OPTIMIZATION AND IMPACT ANALYSIS OF A ROLL CAGE MODEL

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1. **ABSTRACT:-** Roll cage is a three dimensional protected structure around the passengers compartment that will keep the passengers safe in automobiles such as cars, trucks, buses, etc. It is a special structural frame developed by joining the individual roll bars by welding or bolting them together to protect the occupants of a vehicle from the effects of an accident. The roll cage must be constructed of steel tubing, with minimum dimensional and strength requirements dictated by Society of Automotive Engineers (SAE). In this paper the roll cage is designed and analyzed for impact loads, with both conventional and composite material. In the present scenario, due to increase of automobile applications, composite material is gaining advantage over steel in automobile manufacturing. Composites are considered lighter, safer and more fuel efficient vehicle. A composite is composed of high performance fiber (such as carbon) in a matrix material (epoxy polymer) that when combined provides enhanced properties compared with individual material. Composite material weigh one fourth of steel, but are as good in terms of stiffness and strength. Roll cage is designed using CATIA V5R20 software and analyzed using steel and composite in ANSYS16.0 software. Impact tests are performed for both the material and results are compared.

Keywords: Roll Cage, Finite Element Analysis, Optimization

2. INTRODUCTION

The roll cage is one of the most critical safety features available and required in a race car. It is the most stiffening chassis components available in a race car. The roll cage is there to help reduce chassis flex and increase the driver's safety. A roll cage's rigid structure helps prevent that break in structure from occurring, potentially saving the drivers life. That alone makes a roll cage worth it. Another added benefit of introducing a roll cage into your vehicles infrastructure is that it reduces the chance of chassis flex from occurring. Chassis flex is when the structure of your vehicle itself warps during any gravitational forces applied to it through heavy breaking, heavy acceleration or drastic high-speed turns.

3. LITERATURE REVIEW

Denish S. Mevawala et al.[1] determined the roll cage not only forms the structural base but also a 3-D shell surrounding the occupant which protects the occupant in case of impact and roll over incidents. The roll cage also adds to the aesthetics of a vehicle. This paper deals with design of roll cage for an ATV and Various loading tests like Front Impact, Side Impact and rear impact have been conducted. They have focused on every point of roll cage to improve the performance of vehicle without failure of roll cage. They concluded after the analyses that roll cage structure for its strength against the collision from front, rear, as well as side. Factor of safety is under the safe limit. The roll cage is sustained 4G force from front as well as rear & 2G force from side. But, deformation & stresses are under the limit

Thanneru Raghu Krishna Prasad et al.[2] designed the frame & suspension of the Society of Automotive Engineers (SAE) Baja car which is a single-seated all-terrain vehicle and is used for off road usage and endurance on a rough terrain. In many aspects it is similar to an All- Terrain Vehicle (ATV) except that it is much smaller in size and has safer rollover capabilities. The modeling of the frame and suspension is done by using pro-e software. This design is checked by Finite Element Analysis after estimating the load and the weight of the frame. They decided that the usage of solidworks® was very helpful to the design and analysis of the frame and suspension for Mini Baja Car. The finite element analysis gave a very accurate prediction of where failure would occur in this situation.

Khelan Chaudhari et al.[3] studied about design, development and fabrication of the roll cage for All -Terrain Vehicle accordance with the rulebook of BAJA 2013 given by SAE. Material for the roll cage was selected based on strength, cost and availability. The roll cage was designed to incorporate all the automotive sub-systems. A software model is prepared in Pro-engineer. Based on the result obtained from these tests the design was modified accordingly. After successfully designing the roll cage, it was fabricated. They concluded that the design, development and fabrication of the roll cage was carried out successfully. The roll cage was used to build an ATV by integrating all the other automotive systems like transmission, suspension, steering, brakes and other miscellaneous elements.

GAURAV S. CHIMOTE et al.[4] stated that the objective of their design and analysis of an ATV was fun to drive, versatile, safe, durable and was also a high performance off road vehicle. They ensured that the vehicle spastics the limits of set rules. Their vehicle was capable of negotiating the most extreme terrain with confidence and ease. They met these objectives by dividing the vehicle into major component subsystems. They concluded that when undertaking design of any vehicle there were several factors to be considered that were common to all engineering vehicles.

Puneet Malhotra et al. [5] stated that their study was to design of an All-Terrain Vehicle (ATV) in accordance with the SAE BAJA 2014 rule book. A detailed designing of components were carried out by them like Roll cage, Suspensions & Braking mechanism. The main focus of their was on Safety of driver & Stability of vehicle. Roll cage of their vehicles was designed in such a way that in case of rolling of vehicle (mostly occurs in high speed turns & off reading that it will provide double the strength to the roll cage with also considering the Aesthetic of the cage. International standards were followed by them where ever possible and an extensive market survey was also done. Finite Element Analysis was carried out on roll cage & braking mechanism for optimum safety & reliability of the vehicle.

4. METHODOLOGY

For this project, the parametric geometry is created using the Baja SAE India Rulebook design parameters. The model of roll cage is imported to ANSYS to perform finite element analysis. Static analysis is performed on roll cage for conventional material and composite material to determine deflections and stresses. From the analysis, results of both materials are tabulated. From these results, better material is selected based on weight and strength.

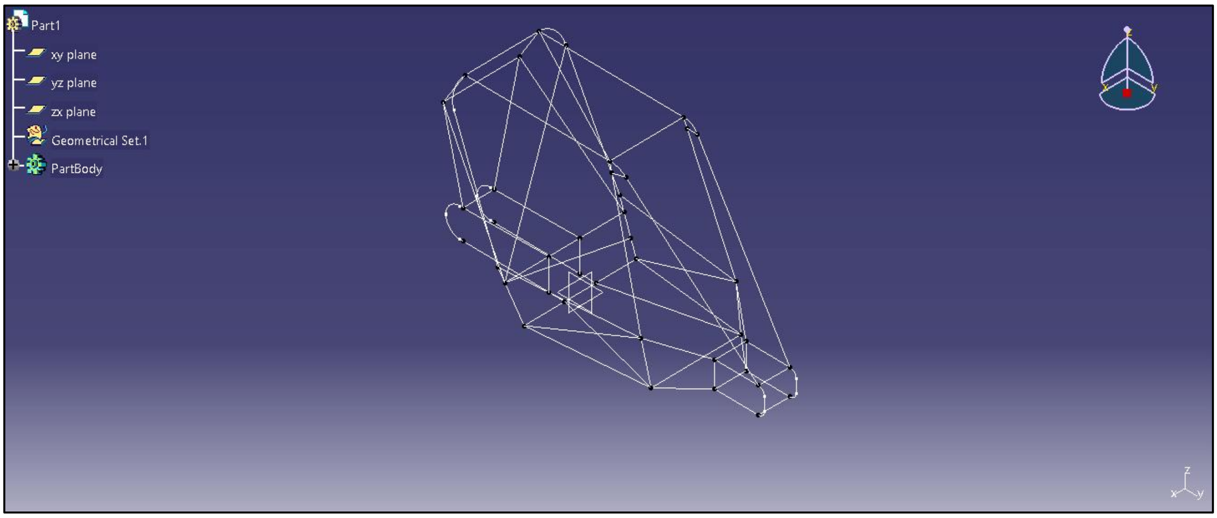
5. DESIGN SPECIFICATIONS

Sl.NO.	PARAMETER	VALUE
1	Pipe outer diameter	25 mm
2	Thickness	3.00 mm
3	Material	4340 steel, Glass epoxy, Carbon epoxy

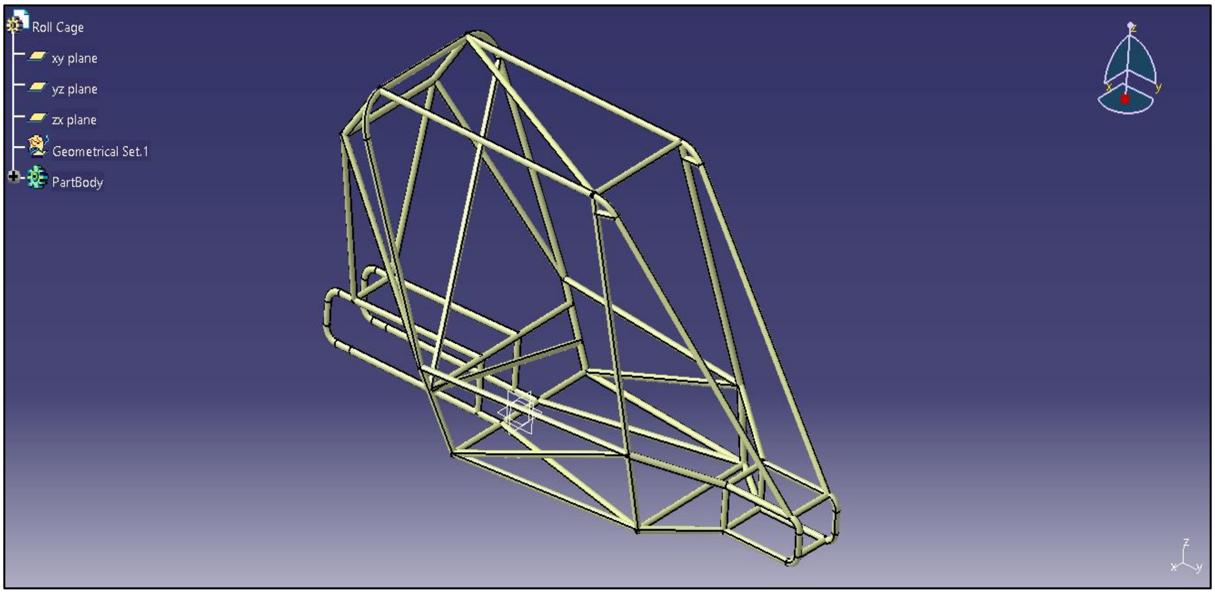
6. DESIGN OF ROLL CAGE STRUCTURE USING CATIA

DESIGN OF ROLL CAGE:

Geometric configuration of the roll cage: The roll cage is considered in the current study. The diameter of tubes is 25mm and wall thickness of 3 mm. Geometric modeling is carried out by using CATIA software.



