CAE ANALYSIS OF SOLAR VEHICLE STRUCTURE

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ABSTRACT

This paper describes computer aided finite element analysis of solar vehicle structure. The present work is an improvement of design of solar vehicle chassis or roll cage to reduce the weight and increase the strength of the vehicle. Tubular space frame type of chassis is used for making structure of the solar vehicle. The chassis employs dozen of circular section tubes which is rigidly joined through welding. Tubular space frame chassis also very strong in any direction as compared with another type of chassis of the same weight. The material of tube for making the chassis is structural steel AISI 1018. This material was chosen because of easy availability and affordability along with adequate strength. Also, it met the baseline requirements of the allowed materials to be used. The CAD modeling of solar vehicle structure has been done in CATIA V5 and for analysis the model is imported in ANSYS-16 workbench. The finite element analysis (FEA) of the solar vehicle structure has been carried out by initially discretizing the model into finite number of elements and nodes and then applying the necessary boundary conditions, Maximum displacement, directional displacement, equivalent stress and weight of the chassis are the output target of this analysis for comparison and validation of the work.

1. INTRODUCTION

Solar vehicle is a kind of vehicle which runs with the help of solar energy. Solar energy is a renewable energy which emits zero emission. Photovoltaic cells are used to convert solar energy into electrical energy and this electrical energy is stored in battery in the form of chemical energy. At the time of running of the vehicle energy gets from the battery and which is helpful for running of the vehicle. Due to the increase of the price of the fuel, pollution etc, it is the need of today to use renewable energy and solar energy is the best alternative. Motor vehicle is mainly supported on chassis to which all other components are attached. Tubular space frame type of chassis is used for modeling the structure of solar vehicle. The material used is structural steel AISI 1018. Design and analysis software can be used to model or simulate and analysis of almost every aspect of a structure or operation. Different parts of solar vehicle can be modeled through CAD software. The finite element analysis (FEA) or finite element method (FEM), is a numerical method which is used for solving problems of engineering and mathematical physics. Structural analysis, fluid flow, heat transfer, mass transport and electromagnetic potential problems are typical areas of interest. Generally require the solution of boundary value problem of partial differential equation for analytical solution of these analytical problems. Problem results in a system of algebraic equations can be formed through finite element method. The method provides approximate solution of the unknowns at different number of points over the domain. To find the solution of the problem, it subdivides a big problem into smaller parts, simpler parts that are known as finite elements. The simple equations which model these finite elements are then joined into a larger system of equations that forms the entire problem. FEM next uses variational methods from the calculus of variations to near a solution by minimizing an allied error function. Computer-aided engineering (CAE) is the extensive usage of computer software to assist in engineering analysis tasks. It contains finite element analysis (FEA), multi body dynamics (MBD), computational fluid dynamics (CFD), durability and optimization. The model of the solar vehicle which is ready with the help of CATIA V5 and the analysis of this structure is done with the help of analysis software ANSYS.

