DESIGN, ANALYSIS AND MANUFACTURING OF SAE INDIA BAJA ATV ROLLCAGE

Abhishek Pandey[1], Ayush Nigam[2], Saumya Singh Tiwari[3]

[1-3]B. tech in Mechanical Engineering Rewa Engineering College Rewa (M.P.)

Under the guidance of – Mr. Sonu Navgotri[4]

[4]Assistant Professor Department of Mechanical Engineering Rewa Engineering College Rewa(m.p.)

Abstract – This research paper is about Design and analysis of Roll Cage of an ATV (acronym for ALL TERRAIN VEHICLE). It is one of the main systems of the ATV on which the other subsystems like Engine, Steering, and Transmission systems, seat, suspension systems etc are mounted. It comes under the spring mass system of the vehicle. The forces acting on the vehicle from different directions are accountable for the breakdown and deformation in the vehicle. Therefore, the stresses are generated viz maximum combined stresses, minimum combined stresses, direct stresses etc in this paper we have made an attempt to figure out these areas by doing crash tests of the roll cage designed on CATIA V5. We have carried out crash analysis (front, rear, side impact, rollover, Bump) and torsional analysis. All these analyses have been carried out in ANSYS R21.0 academic version. The design procedure follows all the rules laid down by SAE rule book for Baja ATV 2021.

Key Words: Roll cage, Finite Element Analysis, Strength, Factor of safety.

INTRODUCTION:

For a finer performance of an ATV, it is very crucial to make sure that all elements work as per the planned design calculations. Being an important system roll cage absorbs all the static and dynamic loads, the structure should be such that it can withstand the stresses generated without getting damaged. different forces from different directions act on the vehicle when it is in static or in dynamic situation. These forces cause deformation which results in stress generation at different points of the roll cage. The stiffness factor of the roll cage should be able to resist these forces. The primary function of roll cage is to absorb all the loads from the suspension with minimum deformation and secondary is that it should act as a mounting member for all the other components on the vehicle. The final and most vital function of it is that it must have more continuous members to distribute the stresses and high torsional stiffness to resist the forces during the competition. The roll cage is made by joining seamless tubes welded together. First a proper design of the roll cage is to be made by taking desired dimensions from as mentioned in the rulebook of SAE India Baja 2021. The pipes are then formed into desired dimensions by cutting and bending. thereafter notching is done on these pipes. Finally, the pipes are welded together to form a roll cage.

MATERIALS AND METHODS:

Material of sufficiently higher yield strength should be selected to maintain the optimum level of stresses in the roll cage. Here the strength of the material especially the ultimate yield strength plays a crucial role. The factors affecting the selection of the material are as follows: -

1. The stresses generated and the factor of safety of the roll cage.
2. The allotments given to other elements (or components) to be mounted on the roll cage.

The factor of safety (FOS) plays a significant role, it is defined as the ratio of the ultimate yield strength to that of the stresses generated in the roll cage. This value of factor of safety for the roll cage must not be greater than 3 and less than 1. If the value is less than 1, it will lead to a significant deformation before reaching the maximum stress value. If the value is greater than 3, then the weight of roll cage will cross the optimum level up to which it should have to be. The vehicle is supposed to perform in various situations such as muddy and off-road terrain conditions. The elements of roll cage need to be either welded or nut bolted. Thus, the material selected must be weldable. Thus, we need a material which has high strength, stiffness and is weldable. considering these requirements, the material selected is AISI 4130 Alloy steel.

Table 1: -

properties	metric
Tensile Strength	750 MPa
Yield strength	650 MPa
Elongation	25.5 %
Modulus of elasticity	205 GA
Density	750 kg/m^3
Percentage of carbon	0.28 %

FRAME DESIGN:

The Roll cage is designed considering many factors such as cross-sectional area of the pipes, front impact force, side impact force, rollover, tortional impact, bump impact forces the vibrations caused by other components while running of the vehicle and vibrations caused by the engine etc.

The cross section is mandatory to be selected as circular tube as it was already mentioned in the rulebook. The outer diameter and thickness of the cross section of circular tubes in the primary and secondary members of roll cage are 25mm and 3mm respectively. The values are taken as per the rulebook of sae India Baja 2021.

