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Material Optimization on Spaceframe Tubular Chassis

Kondusamy V[1], Vivekanandhan M[2], Raguram R S[3], Vignesh G[4],Poovarasan K[5], Vyshaak R B[6]

[1]Assistant Professor, Department of Automobile Engineering, Karpagam college of Engineering, Coimbatore-641032Tamilnadu, India

[2,3,4,5,6] UG Scholars, Department of Automobile Engineering, Karpagam college of Engineering, Coimbatore-641032 ,Tamilnadu, India

Abstract: The material optimization is important for Low weight to strength ratio in a Space frame Tubular chassis and also make the chassis to withstand all type of loads while in dynamic conditions. Lesser weight chassis plays a key role in performance and handling efficiency whereas stress, strain are the major factors that to be achieved as a goal with respect to that various analysis are carried out. And the suitable material was founded out among its fellow materials in comparison.

Keyword: Modeling student formula vehicle.

I. INTRODUCTION

Space frame chassis is commonly known as skeleton system for the Automobiles. This Spaceframe construction is mainly a combination of Triangulated structure, might be any kind of Triangulated structure. Coreobjective for this Triangulated structure is to dissipate the External force though out the each and every part of the chassis without affecting the driver cabin.Every member are tubular pipes and they are properly machined and welded especially in racing concern,Spaceframe chassis are the basic entry for the monocoque type of chassis. Spaceframe chassis are easy to alter if it tends to any kind of deformation or accidental scenario in automobile moreover their efficient is mostly depends on the material used, Machining method and Weldability.

II. OBJECTIVE

The main Objective of this research is to build a space frame tubular chassis with less weight and high strength for that the modules of the research is as follows,

- Material Selection/Properties.
- Material Distinguishing/Comparison.
- Material Diagnostic.

III. METHODOLOGY

The Methodology of the work which was followed to accomplish the above objective.

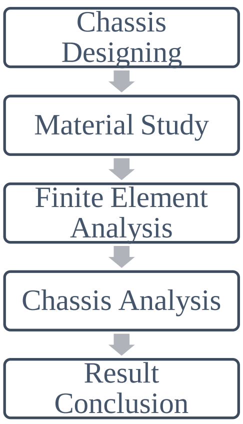

Fig. 1 Methodology of the Research

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IV. CHASSIS DESIGNING

In Chassis Designing there are many influential factors are present in it one of that was Ergonomics. In this concern Space frame structure should be ergonomically designed for all individual Human mankind

Especially for men. So here we satisfy 95th percentile template. In a single-seater Automobiles 95th percentile is works well for Egress purpose in the worst-case scenario adding to that the overall dimension (i.e.) Wheelbase/Wheel track should be fixed as a reference source then with respect to that value, all other construction was carried over. All the computerized design was done with SOLID WORKS2018.

