

Design Analysis of Roll Cage of BAJA ATV

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Abstract

Presented work is an attempt to introduce the material selection procedure, pipe size selection and various tests that need to be done before finalizing the design using ANSYS WORKBENCH 14.0. we used two different material to construct a roll cage primary material and secondary material. In this project work, various factors such as Factor of safety, deformation, von-mises stress, mesh size dependence of generated stress and impact forced are studied and also to understand working process of CNC machine. Our study aims to design, a roll cage, in accordance with the SAE. A roll cage is a skeleton of an All-Terrain Vehicle (ATV). The roll cage is the Structural base which protects the occupant in case of impact and roll over incidents. Here we are going to deal with design of roll cage for an ATV considering various loading tests like Front Impact, Side Impact and Rear Impact. We have focused on every point of roll cage to improve the performance of vehicle without failure of roll cage. Finally the roll cage will be fabricated as per the tools and techniques available in our workshop

Key words: All-Terrain Vehicle (ATV), Fabrication, Simulation

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I. Introduction

Roll cage is the skeleton of an ATV. The roll cage not only forms the structural base but also 3D surrounding the occupant which protect the occupant in case of impact and roll over of vehicle. The roll cage also adds the aesthetics of the vehicle. Roll-Cage is a frame of pipes providing a rigid structure and robust design to the vehicle. They can be used either as the only-frame (like in ATVs) or as the inner supporting structure in the conventional vehicles to provide strength against impacts. Here at the institute we designed and manufactured our roll cage and impact analysis is done using ANSYS. An off-road vehicle is considered to be any type of vehicle capable of driving on and off paved or gravel surfaces. It is generally characterized by having large tires with deep, open treads, and flexible suspension. Off-road vehicles have enthusiastic followers because of their many purposes and unmatched versatility. Several types of motorsports involve racing various models of off-road vehicles. With the growing Indian economy, there is emerging population of rich and wealthy people hungry for recreational activities and growing devoted fans of motorsports. The most popular "4-wheel off-road vehicle" in the Indian market is the hand-bar steering type. With the increased popularity and use of this type of motor vehicle there is a growing safety concern. Several accidents and injuries related to off-road vehicles have been reported. As much as it is fun to ride this type of vehicles, they do not provide safety measures to the drivers. There is an opportunity to introduce a 4-wheel off-road vehicle, which can provide the same experience, but superior safety. This project is focused on the design and manufacture of a 4-wheel off-road vehicle, capable of offering a comfortable and safe driving experience, while producing high performance for the Indian market.

II. Problem Statement

Current off-road vehicles in the market offer performance and entertainment to the Indian customers interested in the motorsport; however, they do not offer minimum safety features in order to prevent the drivers from harm, due to common tipping and collision accidents.

Objective

The goals of this project are to design and manufacture a single-seat 4-wheel off-road vehicle for the Indian market. The vehicle will be capable of providing a safe and comfortable ride to the customer, Off-road Vehicle Design and fabrication while offering maximum performance.

III. Methodology

1. Creation of a cad model of the structure.
2. Generation of mesh.

3. Application of the loads & constraints in depending.
4. Solution of the respective test Determination of the stress values and deformation forces.
5. Modification of Cad- design.

Repetition of the process till safe design is obtained.

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

- a) Most accurate –preferable
- b) Level of assumption is very less
- c) Capture the geometry
- d) Give results on joints
- e) Triad or Quad or mixed element meshing.
- f) Output received von-misses stress & displacement on 1D element.
- g) Only cross section of pipe is required.
- h) Average element size - 4 or 5 mm to capture the geometry properly.

3.1 Important Rules and Dimensional Constraints given in the SAE BAJA Rule Book.

1. The rules and regulations given in the SAE BAJA rule book need to be followed while designing the roll cage. The clearance and dimensional limitations are the main design
2. The intersection point D shown in the Figure 5 need to be properly designed as shown in the image.
3. Dimensional requirements of the roll cage member material: Wall thickness : 3.05mm Outer diameter : 25.4mm With carbon content at least 0.18%
4. The above given dimensions is for AISI 1018, if you are not using AISI 1018 then we have to select a material such that it should have the bending strength and bending stiffness at least equal to AISI 1018.
5. If we are using different material other than AISI 1018 then the wall thickness should be at least 1.57mm. With carbon content at least 0.18%.
6. Dimensions given in the rulebook are measured between centerlines.
7. Length of the straight member must not exceed 40 inches between the named points.
8. Bends must not have a bend greater than 30 degrees and should not exceed 28 inches between the named points.
9. Small bend radii 6 inches and terminate at named points
10. Named points must lie between the tangents of the bend.

