Roll Cage and Material Selection

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1. Abstract:- A roll cage is a specially engineered and constructed frame built in (or sometimes around, in which case it is known as an exo cage) the passenger compartment of a vehicle to protect its occupants from being injured in an accident, particularly in the event of a roll over. The base frame of a vehicle is called a chassis. These two structures unite to form a closed or semi closed compartment (frame) in/on which other systems and subsystems are mounted.
Keeping in mind the basic requirements of a vehicle frame (aerodynamics and efficiency), we started designing the same which is compact in size, aesthetic in looks, ergonomic and capable of protecting its drivers in case of impact.

Keywords: CAE analysis, simulation

2. FRAME MATERIAL OPTIONS

Considering the basic utility of a vehicle frame and availability in the market, following materials can be considered for fabricating our vehicle frame.

i.   Aluminium (6063)-T6
Cross-Section; 38.1 x 36.1 x 2 mm
Composition:-
Cu- 0.1%
Fe- 0.35%
Mn- 0.1%
Mg- 0.45%-0.9%,
Cr- 0.1%
☐ For the below table, consider the following abbreviations:

- ρ = Density of material
- S_{YT} = Yield strength
- S_{UT} = Ultimate Tensile strength
- E = Modulus of elasticity
- C = Cost
- D = Estimated days for Delivery

MATERIAL	ρ (g/cc)	SYT (MPa)	SUT (MPa)	E (GPa)	C (Rs/feet)	D
AISI 6063-T6	2.7	214	241	68.3	70	7

3. CALCULATION OF BENDING STRENGTH AND BENDING

4. Aluminium (6063/T6)
Outer   diameter (Do) = 38.1 mm
Inner   diameter (Di)   = 34.1 mm

E = 68.9 GPA
S_Y = 214 MPA
R = 19.05 mm
Thickness (t) = 2 mm

A) MOMENT OF INERTIA: -

$$I = \frac{\pi}{64} * (D_o{}^4 - D_i{}^4) \hspace{4cm} (1)$$
$$= \frac{\pi}{64} * (38.1^4 - 34.1^4)$$

$$= 37063.16 \text{ mm}^4$$

B)   BENDING   STIFFNESS: -

Bending stiffness $\hspace{2cm} = E * I$

$\hspace{3cm} 68.9 * 37063.16 * 10^3 \text{ N mm}^2$

$\hspace{2.5cm} \propto \hspace{3cm} 2.5536 * 10^9 \quad \text{N mm2}$

C)   BENDING STRENGTH :-

Bending   strength $= (S_Y * I / C)$
$\hspace{3cm} = (214 * 37063.16) / (19.05) \text{ N mm}$
$\hspace{3cm} = 4.16 * 10^5 \text{ N mm}$

4. CAE ANALYSIS OF VEHICLE/FRAME

The frame is so designed to sustain significant loads and impacts (front, side, rollover and torsional). It should provide optimum damage protection to the drivers as well as to the vehicle itself in case of various impacts as mentioned below.
 To be absolutely sure about the amount of safety a frame provides to the drivers, the CAD models of the frames employing the above four materials are simulated using software for-
•   Front impact
•   Side impact
•   Roll over
•   Torsion

ASSUMPTIONS CONSIDERED:

•   The frame material is considered to be isotropic and homogenous.
•   The tube joints are considered to be perfect.

4.1. FRONTAL IMPACT ANA0LYSIS
Material-4 (Aluminum 6063 T6, 38.1*34.1*2)
a)   Assumption & Considerations:
•   Front impact test was carried out assuming that the vehicle is having a mass of 240 kg (including the mass of both the drivers and dead weight) and travelling with a velocity of 40 kmph colliding head on with a stationary wall.
•   All the points at wheel mountings are fixed with zero degree of freedom constraints.
•   The load is applied at the front 4 nodes.
•   The mesh generated during this process is beam mesh with defined mesh control and fine density.
•   As per the rule specified by NHTSA (National Highway Safety Traffic Administration), the minimum impact time is of the order 250ms.