- **Area Moment of Inertia**

I = (π/64) x (D4 – d 4)

$= (\pi/64) \times (25^4 - 19^4)$

$= 1.27\text{x}10^{-8}\ m^4$

- **BENDING STRENGTH:**

$= \text{sy} \times \frac{I}{y}$: Y= D/2

$= 405.3320505\ \frac{N}{m^2}$

- **BENDING STIFFNESS:**

= E X I

$= 2.05 \text{ X } 10^{11} \text{ X } 1.27 \text{ X } 10^{-8}$

$= 2603.5\ \frac{N}{m}$

- **MODELLING**

Considering SAE India Baja Rulebook 2021 as the guide book for extracting all the dimensions, and constraints required to make the roll cage, and then using CATIA v5 software the wireframe of the model is designed as shown in the image below.

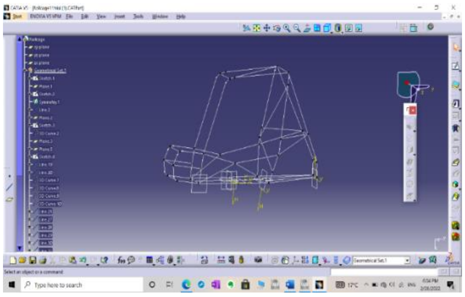

Fig1: wireframe model of the Roll cage.

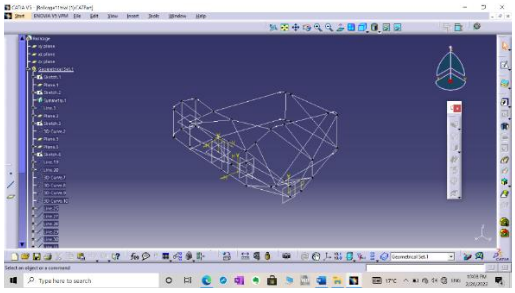

Fig2: Isometric View of the roll cage model.

METHODOLOGY

1. Creation of a wireframe of the structure in the CATIA V5 software.
2. Giving it cross section by importing it on design modeller of Ansys R21.0 ACADEMICS
3. Doing the normal modal analysis to check weather each element of the roll cage is perfectly connected or not.
4. Generation of mesh in mechanical modeller.
5. After setting all the analysis and frequency setting calculate total deformation.
6. Then in static structural workbench after applying all the necessary loads and constraints do all the analysis viz,
   - front impact analysis
   - rear impact analysis
   - side impact analysis
   - roll over impact analysis
   - bump impact analysis
   - tortional impact analysis

7. Then modify the wireframe CAD model to get minimum deformation values.

8. Repeat the same process until you get the safe design.

- We have selected 1D meshing for analysis of Roll Cage by taking consideration of factor which are given below

1. Most accurate –so preferable
2. Level of assumptions is very less as compared to other types of meshing
3. Give results on joints quickly.
4. Outputs received are total deformation, direct stress, maximum combined stress, minimum combined stress.
5. Only cross section of pipe is required to give as circular tubes.

FINITE ELEMENT ANALYSIS (FEA):

This FEA software (in our case Ansys R21.0 ACADEMICS) is used to highlight the failure and stress concentration in the design before going into manufacturing and also shows whether a product will damage, wear out, or work the way it is designed or not. Therefore, the cost of manufacturing can be optimized. Here depending upon the element size the roll cage is divided into small elements called nodes to form a perfect mesh so that the results obtained will be more accurate. To finalize the material and structure of roll cage FEA was performed on it on the aforementioned software.

The meshed model of the roll cage and number of nodes are shown in images below: -