DESIGNING THE ROLL CAGE

1. Start by reading the rulebook issued by SAE BAJA. You should be thorough with all the terms, constraints and rules mentioned in the rulebook.
2. Consider the tallest member of the team as the driver and make him to sit in driving position with this in reference start making a chalk diagram of the belly pan.
3. Take inputs from all departments for mounting of suspension arms, engine, gearbox, seat, braking components. The Track width, Wheel base and the Driver constraints should be the first factor that need to be considered. This should always be maintained in the design of the roll cage.
4. The Rear Roll Hoop (RRH) should be the first feature need to be designed. It can be angled at 90 degrees to 75 degrees the air drag need to be considered while deciding it as the RRH of the roll cage decides the frontal area of the vehicle.
5. Working forward, the front end should be designed according to suspension mounting points which need to be predetermined already by the suspension team.

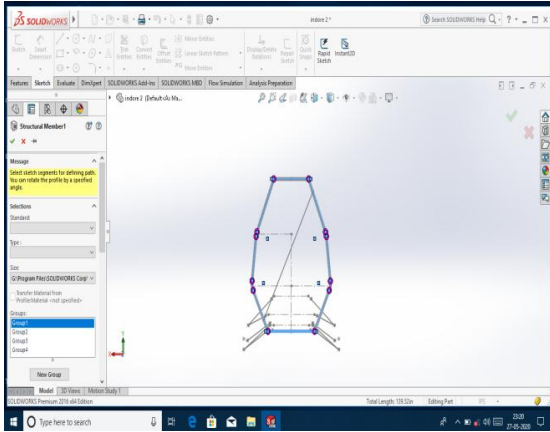


Fig.(a)
Design of Down section of roll cage

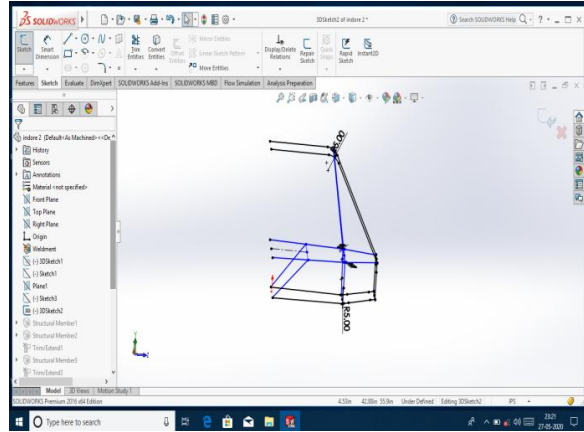


Fig.(b)
Design of front view of roll cage

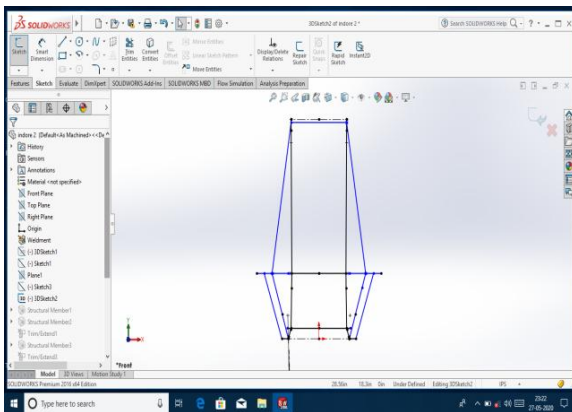


Fig.(c)
Design of back view of roll cage

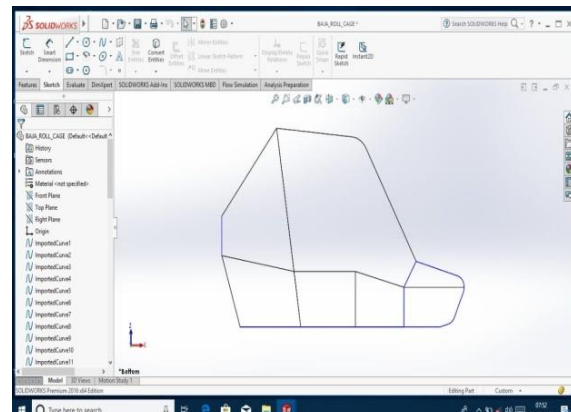


Fig.(d)
Side view of roll cage design.