b)   Calculation of Impact Forces:
Mass of vehicle including mass of drivers (m) =240kg
At the time of impact, velocity of the vehicle (v_{in}) $\hspace{4cm}$ (2)
= 40kmph = 11.11 mps
Final velocity of the vehicle (v_f) = 0 kmph
Impact time (Δt) = .25 sec
We know,
 Work done (W) = Change in Kinetic Energy
$\hspace{1.5cm} W = \frac{1}{2} * m * (v_{in}{}^2 - v_f{}^2)$
W=1/2 * 240 * (11.11^2 - 0)
$\hspace{1.5cm}$ W=14811.852 J   Acceleration (a) = $\Delta v/t$ $\hspace{1cm}$ a = 11.11/0.25 $\hspace{1cm}$ a = 44.44 m/s^2
Applying second equation of motion
$\hspace{1.5cm} s = ut - \frac{1}{2}at^2$
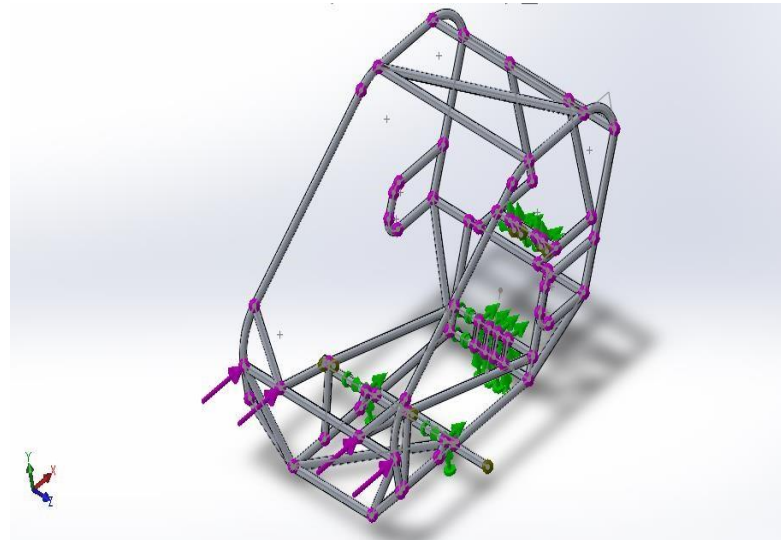$\hspace{1.5cm} s = 11.11*.25 - 0.5*44.44*0.25^2$
$\hspace{1.5cm} s = 1.3887 \text{ m}$
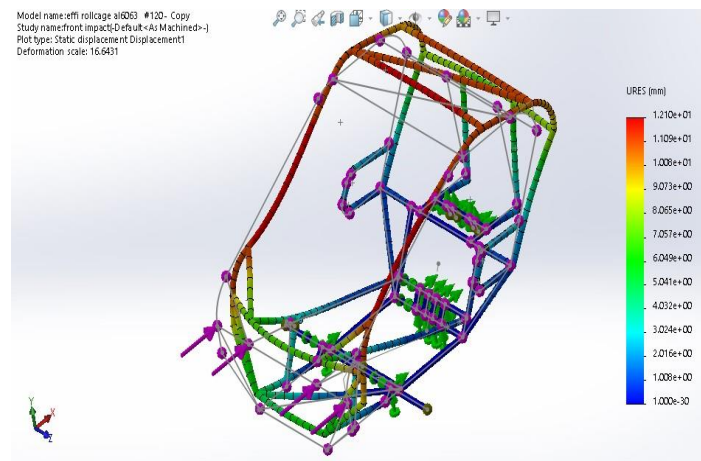
Fig.1.4(a Forces and Fixtures

1) Maximum Deformation = 5.39 mm

Fig.1.4(b) Maximum Deformation Analysis

Now,

Work done = Force(F) *   Displacement(s)