Table I
DIMENSIONS

Co-ordinates	**Length (mm)**
X-axis	630mm
Y-axis	1100mm
Z-axis	2300mm

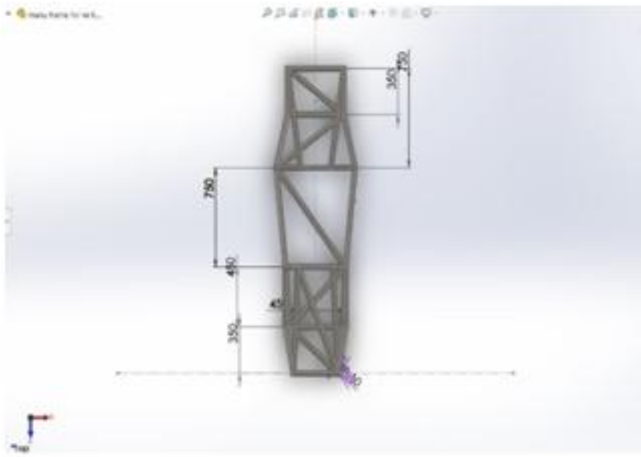

Fig. 2 X-axis measurement

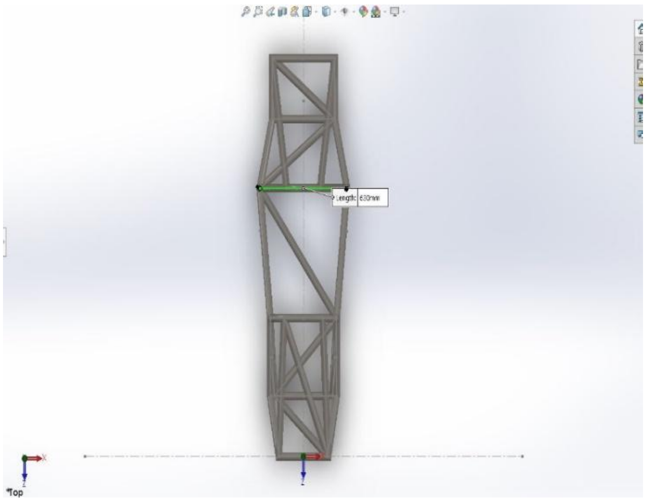

Fig. 3 Y-axis measurement

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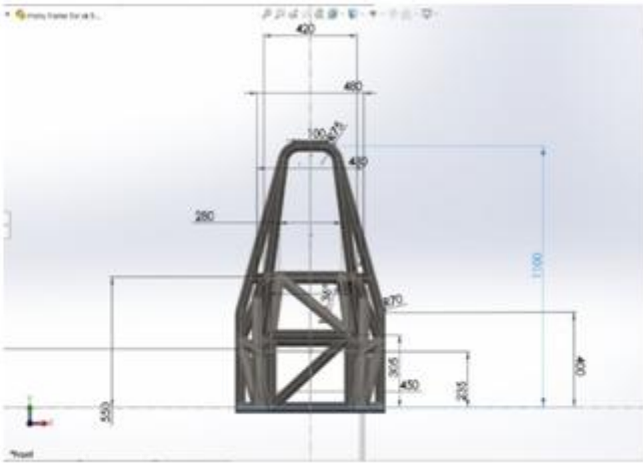

Fig. 4 Z-axis measurement

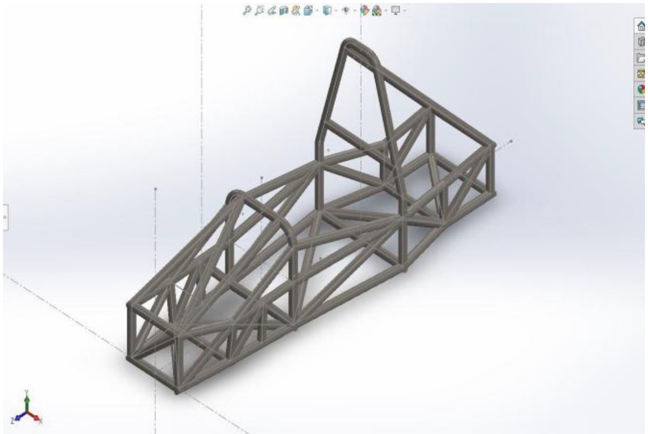

Fig. 5 Isometric view

V. MATERIAL STUDY

The Characteristics of the Space frame tubular chassis is defined by the kind of material used in to it. To get maximum equivalent stress, material selection is the integral part for that required results. Moreover, weight reduction is the key goal to be achieved in the engineering design along with high strength character.

To satisfy the above three demands we selected the materials which are listed below.

- AISI 1018.
- AISI 4130.
- Aluminum alloy 6063 T6.

These three materials are shortlisted after a huge Literature survey by considering the market availability factor and also considering the cost cap for the Fabrication.

Table II

MATERIAL PHYSICAL PROPERTIES

	Materials name/Ref no.

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	AISI 1018(1)	**AISI 4130(**2)	**Aluminum T6(**3)
Bulkmodulus(GPa)	159	140	-
Poisson'sratio	0.29	0.285	0.33
Modulus of elasticity (GPa)	205	205	69
Ultimate strength (MPa)	440	731	240
Yield strength (MPa)	370	460	215
Shear modulus (GPa)	80	80	25.8

