Designing of All Terrain Eco-Green Vehicle (ATV)

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***Abstract*—*This paper provides an in-detail description of the design considerations, static & dynamic analysis and mathematical data involved in the design of an ELECTRIC MOTOR POWERED ALL TERRAIN VEHICLES (ATV). The main objective of this paper is to reduce the weight of the electric powered vehicles and to design a vehicle which works efficiently in the emerging electric vehicle sector. In order to maintain the speed levels of the vehicle, seamless decision were made in motor selection. The main focus had been laid on the simplicity of the design, high performance, easy maintenance and safety at a very affordable price. The design and development comprise of material selection, chassis and frame design, cross section determination, determining strength requirements of roll cage, stress analysis and simulations to test the ATV against failure [1]. During the entire design process, consumer interest through innovative, inexpensive, and effective methods was always the priority. Most of the components have been chosen based on their easy availability and reliability. According to recognition of customer's need the vehicle is designed to be ergonomic, aerodynamic, highly engineered and easily manufactured. Hence, it makes the vehicle more efficient. This vehicle can navigate through almost all terrains, which ultimately is the main purpose behind the making of any all-terrain vehicle [5].*

This report tries to summarize the steps taken in finalizing the design and analysis of the all-terrain vehicle (ATV) in a nutshell.

Keywords—*All Terrain Vehicle, Modelling, FEA, Roll cage, Strength, Stiffness, Impact loads.*

I. Introduction

The aim of the study is to determine the best design for the new age of eco-green vehicles that would provide maximum efficiency in consideration of fuel utilization and to develop the roll cage for All-Terrain Vehicle. The material used for the roll cage is selected based on strength, cost and availability. A software model is prepared in SOLID-WORKS software and CATIA software. Later the design is tested against all modes of failure by conducting various simulations and stress analysis with the aid of ANSYS Software (14). Based on the result obtained from these tests the design is modified accordingly. After successfully designing the roll cage, it is ready for the fabrication. As weight is the critical aspect in a vehicle which is powered by a small electric motor, balance must be found between the strength and weight of the design. This design is both cost efficient and has a good strength [1, 2]. The chassis is the component in charge of supporting all other vehicle's subsystems and also to safeguard the driver at all time. The chassis design needs to be prepared for impacts that take place in any certain crash or rollover. Thus, the design of chassis plays a vital role in the designing of an ATV.

II. Design Methodologies

A. Main design focus-

The main design of the vehicle is focused on lighter and more rigid and ascetics oriented frame, robust suspension design and a more versatile drive train. In addition, the design of steering and braking with high safety and precision was aimed at. It is also necessary to keep weight of the roll cage as low as possible to achieve better acceleration and it is also important to maintain the Centre of gravity of the as low as possible to avoid toppling. [3] Mounting heavier components such as engine, driver seat etc., directly on chassis is one way of achieving low Centre of gravity.

B. Frame Design-

The objective of the chassis is to encapsulate all components of the car, including a driver, efficiently and safely. Principal aspects of the chassis is focused during the design and implementation which includes driver safety, suspension and drive train integration, structural rigidity, weight, and operator ergonomics.

The number one priority in the chassis design was driver safety.

C. Design Considerations-

The goals for the roll cage design include [2]:

- Increase comfort for the driver.
- Decreased weight, and overall length.
- Improved packaging for subsystems.
- Aesthetic considerations.
- Attractive design.
- Durable.
- Lower C.G value.

Material Selection: Material selection is one of the key factors in designing the frame of the ATV as it is the measure of safety, reliability, performance and strength of the roll cage. To ensure that the optimal material is chosen, extensive research was carried out and the results were compared with materials from multiple categories [3]. Since safety of driver is paramount to us, the roll cage is required to have adequate factor of safety even in worst case scenario. The strategy behind selecting the material for roll cage was to achieve maximum welding area, good bending stiffness, minimum weight and maximum strength for the pipes. So after market analysis on cost, availability and properties of many materials it is concluded that using either AISI 1018 or AISI 4130 are the best options. Among these materials AISI 4130 is chosen due to the following reasons which were observed from the comparison table as shown in *Table 1* [6]:

Table 1: Material Comparison Chart.