2. LITERATURE REVIEW

Anoop kumar et al. (2017) tells the history and future of electric and solar vehicles and provides and overview of a typical solar powered automobile. They discuss the working and their different component which is related to solar vehicle. *A. Karim and Z. Shahid (2018)* presents important details about the change of a conventional fossil fuel-based car into a solar-electric hybrid (SOLECT) car. Change of a conventional car into a SOLECT car can help people to protect environment and save on fuel costs. Study on vehicles are getting transformed from a one source of energy to multiple sources of energy due to environment-related issues and ever-increasing fuel problems. *Ankit Vijayvargiya et al. (2017)* focuses on an idea about solar car technology and its integration into society which solves the major problem of pollution and fuel in now days. A complete experiment of solar car has been prepared in this paper by using a car. It is clear that this paper is able to get acquainted with this new area of photovoltaic solar energy application. The aim of author is to implement the less polluting and most efficient vehicles. In this the solar vehicle combine with the batteries, LM317 voltage controlling IC, and BLDC motor of an electric vehicle resulting in twice the fuel economy of earlier vehicle. *Umang R. Agravat et al. (2017)* provide ease for the rider while riding a bicycle and also to save energy by all possible means. The Solar rays charge the battery through the solar panel when the solar electric bicycle is kept under sunlight placed above the carrier of the bicycle. The battery gives energy to the electric motor in the back wheel. It also help in to down the resistance in pedaling to make it helpful to go up hills. *T. Vignesh et al. (2017*) proposed an improvement of the energy management system of a hybrid electric vehicle using an arduino processor. Hybrid power generation system is good and effective solution for power generation than conventional energy resources. It has greater efficiency. It can provide to remote places where government is unable to reach. So that the energy can be consume where it produced so that it will reduce the cost and transmission losses. Cost reduction can be done by increasing the production of the equipment. *Abhinya Chaturvedi et al (2015)* study of all previous works related to the electric and solar cars have been done. Solar powered vehicle is a three wheel drive and has been used for shorter distances. The main concentration was made on improving the design and making them cost effective. Energy from Sun is captured by the solar panels and is converted to electrical energy. Also, the rate of conversion of energy is not satisfactory (only 17%). But these disadvantages can be easily overcome by conducting further research in this area; like the problem of solar cells can be solved by using the ultra efficient solar cells that give about 30-35% efficiency. *Yasuji Shibahata et al. (2004)* talk about the chassis technology earlier to the 1980s had been progress as a technology of mechanical engineering field of that time. After the mid-eighties invention and practical application of four-wheel-steering system (4WS), especially the vehicle dynamics performance field out of chassis technology became a main stream of research and development for control technology. From then on, research and development of vehicle dynamics performance has been carried out as a collaborated technology of mechanical engineering and control engineering. *Pierluigi Pisu et al.(2001)* present fault detection and isolation is becoming one of the most important aspects in vehicle control system design. In order to achieve this FDI schemes, particular vehicle subsystems integrated with a controller have been proposed. This paper introduces a new Model-Based Fault Detection and Fault