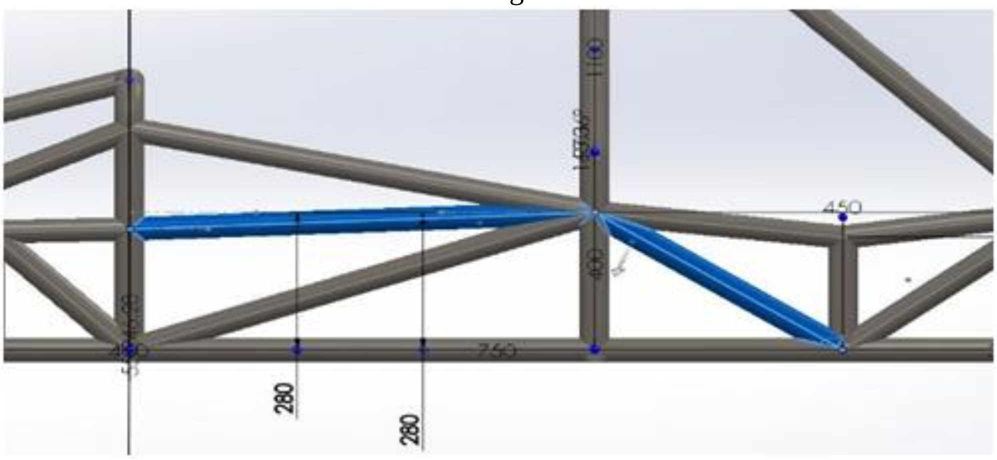
VI. FINITE ELEMENT METHOD

In this Finite element analysis, we decided to study the elemental displacement and stress development inside the material and the force transformation. For this concern we've isolate the two members from the spaceframe tubular chassis and consider as a Truss element.

Truss is described as a structure, made from numerous bars, riveted or welded collectively. The following assumptions are made even as locating the forces in a truss.

- All the contributors are pin joined.
- The truss is loaded handiest on the joints.
- The self-weight of the members is unnoticed except said

Fig.6 Members for FEA



The above members are selected to find the nodal displacement and stress developed into it the calculation part is as follows,

Calculation:

Some of the factors are consider for analysis,

Material used **AISI 4130,** the selected part is placed over the **X** and **Y** reference plane, and then the force substituted here is taken as a Frontal impact nature with a value of **20G** force.

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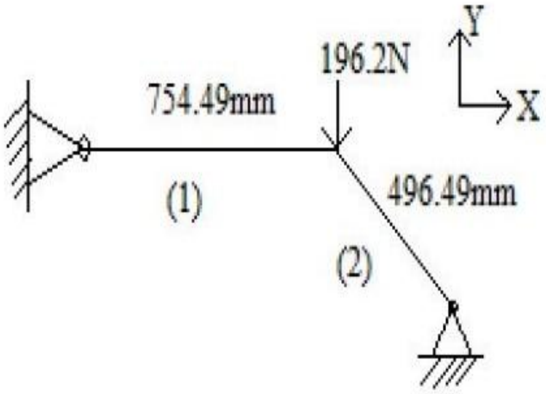

Fig. 7Free body diagram

Data:

Area (A_1) = 109711.47mm^2
Area (A_1) = 62850.55^2
Young's modulus (E) = 205GPa
Force (F) = 196.2N

Consider node 1 as the origin the Co-ordinates of various nodes are given below,

- Node1 = (0, 0) = (X_1, Y_1)
- Node2 = (-754.49, 0) = (X_2, Y_2)
- Node3 = (351.071, -351.071) = (X_3, Y_3)

For Element (1),

Length l_{e1}=$\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$
=$\sqrt{(-754.49 - 0)^2 + (0 - 0)^2}$
l_{e1}=754.49mm

Direction cosines,

L_1= (x_2-x_1)/l_{el}
= (-754.49-0)/754.49
L_1 = -1
M_1 = (y_2– y_1)/ l_{e1}
= (0-0) /754.49
M_1 = 0

For Element (2),

Length l_{e2}=$\sqrt{(x_3 - x_1)^2 + (y_3 - y_1)^2}$
= $\sqrt{(351.071 - 0)^2 + (-351.071 - 0)^2}$
l_{e2} =496.489mm
Direction cosines,