Material	1018 steel	4130 steel
outside diameter	2.54cm	3.175cm
wall thickness	0.304cm	0.165cm
bending stiffness	3791.1N/m^2	3635.1 N/m^2
bending strength	391.3N-m	487N-m
Weight perimeter	1.686kg	1.229kg
young's modulus	205Gpa	190-210Gpa
poisons ratio	0.29	0.27-0.30
carbon content	0.14-0.2	0.28-0.33
Tensile yield strength	365 MPa	460 MPa

D. Size Specifications of Material-

In order to reduce the weight of the roll cage, different sizes of the tubes were considered in.

- Primary tubes:

Normalized Al-Si4130 Chrome-Moly Steel.

Outer diameter—31.75mm
Wall thickness—1.65mm

- Secondary tubes:
  Outer diameter—25.4mm
  Wall thickness—1.65mm

E. Design Stage:

A number of models of the roll cage were designed and modified to reach the design considerations. The frame was designed using CATIA and SOLIDWORKS packages and analysis was performed in ANSYS.
The main steps to be followed while designing the frame of the vehicle are:

- Proper clearances must be maintained between the driver and the frame by taking the measurements of the common driver dimensions.
- Wheel base and track width must be fixed initially before designing the roll cage.
- Proper leg room must be provided.

F. Bending strength & stiffness calculation:

The bending strength of a material is given by the bending moment equation [4].

$$\frac{M}{I}=\frac{\sigma}{Y}=\frac{E}{R}$$

Where
M is the bending moment/strength
I is the moment of inertia
σ is the bending stress
Y is the distance from the neutral axis
E is the young's modulus.
From the above bending moment equation

$$M=\frac{\sigma * I}{Y}$$

Where I Is the moment of inertia is given by

$$I=\frac{\pi}{64}(D_0^4-D_i^4)$$

Similarly bending stiffness is given by the equation:

$$Bending\ stiffness = E * I$$

For AISI 1018:

1. ***For pipe 1 with given dimensions :-***

Outside diameter D_0 = 2.54 cm
Wall thickness (t) = 0.304 cm
Inner diameter $D_i = D_0 - 2t$
=2.54 – (2*0.304)
D_i = 1.932 cm.
Bending strength = 390456 N-mm.
Bending stiffness = 278.507*10^7 N-mm^2.

2. ***For pipe 2 with given dimensions*** :-

Outside diameter D_0 = 3.175 cm
Wall thickness (t) = 0.165 cm
Inner diameter $D_i = D_0 - 2t$

=3.175 – (2*0.165)

D_i= 2.845 cm.

Bending strength =407291.4 N-mm.

Bending stiffness = 363.144*10^7 N-mm^2.

3. ***For pipe 3 with given dimensions :-***

Outside diameter D_0 = 2.54 cm

Wall thickness (t) = 0.165 cm

Inner diameter $D_i = D_0 - 2t$

=2.54 – (2*0.165)

D_i = 2.21 cm.

Bending strength =250550.2 N-mm.

Bending stiffness = 178.714*10^7 N-mm^2.

FOR AISI 4130:

4. ***For pipe 1 with given dimensions :-***

Outside diameter D_0 = 2.54 cm

Wall thickness (t) = 0.304 cm

Inner diameter $D_i = D_0 - 2t$

=2.54 – (2*0.304)

D_i = 1.932 cm.

Bending strength = 492081.6 N-mm.

Bending stiffness =285.300*10^7 N-mm^2.

5. ***For pipe 2 with given dimensions :-***

Outside diameter D_0 = 3.175 cm

Wall thickness (t) = 0.165 cm

Inner diameter $D_i = D_0 - 2t$

=3.175 – (2*0.165)

D_i= 2.845 cm.

Bending strength = 513298.8 N-mm

Bending stiffness = 372.002*10^7 N-mm^2.

6. ***For pipe 3 with given dimensions :-***

Outside diameter D_0 = 2.54 cm

Wall thickness (t) = 0.165 cm

Inner diameter $D_i = D_0 - 2t$

=2.54 – (2*0.165)

D_i= 2.21cm.

Bending strength = 315761.9 N-mm.

Bending stiffness =183.073*10^7 N-mm^2.

From the above observations it is clear that the bending strength of the AISI 4130 is always greater than the AISI 1018 and the variation in the bending stiffness is very negligible and comparatively AISI 4130 is having higher bending stiffness. Based on above conclusion the material for the roll cage is chosen to be AISI 4130.

