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Design and Development of Roll Cage :-A Review

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Abstract - A Roll-Cage is the framework of an ATV (All-Terrain Vehicle) around which the whole vehicle parameters will revolve. Proper methods of designing ensure a strong and safe ATV in return providing a more appealing and aesthetic vehicle. The design modeling guidelines used are according to the safety and comfort of the driver. The whole process is done on various software used by various designers such as Catia V5, Solid-Works, Creo. Material selection is also done with help of optimization to find best material to make the vehicle lighter for better performance. The analysis of the designed roll-cage is done to find the short comings and to overcome that further developments are done. So analysis is major part in development of a Roll Cage. Impact test are performed on the designed roll cage. This test includes Side impact test, Front impact test, Rear impact test and Torsional test. These tests help us to identify the condition of our vehicle in worst scenario at maximum bearing capacity. This is done on ANSYS Software.

Keywords—Roll Cage,Optimization,Development.

INTRODUCTION

An ATV also know as quad bike, three-wheeler or four wheeler, is defined by the American National Standards Institute(ANSI) as a vehicle that travels on low pressure tires, with a seat that is straddled by the operator, along with handlebars for steering control. A roll cage is the skeleton of the ATV. The roll need to be properly design and developed. The design and development of a roll cage involves steps which have been studied accordingly through the various papers. This steps involved are material selection, frame design, cross section determination and then analysis of the designed roll cage.

A) Design Guidelines:-

Mostly the design guidelines used are the rule setup by SAE (Society of Automotive Engineering) organized event BAJA. In which they test the skills of students by setting limitation in designing. These guidelines are mainly made for the safety of the driver in worse condition as life is everything that matters. These rules fix the geometry to some extend beyond which we cannot make changes. The development done with this guideline will make the ATV the best or the worst.

B) Review

A systematic review of all the papers from the year 2012 to 2014 is done. This paper deals with a systematic study of the improvement done year by year by various teams which have helped them to improve their vehicle for better result. The points to be emphasized are as follows

Methodology used for

1) Material selction
2) Frame Designing
3) Analysis (FEA)

Review

Method 1[1]

Simulation of the roll cage was done on ANSYS software. While designing the main concern was passenger safety and reduction in weight of the roll cage by reducing the size of the vehicle up to the tolerated limits i.e. making it as per the dimensional limits. After the designing proper meshing of the roll cage is always a key factor to perform FEA (Finite Element Analysis). Hexahedron meshing was done here. The boundary conditions that rear member bear zero degree of freedom and the front member will come across the applied load are applied. Material used for roll cage is AISI 1020.

Analytical calculation for frontal impact is done using the equation

W_{net}= *force*displacement*

$W_{net} = \frac{1}{2}mv^2(final) - \frac{1}{2}mv^2(initial)$

A.1. Result: - The test values are as follows

Yield strength of material = 294.8MPa
Maximum value after impact = 191.299MPa
Factor of safety obtained = 1.54
The stress generated in impact is well within the limit so the design is accepted and further work was preceded.

Method 2[2]

The objective of design and development of roll cage was done according to the norms and standard guidelines set up by SAE organized mini BAJA event. A thorough study of the rule book has been done for designing the chassis. In chassis the frame work is designed as per manufacturing feasibility and well within the dimensions of safety and comfort. The objective was to minimize the number of welded joints on the frame in favor of bent members as bending shows a much lower stress concentration. While performing the work of initial design the roll hoop, horizontal hoop and two perimeter hoops are made using solid-works software.

Material Selection plays an important role in reduction of weight and increasing safety of the vehicle the following materials were shortlisted for the chassis:- 1020 DOM, 4130 Chromalloy, IS 3074 CDS4, 1018 Steel

Analysis of the designed roll cage is done in ANSYS software. Various impact test are performed on the roll cage they are as follows:- Front impact, Rear impact, Side impact, Roll over, Front bump, Rear bump, Torsion test.

B.1. Result:-

The following tables show the result of materials selecting for the chassis

Parameter	IS 3074 CDS4	1018 STEEL	1020 DOM	4130 CHROMOLY
Yield Strength	430 M Pa	365 M Pa	350 M Pa	470 M Pa
Bending Stiffness	2390 Nm²	1572.3 Nm²	1572.3 Nm²	1572.3 Nm²
Bending Strength	274.95 Nm	223.96 Nm	214.76 Nm	266.92 Nm
Weight (kg/ft)	0.390 Kg	0.508 Kg	0.371 Kg	0.371 Kg
Cost/ft	121 Rs/ft	80 Rs/ft	112 Rs/ft	400 Rs/ft
REMARKS	MIG Welding, easy availability.	More weight, Base Metal.	Less Availability.	High cost, TIG Welding.