L_2 = (x_3-x_1)/l_{e2}
= (-351.071-0)/496.489

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$L_2 = 0.7071$

$M_2 = (y_3 - y_1)/ l_{e2}$

$= ((-351.07)-0) / 496.489$

$M_2 = -0.7071$

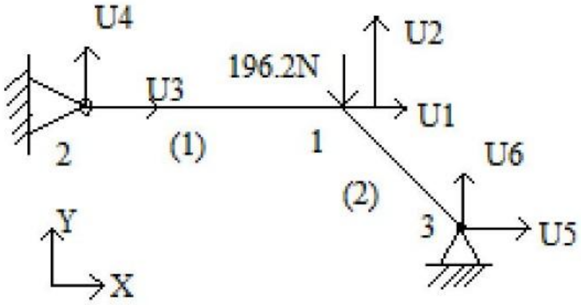

Fig.8 Displacement diagram

For element (1),

(Displacements are u_1, u_2, u_3, u_4)

Stiffness matrix for a truss element is given by,

$$[K_1]= ((A_1E_1)/l_{e1}) * \begin{bmatrix} {l_1}^2 & l_1m_1 & -{l_1}^2 & -l_1m_1 \\ l_1m_1 & {m_1}^2 & -l_1m_1 & -{m_1}^2 \\ -{l_1}^2 & -l_1m_1 & {l_1}^2 & l_1m_1 \\ -l_1m_1 & -{m_1}^2 & l_1m_1 & {m_1}^2 \end{bmatrix}$$

$$=(109711.47*205*10^3)/(754.49)* \begin{bmatrix} 1 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 \\ -1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$[K_1] = 29809343.2 * \begin{bmatrix} 1 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 \\ -1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \ldots\ldots. (1)$$

For Element (2),

(Displacement u_1, u_2, u_5, u_6)

$$[K_2]= ((A_2E_2)/l_{e2}) * \begin{bmatrix} {l_2}^2 & l_2m_2 & -{l_2}^2 & -l_2m_2 \\ l_2m_2 & {m_2}^2 & -l_2m_2 & -{m_2}^2 \\ -{l_2}^2 & -l_2m_2 & {l_2}^2 & l_2m_2 \\ -l_2m_2 & -{m_2}^2 & l_2m_2 & {m_2}^2 \end{bmatrix}$$

$$=(62850.55*205*10^3)/(496.489)* \begin{bmatrix} 0.7071 & -0.49 & -0.7071 & 0.49 \\ -0.49 & -0.7071 & 0.49 & -0.7071 \\ -0.7071 & 0.49 & 0.7071 & -0.49 \\ 0.49 & -0.7071 & 0.49 & 0.7071 \end{bmatrix}$$

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$$[K_2]=25950953.09*\begin{bmatrix} 0.7071 & -0.49 & -0.7071 & 0.49 \\ -0.49 & -0.7071 & 0.49 & -0.7071 \\ -0.7071 & 0.49 & 0.7071 & -0.49 \\ 0.49 & -0.7071 & 0.49 & 0.7071 \end{bmatrix}\ldots\ldots\ldots(2)$$

Assemble the stiffness matrix [K], i.e., assemble the equation (1)&(2),

$$[K]=14917647.08*\begin{bmatrix} 1.7071 & -0.49 & -1 & 0 & -0.7071 & 0.49 \\ -0.49 & 0.7071 & 0 & 0 & 0.49 & -0.7071 \\ -1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ -0.7071 & 0.49 & 0 & 0 & 0.7071 & -0.49 \\ -0.49 & -0.7071 & 0 & 0 & -0.49 & 0.7071 \end{bmatrix}$$

Note: The two members has 3 nodes and each node has 2 degrees of freedom. So, total degrees of freedom is 6 (u_1, u_2, u_3, u_4, u_5, u_6). Hence the stiffness matrix size is [6x6].

General finite element equation is

{F}=[K] {u}

[K] {u} = {F}

$$4917647.08*\begin{bmatrix} 1.7071 & -0.49 & -1 & 0 & -0.7071 & 0.49 \\ -0.49 & 0.7071 & 0 & 0 & 0.49 & -0.7071 \\ -1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ -0.7071 & 0.49 & 0 & 0 & 0.7071 & -0.49 \\ -0.49 & -0.7071 & 0 & 0 & -0.49 & 0.7071 \end{bmatrix}*\begin{Bmatrix} u_1 \\ u_2 \\ u_3 \\ u_4 \\ u_5 \\ u_6 \end{Bmatrix}=\begin{Bmatrix} F_1 \\ F_2 \\ F_3 \\ F_4 \\ F_5 \\ F_6 \end{Bmatrix}$$

Applying boundary conditions [ref Fig 7]

- Node 2 is fixed. So, $u_3 = u_4 = 0$.
- Node 3 is fixed. So, $u_5 = u_6 = 0$.
- A point load of 196.2N is acting at node 1 in downward direction. So, $F_2 = -196.2$N.
- Self-weight is neglected. So,
  $F_1=F_3=F_4=F_5=F_6=0$.