W = F * s

F = W/s

F = 14811.852/1.388

F = 10671.36 N

So, let front loading impact Force is 10700 N

F = 10700 N

Number of nodes at front = 4

Load per nodes at front = 10900/4

= 2675 N

Load per nodes at front = 10900/4
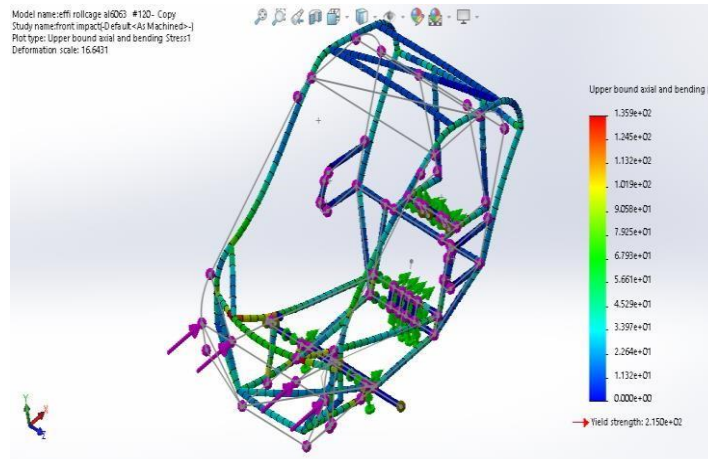
= 2675 N

2) Maximum Stress Generated = 119 MPa

Fig.1.4(c) Maximum Stress Analysis

3) Factor of Safety
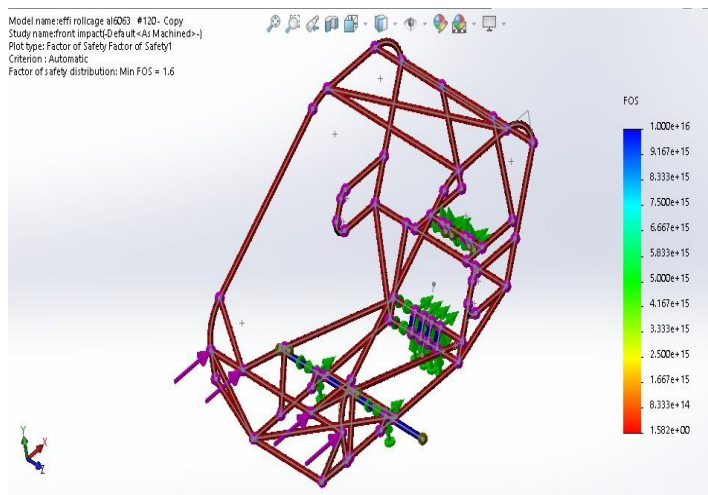

Fig.1.4(d) Factor of safety

4. ANALYSIS RESULTS :-

Maximum stress in rollcage = 119 Mpa

Allowable stress = 215 Mpa

FOS = $\dfrac{\text{Maximum allowable steess}}{\text{Maximum stress generated}}$

= $\dfrac{215}{119}$

= 1.8

Optimizations:

During the preliminary analysis of the proposed design, it was found that the design was not strong enough in various portions to fulfill the requirements.

The reason behind it was stress concentration between the welded joints. So as to reduce the stress developed or to distribute it along the members, various supporting members were attached and the redundant members were removed.

Apart from that various other modifications were done in order to acquire good ergonomics, aesthetics, weight reduction etc.

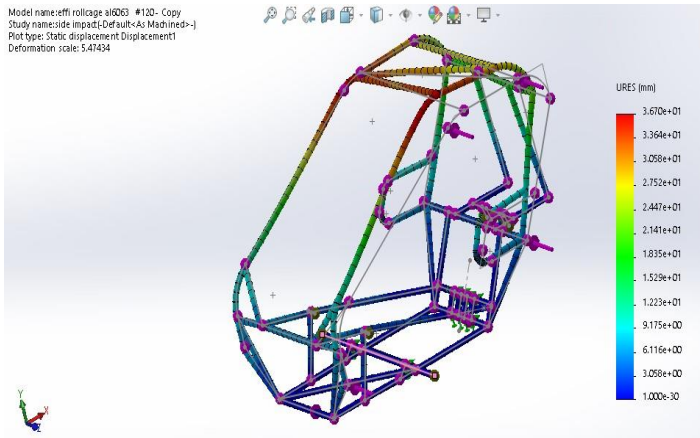**Material-1 (Aluminum/6063 T6, 38.1*34.1*2)   (3)**