Diagnosis method for monitoring the vehicle chassis performance. In this paper, a hierarchical model-based FDI scheme has been presented. The possibility of estimating the states of the vehicle has been demonstrated for a brake-by wire subsystem without mechanical backup. The validity of the proposed approach is examined by the extensive number of simulations performed. *Rafał Burdzik et al(2012)* provide a conversation on the studies comprising active experiments conducted on elected structural elements of vehicles, the aim of which was to evaluate the vibration propagation in vehicles construction. The vibration excitation was achieved by applying an engine working on idle gear. The studies were conducted on vibration propagation for different constant rotational velocity. The changes of the signals were observed in time, frequency and simultaneously in time frequency domains. *Chen Tang et al.(2018)* presents the design of an integrated suspension tilting mechanism for narrow tilting vehicles. The challenge in the design of such suspension tilting mechanisms is to permit large suspension travels to produce sufficient tilting angles to balance the vehicle in cornering, while at the same time remain as compact as possible to save the space for passengers and cargos. Existing solutions, which are frequently based on parallel mechanisms, are not space-friendly and add extra weight to the probable compact and light-weighted urban vehicles. *Gonzalo De La Torre (2018)* conclude that self-driving vehicles become increasingly popular, new generations of attackers will seek to exploit vulnerabilities introduced by the technologies that underpin such vehicles for a range of motivations (e.g. curiosity, criminally-motivated, financially-motivated and state-sponsored). For example, vulnerabilities in self-driving vehicles may be exploited to be used in terrorist attacks such as driving into places of mass gatherings (i.e. using driverless vehicles as weapons to cause death or serious bodily injury). *Krishan Kumar(2013)* paper describes computer aided finite element analysis of parabolic leaf spring. The present work is an improvement in design of EN45A parabolic leaf spring used by a light commercial automotive vehicle. Development of a leaf spring is a long process which requires lots of test to validate the design and manufacturing variables. A three-layer parabolic leaf spring of EN45A has been taken for this work. The thickness of leaves varies from center to the outer side following a parabolic pattern. These leaf springs are designed to become lighter, but also provide a much improved ride to the vehicle through a reduction on interleaf friction. The CAD modeling of parabolic leaf spring has been done in CATIA V5 and for analysis the model is imported in ANSYS-11 workbench. *Krishan Kumar(2015)* conclude that there are literally several studies accomplished to predict the fatigue life of leaf springs but estimation of fatigue life of a parabolic leaf spring by using CAE tools has not yet been executed in the past. Parabolic spring is an important component in a vehicle suspension system. It needs to have excellent fatigue life and in today's scenario manufacturers rely on constant loading fatigue analysis. The objective of this work is to perform the fatigue analysis of parabolic leaf spring by three different methods where CAE analysis is performed to observe the distribution of stress fatigue life and damage using Goodman approach. *Krishan Kumar(2016)* states that shot peening is a method of cold working in which compressive stresses are induced in the exposed surface layers of metallic parts by the impingement of a stream of shots directed at the metal surface at high velocity under controlled conditions. The shot peening can be applied to various materials and their weldment like steels, cast iron, copper alloys, aluminum alloys, Ti alloys and some plastics. Shot peening improves the fatigue and abrasion resistance of metal parts. *Ken Hashimoto(2014)* developed a highly reliable CAE analysis model of the mechanisms that cause loosening of bolt fasteners, which has been a bottleneck in automobile development and design, using a technical element model for highly accurate CAE that we had previously developed, and verified its validity. Specifically, drawing on knowledge gained from our clarification of the mechanisms that cause loosening of bolt fasteners using actual machine tests, we conducted an accelerated bench test consisting of a three-dimensional vibration load test of the loosening of bolt fasteners used in mounts and rear suspension arms, where interviews with personnel at an automaker indicated loosening was most pronounced, and reproduced actual machine tests with CAE analysis based on a technical element model for highly accurate CAE analysis. *Takashige Takahashi(2010)* the authors propose a model for a highly precise CAE analysis approach, which is intended to contribute to the regeneration of development and design. This model has been applied with significant results in making proposals for bolt tightening behavior analysis, which continues to be an area of concern. *Thombare Shreyash Shripad(2017)* states that conventional combustion engine vehicles are very much responsible for various kinds of pollutions in current decade due to emission of Green-house gases. To control the problem of pollution occur by Combustion engines and also reduce the effect of Global warming, renewable energy sources are come in picture. Various kind of renewable energy sources are used for domestic as well as industrial applications. In Asian Countries Solar energy is accomplished in very large amount. *V. Sankaranarayanan(2008)* paper presents an adaptive semi-active control strategy to improve the stability and performance of a light commercial vehicle equipped with four continuously varying dampers. A choice between ride comfort or road holding of the vehicle is made automatically using a rule based adaptive algorithm based on various factors such as roll rate and yaw rate. The damping factor or the controller configuration of each damper is modified using a rule based adaptive algorithm and this technique is named Individual Damping Control (IDC) in this paper.

3. CAD MODELING

3.1 Introduction to CAD Modeling

CAD Modeling of any project is one of the most time consuming process. One cannot shoot directly from the form sketches to Finite Element Model. CAD Modeling is the base of any project. Finite Element software will consider shapes, whatever is made in CAD model. Although most of the CAD Modeling software have capabilities of analysis to some extent and most of Finite Element software have capabilities of generating a CAD model directly for the purpose of analysis, but their off domain capabilities are not sufficient for large and complicated models which include many typical shapes of the product. CAD modeling software is dedicated for the specialized job of 3D-modeling. From the sketcher to the rendering skills, all is to do by the single specialized software. The model of the solar vehicle structures also includes many complicated parts, which are difficult to make by any of other CAD modeling as well as Finite Element software. CAD modeling of the complete solar vehicle structure is performed by using CATIA V5 software. CATIA is having special tools in generating surface design to construct typical surfaces, which are later converted into solid models. Solid model of all parts of the structures are then assembled to make a complete structure. The process of assembly is very much analogous to general process of fabricating structures while real production. The CATIA design modulation software not only permits the CAD modeling but also the drafting feature which enables us to view the sectioned and oblique projections of the assembly. Drafting feature also enables to specify the different dimensioning technique on a 2D planer view. This feature shows the commercial application and advantage of CATIA as compared to other CAD modeling softwares.CAD model of our problem consist of different parts which are assembled together in assembly design to make a complete model of solar vehicle chassis out of all parts, some parts are similar in shape & size. The CAD model of a solar vehicle structure use for analysis is shown in Fig:-1 the CAD model has been prepared from various 2D drawings.