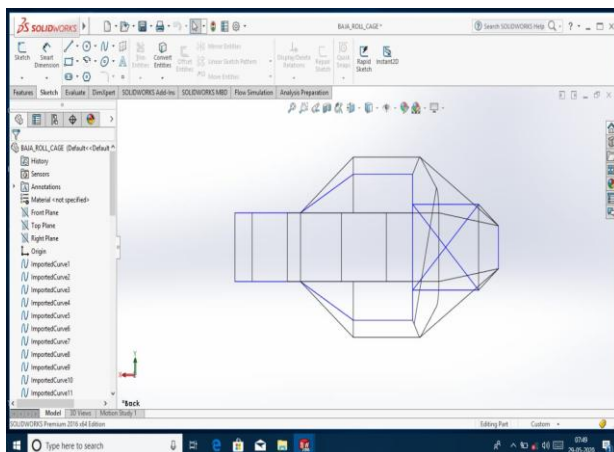
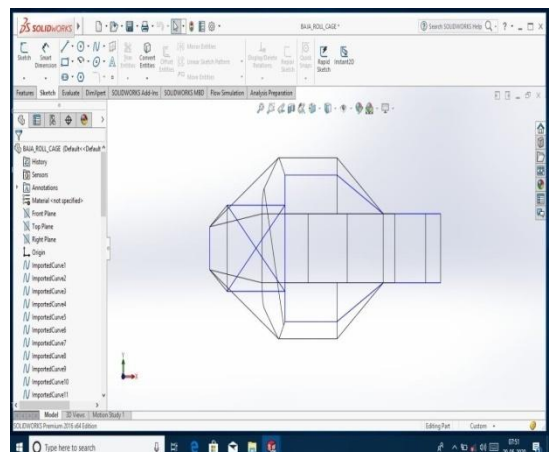