Table.1 material properties

PARAMETER	IS 3074 CDS4	1018 Steel	1020 DOM	4130 CHROMOLY
Weight	4	2	4	4
Cost	3	4	3	1
Manufacturability	4	4	4	2
Strength	4	1	3	4
Total	15	11	14	11

Table.2 material comparison matrix

From the above table it is clear that the material to be selected is 3074 CDS4 with the help of proper optimization.

The following table will show the result of impact stress

Load Type	Load Applied	Factor of Safety	REMARKS
Front Impact	10G	2.14	Satisfied
Side Impact	5G	1.78	Need additional bracings to fire wall
Rear Impact	5G	4.5	Satisfied
Roll–over	3.5G	2.22	Satisfied
Front-Bump	3G	3.62	Satisfied
Rear-Bump	3G	2.2	Should add bracings to fire wall
Torsion	2.5G	3.86	Satisfied

From the above results the final changes are made and the design is finalized.

C. Method 3[3]

The design, development and fabrication of the ATV is done according to the guidelines set by BAJA 2013. The roll cage adds to the aesthetics of the ATV. The design and development follows the same set of process.

In material selection process the selected material should have at least 0.18% carbon content. Which helped in short listing the following materials:- AISI 1018, AISI 4130, AISI 1026.

The frame design of an ATV begins with some design guidelines fixed for the arrangement of all the ATV needs such as engine and transmission etc. while designing it is necessary to keep the weight and centre of gravity of the roll cage as low as possible for better acceleration and to avoid toppling respectively. Bends are preferred than welds.

Finally the analysis of the roll cage is done with the help of finite element analysis. To test the full strength of the roll cage the following test are done front impact test, wheel bump test and longitudinal torsion test.

C.1. Calculations:-

C.1.1. Material selection:-The design is tested for the shortlisted materials and the following results are obtained.

For AISI 1018 - Total Weight of the Roll Cage: 80 kg

Total Cost: Rs. 4400

For AISI 1026 - Total Weight of the Roll Cage: 70 kg

Total Cost: Rs. 4620

For AISI 4130 - Total Weight of the Roll Cage: 55 kg

Total Cost: Rs. 8250

A balance is struck between the strength, weight and cost of the materials and AISI 1026 with carbon content 0.2% is selected as the roll cage material

C.1.2. Front impact test:- Mass of vehicle is 350kg and speed is 60kmph is set .

By applying Newton's 2nd law,

F = change in momentum/time

F= (m*(v-u))/t

F= (350*(0-16.67))/0.18

F = 32413N

Max Bending Moment (M) = 2390 kg-inch = 595.52 N-m

M/2 = 297 N-m, which is less than the permissible value of AISI 1026.

C.1.3 Wheel Bump test

The maximum stress value obtained is 126.729 KN/in^2 (196.43 MPa). Therefore the design is safe

C.1.4 Longitudinal Torsion test

The maximum stress value obtained is 126.729 KN/in^2 (196.43MPa). Therefore the design is safe

C.2. Result:-

From the above calculation the design is safe so it is finalized for further fabrication and all.

Method 4[4]

Society of automotive engineers organized BAJA is an student design competition to inculcate in students the general practice of good engineering. For the design purpose the further process have been followed

The designing of the roll cage is done in 3-D environment of CATIA V5. Then further material selection process was done from the material options provided by BAJA. The material selected was AISI 1018 with uniform cross section. The following table shows the properties of the material

Parameter	Value	Unit
AISI 1018	-	
Outer Diameter	25.4	Mm
Thickness	3	Mm
Young's Modulus of Elasticity	250	GPa
Permissible Yield stress	365	N/mm^2
Poisson's ratio	0.3	-
Carbon Content	0.18	%

Analysis of the chassis is performed on ANSYS APDL. The line type element PIPE 16 is used. The analysis is done with some assumption such as material is isotropic and homogenous chassis joint are perfect.

Calculation of the analysis is as follows

Impact force determination by speed limit:-

Impact force=$\frac{1}{2}mv^2$

Where m=275kg and v=16.66m/s^2

Impact Force by Speed Limit(F1) ≈ 23,000 N

Impact force determination by acceleration limit:-

The 'Motor Insurance Repair Centre' has analyzed that the baja car will see a maximum of 7.9 G's of force during impact

Impact Force by Acceleration Limit (F2) ≈ 21,400 N

Impact force determination for worst case scenario:-

A value of 10 G's was considered for an extreme worst case collision

$F3$ = 26,700 N

Assuming a factor of safety of 1.25 for the body frame, a force of 33,000 N is applied in the analysis

D.1. result

A complete study of material used with analysis has been done.