a)   **Assumptions & Considerations**

b)   Side impact test was carried out assuming that the vehicle is having a mass off 240 kg (including the mass of both the drivers and dead weight) and travelling with a velocity of 40 kmph colliding with another vehicle travelling with same speed.

c)   All the points at wheel mountings are fixed with zero degree of freedom constraints.

d)   The load is applied on 6 nodes at any one of the sides of the frame.

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e) The mesh generated during this process is beam mesh with defined mesh control and fine density.

f) As per the rule specified by NHTSA (National Highway Safety Traffic Administration), the minimum impact time is of the order 250ms.

b) Calculation of Impact Forces:

During side impact, it is assumed that the efficycle is at rest and another efficycle hits the first efficycle sideways. Impact time in this case is taken as 0.25 seconds.

Mass of the efficycle including mass of drivers (m) = 240 kg

Impact time (Δt) = 0.25 sec

We know,

Work done (W) = Change in Kinetic Energy

$$W = \frac{1}{2} m (v_{in}^2 - v_f^2)$$

(4)

$$W = 1/2 * 240 * (11.11^2 - 0)$$

At the time of impact, velocity of the vehicle (v_{in}) = 40kmph = 11.11 mps

$$W = 14811.852 \text{ J}$$

Acceleration (a) = $\Delta v/t$ a = 11.11/0.25   a = 44.44 m/s^2

Applying second equation of motion

$$s = ut - \frac{1}{2}at^2$$
$$s = 11.11*0.25 - 0.5*44.44*0.25^2$$
$$s = 1.388 \text{ m}$$

Also,

Work done = Force (F) * Displacement (s)

$$W = F * s$$
$$F = W/s$$
$$F = 14811.852 / 1.388$$
$$F = 10700 \text{ N}$$
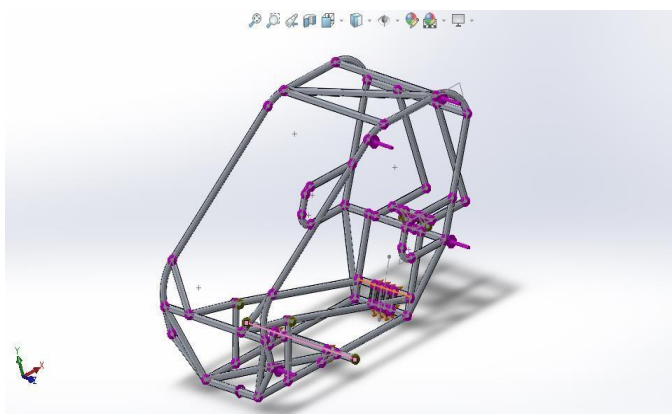
So, let front loading impact Force is 10700 N

$$F = 10700N$$

Number of nodes at front = 6

Load per nodes at front = 10700/6
= 1750 N

(5)

Fig:- forces and fixtures

a) Analysis Results:

