_SHELL281.html

[10] Engineering Mechanics of Composites- Isaac. M. Daniel

[11] Fiber Reinforced Composites – P.K Malik

[12] Mechanics of Composites – Richard Kristensen

[13] Eric Richardson Tobby , Amir Bahaadini ,Design Analysis and Verification of Composite Components Subjected to Crash Load Cases , Department of Mechanical Engineering , Blekinge Institute of Technology , Sweden, 2015

[14] Pedro Ponces Camandho, Failure Criteria of Fiber Reinforced Composites, University de Pordo, 2002

[15] Thor Fraser, Daren Goldenberg Muhammad Yazid, Alex, Design of Automotive Central Pillar Reinforcement to Resist Roof Crush in F Series Crew Cab, 11 December 2007

BIOGRAPHICAL STATEMENT

Nitish Sharma was born on 8th June 1994. He received his Bachelor of Engineering in Mechanical Engineering from the University of Pune, India in 2016. He worked as team lead in FSAE from 2014 to 2016. He enrolled into Master of Science in Mechanical Engineering program at the University of Texas at Arlington in Fall 2016. From December 2017, he started working under Dr. Andrey Beyle, on composites. He is proficient in Solidworks, ANSYS workbench, ANSYS Composite PrepPost and Auto-Cad. He has a certification CSWA in Solidworks. He also trained and motivated new members in field. He served as a Graduate Research Assistant at University of Texas at Arlington Research Institute from summer of 2017 to summer of 2018 in Biomedical Technologies Division.