Isometric View of the Roll Cage



7. FINITE ELEMENT METHOD

The basic idea in the Finite Element Method is to find the solution of complicated problems with relatively easy way. The Finite Element Method has been a powerful tool for the numerical solution of a wide range of engineering problems. Applications range from deformation and stress analysis of automotive, aircraft, building, defence, and missile and bridge structures to the field of analysis of dynamics, stability, fracture mechanics, heat flux, fluid flow, magnetic flux, seepage, and other flow problems.

To predict the behaviour of structure the designer adopts three tools such as analytical, experimental and numerical methods. The analytical method is used for the regular sections of known geometric entities or primitives where the component geometry is expressed mathematically.

In recent years, structural optimization has been combined with finite element analysis to determine component gauges that may minimize weight subject to a number of constraints. Such tools are becoming very useful and there are many examples of substantial weight reduction using these methods.

The Finite Element Method is used to solve physical problems in engineering analysis and design. The physical problems typically involve an actual structure component subjected to certain loads. The idealization of the physical problem to a mathematical model requires certain assumptions that together lead to differential equations governing the mathematical model.

The Finite Element Analysis solves the mathematical model, which describes the physical problem. The FEM (Finite Element Method) is a numerical procedure; it is necessary to assess the solution accuracy. If the accuracy criteria are not met, the numerical solution has to be repeated with refined solution parameters until a sufficient accuracy is reached. It is clear that the Finite Element solution will solve selected mathematical model with all the assumptions, which reflects on the predicted response.

The approximate selection of mathematical model will influence the accuracy of the solution. The mathematical model is solved and checked for the accuracy then refinement is made if required. Depending upon the level of accuracy, the optimization of section or shape is performed by linking the optimization techniques with Finite Element Method.

There are three basic steps involved in this procedure

1. Pre Processor (Building the model (or) Modeling)
2. Solution (Applying loads and solving)
3. Post Processor (Reviewing the results)

8. RESULTS AND DISCUSSION

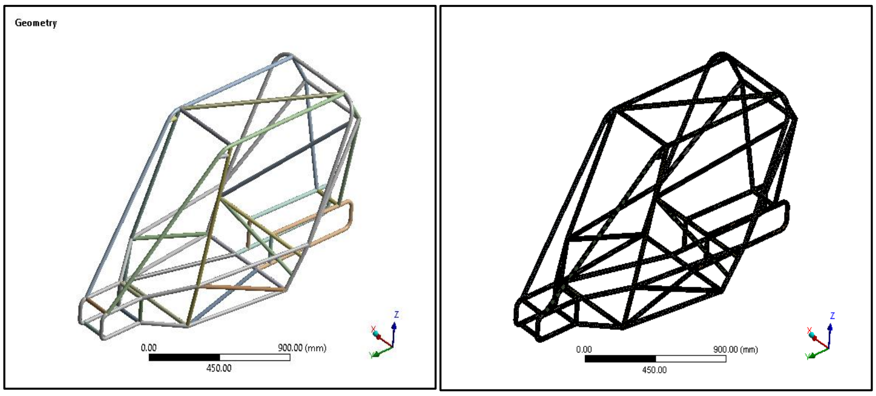
8.1 FORCE ESTIMATION FOR LOADING CONDITION

Total mass of the vehicle is considered as 400 kg which includes self weight and all other weights. The static impact analysis, Deceleration of 4G"s was assumed for the loading which is equivalent to a static force of 16000 N load on the vehicle, assuming the weight of the vehicle is 400 kg.

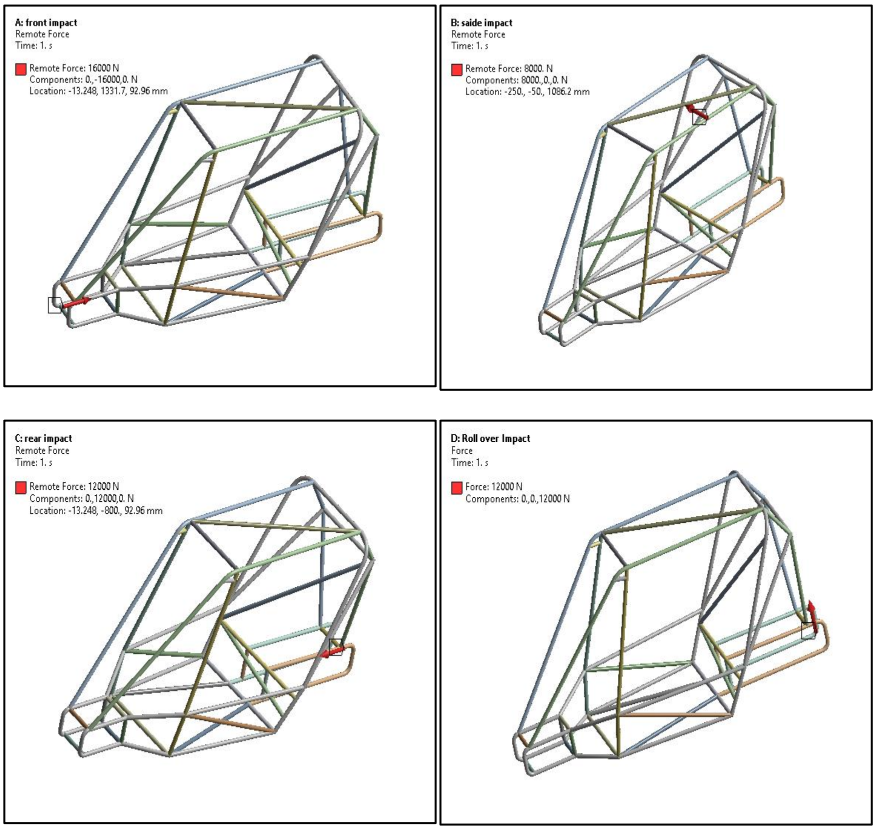
Force, F = mass*acceleration = 4mg = 400*4*10 = 16000 N

We apply a 16000 N from the front for the test of front impact of the roll cage structure of the vehicle for determining the strength at the time of front collision. Similarly, 2G force of 8000N is applied for side impact and, 3G force of 12000N is applied for rear impact and roll over impact. Front, side, rear, and roll over impact analysis is applied for steel and composite material

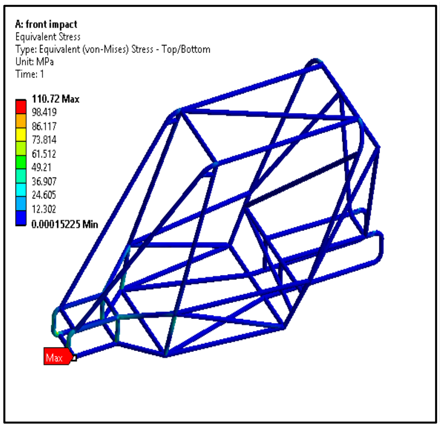
8.2 GEOMETRY OF THE ROLL CAGE & FINITE ELEMENT MODEL