The shown **Figure 1**represents the variation of bending strength with that of thickness of the primary tube.

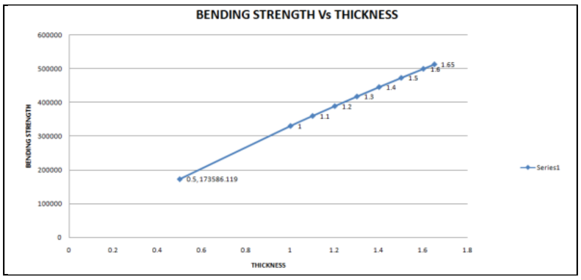

Figure 1: Variation of bending strength with thickness of tube.

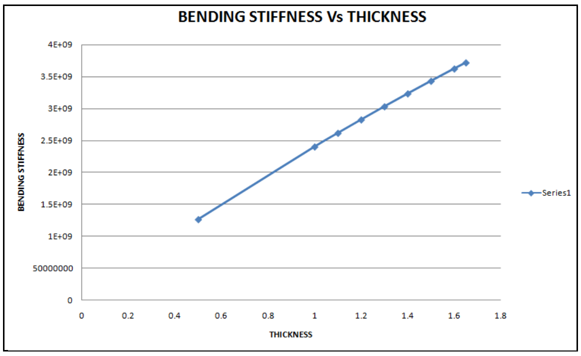

Figure 2: Variation of bending stiffness with thickness of primary tube.

The above shown Figure 2 represents the variation of bending stiffness with that of the thickness of the primary tube.

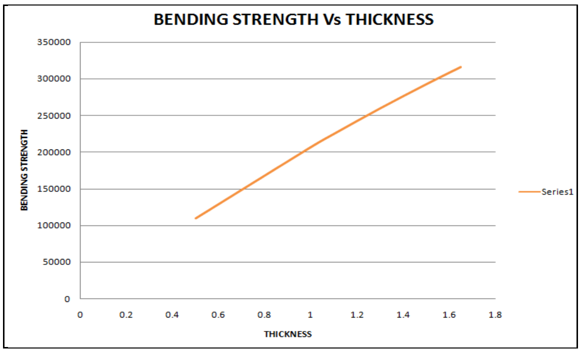

Figure 3: Bending strength versus thickness of secondary tube.

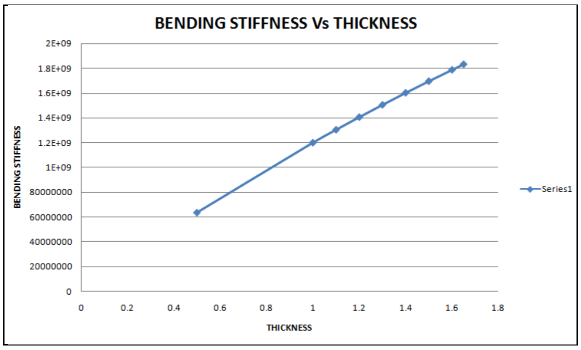

Figure 4: Bending stiffness versus thickness for secondary tube.

The above shown Figure 2 & Figure 4 represents the variation of bending strength and bending stiffness with that of the thickness of the secondary tube.

Thickness	Strength	Thickness	Stiffness
1.65	513298.8	1.65	3.72E+09
1.6	500134.8	1.6	3.62E+09
1.5	473388.5	1.5	3.43E+09
1.4	446078.2	1.4	3.23E+09
1.3	418196	1.3	3.03E+09
1.2	389733.9	1.2	2.82E+09
1.1	360684	1.1	2.61E+09
1	331038.2	1	2.4E+09
0.5	173586.1	0.5	1.26E+09

Table 2: Data for strength and stiffness versus thickness graphs for primary tube.

Thickness	Strength	Thickness	Stiffness
1.65	315761.9	1.65	1830732376
1.6	308037.1	1.6	1785945336
1.5	292271.2	1.5	1694537742
1.4	276077.4	1.4	1600648661
1.3	259447.9	1.3	1504233583
1.2	242374.9	1.2	1405247604
1.1	224850.7	1.1	1303645422
1	206867.4	1	119938131
0.5	109783.5	0.5	636505385

Table 3: Data for strength and stiffness versus thickness graphs for secondary tube.