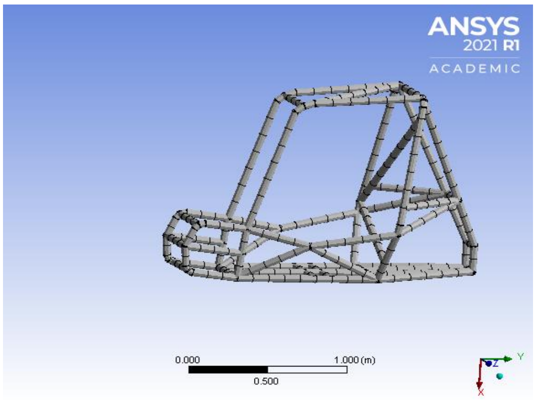

Fig3: meshed model of the roll cage of ATV

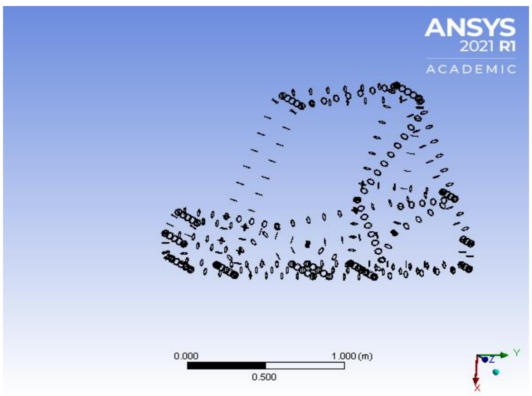

Fig 4: nodes on Roll cage

- Following test were performed on the roll cage: -

1. Front Impact Analysis
2. Rear impact Analysis
3. Side Impact Analysis
4. Tortional Impact Analysis
5. Roll Over Impact Analysis
6. Bump Impact Analysis

1. **FRONT IMPACT ANALYSIS:** The front impact analysis is done in an assumption that when the impact will occur at the front part of the ATV the stresses will be generated at the front part, so the deformation is observed. By those results it will be easy to analyse that whether this roll cage can withstand to that impact or not. The crash analysis has been performed in Ansys 21.0 ACADEMICS version.

The nodal displacement and nodal rotation are kept fixed for rear suspension mountings and forces are applied on front side of the roll cage, in suspension mountings nodal rotations are kept fixed and nodal displacement for perpendicularly downward direction is kept 0