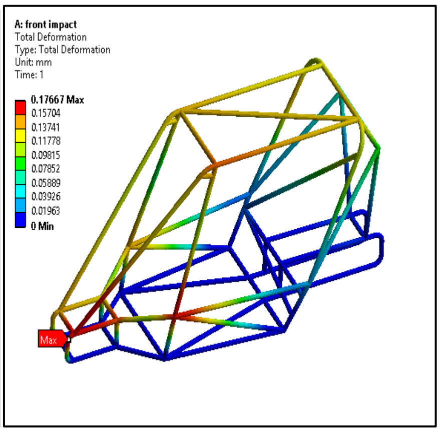


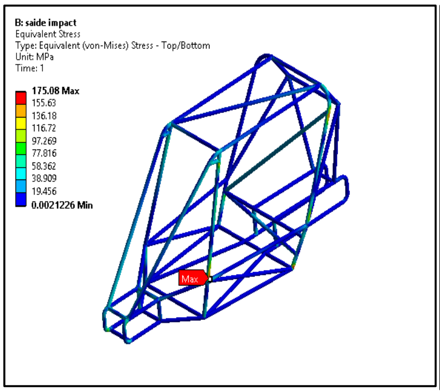
8.3 BOUNDARY CONDITIONS

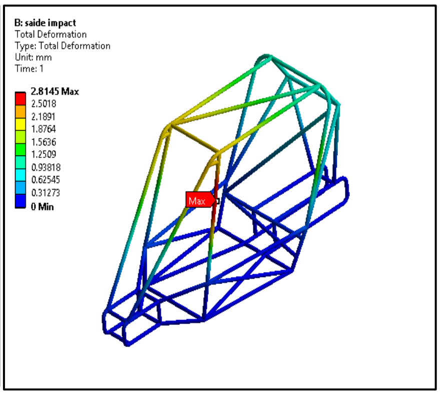


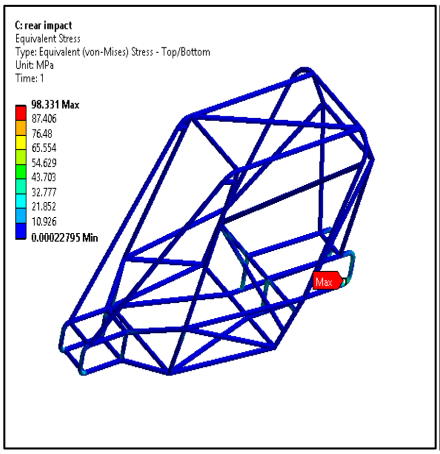
8.4 EQUIVALENT STRESS AND TOTAL DEFORMATION OF STEEL UNDER DIFFERENT IMPACT

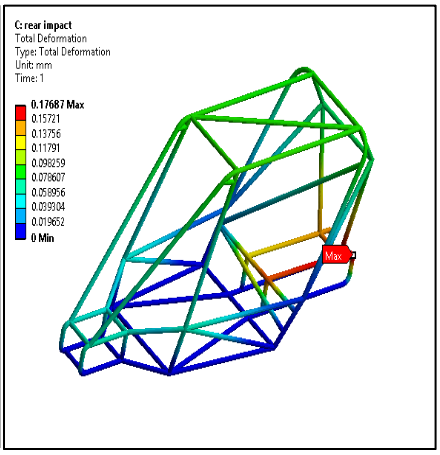


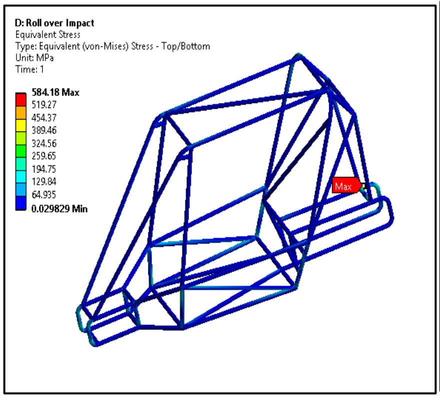


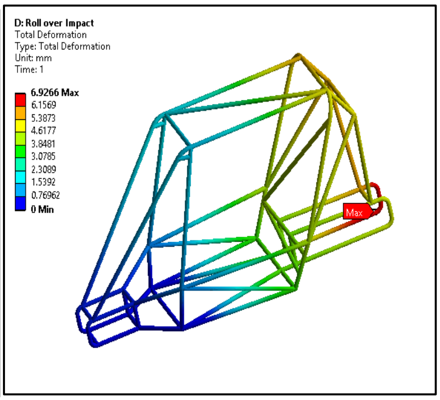








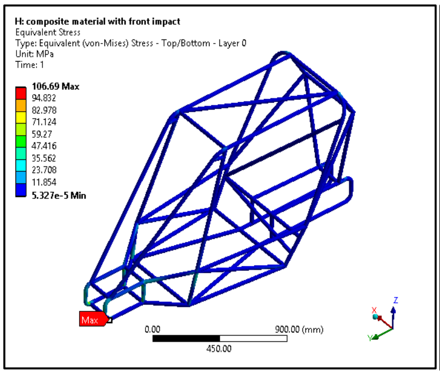


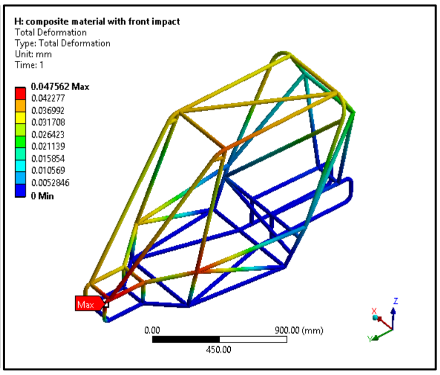


IMPACT ANALYSIS FOR STEEL		
IMPACT	MAXIMUM VON-MISES STRESS (Mpa)	DEFORMATION (mm)
FRONT	110.72	0.17667
SIDE	175.08	2.8145
REAR	98.331	0.17687
ROLL OVER	584.18	6.9266

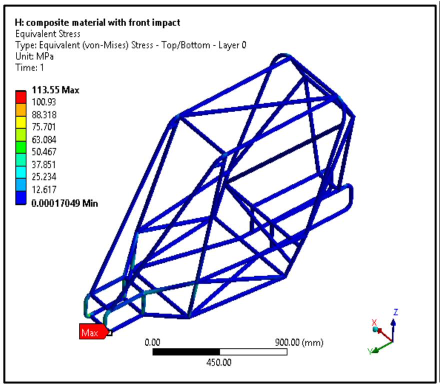
8.5 FRONT IMPACT ANALYSIS FOR GLASS EPOXY