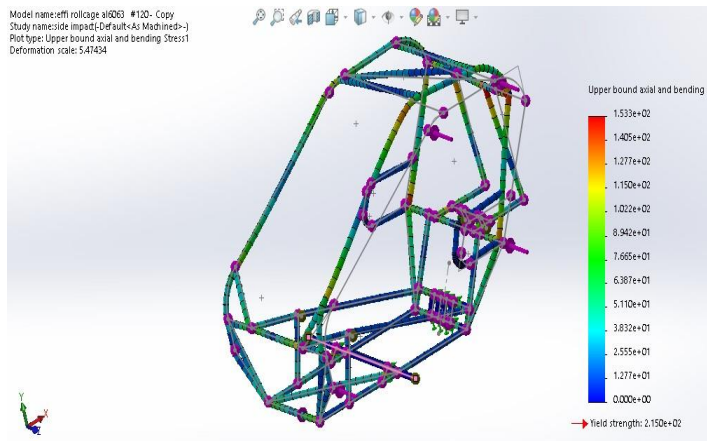1)   Maximum Deformation: 46.3 mm

Fig. 2.4(b) Maximum Deformation Analysis

2)   Maximum Stress: 186.5 MPa
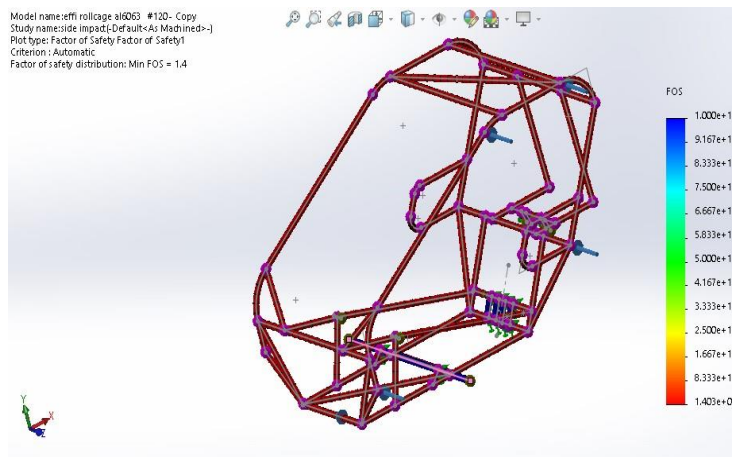
3)   Factor of Safety:

Fig.2.4(c) Maximum stress Analysis

Maximum stress in roll cage = 186.5 MPa
Allowable stress = 215 MPa

Factor of Safety =   Maximum Allowable stress
                        ─────────────────────────
                        Maximum stress generated

         F.O.S = 1.15

a) Optimizations:
During the preliminary analysis of the proposed design, it was found that the design was not that strong in various portions or else we can say that the frame structure was not strong enough to fulfill the requirements.
The reason for this was the stress concentration between the welded joints, so as to reduce the stress developed or to distribute it along the members, various supporting members were attached and the redundant members were removed.
Apart from that various other modifications were done in order to acquire good ergonomics, aesthetics, weight reduction etc.
Material-1 (Aluminium/6063 T6, 38.1*34.1*2000)
a) Assumption & Considerations   **(6)**
•   Rollover analysis was carried out assuming that the vehicle is having a mass of 240 kg (including the mass of both the drivers and dead weight) and the vehicle rolls upside down because of any external impact.

- All the points at wheel mountings are fixed with zero degree of freedom constraints.
- The vehicle is assumed to have been dropped from a height of 10 feet onto its top surface on the ground. This assumption is made to stimulate roll over condition.
- The mesh generated during this process is beam mesh with defined mesh control and fine density.
- It is assumed that the impact time of roll over is

0.25 seconds.

b) Calculation of Impact Forces:

Mass of the vehicle including mass of drivers (m) = 240 kg

Height from which vehicle is assumed to be dropped (h) = 10 feet = 3.048 m

Since the vehicle is dropped from a height, its potential energy changes into kinetic energy at the time of impact.

i.e. $mgh = \frac{1}{2} mv^2$

$v = (2*g*h)^{1/2}$

$v = (2*9.81*3.048)^{1/2}$ $v = 7.73$ m/s   (8)