The above shown Table 2 &Table 3 represents the mathematical data involved in the graphical representation of strength and stiffness versus thickness of primary and secondary tubes.

G. Geometry Creation:

The design was done using the CATIA and SOLIDWORKS software's. The model was made fully parametric. This means the features of the model will change according to any modifications to the parent features. The usage of parametric design was extremely important with this design. As so many factors interact in the design of the frame, the parametric properties allowed the change of a single part to automatically change the design of all parts interacting with it [4].
By fulfilling all the design considerations a 3D model was designed.

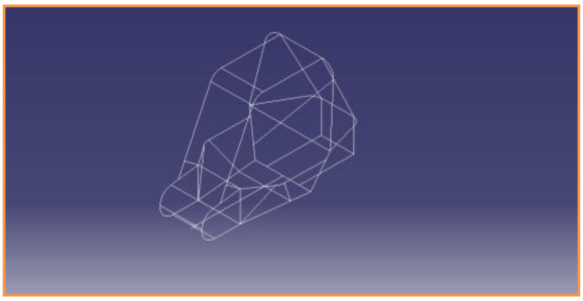

Figure 5: Wireframe model of the roll cage.

The above shown Figure 5 represents the wireframe model of the roll cage which is designed in CATIA software package.

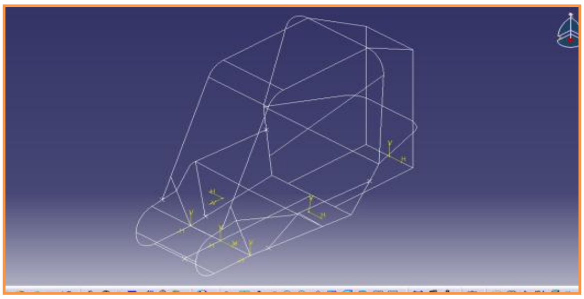

Figure 6: Modified wire frame of the roll cage.

The above shown Figure 6 represents the modified wireframe model of the roll cage which is designed in CATIA software package.

Figure 7: Fabricated roll cage.

The above shown Figure 7represents the manufactured model of the roll cage which is designed in CATIA software package.

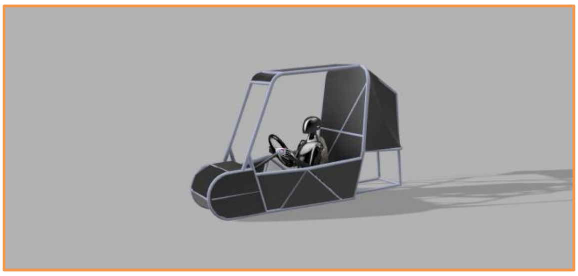

Figure 8: Roll cage model with the driver.

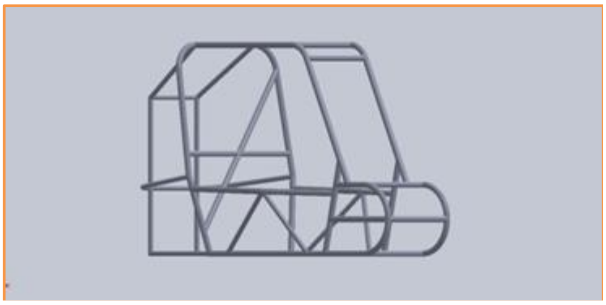

Figure 9: Roll cage with structural tubes.

The above shown Figure 8 &Figure 9 represents the structural model of the roll cage which is designed in SOLIDWORKS software package.

H. Roll Cage Design Specifications:

The various specifications of the roll cage are described in the below shown Table 4.

Type	Space Frame
Material	Normalized AISI 4130 Chrome-Moly. Steel
Mass of roll cage	34 kg
Length of roll cage	72 inch
Width of roll cage	35 inch
Height of roll cage	46 inch
Total length of pipes	130 feet
Weld joints	34
Number of bends	14
Cross section	Circular

Table 4: Roll cage specification.

III. Finite Element Analysis

Finite Element is a method for the approximate solution for differential equations that models the physical problems such as solution for elasticity problems, transient dynamic, steady state dynamic, i.e. subject to sinusoidal loading [6]. After completion of the design of roll cage, Finite Element Analysis (FEA) was performed using ANSYS 14.0 to ensure the expected loadings do not exceed material specifications, also, the stress analysis was done under worst case scenario and maximum forces were applied during the analysis. Various tests were conducted on the frame to find the strength, reliability and safety of the vehicle.