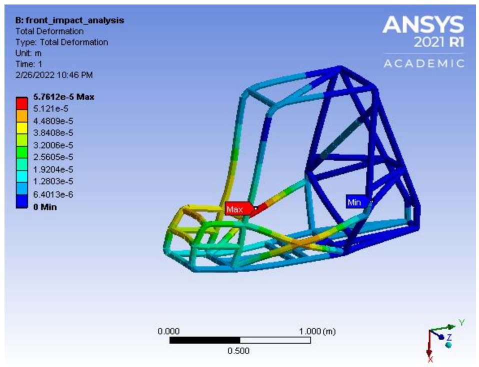

Fig5: Total deformation

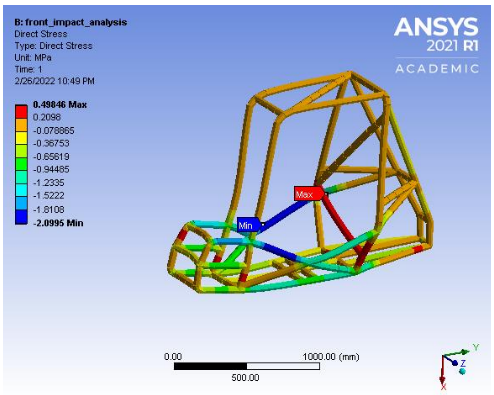

Fig6: Direct Stress

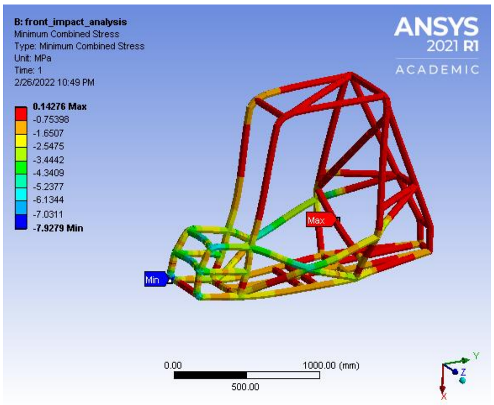

Fig7: Minimum Combined Stress

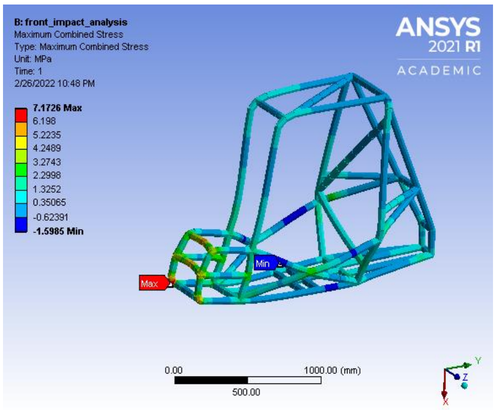

Fig8: Maximum Combined Stress

BOUNDARY CONDITIONS

- The total weight of the roll cage is considered as 260 kg.
- Initial velocity = 50 km/hr.
- Final velocity = 0 km/hr.
- Impact time = 0.376 seconds
- W=$\frac{1}{2} \times mv_f^2 - \frac{1}{2} \times mv_i^2$
  W= $\frac{1}{2} \times 260 \times 13.88^2$
- W= 25045.07 Nm

Displacement= V X T

S= $V_i \times T = 13.08 \times 0.37$

S= 5.135 m

Force = W/S= 4877.32m

RESULTS:

Total deformation =0.057612 mm

Direct stress= 0.49846 MPa

Maximum combined stress= 7.1726 MPa

Minimum Combined Stress = 0.14276 MPa

Hence, the design is safe.

2. REAR IMPACT ANALYSIS

The rear impact analysis is done in an assumption that when the impact will occur at the rear part of the ATV, the stresses will be generated at the rear part so that the deformation can be observed and analysed. By those results it will be easy to manipulate that whether this roll cage can withstand to that impact or not. The crash analysis has been performed in Ansys 21.0 ACADEMICS workbench.

All the translational and rotational degrees of freedom are kept fixed on the front side of the Roll Cage and forces are applied on rear side of roll cage, in suspension mountings nodal rotations are kept fixed and nodal displacement for perpendicularly downward direction is kept 0 (+x direction in our case).

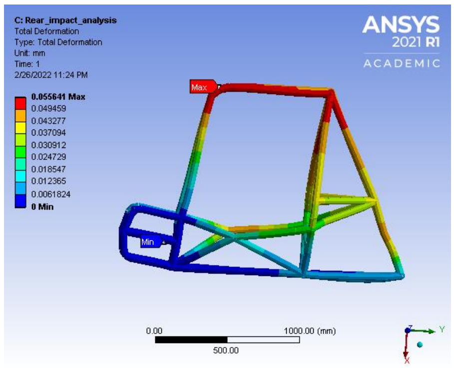

Fig9: Total Deformation

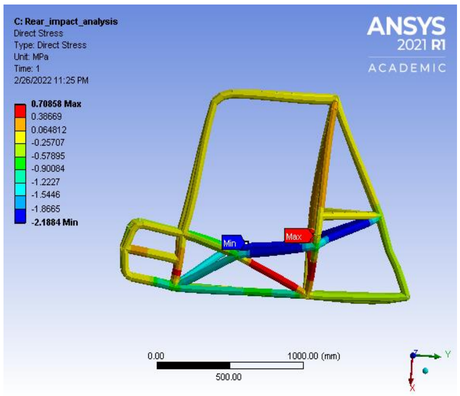

Fig10: Direct Stress

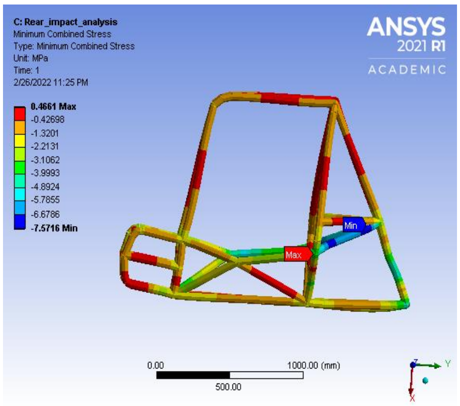

Fig11: Minimum Combined Stress

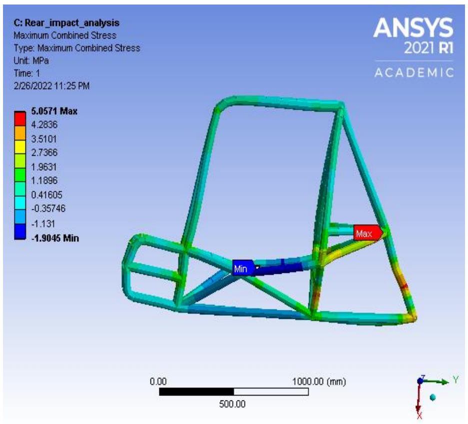

Fig12: maximum Combined Stress

Boundary Conditions: -

Total Vehicle weight is considered as 260 kg
Initial velocity of the vehicle = 50.1 km/hr = 13.88 m/s
Final velocity = 0 km/hr.
Impact time = 0.376 seconds