Substitute the above values in above equation.

$$=>14917647.08*\begin{bmatrix} 1.7071 & -0.49 & -1 & 0 & -0.7071 & 0.49 \\ -0.49 & 0.7071 & 0 & 0 & 0.49 & -0.7071 \\ -1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ -0.7071 & 0.49 & 0 & 0 & 0.7071 & -0.49 \\ -0.49 & -0.7071 & 0 & 0 & -0.49 & 0.7071 \end{bmatrix}*\begin{Bmatrix} u_1 \\ u_2 \\ 0 \\ 0 \\ 0 \\ 0 \end{Bmatrix}=\begin{Bmatrix} 0 \\ -196.2 \\ 0 \\ 0 \\ 0 \\ 0 \end{Bmatrix}$$

In the above equation $u_3 = u_4 = u_5 = u_6 = 0$. So, delete third row third column, fourth row, fourth column, fifth row fifth column and sixth row sixth column of [K] matrix. Hence the equation reduces to

$$=> 14917647.08\begin{bmatrix} 1.7071 & -0.49 \\ -0.49 & 0.7071 \end{bmatrix} * \begin{Bmatrix} u_1 \\ u_2 \end{Bmatrix} = \begin{Bmatrix} 0 \\ -196.2 \end{Bmatrix}$$

$$=> 14917647.08(1.7071\ u_1-0.49\ u_2) = 0$$

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=> 14917647.08(-0.49 u_1-0.7071 u_2)=-196.2

Solving the above two equations,

u_1= -4.51*10^{-12} mm

u_2= -2.321*10^{-5} mm

For element (1),

Stress, σ = E/$l_e$$[-l \quad -m \quad l \quad m]*\begin{Bmatrix} u_1 \\ u_2 \\ u_3 \\ u_4 \end{Bmatrix}$

For element (2),

(Displacements are u_1, u_2, u_5, u_6)

Stress, σ_2 = E/l_{e2}*

$[-l_2 \quad -m_2 \quad l_2 \quad m_2]*\begin{Bmatrix} u_1 \\ u_2 \\ u_5 \\ u_6 \end{Bmatrix}$

= ((205*10)/496.489)* $[-0.7 \quad 0.7 \quad 0.7 \quad 0.7]*\begin{Bmatrix} -4.5 * 10^{-12} \\ -2.321 * 10^{-5} \\ 0 \\ 0 \end{Bmatrix}$

= 412.899 [(-0.7071*(-4.51*10^{-12})) + (0.7071-(2.321*10^{-5}))]

σ $_2$=-6.7764*10^{-3}N/mm^2.[Compressive]

Result:Therefore, from the above calculation it is observed that the Displacement of node 1, U_1= -4.51*10^{-12} mm and U_2 = -2.321*10^{-5} mm and the Stress in the element (2) is

σ $_2$ = -6.7764*10^{-3}N/mm^2.

From this result we can able to observe that the stress developed inside each and every tubular member's element in the whole chassis was a compressive stress.Moreover, displacement occurs according to that stress nature particularly in AISI 4130 materialized chassis.

VII. CHASSIS ANALYSIS

The Chassis analysis is carried out in SOLIDWORKS 2018 software with three core materials. They are AISI 1018, AISI 4130 and Aluminium T6. The total deformation and equivalent stress analysis of chassis was conducted over the front, rear and side faces of the Space frame tubular chassis then the results are compared graphically with one another and also with Impact calculation for the chassis now the Analysis as follows,

- Front impact calculation:

For the frontal impact case the vehicle was gone through some consideration. The straight speed was around 90km/hr or 25m/s and with the displacement of 0.5m. Then this state of consideration was tamed into computational analysis and also the force observed here was termed to be Kinetic energy with respect to the real time conditions,

Mass of the vehicle, m = 270kg

Kinetic energy, KE =0.5 * 270 * 25^2

KE = 84375 N.