Now,

Work done (W) = $\frac{1}{2} mv^2$

$W = \frac{1}{2} * 240 * 7.73^2$

$W = 7170.34$ J

Displacement (s) = t * v

= 0.25 * 7.73

= 1.9325 m
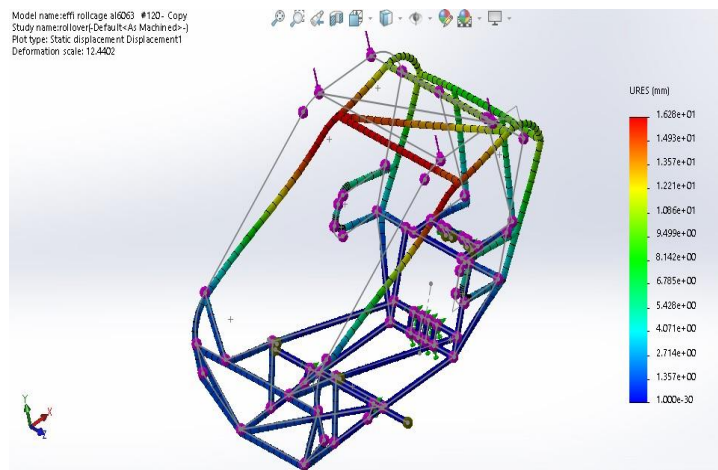
Fig:- Maximum Deformation analysis

= 1.9325 m

We know,

Work done (W) = Force (F) * Displacement (s)

W = F * s

F = W/s

F = 7170.348/1.9325

F = 3710.4

So, let the top loading force is 3712 N

F = 3712 N

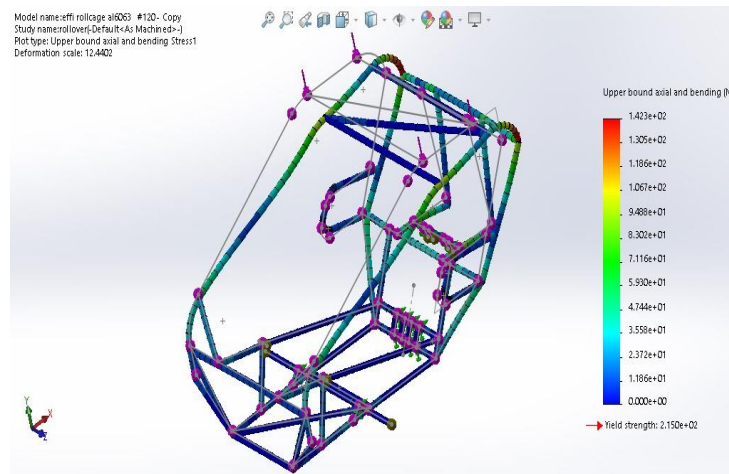1. Maximum stress generated = 130 MPa   (9)

Fig:- Maximum Stress Analysis

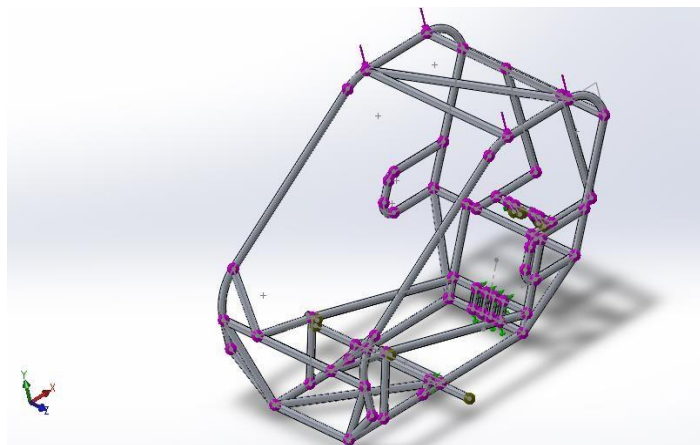Number of nodes at top = 4
Load per nodes at front = 3712/4
= 928 N