$$W=\frac{1}{2}\times mv_f^2-\frac{1}{2}\times mv_i^2$$

$$W=\frac{1}{2}\times 260\times 13.88^2$$

W= 25045.07 Nm

Displacement= V X T

$$S=V_i\times T=13.08\times 0.37$$

S= 5.135 m

Rear impact Force = W/S= 4877.32m

RESULTS

- Total Deformation= 0.055641 mm
- Direct stress= 0.70858 MPa
- Maximum Combined Stress= 5.0751MPa
- Minimum Combined Stress= 0.4661 MPa

3. SIDE IMPACT ANALYSIS

The side impact analysis is done in an assumption that when the impact will occur at the side members of the ATV (i.e., SIM members), the stresses will be generated at the side part so that the deformations can be observed. By those results it will be easy to manipulate then that whether this roll cage can withstand to that side impact or not. The crash test is done on Ansys 21.0 ACADEMIC workbench. All the translational and rotational degrees of freedom are kept fixed for front and f applied only on the side members.

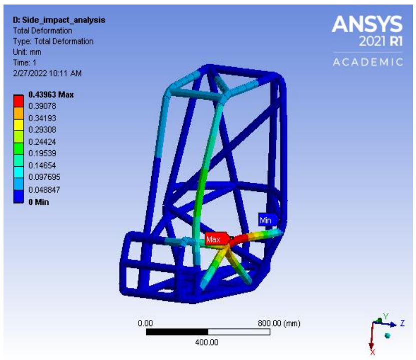

Fig13: Total Deformation

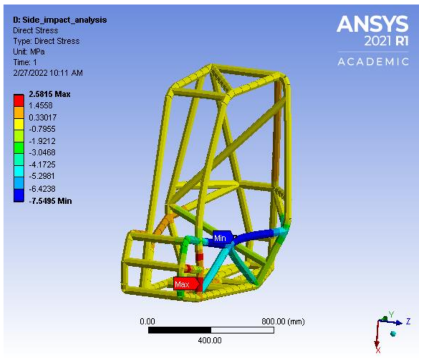

Fig14: Direct Stress

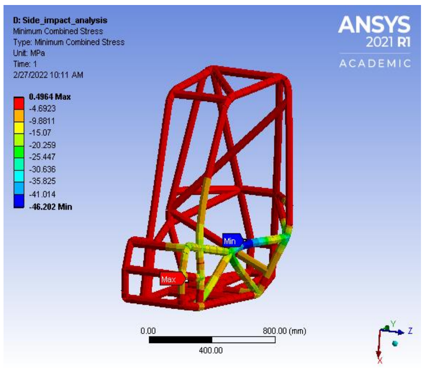

Fig15: Minimum Combined Stress

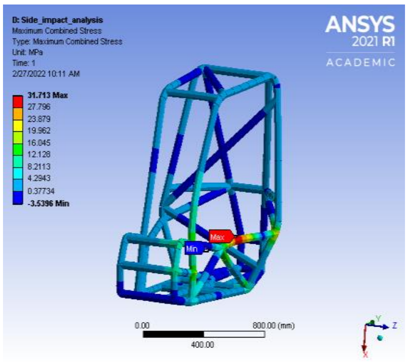

Fig16: Maximum Combined Stress

Boundary conditions:

- The weight of the roll cage is considered as 260 kg
- All the nodes on the front and rear suspension mountings for nodal displacements and nodal rotation are kept fixed.
- Forces are applied on the side members.
- Initial velocity = 50 km/hr= 13.88 m/s
- Impact time = 0.376 s
- Final velocity = 0 m/s
- Deceleration it will go on:
- $= \frac{v-u}{t}$
- = 13.88/0.376= 36.914 $\frac{m}{s^2}$
- Force:
- = ma
- = 260 × 36.914
- = 9597.64 N

RESULTS:

- Total deformation=0.43963 mm
- Direct stress= 2.5815 MPa
- Maximum combined stress= 31.713 MPa
- Minimum combined stress= 0.4964 MPa
- The values are optimum and the design is safe for side impact.