In the case of true factor of safety, the kinetic energy produced in chassis and the Frontal impact value should be equal for the **FOS** concern.

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So, now average Force (F_{avg}),
Displacement, d = 0.5m
F_{avg}*d = KE
F_{avg}= KE/d
= 84375/0.5
F_{avg} = 168750 N

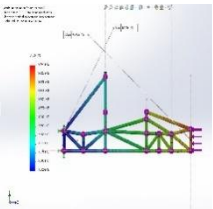
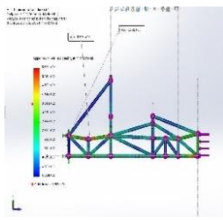
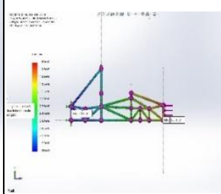
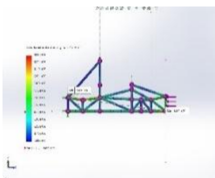
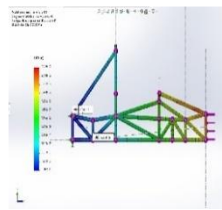
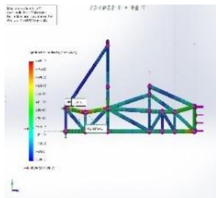
- Rear impact calculation:

The rear impact force was calculated as same as the above cases here the velocity value is taken as 82km/hr or 22.7778m/s as per ENCAP norms,
KE = $0.5mv^2$
= $0.5*270*22.777^2$
KE =70036.88 N.
Work done = Kinetic energy
F_{avg} *d = $0.5mv^2$
F_{avg} =KE/d
= 70036.88/0.5
F_{avg} = 140073.7 N

- Side impact calculation:

The side impact force was determined with velocity value of 65km/hr or 18.0556m/s as per ENCAP standard then the Average force value is,
KE = $0.5mv^2$
= $0.5*270*18.0556^2$
KE =44010.633 N.
Work done = Kinetic energy
F_{avg} *d = $0.5mv^2$
F_{avg} =KE/d
= 44010.633/0.5
F_{avg} = 88021.266 N

TableIII
ANALYSIS RESULTS

Views	**AISI 1018**		**AISI 4130**		**Aluminium T6**	
	Total Deformation	**Equivalent Stress**	**Total Deformation**	**Equivalent Stress**	**Total Deformation**	**Equivalent Stress**
Front Impact						

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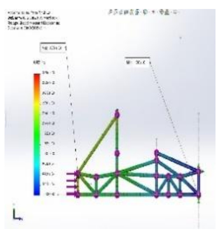
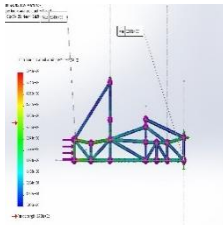
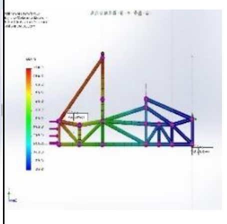
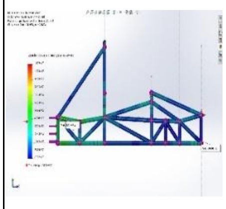
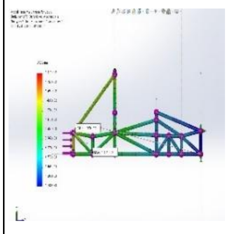
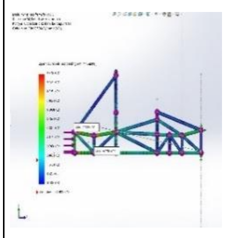
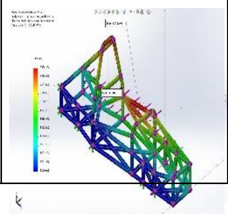
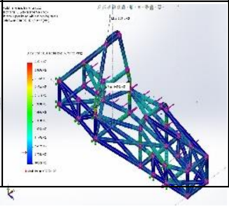
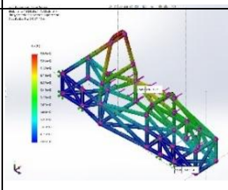
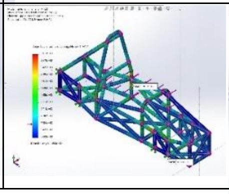
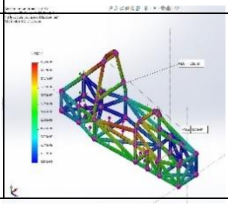
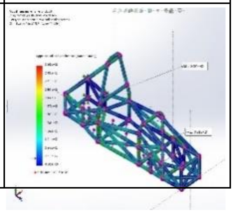
Rear Impact						
Side Impact						