Fig.(e)
Design of left view of roll cage



FFig. (f)
Design of right view of roll cage

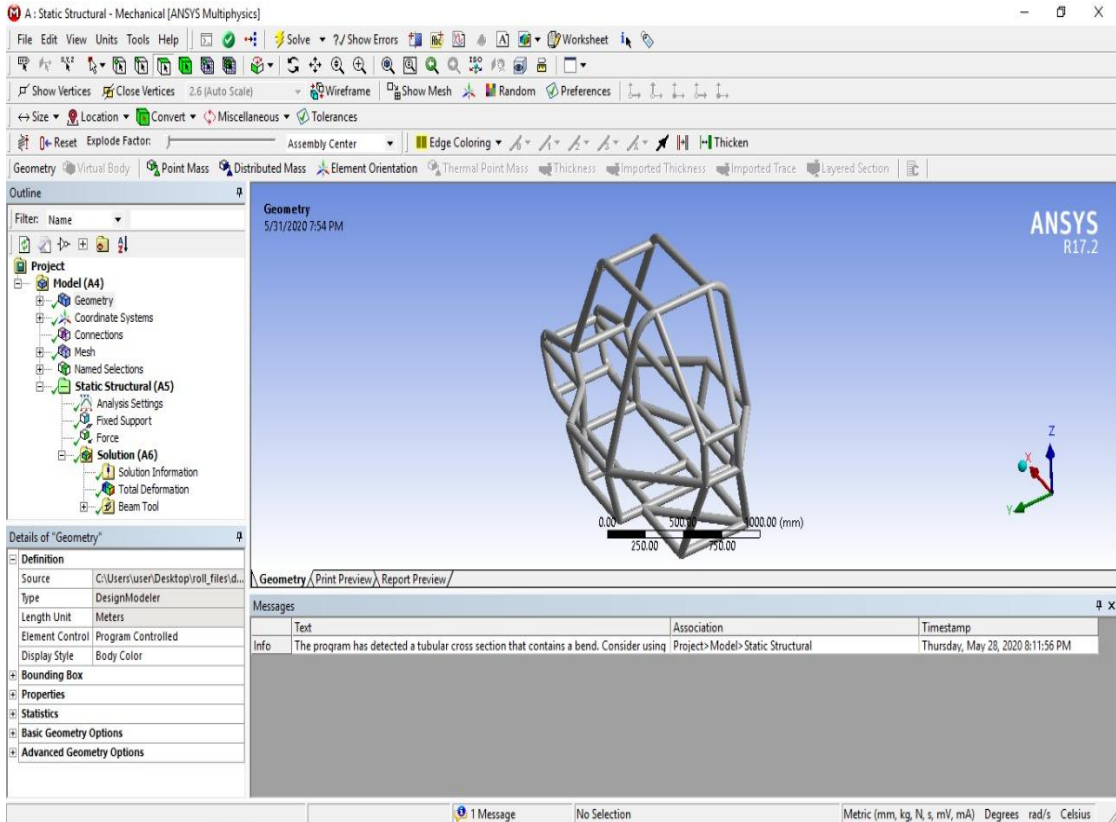


Fig.(g)
Mesh generation of roll cage design

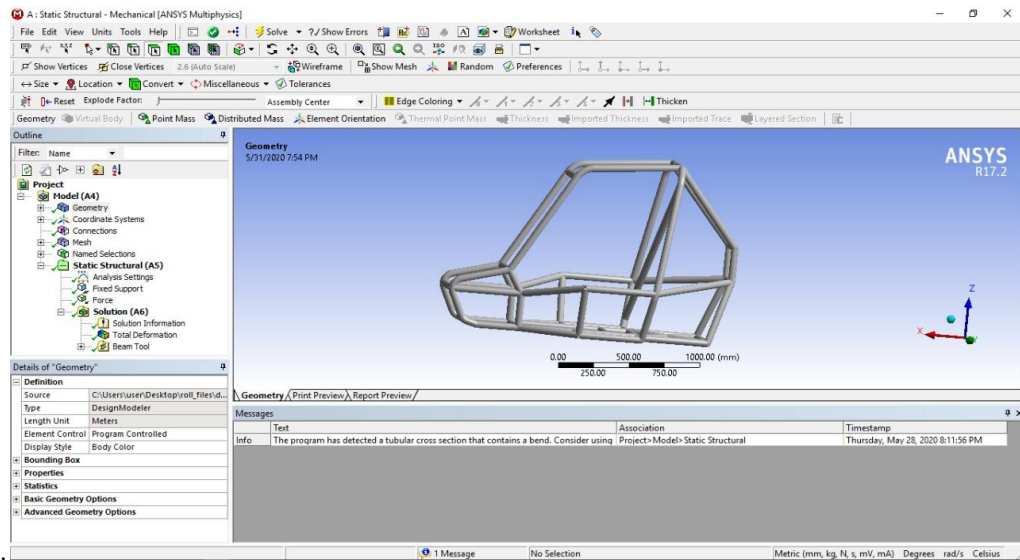


Fig.(h)
Material Applied on the roll cage design

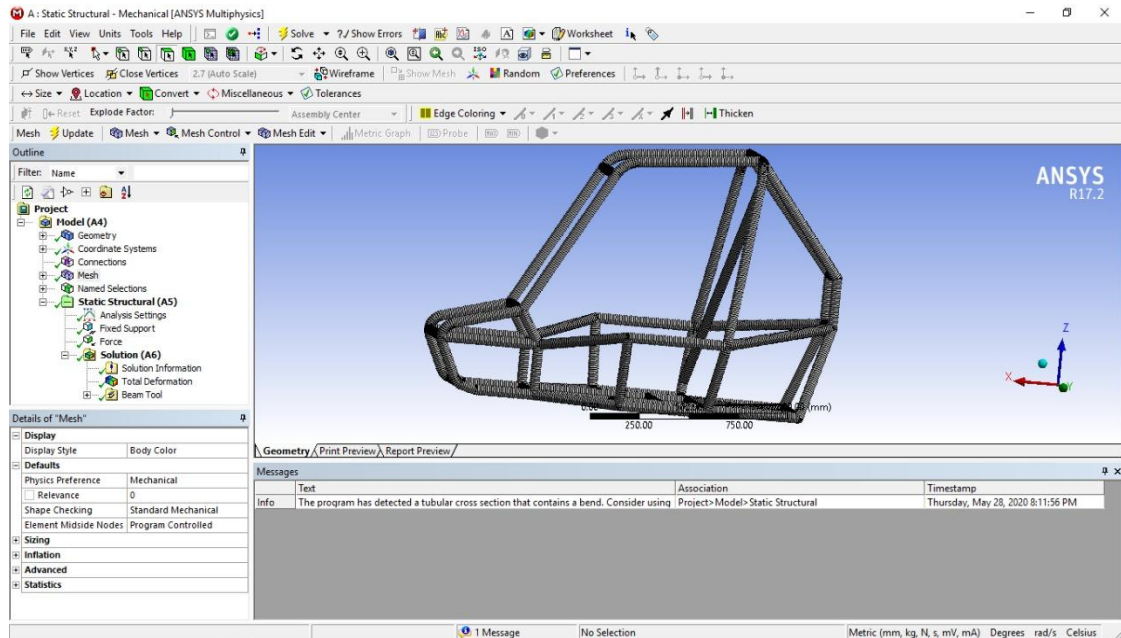


Fig.(i)
Final design of roll cage of BAJA ATV

IV. Design Consideration

Selection of proper material for building of roll cage is very important. There are various material available. For this consideration various parameter like cost, weight, availability, mechanical properties and manufacturing conditions comparison various material is show in table.

4.1 Design

For designing the roll cage of the ATV several software are available and it is up to you which software you choose. I used Siemens NX 10 software developed by Siemens. Before starting on the software I recommend sketching it on a rough paper. Get your team together and note down all the ideas that are floating in your mind. The key points while sketching your design could be as flows:

1. Avoid sharp edges as much as possible. Sharp edges have a higher stress concentration on its surface and this decreases the overall strength of the vehicle.
2. Check for the ergonomics of the driver as the whole body of the driver should always be inside the cage and sufficient spaces should be left to achieve that.
3. The vehicle should not be too long. In our case we were building the ATV for a competition so we were given a maximum value.