4. ROLL OVER IMPACT ANALYSIS

In roll over impact testing, it is observed that weather all the members associated with the RHO members along with diagonal members are able enough the loads or not. This analysis is done in Ansys 21.0 R1 ACADEMIC workbench. All the degrees of freedom on the front and rear suspension mountings are kept fixed and forces are applied on the front bracing members and RHO members by introducing a new coordinate system in the workbench

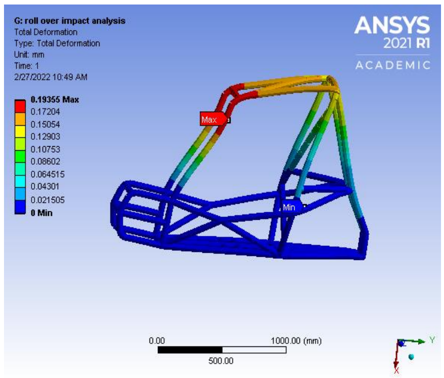

Fig17: Total Deformation

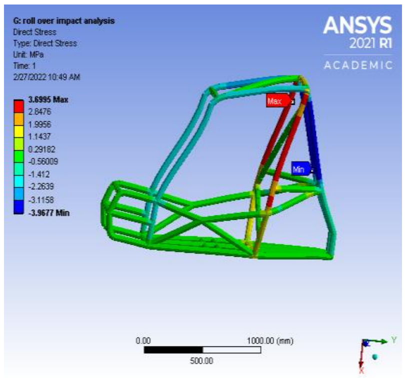

Fig18: Direct Stress

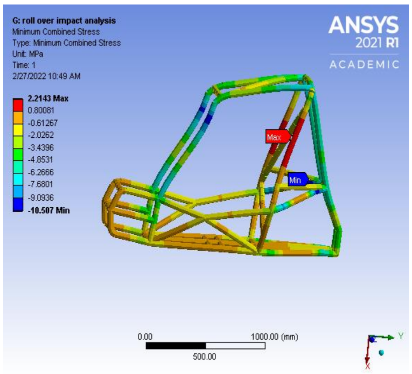

Fig19: Minimum Combined Stress

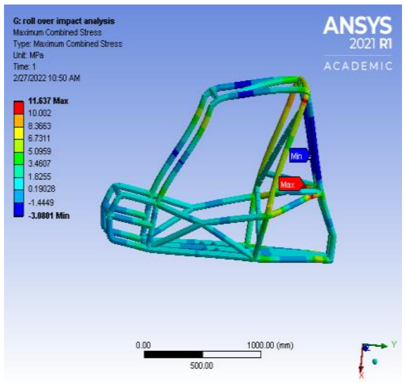

Fig20: Maximum Combined Stress

Boundary condition:

- weight of the Roll cage is considered to be 260kg.
- impact time= 0.17 sec
- ATV dropped from height = 1.75 m
- Height= 1.75m
- Potential energy = kinetic energy
- Mgh = $\frac{1}{2}mv^2$
- $v = \sqrt{2gh} = \sqrt{2 \times 9.81 \times 1.75} = 5.85\frac{m}{s}$
- $W = \left|\frac{1}{2}mv^2\right|$
- $W = \frac{1}{2} \times 260 \times 5.85^2 = 4448.925\ Nm$
- Displacement S= v $\times t$ = 5.85 $\times$ 0.17 = 0.994m
- F=W/s= $\frac{4448.92}{0.994}$
- **F= 4500N**

RESULTS:

- Total deformation= 0.19355 mm
- Direct stress= 3.6995 MPa
- Minimum combined stress= 2.2143MPa
- Maximum combined stress= 11.637 MPa
- Hence the design is safe in the roll over impact analysis

5. TORTIONAL IMPACT ANAYSIS

Torsional analysis is used to analyse the torsional stiffness of the roll cage i.e., how much the structure can resist the twisting. It is very important parameter of any vehicle to resist torsional stress and deflection during the turning, drifting, cornering and undulating road surface. So, the ATV should have high torsional stiffness so it can withstand bending in any direction.