Fig. 3.4(a) Forces and Fixtures

Allowable stress = 215 MPa

a)   Analysis Results:-

1) Maximum Deformation: 24.89 mm

Factor of Safety =   Maximum Allowable stress
_____

Maximum stress generated

F.O.S = 215/130 = 1.65

1)   Factor of safety = 1.65

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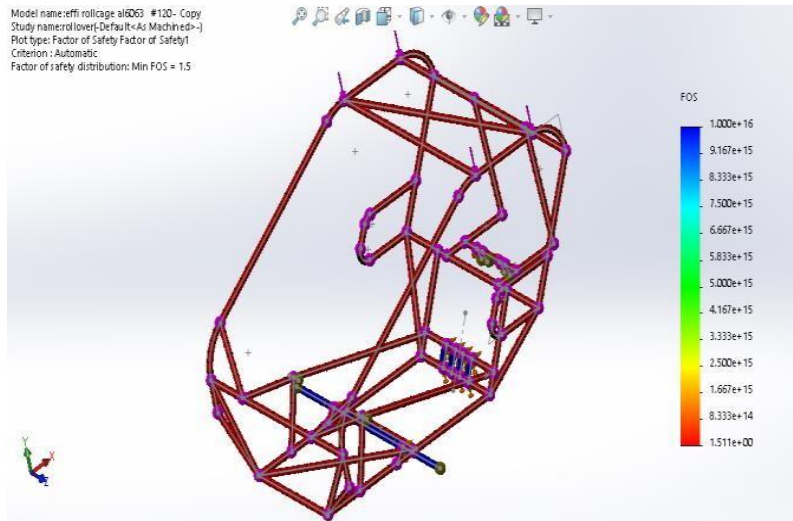**Vol. 9 Issue 03, March-2020**

Fig.3.3(d) Factor of safety

a) Optimizations:

During the preliminary analysis of the proposed design, it was found that the design was not that strong in various portions or else we can say that the frame structure was not strong enough to fulfill the requirements.

The reason for this was the stress concentration between the welded joints, so as to reduce the stress developed or to distribute it along the members, various supporting members were attached and the redundant members were removed.

Apart from that various other modifications were done in order to acquire good ergonomics, aesthetics, weight reduction etc.

3.4. TORSIONAL ANALYSIS

$$F.O.S = 460/145.1 = 3.2$$

Material-1 (Aluminium/6063 T6, 38.1*34.1*2)   (11)

a) Assumption & Considerations:

•   Torsional analysis was carried out assuming that the vehicle is having a mass of 240 kg (including the mass of both the drivers and dead weight). The front wheels' experience bump on one side and droop on another.

•   The point at the rear swing arm hub is fixed with zero degree of freedom constraints.

•   One fourth of the load applied in front impact is applied at the two side nodes in equal magnitude and opposite direction.

•   The mesh generated during this process is beam mesh with defined mesh control and fine density.

b) Calculation of Impact Forces:

For Torsion, the twisting effect is assumed to be one fourth of the force in front impact.   Force = (front impact force)/4