A. Loading Analysis:

1) ***FEA of roll cage:***

A geometrical model of roll cage design was constructed in CATIA, SOLID WORKS and was imported into ANSYS APDL in IGES format. ANSYS was used to create finite element formulation of both structural and dynamic analysis [6]. The BEAM 189 element was used in creating frames and automatic fine meshing is done for the entire roll cage, with real constants as the thickness and diameter of the pipes.

For AISI 4130 steel

Young's modulus – 190-210 GPa.
Poisson ratio-0.3
Yield stress = 460 Map.
For all the analysis the weight of the vehicle is taken as 320 Kg.

B. Objectives of FEA of Roll Cage:

- To have adequate factor of safety even in the worst-case scenario.
- To ensure minimum deflection under dynamic loading [6].

Static Analysis:
- Front impact.
- Rear impact.
- Side impact.
- Roll over test.

The impact load for these tests was calculated from the mass-momentum equation. The impacts are purely elastic collision.

C. Front impact analysis:

The mass of the vehicle is 320 kg. The impact test is performed assuming vehicle hits the static rigid wall at top speed of 45 Kmph. The collision is assumed to be perfectly plastic i.e., vehicle comes to rest after collision.

Initial velocity = u = 12.5 m/s.
Final velocity = v = 0m/s.

D. Impact Load Calculations

Using the projected vehicle/driver mass of 320Kg, the impact force was calculated based on a G-load of 4.

$$F = M * a$$

=320*4*9.81
=12556.8N.

$$ImpulseTime = weight * (\frac{velocity}{load})$$

=320*(12.5/12556.8)
= 0.31 sec.

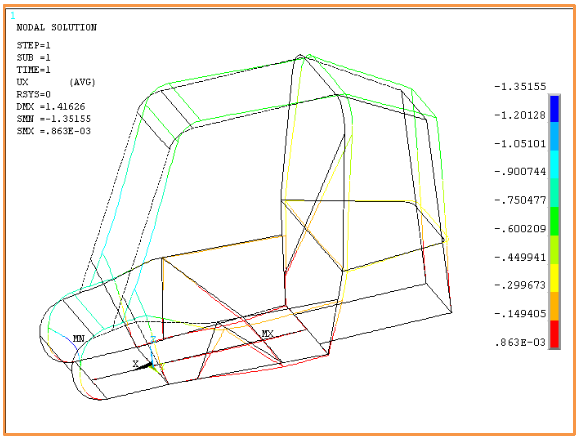

Figure 10: Deformation along X- direction.

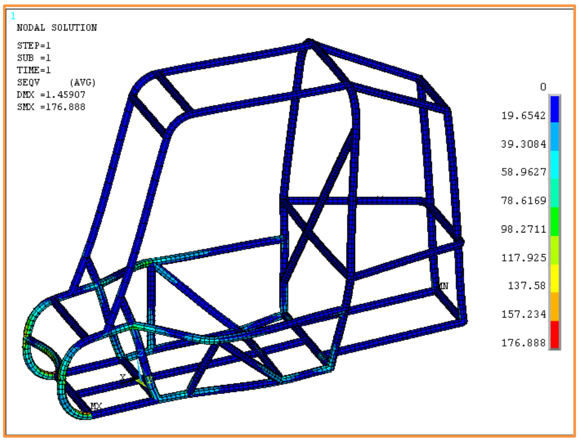

Figure 11: Vonmises stress distribution.

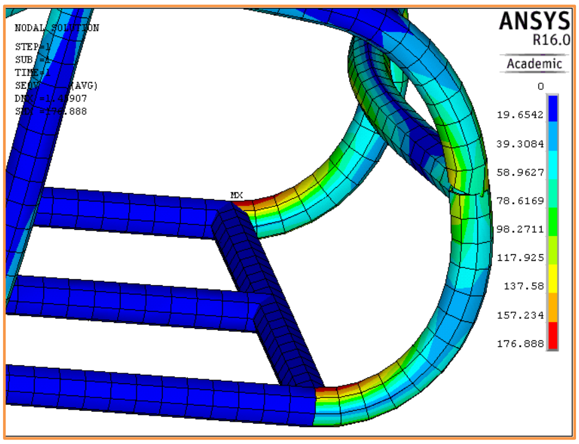

Figure12: Maximum stress position.