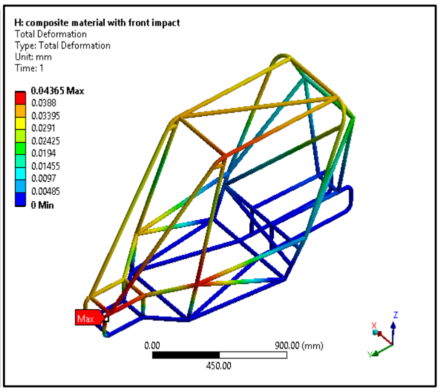
GLASS EPOXY AT 0^0 DEGREE



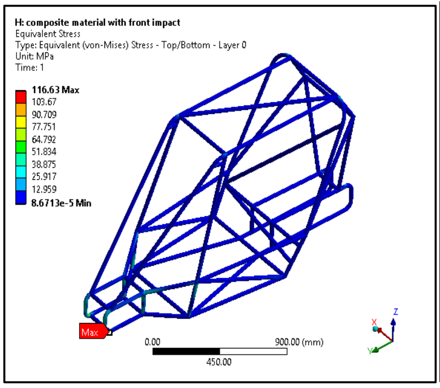


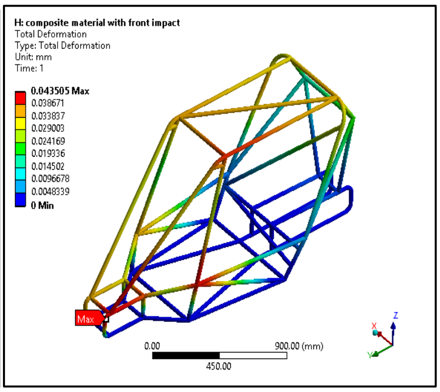
GLASS EPOXY AT 30^0 DEGREE



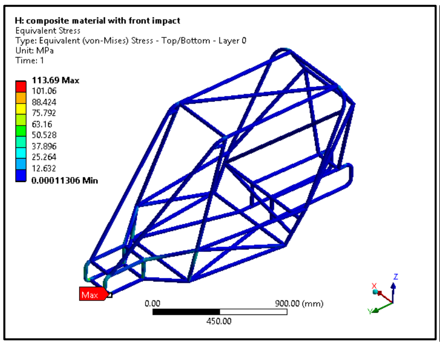


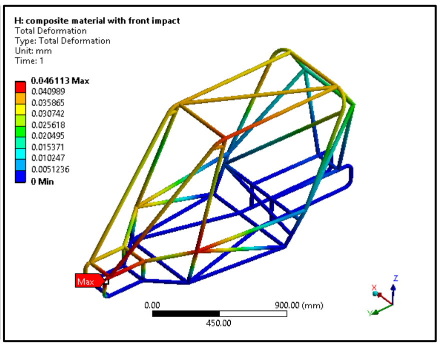
GLASS EPOXY AT 45^0 DEGREE



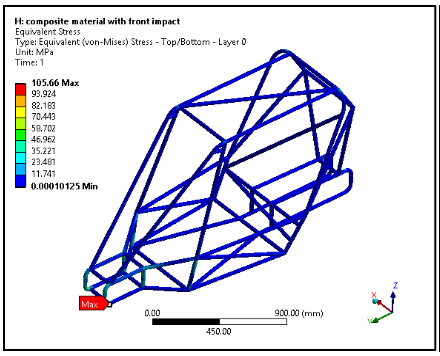


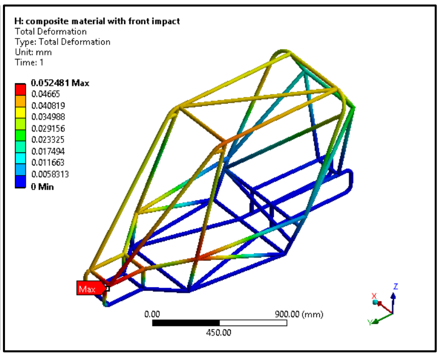
GLASS EPOXY AT 60⁰ DEGREE





GLASS EPOXY AT 90⁰ DEGREE

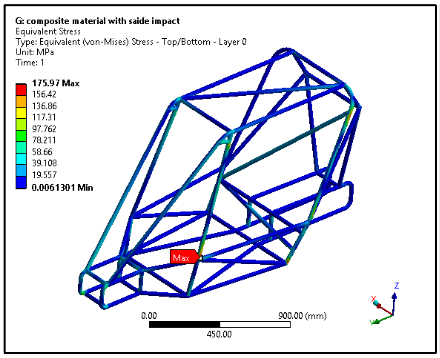


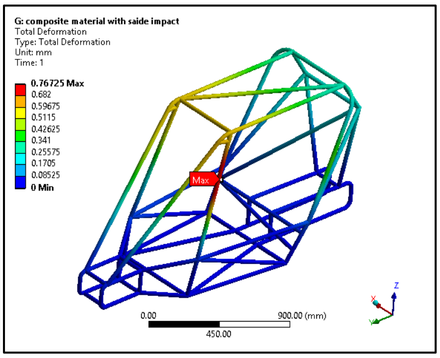


FRONT IMPACT ANALYSIS FOR GLASS EPOXY		
ANGLE OF ORIENTATION (DEG)	MAXIMUM VON-MISES STRESS (Mpa)	DEFORMATION (mm)
0	106.69	0.047562
30	113.55	0.045365
45	116.63	0.043505
60	113.69	0.046113
90	105.66	0.052481

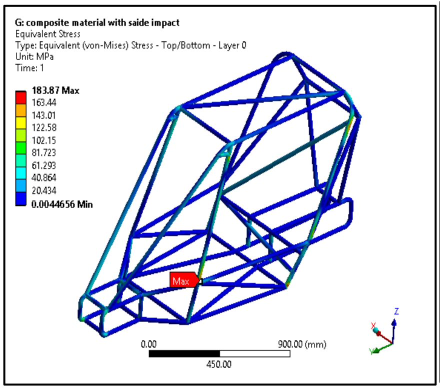
8.6 SIDE IMPACT ANALYSIS FOR GLASS EPOXY

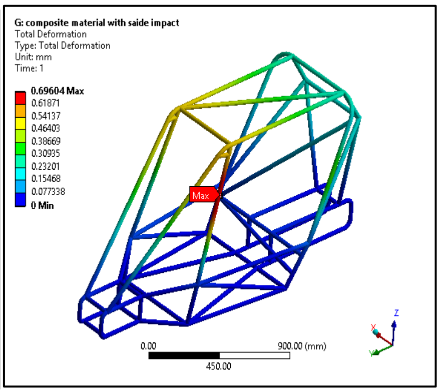
GLASS EPOXY AT 0⁰ DEGREE



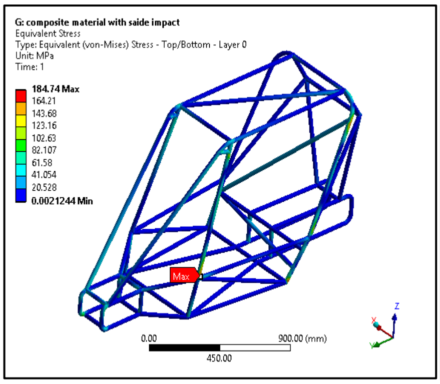


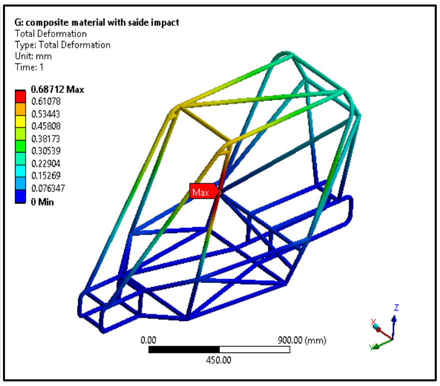
GLASS EPOXY AT 30^0 DEGREE



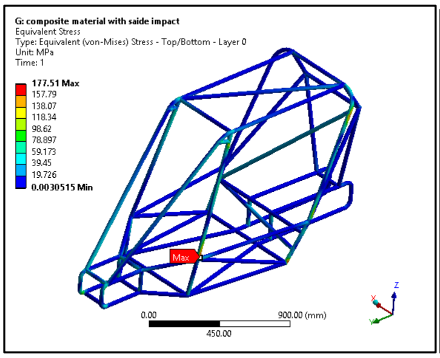


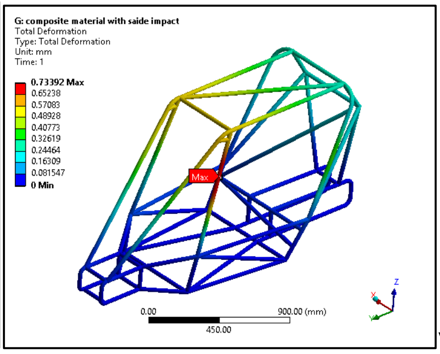
GLASS EPOXY AT 45^0 DEGREE



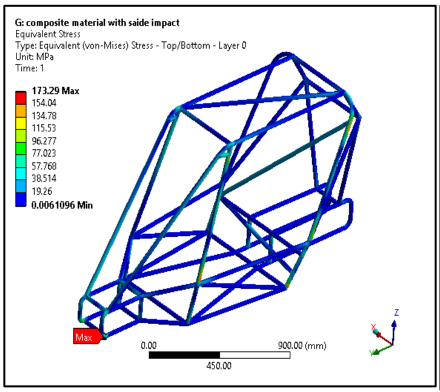


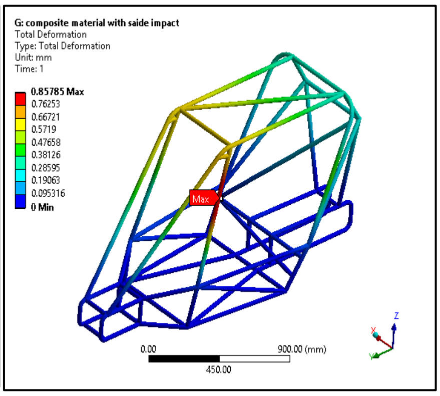
GLASS EPOXY AT 60^0 DEGREE





GLASS EPOXY AT 90^0 DEGREE

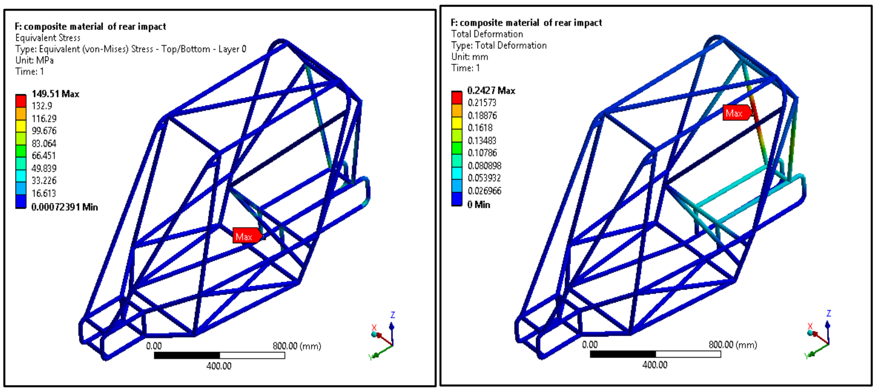




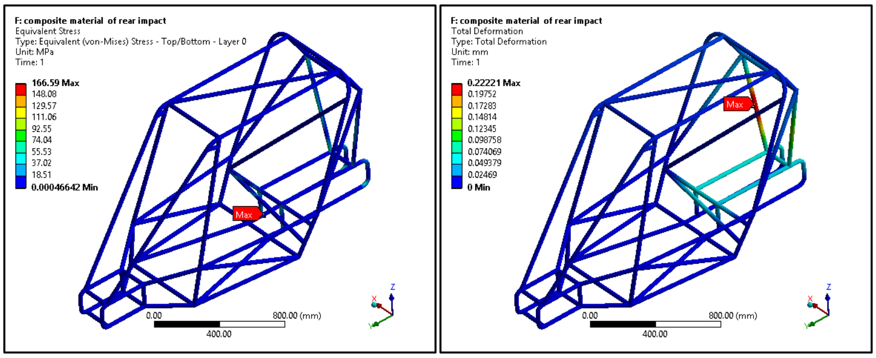
SIDE IMPACT ANALYSIS FOR GLASS EPOXY		
ANGLE OF ORIENTATION (DEG)	MAXIMUM VON-MISES STRESS (Mpa)	DEFORMATION (mm)
0	175.97	0.76725
30	183.87	0.69604
45	184.74	0.68712
60	177.51	0.73392
90	173.29	0.85785