Now once you are done with the sketching and have few sketches to design. Model them on the software. Always keep the weight is mind because the overall weight of the vehicle should be as low as possible. Now to keep the weight to a minimum we used variable thickness for the tubes. We kept the thickness of primary member as 4mm and secondary members had a thickness of 3mm. this way we reduced the weight and did not compromise much on the strength of the vehicle. We also recommend working with triangles especially for side members. The advantage of using triangle shaped side members is that they are able to take more load than the usual straight or any other shaped side member. Always try to reduce space where ever you can this could help you in reducing the weight of the roll cage.

4.2 Front Impact Test

Few approximations were taken Weight=300kg $v(\text{initial})=16.67\text{m/s}$.

$v(\text{final})=0$

Impact time=0.1sec

$a=v/t$

$a=16.67/0.1=166.7$

$F=m*a$

$=300*166.7=50,000\text{N}$

Now this is the impact force applicable on the front of the roll cage and by ansys we came with the following results:

A) Stress concentration	
B) Total deformation	
Front impact	50,000N
FOS	1.90
Total deformation	11.874mm
Maximum stress	498.67Mpa

FOS stands for factor of safety and it is suitable to have a FOS of 1.5 or above. We took impact force as 50,000N and got a max stress concentration of 498.67Mpa. We took the tube material as AISI 4130 so all the calculations are done with respect to that.

Crash test is a form of destructive testing usually performed in order to ensure safe design and standards in crashworthiness and crash compatibility for various modes of transportation or related systems and components. Front impact test which is what most people initially think of when asked about a crash test. Vehicles usually impact a solid concrete wall at a specified speed, but these can also be vehicle test.