It is seen from **Error! Reference source not found.**that the maximum stress value in the roll cage equals 191.49 MPa which doesn't exceeds the safe value of 460 MPa. Hence the design is safe.
From the above details the incorporated factor of safety is given by

Incorporated factor of safety = yield stress/Max stress.

$$F.O.S = \sigma_{yt}/_{\sigma_{permissible}}$$

Tensile yield stress of the AISI 4130 is 460Mpa.
F.O.S = 460/176.888
=2.60.

Front impact	12544N
Max. Deformation	0.86E-03
Max. Stress	176.888Mpa
Factor of safety	2.60

RESULT: From the above ANSYS reports it is clear that the induced or incorporated stress is less compared to that of the yield stress of the material which indicates that the design is safe.

E. Side impact analysis:

The next step in the analysis is to analyze a side impact with a 3G load. The model is impacted on its side.For worst case scenario in case of side impact, one ATV is considered to be in rest and impact is subjected on its side by a similar ATV having a velocity of 45 km/h. For analysis the roll cage of ATV is given velocity 45 km/h and allows hitting the roll cage of 2nd ATV which is at rest on its side [7].
The impact force was calculated based on a G-load of 3.

$$F = M * a$$
=320*3*9.8
=9417.6N.

$$Impulse\ Time = weight * (\frac{velocity}{load})$$

=320*(12.5/9417.6)
= 0.424 sec.

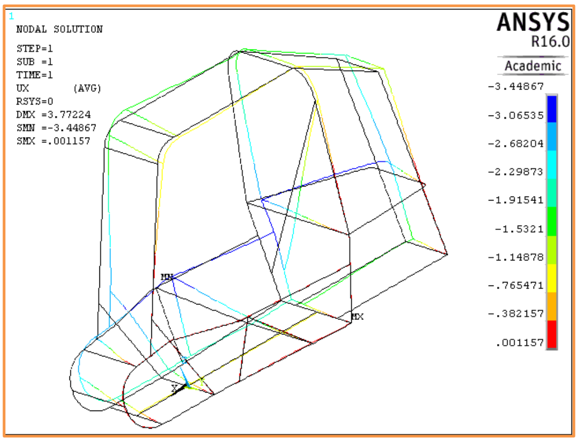

Figure 13: Deformation along X- direction.

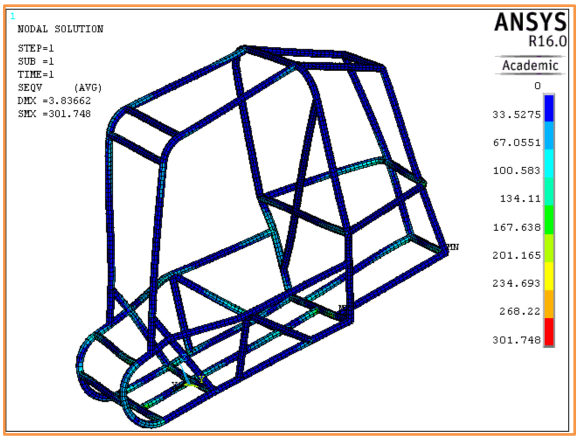

Figure 14: Vonmises stress distribution.

It is seen from **Error! Reference source not found.**that the maximum stress value in the roll cage equals 307.929 Mpa which doesn't exceeds the safe value of 460 MPa. Hence the design is safe.

From the above details the incorporated factor of safety is given by
Incorporated factor of safety = yield stress/Max stress.
Tensile yield stress of the AISI 4130 is 460Mpa.
F.O.S = 460/301.748
=1.52

Side impact	8232 N
Max. Deformation	0.001157 mm
Max. Stress	301.748 Mpa
Factor of safety	1.52

RESULT: From the above ANSYS reports it is clear that the induced or incorporated stress is less compared to that of the yield stress of the material which indicates that the design is safe.