8.7 REAR IMPACT ANALYSIS FOR GLASS EPOXY

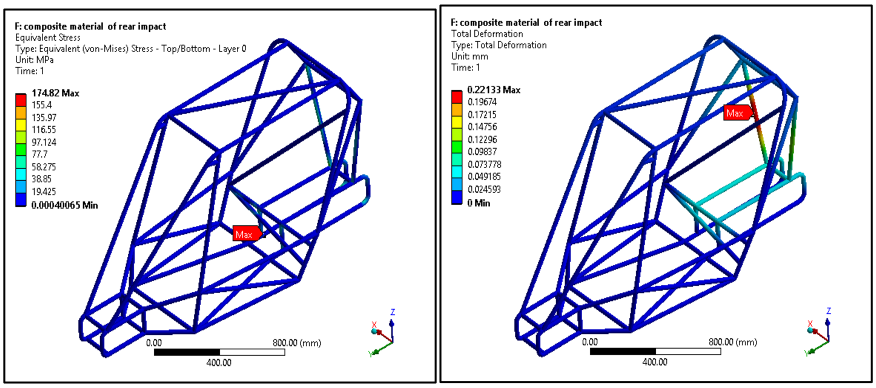
GLASS EPOXY AT 0^0 DEGREE



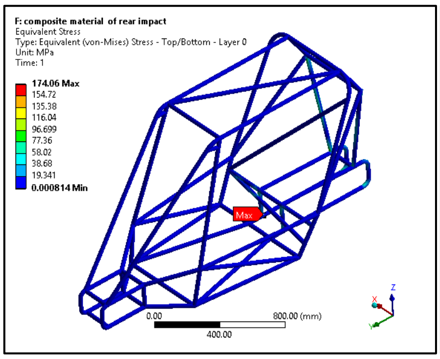
GLASS EPOXY AT 30^0 DEGREE

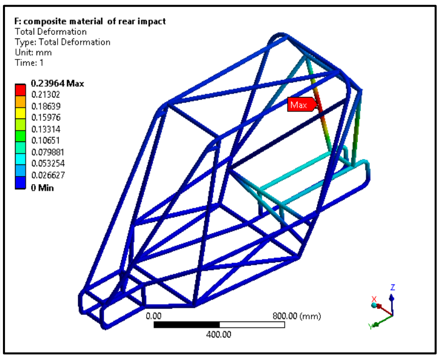


GLASS EPOXY AT 45^0 DEGREE

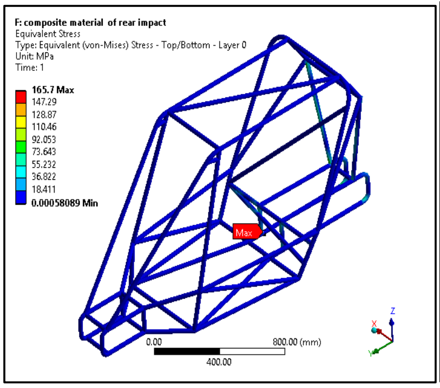


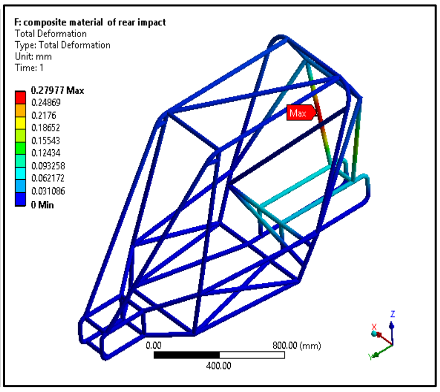
GLASS EPOXY AT 60⁰ DEGREE





GLASS EPOXY AT 90⁰ DEGREE

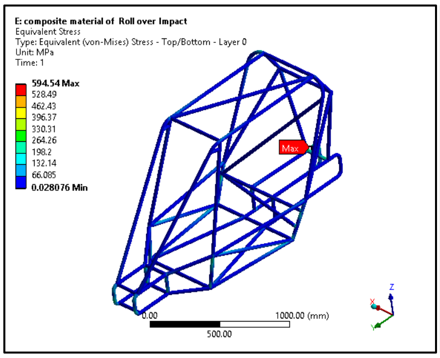


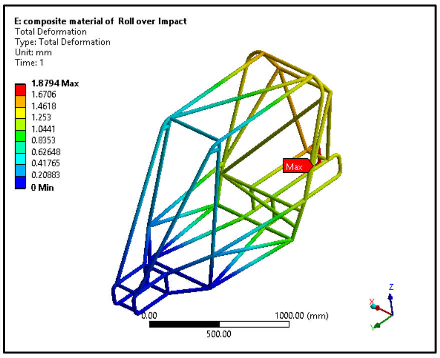


REAR IMPACT ANALYSIS FOR GLASS EPOXY		
ANGLE OF ORIENTATION (DEG)	MAXIMUM VON-MISES STRESS (Mpa)	DEFORMATION (mm)
0	149.51	0.2427
30	166.59	0.22221
45	174.82	0.22133
60	174.06	0.23964
90	165.7	0.27977

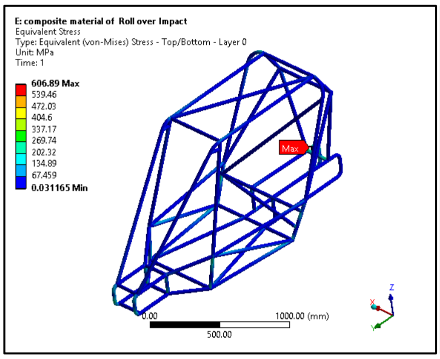
8.8 ROLL OVER IMPACT ANALYSIS FOR GLASS EPOXY