Table .1
Material properties

	AISI 1018	AISI 1040	AISI 4130	AISI 5130	AISI 1020
Density kg/m ²	7700	7845	7700	7700	7700
Ultimate strength N/mm ²	634	518.08	560	580	394
Yield Strength N/mm ²	388	353.4	480.8	430	294.8
Young's Modulus GPa	200	200	200	200	200
Hardness BHN	197	149	156	379	111

Table . 2
Material selection and dimension

	Material	Outer Diameter	Inner Diameter	Wall Thickness
Primary member	AISI 4130	25.4 mm	22.1 mm	1.65mm

Here we have taken a single material AISI 4130 but we can also use other materials such as AISI 1018 AND AISI 1026. AISI 4130 material having a good strength and it can weld easily and it have a low weight.

V. Modeling

Preparation of CAD Model

For setting dimensions reference of SAE INIDA BAJA 2016 Rule book was Taken .Consider all the other points dimensions all member were set and model of roll cage was prepared using solid work.

The finite element model is prepared in CAD system which involves feature recognition and detail removal. In order to make the analysis conforms to practical needs and improve computational efficiency, additional operations are added in local regions before mesh generation to control local mesh density.

In spite of the widespread use of Computer Aided Design (CAD) systems for design and Computer Aided Analysis (CAE) systems for analysis, the two processes are not well integrated because CAD and CAE models inherently use different types of geometric models and there currently exists no generic, unified model that allows both design and analysis information to be specified and shared. In this paper, finite element-based model transformation method is proposed to realize information mapping from CAD to CAE. The element and node information is abstracted from finite element model and transformed to CAE system. CAD is mainly used for detailed engineering of 3D models or 2D drawings of physical components, but it is also used throughout the engineering process from conceptual design and layout of products, through strength and dynamic analysis of assemblies to definition of manufacturing methods of components. It can also be used to design objects such as jewelry, furniture, appliances, etc. Furthermore, many CAD applications now offer advanced rendering and

animation capabilities so engineers can better visualize their product designs. CAD has been proven to be useful to engineers as well. Using four properties which are history , features, parameterization, and high-level constraints. The construction history can be used to look back into the model's personal features and work on the single area rather than the whole model. Parameters and constraints can be used to determine the size, shape, and other properties of the different modeling elements. The features in the CAD system can be used for the variety of tools for measurement such as tensile strength , yield strength, electrical or electromagnetic properties.

VI. Material Selection

AISI 4130 alloy steel contains chromium and molybdenum as strengthening agents. It has low carbon content, and can be welded easily. The datasheet below provides further detail.

Chemical Composition

The chemical composition of AISI 4130 alloy steel is listed in the following table.

**Table.3
Chemical composition**

Element	Content (%)
Iron, Fe	97.03
Chromium, Cr	0.80
Manganese, Mn	0.40
Carbon, C	0.280
Silicon, Si	0.15
Molybdenum, Mo	0.15
Sulfur, S	0.040
Phosphorous, P	0.035

**Table.4
Physical Properties**

Properties	Metric	Imperial
Density	7.85 g/cm ³	0.284 lb/in ³
Melting point	1432°C	2610°F

Conversion

1mm=0.03937 inch.

1cm=0.3937 inch.

1gm=0.0022 pound.

1 Celsius=33.8 Fahrenheit.

**Table.5
Mechanical Properties**

Properties	Metric	Imperial
Tensile strength, ultimate	560 MPa	81200 psi
Tensile strength, yield	460 MPa	66700 psi
Modulus of elasticity	190-210 GPa	27557-30458 ksi
Bulk modulus (Typical for steel)	140 GPa	20300 ksi
Shear modulus (Typical for steel)	80 GPa	11600 ksi
Poissons ratio	0.27	0.27
Elongation at break (in 50 mm)	21.50%	21.50%
Reduction of area	59.6	59.60%
Hardness, Brinell	217	217
Hardness, Knoop (Converted from Brinell hardness)	240	240
Hardness, Knoop (Converted from Brinell hardness)	240	240
Hardness, Rockwell B (Converted from Brinell hardness)	95	95
Hardness, Rockwell C (Converted from Brinell hardness, value below normal HRC range, for comparison purposes only.)	17	17
Hardness, Vickers (Converted from Brinell hardness)	228	228
Machinability (Annealed and cold drawn. Based on 100% machinability for AISI 1212 steel.)		