F. Rear Impact Analysis:

The next step is to analyze the model for rear impact with G-Load of 4.For worst case hit another similar ATV on its rear part with a maximum scenario in rear impact, the ATV is considered to velocity of 45 km/h. For analysis the roll cage of 2nd ATV is given a velocity of 45 km/h and allows hitting the roll cage of 1st ATV which is at rest on its rear part [7].

$$F = M * a$$
=320*4*9.8
=12556.8 N.

$$Impulse\ Time = weight * \left(\frac{velocity}{load}\right)$$

=320*(12.5/10976)
= 0.364 sec.

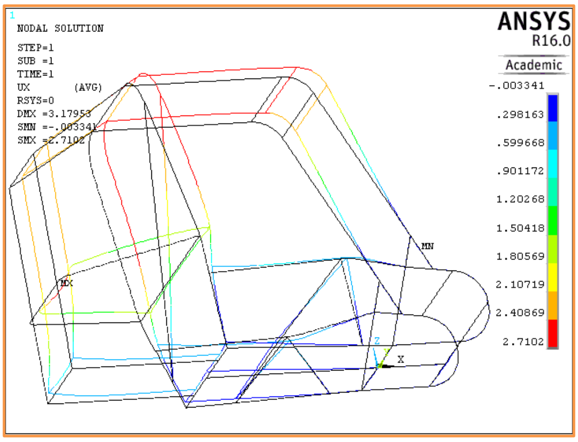

Figure 15: Deformation along X-axis.

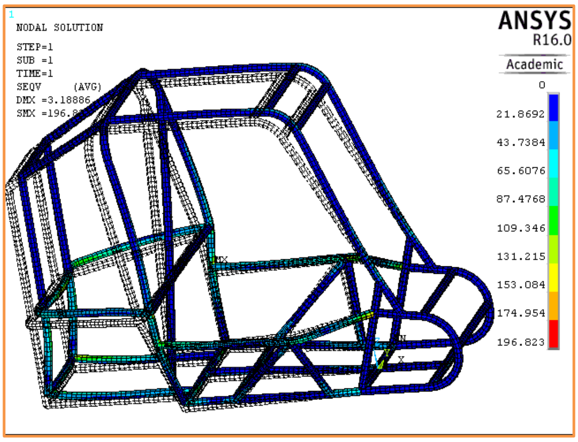

Figure 16: Vonmises stress distribution.

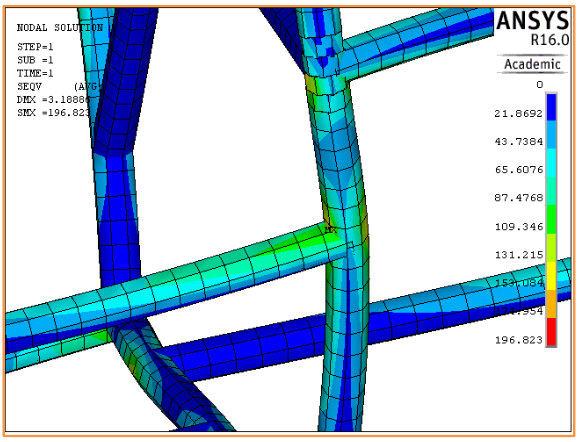

Figure 17: Maximum stress distribution.

It is seen from **Error! Reference source not found.**that the maximum stress value in the roll cage equals 198.726 Mpa which doesn't exceeds the safe value of 460 MPa. Hence the design is safe.
From the above details the incorporated factor of safety is given by

Incorporated factor of safety = yield stress/Max stress.

Tensile yield stress of the AISI 4130 is 460Mpa.

F.O.S = 460/196.823

=2.337.

Rear impact	12544N
Max. Deformation	2.7102 mm
Max. Stress	196.823 Mpa
Factor of safety	2.33

RESULT: From the above ANSYS reports it is clear that the induced or incorporated stress is less compared to that of the yield stress of the material which indicates that the design is safe.

G. *Roll Over Impact Analysis:*

The final step in the analysis was to analyze the stress on the roll cage caused by a roll over with a G-Load of2.5 on the frame.

In roll over impact, ATV is considered to be dropped on its roof on road or ground from a height of 10 feet.10 feet for the drop height is selected because it is sufficiently greater than anything expected at the event site. Since road and ground are non-deformable bodies [7].

$$F = M * a$$

=320*2.5*9.8

=7848 N.

$$Impulse\ Time = weight * (\frac{velocity}{load})$$

=320*(12.5/7848)

= 0.509 sec.