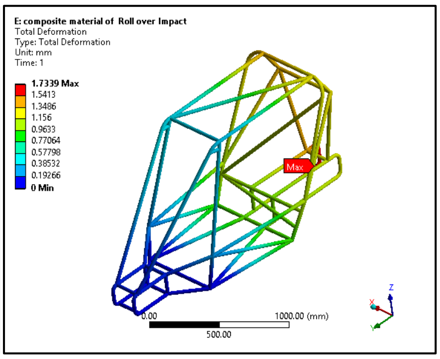
GLASS EPOXY AT 0⁰ DEGREE



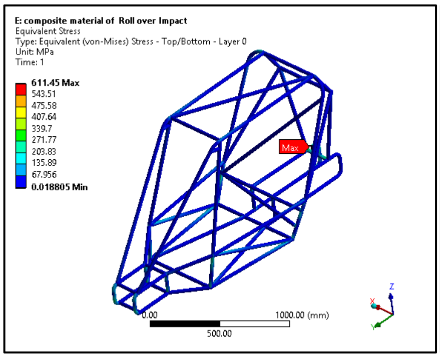


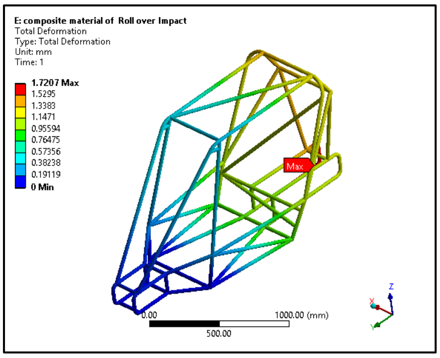
GLASS EPOXY AT 30⁰ DEGREE



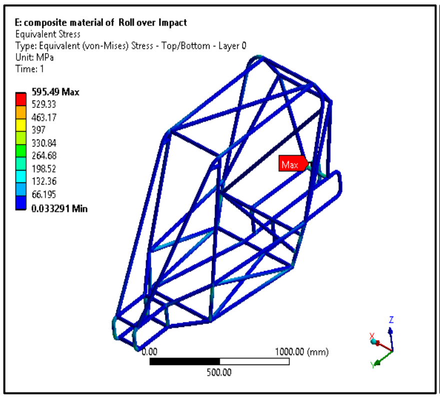


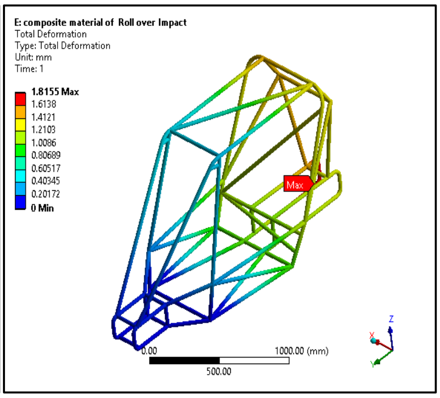
GLASS EPOXY AT 45⁰ DEGREE



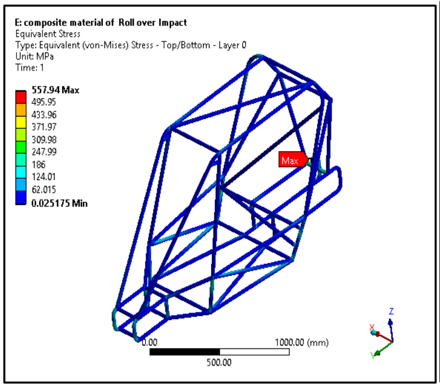


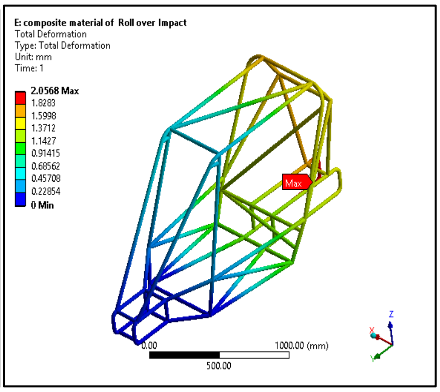
GLASS EPOXY AT 60⁰ DEGREE





GLASS EPOXY AT 90⁰ DEGREE

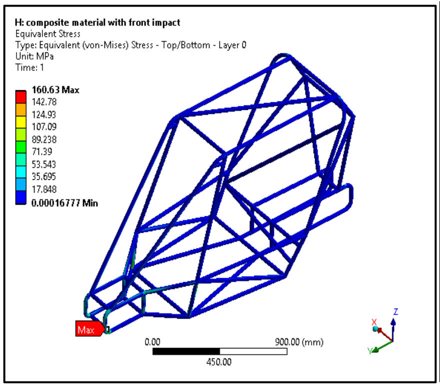


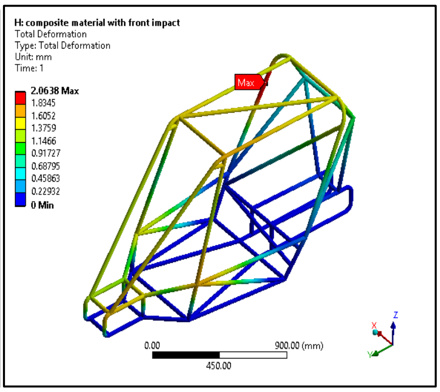


ROLL OVER IMPACT ANALYSIS FOR GLASS EPOXY		
ANGLE OF ORIENTATION (DEG)	MAXIMUM VON-MISES STRESS (Mpa)	DEFORMATION (mm)
0	594.54	1.8794
30	606.89	1.7339
45	611.45	1.7207
60	595.49	1.8155
90	557.94	2.0568

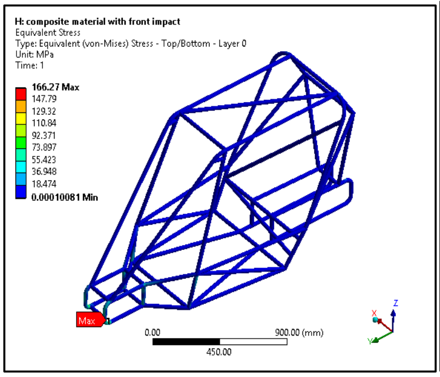
8.9 FRONT IMPACT ANALYSIS FOR CARBON EPOXY

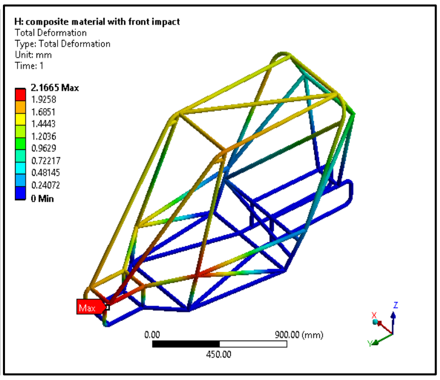
CARBON EPOXY AT 0^0 DEGREE



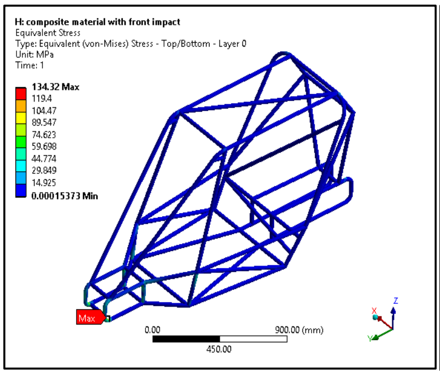


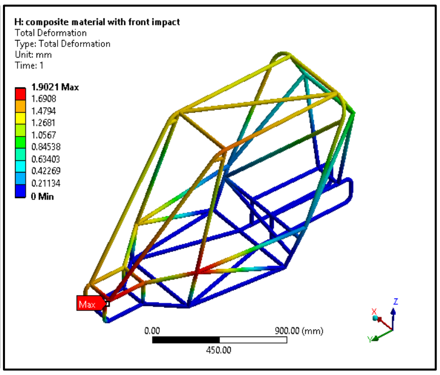
CARBON EPOXY AT 30^0 DEGREE



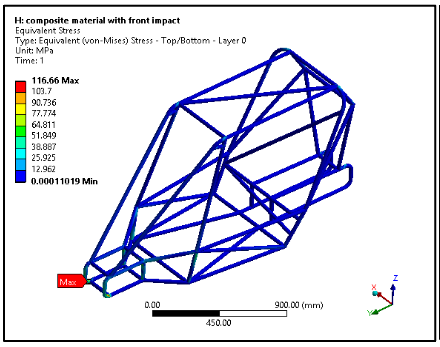


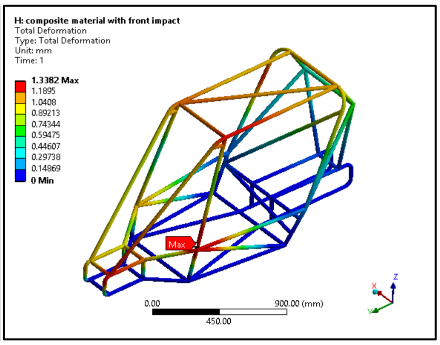
CARBON EPOXY AT 45^0 DEGREE



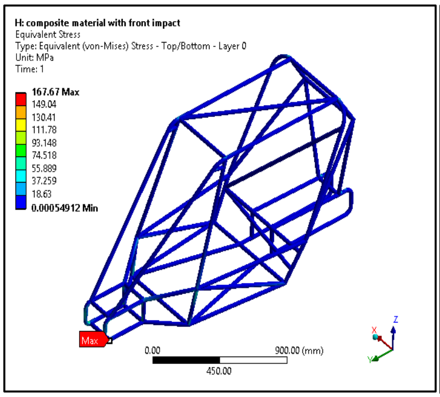


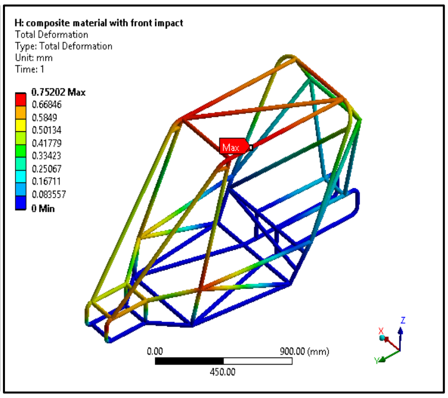
CARBON EPOXY AT 60⁰ DEGREE





CARBON EPOXY AT 90⁰ DEGREE

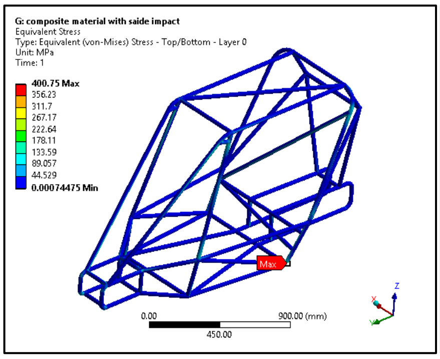


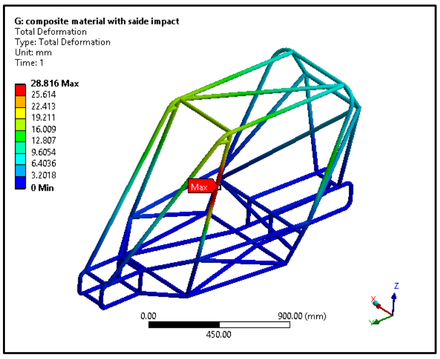


FRONT IMPACT ANALYSIS FOR CARBON EPOXY		
ANGLE OF ORIENTATION (DEG)	MAXIMUM VON-MISES STRESS (Mpa)	DEFORMATION (mm)
0	160.63	2.0638
30	166.27	2.1665
45	134.32	1.9021
60	116.66	1.3382
90	167.67	0.75202

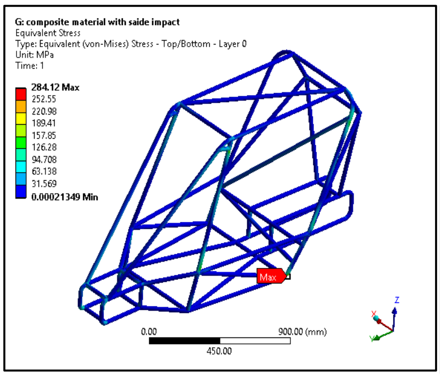
8.10 SIDE IMPACT ANALYSIS FOR CARBON EPOXY