Method 5[5]

For designing of any component three major principles is used

1) optimization
2) safety
3) comfort

The primary objective of the roll cage is to provide a 3-d space to keep the driver safe. For the roll cage manufacturing should be done at low cost with proper material selection and lest number of welds. Use more of bends. Through optimization the material is selected. The design of the roll cage is done by using pro-e software. Improvement is the main motto without failure of roll cage. The design is done within the guidelines provided. To obtain low centre of gravity the engine, seat etc is mounted on the chassis.

Material property

Subject	Property	
Material	ST-52	
Carbon%	0.20%	
Density	7.8 *10^3 kg/m^3	
Yield strength	355MPa	
Young's modulus	210GPa	
Poisons ratio	0.30	
Roll cage weight	56kg	
Total weight of the vehicle	275 kg(appr)	

Finite Element Analysis is done after the final design of the roll cage is done. The various test that are performed are front impact test, side impact test, rear impact test.

Calculation

Impact load test:-

Using the projected vehicle/driver mass of 400 kg, the impact force was calculated base on a G-load of **4**.

F = ma .... (1)
= 400*4*10
= 16000 N

Impulse time =400*(16.67/16000)
= 0.32

Result:-

Successful analysis of the roll cage structure for its strength against the collision from front, rear, as well as side is done. Factor of safety is under the safe limit. The roll cage is sustained 4G force from front as well as rear & 2G force from side. Hence, deformation & stresses are under the limit.

Method 6[6]

The ATV design consist of all parts such as the chassis, suspension, steering etc which requires an thorough study and proper analysis. The process for design begins with the basic frame design and material selection. The material selected for the process of the roll cage manufacturing is 4130 Chrome Moly Steel. The reasons for selection of 4130 over the 1018 is its greater strength to weight ratio. Different sizes were consider from which it was decided that the roll cage will be manufactured using an pipe of 1 inch outer diameter and 3mm thick wall of 4130 steel. The below table shows the detail:-

MATERIAL	1018 STEEL	4130 STEEL	4130 STEEL
OUTSIDE DIAMETER	2.540 cm	2.540 cm	3.175 cm
WALL THICKNESS	0.304 cm	0.304 cm	0.165 cm
BENDING STIFFNESS	3791.1 Nm^2	3 791.1 Nm^2	3635.1 Nm^2
BENDING STRENGTH	391.3 Nm	467.4 Nm	487 Nm
WEIGHT PER METER	1.686 kg	1.686 kg	1.229 kg

*The yellow color shows the selected material.

Roll cage design considerations are as follows:-

Type	**Space Frame**
Material	Normalized AISI 4130 Chrome-Moly. Steel
Mass of Roll cage	21.61 kg
Length of Roll cage	64.14 inches
Width of Roll cage	10.5 inches
Height of Roll cage	22.29 inches
Total length of pipes	13.04 m
Weld joints	42
No. of Bends	15
Cross section	Outer Diameter - 25.4 mm Thickness - 3mm

Finally the analysis of the roll is done with the help of finite element analysis. Various consideration are done while analysis. For consideration they found out that the human body will pass out at 7g force and crash pulse scenario by industry is 0.15 to 0.3 sec but they considered 2.5 sec. The software used for analysis was ANSYS.

Static analysis of roll cage consist of :-

Front impact, side impact, roll over, one wheel bump, torsional rigidity, heave analysis.

Frontal Impact Analysis:-

Frontal Impact	6G(15303.6 N)
Max. Deformation	2.43 mm
Max. Stress	150.331 Mpa
Factor of Safety	3.05 (> 2 Design is Safe)

Roll Over Impact Analysis –

Roll over Impact	3.5G (8927.1 N)
Max. Deformation	0.46 mm
Max. stress	80.63 Mpa
Factor of safety	5.70 > Design is Safe)

CONCLUSIONS

A thorough review of all the six papers has been done. The papers study is done in chronological order of year from 2012 to 2014. From which it was easy to see that improvement in method of design, material selection and analysis.

Material selection:-

Material selection as a whole has gone through a proper growth which includes a proper optimization of all the materials, strength to weight ratio check, cost consideration and reduction in weight for better performance in common.

Frame designing:-

The frame design also has gone the same growth which includes reduction in number of members and use of more professional software's for design.

Analysis:-

The analysis growth is also considerable, improvement is done with various addition of different impact test, roll over.

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