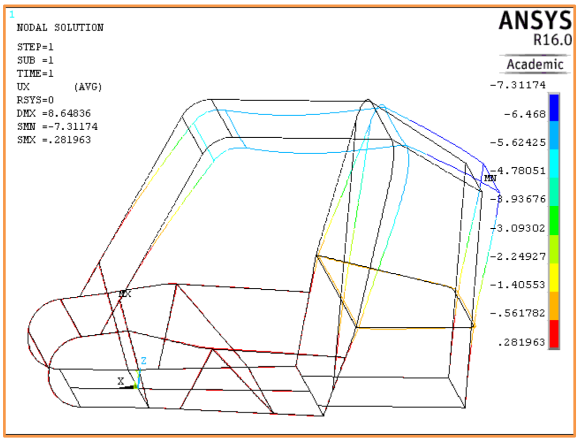

Figure 18: Deformation along X-axis.

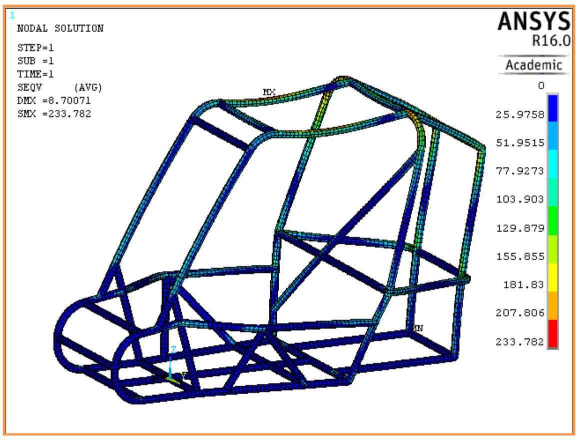

Figure 19: Vonmises stress distribution.

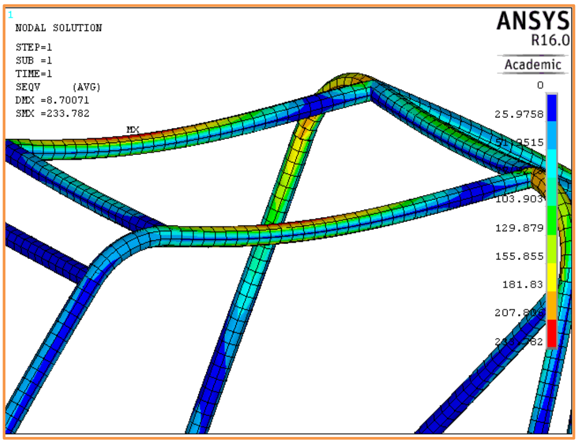

Figure 20: Maximum stress distribution.

It is seen from **Error! Reference source not found.**that the maximum stress value in the roll cage equals 233.782MPa which doesn't exceeds the safe value of 460 MPa. Hence the design is safe.

From the above details the incorporated factor of safety is given by

Incorporated factor of safety = yield stress/Max stress.

Tensile yield stress of the AISI 4130 is 460Mpa.

F.O.S = 460/233.782

=1.96.

Roll Over impact	7848 N
Max. Deformation	0.2819 mm
Max. Stress	233.782 Mpa
Factor of safety	1.96.

RESULT: From the above ANSYS reports it is clear that the induced or incorporated stress is less compared to that of the yield stress of the material which indicates that the design is safe.

IV. CONCLUSIONS

The project aimed at designing, analyzing, fabrication and testing of the roll cage. The design is first conceptualized based on the personal experiences and intuition. Engineering principles and design processes are then used to verify and create a vehicle with optimal performance, safety, manufacturability, and ergonomics. The roll cage has been designed and fabricated to the best of its possible. The design process included using solid works, CATIA and ANSYS software packages to model, simulate, and assist in the analysis of the completed vehicle. The primary objective of this project is to identify and determine the design parameters of the vehicle with a proper study of vehicle dynamics. This project helped us to study and analyze the procedure for vehicle roll cage and to identify the performance affecting parameters. It also helps us to understand and overcome the theoretical difficulties of vehicle design. The entire designing and manufacturing period was a great experience for the team as we were introduced into the amazing world of automobile engineering. It was a learning experience in which we were the proud beneficiaries.

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