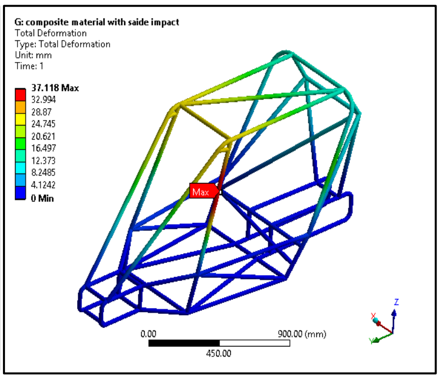
CARBON EPOXY AT 0⁰ DEGREE



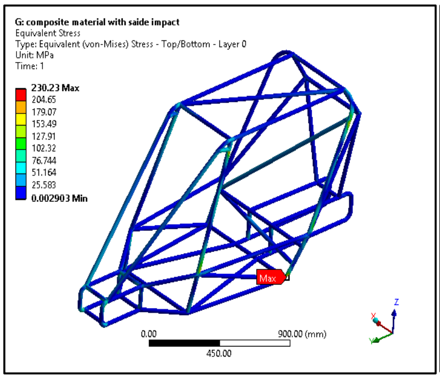


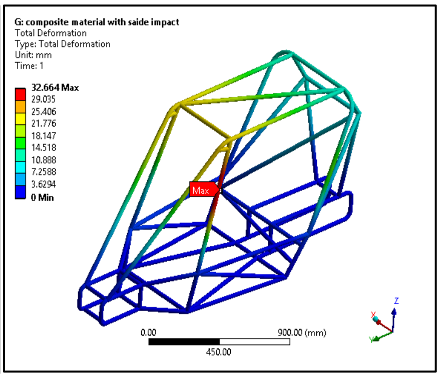
CARBON EPOXY AT 30⁰ DEGREE



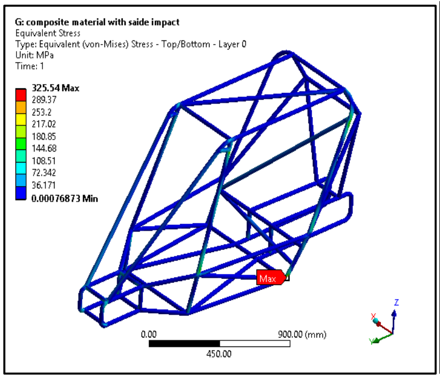


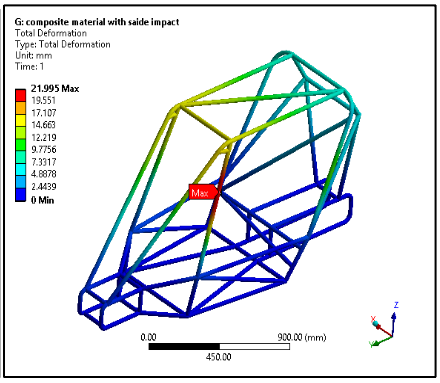
CARBON EPOXY AT 45⁰ DEGREE



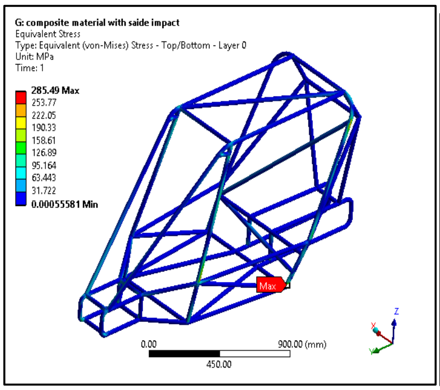


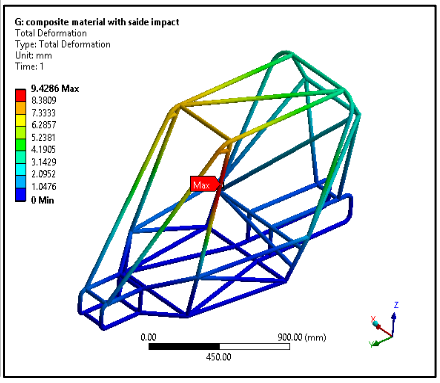
CARBON EPOXY AT 60⁰ DEGREE





CARBON EPOXY AT 90⁰ DEGREE

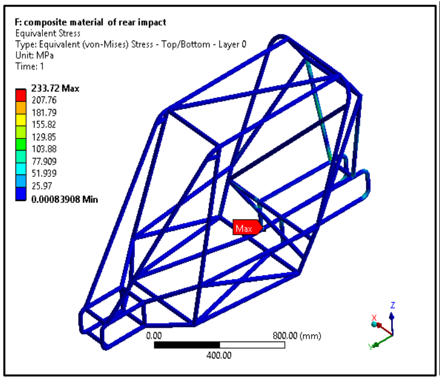


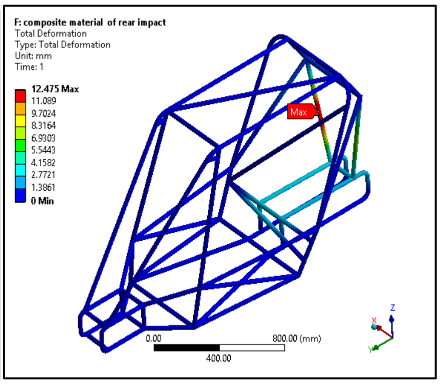


SIDE IMPACT ANALYSIS FOR CARBON EPOXY		
ANGLE OF ORIENTATION (DEG)	MAXIMUM VON-MISES STRESS (Mpa)	DEFORMATION (mm)
0	400.75	28.816
30	284.12	37.118
45	230.23	32.664
60	325.54	21.995
90	285.49	9.4286

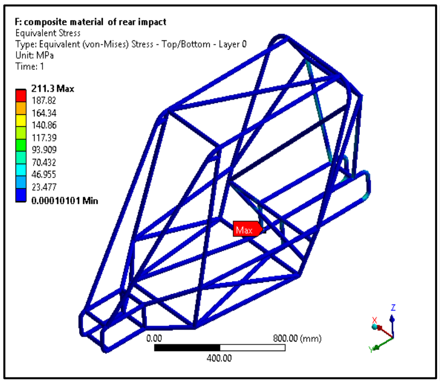
8.11 REAR IMPACT ANALYSIS FOR CARBON EPOXY