= 10700/4

= 2675 N

Number of nodes at side = 2

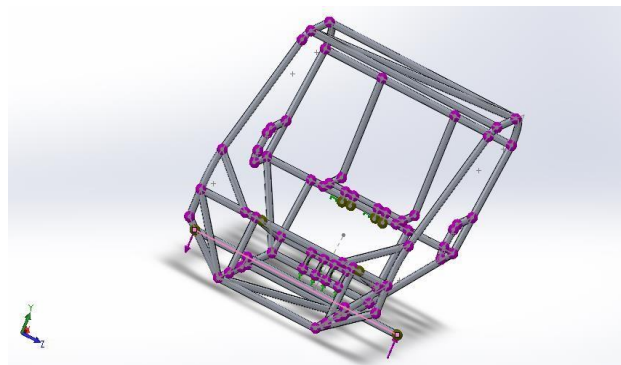Load per node at side = 2675/2

= 1337.5 N

Fig. 4. 4(a) Forces and Fixtures

Analysis result:-

1) Maximumm Defirmation : 17.85
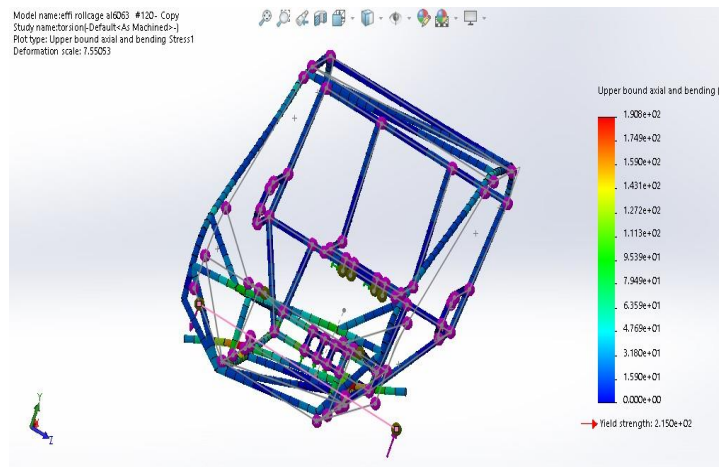
Load per node = 2675
= 1375.5 N

(11)

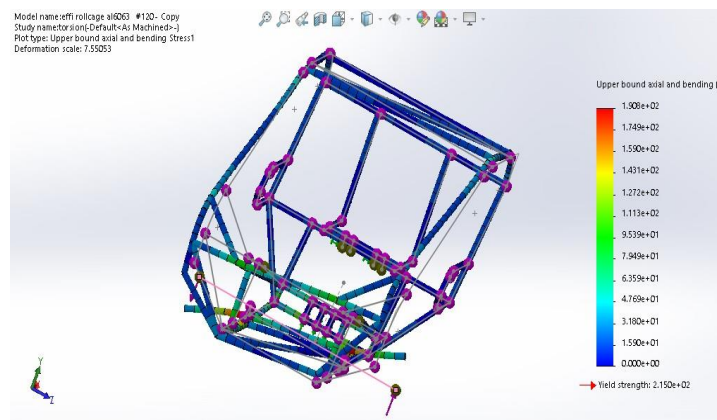Fig.4.4(b): Maximum Deformation Analysis

2) Maximum Stress: 137 MPa

Fig.4.4(c) Maximum Stress Analysis
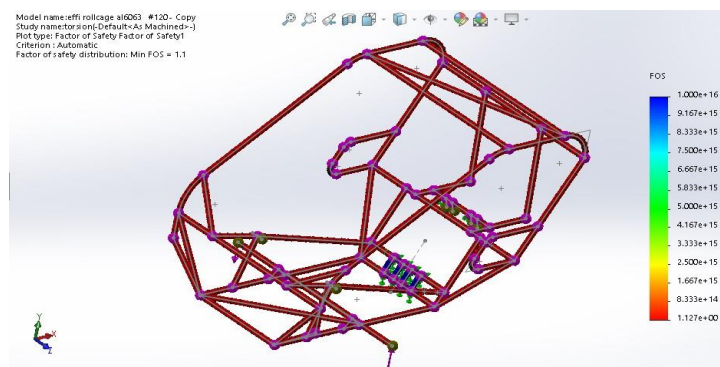
3) Factor of Safety:

Fig.4.4(d) Factor of safety

Maximum stress in roll cage = 137 MPa

Materials Selected for Frame:

Allowable stress = 215 MPa

i. Aluminium 6063, Tubular Cross section

Factor of Safety =   Maximum Allowable stress

38.1*34.1*2.

$\overline{\qquad\qquad\qquad\qquad}$

Maximum stress generated

F.O.S = 215/13 = 1.557 ~ 1.6

As clear from the table, Aluminium 6063 scored a total of 52 out of 60. It stood remarkably well on industrial as well as on road aspects of a vehicle.

Table 6.1 (Material Comparison)

W	9	9	9	8
W.O.F	9	7	8	9
D	5	8	6.5	9
C	7	8	7.5	8.5
S	9	9	8.5	8
Total	48	49	47.5	52.5

COCLUSION

After performing calculations and simulations on the rollcage we found that aluminium 6063-T6 is taken selected for manufacturing of rollcage of dimension 38.1*34.1*2.

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