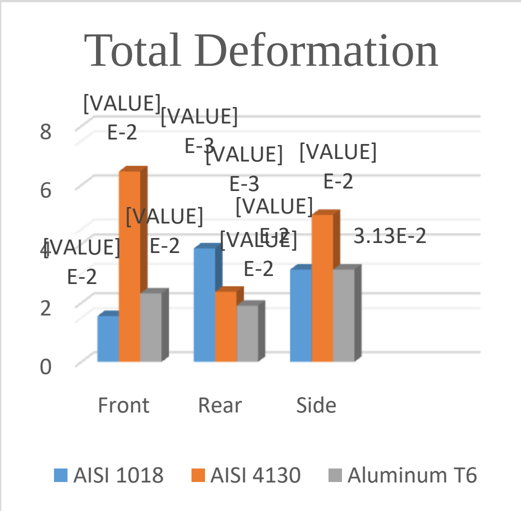


Fig.9Total deformation graph

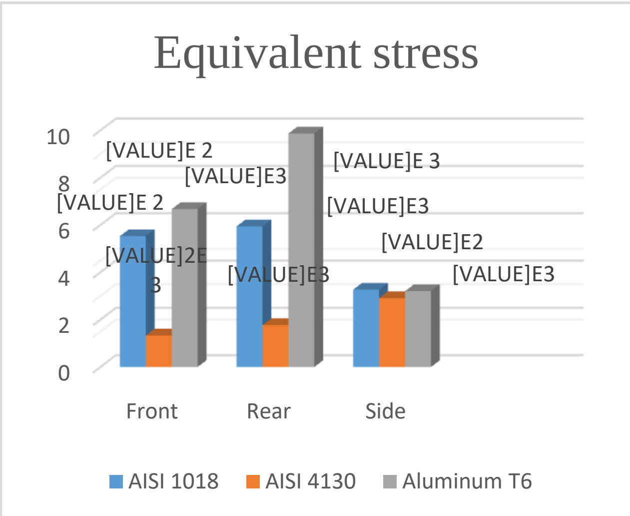


Fig.10 Equivalent stress graph

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VIII. RESULT AND DISCUSSION

All the analysis part was done and the results of various material was compared in the above graphical data but the front impact data alone was taken into an account. Since this Frontimpact have the highest probability of real time scenario. So, the Maximum Deformation occurs in AISI 4130 with a value of $6.464*10^{-2}$m and the Minimum Deformation occurs in AISI 1018 with a value of $1.557*10^{-2}$m and the Maximum Equivalent Stress occurs in $6.670*10^{2}$MPa and the Minimum Equivalent stress occurs in AISI 4130 with a value of $1.332*10^{3}$MPa.

Table IV
RESULTS FOR STRUCTURAL ANALYSIS

Name of Material	Total Deformation (m)	Equi., Stress (Mpa)	Equi.,Strain (pa)	Weight (kg)
AISI 1018	$1.557*10^{-2}$	$5.529*10^{2}$	$2.40*10^{6}$	141.12
AISI 4130	$6.464*10^{-2}$	$1.332*10^{2}$	$2.40*10^{6}$	137.19
Aluminum T6	$2.325*10^{-2}$	$6.670*10^{2}$	$2.41*10^{6}$	47.19

IX. CONCLUSION

The Objective of this research is to select a suitable material for a single seater vehicle made of Spaceframe tubular chassis and that material should be least Equivalent stress and least Equivalent strain. So, we did series of analysis for that study along with FEA calculation for a particular welded memberhere based on our simulations and calculations it is concluded that AISI 4130 shows the low Equivalent stress and Equivalent strain. Even though ALUMINUM T6 stands for Low weight by considering the Price factor AISI 4130 is the Optimistic material above all the three materials and it is BEST for Manufacturing purpose. And also, this material was suitable for building the Student formula racing car which highly demands the above optimization.

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