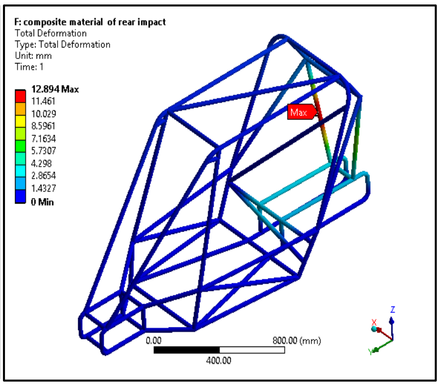
CARBON EPOXY AT 0^0 DEGREE



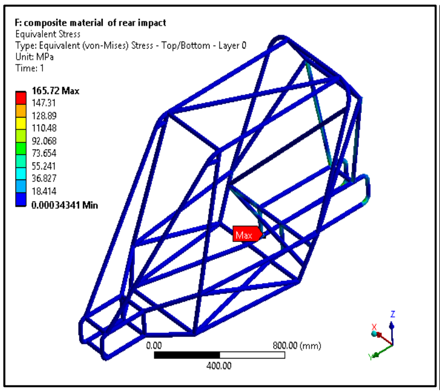


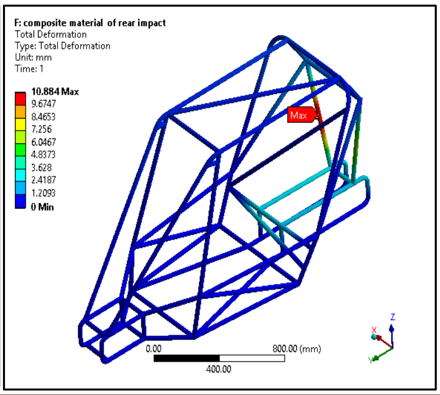
CARBON EPOXY AT 30^0 DEGREE



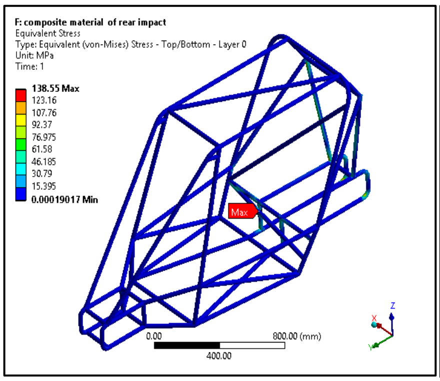


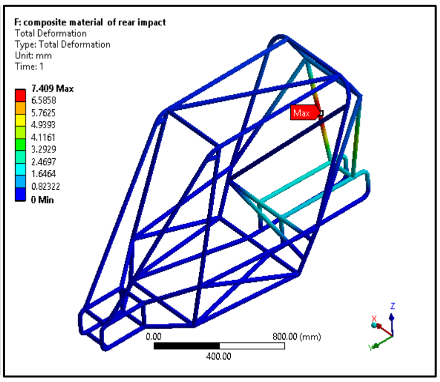
CARBON EPOXY AT 45^0 DEGREE



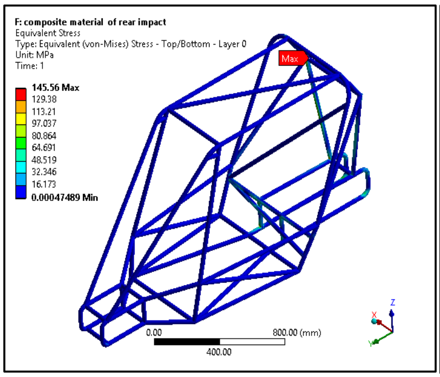


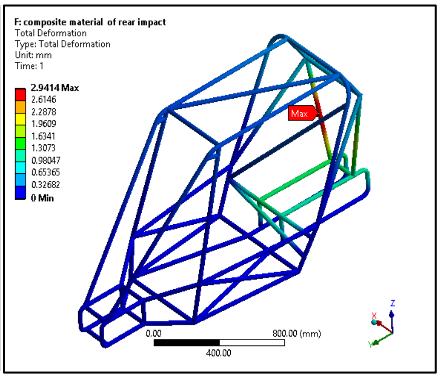
CARBON EPOXY AT 60⁰ DEGREE





CARBON EPOXY AT 90⁰ DEGREE

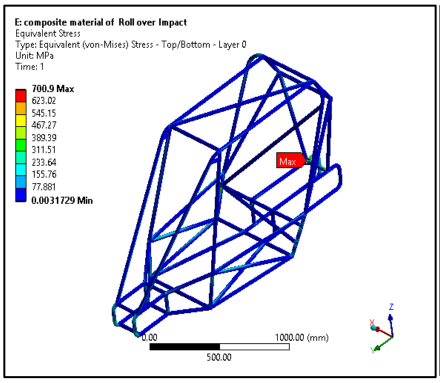


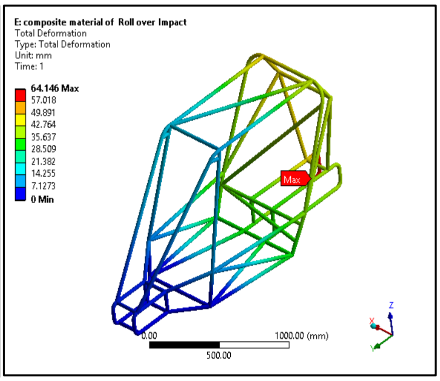


REAR IMPACT ANALYSIS FOR CARBON EPOXY		
ANGLE OF ORIENTATION (DEG)	MAXIMUM VON-MISES STRESS (Mpa)	DEFORMATION (mm)
0	233.72	12.475
30	211.3	12.894
45	165.72	10.884
60	138.55	7.409
90	145.56	2.9414

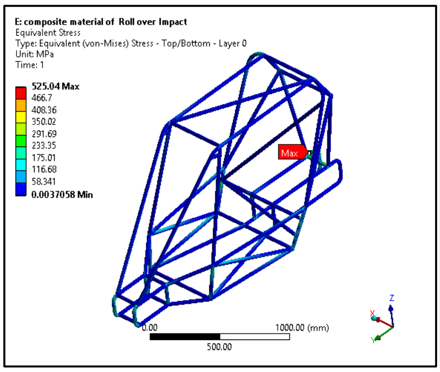
8.12 ROLL OVER IMPACT ANALYSIS FOR CARBON EPOXY

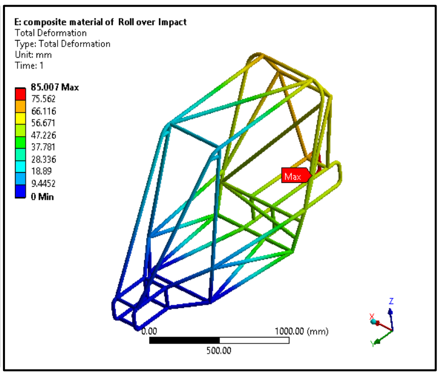
CARBON EPOXY AT 0⁰ DEGREE



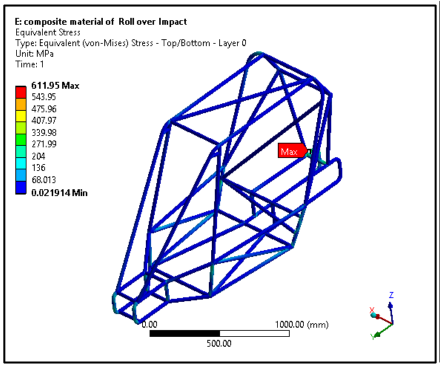


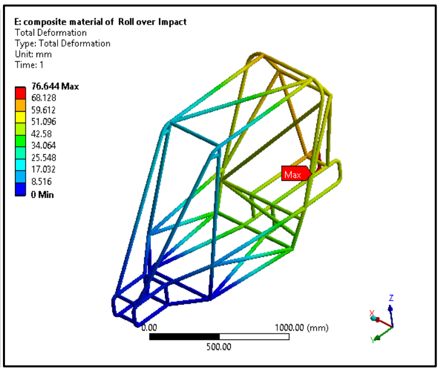
CARBON EPOXY AT 30⁰ DEGREE



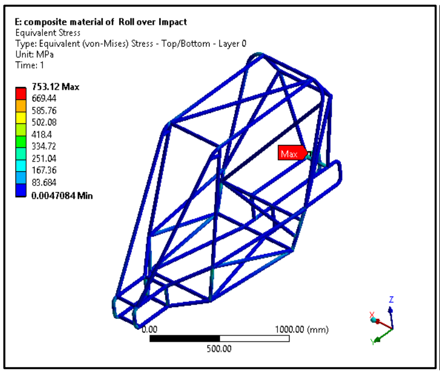


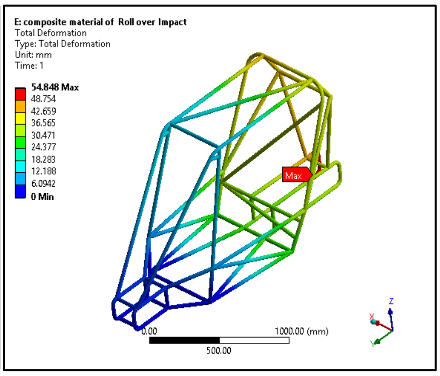
CARBON EPOXY AT 45⁰ DEGREE



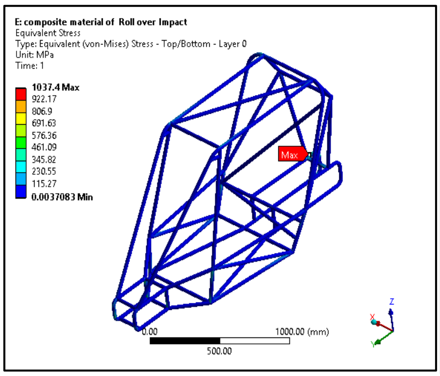


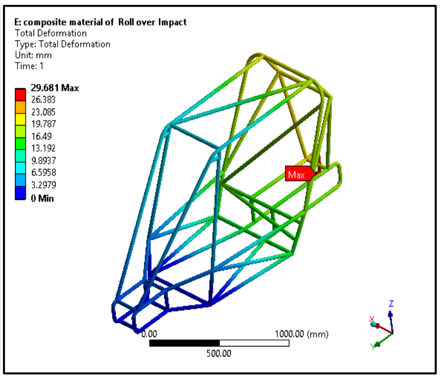
CARBON EPOXY AT 60⁰ DEGREE





CARBON EPOXY AT 90⁰ DEGREE





ROLL OVER IMPACT ANALYSIS FOR CARBON EPOXY		
ANGLE OF ORIENTATION (DEG)	MAXIMUM VON-MISES STRESS (Mpa)	DEFORMATION (mm)
0	700.9	64.146
30	525.04	85.007
45	611.95	76.644
60	753.12	54.848
90	1037.4	29.681

9. CONCLUSIONS

1) The von Mises stress diagram represents the stress in individual member during the applied load. From the solution of analysis we found that the maximum von Mises stress are developed for roll over impact analysis, which is much less than its yield strength. The maximum total displacement is also within the permissible limits of the material Steel and Glass Epoxy. For Carbon Epoxy, total deformations are more.

2) Among all the impact analysis in steel, Glass Epoxy and Carbon Epoxy, the roll over case is having the highest stress and deformation. So for design purpose we considered these values i.e. 584.18 Mpa for steel, 611.45 Mpa for glass epoxy and 1037.4 Mpa for carbon epoxy.

   The Factor of safety for steel is 1.27529
   The Factor of safety for Glass Epoxy is 2.8620
   The Factor of safety for Carbon Epoxy is 2.120686

   As factor of Safety for automobiles goes up to 8, hence the design is safe against specified stresses.

3) The weight of the designed steel roll cage is 62.915kg, Glass Epoxy roll cage is 16.818kg and Carbon epoxy roll cage is 12.013. This shows the weight of the Glass Epoxy roll cage is one fourth the steel roll cage and Carbon Epoxy roll cage is one fifth the steel roll cage. Therefore light weight with high strength is achieved for composite material.

   The finite element method is an efficient technique in analyzing stresses. After material optimization the structure is substituted to static conditions by comparing results, the modified design shows Glass Epoxy has given best results compared to other material.

   The Value result of Von-Misses Stresses from the analysis is far than material yield stress so the design is safe. The results suggest a good comparative material with that of current industrial material i.e. Glass Epoxy gives better results to that of other materials. The factor of safety for glass epoxy is higher.

10. REFERENCES

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