Translational and rotational degrees of freedom for rear suspension mountings are kept fixed and in the front suspension mountings the right and left members are applied with equal forces in opposite direction.

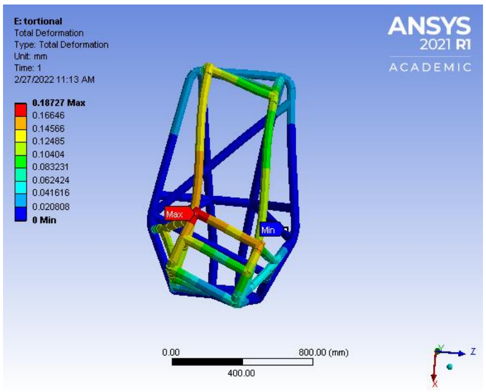

Fig21: TotalDeformation

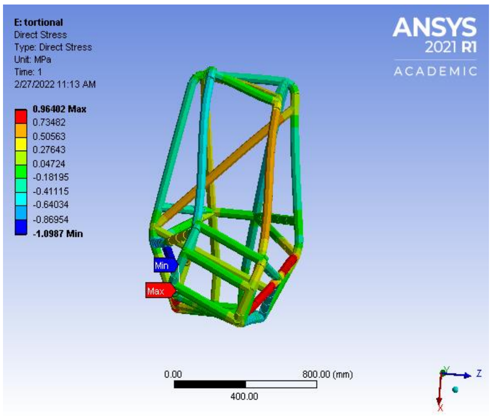

Fig22: Direct stress

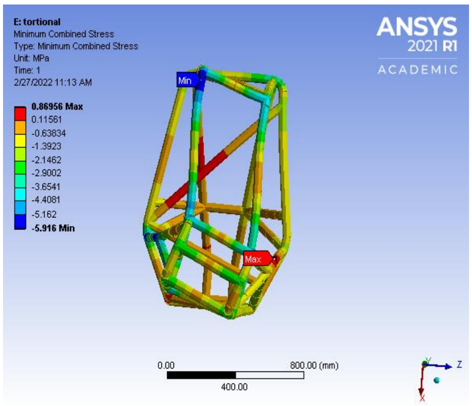

Fig23: Minimum Combined Stress

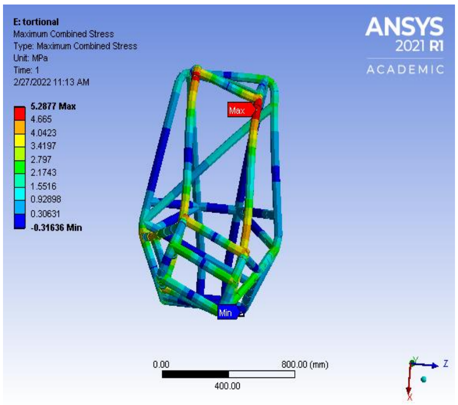

Fig24: Maximum Combined Stress

Boundary conditions:

- Weight of the roll cage is considered as 260 kg
- Impact time = 0.376 s
- Weight distribution:
- $\frac{rear}{front} = \frac{60}{40}$
- Weight on front axle
  = 0.6$\times$ 260 $\times$ 9.81
  = 1530 N
- **Torsional force= 1530N**
- **Calculation for torsional stiffness:**
- Roll cage weight = 50.1 Kg
- Car weight = 260 Kg
- Force (F) = 1530N
- Track width= 1320.8mm

- Torque = F× $(\frac{1}{2})$×track width = 1530× $(\frac{1}{2})$×1.3208 = 1010.412 N-m
- θ = Angle of deflection = $tan^{-1}(\frac{vertical\ displacement}{\frac{1}{2}\times track\ width})$

  $= tan^{-1}(0.18727/(\frac{1}{2}\times 1320.8))$

  = 0.0162°
- **Tortional stiffness**

  = $\frac{torque}{angle\ of\ deflection}$

  =1530/0.0162

  =9444.44 Nm/degree

RESULS:

- Total deformation= 0.18727mm
- Direct stress= 0.96402 MPa
- Minimum combined stress= 0.86956 MPa
- Maximum combined stress= 5.2877 MPa

6. BUMP IMPACT ANALYSIS:

All the translational and rotational Degrees of freedom of rear suspension mountings are kept fixed and forces are applied on right and left front suspension mountings in downward direction.