Thermal Properties

Properties	Metric	Imperial
Thermal conductivity (100°C)	42.7 W/mK	296 BTU in/hr.ft2. °F

VII. Future Scope Of Roll Cage Design Model

1. Machinability - AISI 4130 steel can be easily machined using conventional methods. However, machining becomes difficult when the hardness of the steel is increased.
2. Forming of AISI 4130 steel can be performed in the annealed condition.
3. Welding of AISI 4130 steel can be performed by all commercial methods.
4. Heat Treatment - AISI 4130 steel is heated at 871°C (1600°F) and then quenched in oil. This steel is usually heat-treated at temperatures ranging from 899 to 927°C (1650 to 1700°F).
5. Forging of AISI 4130 steel can be performed at 954 to 1204°C (1750 to 2200°F).
6. Hot working of AISI 4130 steel can be done at 816 to 1093°C (1500 to 2000°F).
7. AISI 4130 steel can be cold worked using conventional methods.
8. AISI 4130 steel can be annealed at 843°C (1550°F) followed by air cooling at 482°C (900°F).
9. Tempering of AISI 4130 steel can be performed at 399 to 566°C (750 to 1050°F), depending on the desired strength level.
10. Hardening of AISI 4130 steel can be done with cold working or heat treatment.

VIII. Material Calculation

As per the constraint given in the SAE BAJA rulebook, the roll cage material must have at least 0.18% carbon content. After an extensive market survey the material which can be used for the roll cage is shortlisted, the comparative study of these shortlisted materials is done on the basis of strength, availability and cost. The shortlisted materials are as follows.

1. AISI 1018
2. AISI 4130
3. AISI 1026
4. AISI 4130

4130 steel gets its name from specific rules outlined by the AISI and SAE. The first digit of the alloy designates the class of the steel, including its major alloying component(s). The second digit represents the relative percentage of this alloying element and/or other important secondary elements.

Below is an exact chemical breakdown of 4130 steel, with tolerances:

- 0.28 - 0.33% Carbon
- 0.8 - 1.1% Chromium
- 0.7 - 0.9% Manganese
- 0.15 - 0.25% Molybdenum
- ≤ 0.035% Phosphorus
- 0.15 - 0.35% Silicon
- ≤ 0.04% Sulphur

AISI 1026

Carbon steels are steels that contain only carbon as their specific alloying element. Traces of 0.4% silicon and 1.2% manganese can be found in these steels.

1026 carbon steel is outlined in the following table.

Element	Content (%)
Iron, Fe	98.73
Carbon, C	0.220
Manganese, Mn	0.60
Sulfur, S	0.05
Phosphorous, P	0.04

AISI 1018 Mild/Low Carbon Steel

AISI 1018 mild/low carbon steel has excellent weldability and produces a uniform and harder case and it is considered as the best steel for carburized parts. AISI 1018 mild/low carbon steel offers a good balance of toughness, strength and ductility. Provided with higher mechanical properties, AISI 1018 hot rolled steel also includes improved machining characteristics and Brinell hardness.

Chemical Composition

The chemical composition of AISI 1018 carbon steel is outlined in the following table.

Element	Content (%)
Manganese, Mn	0.60
Carbon, C	0.15
Sulfur, S	0.05
Phosphorous, P	0.04

IX. Conclusions

The use of finite element analysis was valuable to the design and analysis of the frame for SAE BAJA off road vehicle. We had successfully analyzed the roll cage structure for its strength against the collision from front, rear as well as side.

This paper thoroughly deals with various load analysis on roll cage and optimization has been achieved by reducing the weight of the roll cage. Roll cage designed is perfect for use in BAJA SAE event with all the systems perfectly mounted on it.

Material selection for each and every component remained a priority for the team considering an optimum strength to weight ratio, durability, cost effectiveness and feasibility. Real time conditions were simulated using various FEA packages like Solidworks, ANSYS, and critical parts of ATV were analyzed for safety and optimization issues. The parts were manufactured in techniques which can be considered suitable for mass production of this model, if introduced in market.

After having lots of study, efforts and observations we came to the conclusion that our project results into light weight compared to other roll cages, reduced space requirements, reduction in material wastage, reduction in cost, multiple usage, easy for implementation, survival in un-ground surfaces and gives safety to the driver for smooth driving.

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