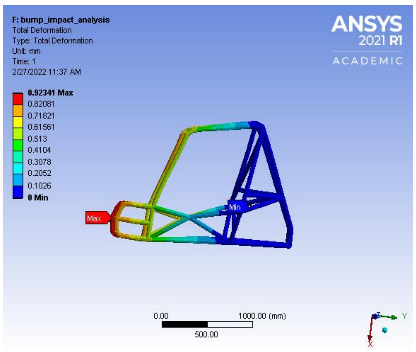

Fig25: Total Deformation

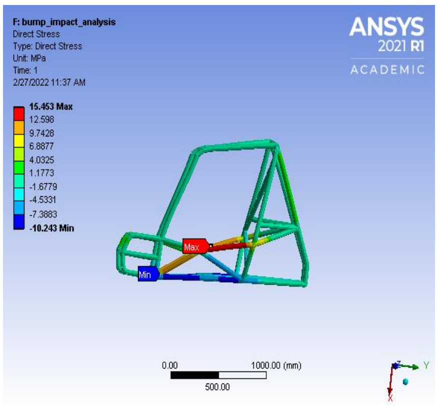

Fig26: Direct Stress

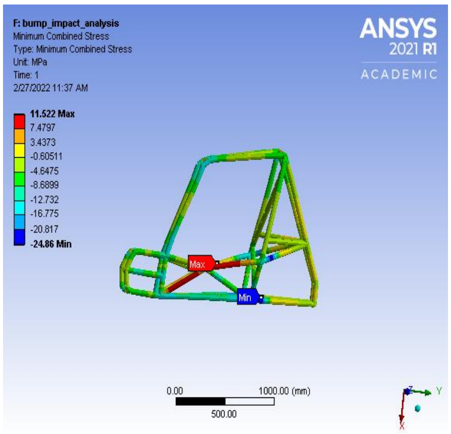

Fig27: Minimum Combined Stress

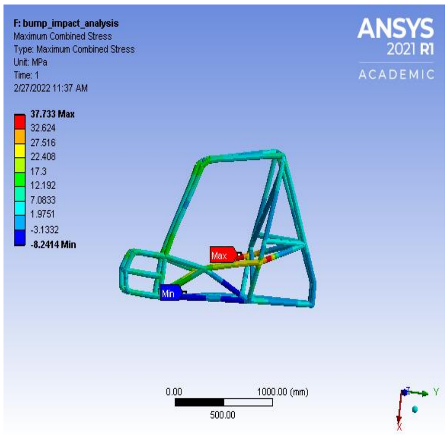

Fig28: Maximum Combined Stress

Boundary condition:

- Weight of the roll cage= 260 kg
- Radius of bump= 17m
- Speed= 20km/hr= 5.55 m/s
- Mass of passenger = 75kg
- **Bump force:**

  F= $m\times\frac{v^2}{r}$ + mg

  $= 75\times\frac{5.55^2}{17}+75\times 9.81$

  =871.64 N

RESULTS:

- Total deformation=0.92341 mm
- Direct stress= 15.453 MPa
- Minimum combined stress= 11.522 MPa
- Maximum combined stress=37.733 MPa

7. FEA ANALYSIS RESULT:

Table 2:

Metric/ analysis-	FIA	RIA	SIA	ROIA	TIA	BIA
TD	0.057612	0.055641	0.43963	0.19355	0.18727	0.92341
DS	0.49	0.70	2.5	3.6	0.9	15.

	846	858	815	995	640 2	453
MiCS	7.17 26	5.07 51	31. 713	2.2 143	0.8 695 6	11. 522
MaCS	0.14 276	0.46 61	0.4 964	11. 637	5.2 577	37. 733

CONCLUSION

The use of finite element analysis was proved to be very useful for the design of our roll cage for SAE India BAJA all-terrain vehicle (ATV). We successfully analysed the roll cage for its strength against the impacts from front, rear, side, tortional, roll over and bump impacts.

This paper describes in detail with various impact analysis on the roll cage and optimization is brought by reducing the weight of it. The design is perfect for use in the event with all the systems perfectly mounted on it

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