3.2 Part Modeling

Part modeling is the basic tool used by CAE Engineers in CATIA. Actually designing a part from scratch will require designing a sketch. Sketching profile is performed in the sketcher workbench, which is fully integrated in to part design. The sketcher workbench then provides a large number of tools allowing you to sketch the profile you need. Part modeling of anybody comprises of different techniques such as profile generation, padding, grooving, multi padding, pocketing, chamfering, filleting, shaft, angular pattern and material addition including many more advanced tools for different requirements. Part model of a component used in the assembly of solar vehicle is shown in the Fig:-1 below.

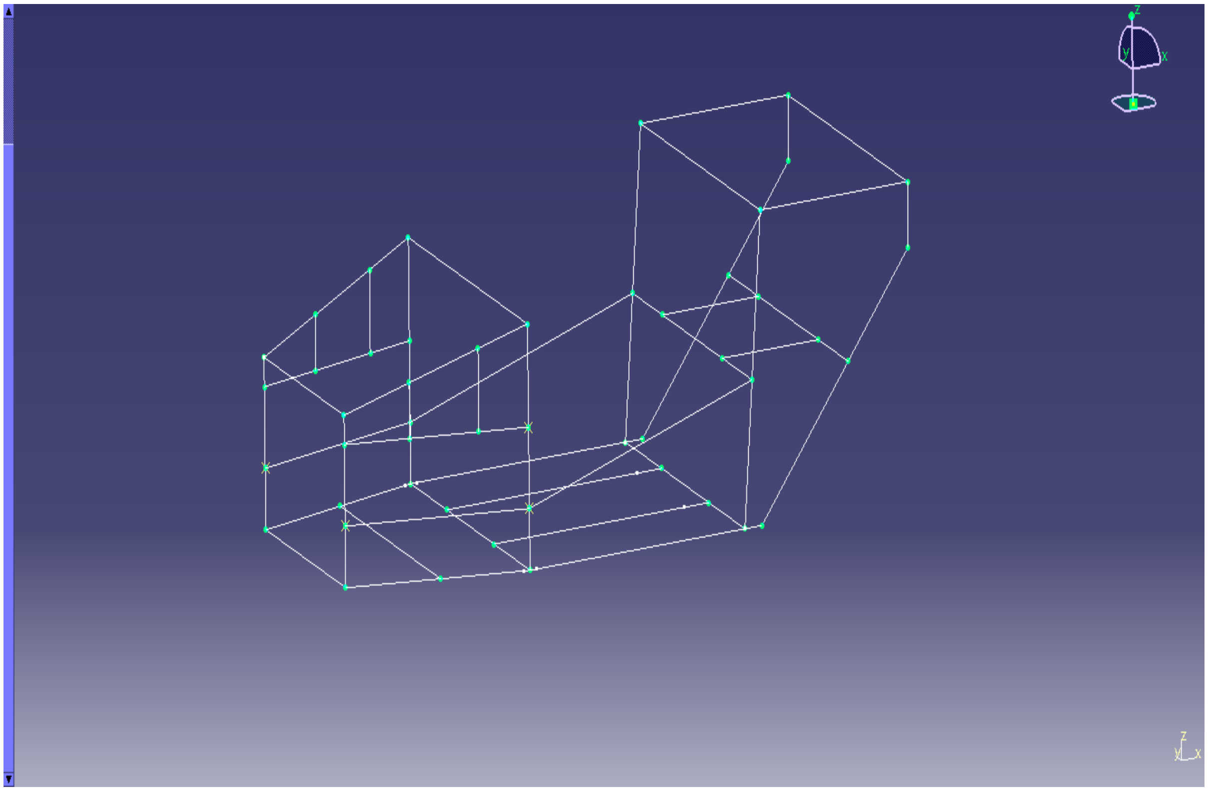

Fig:-1 Line view of chassis or roll cage

3.3 Assembly Design

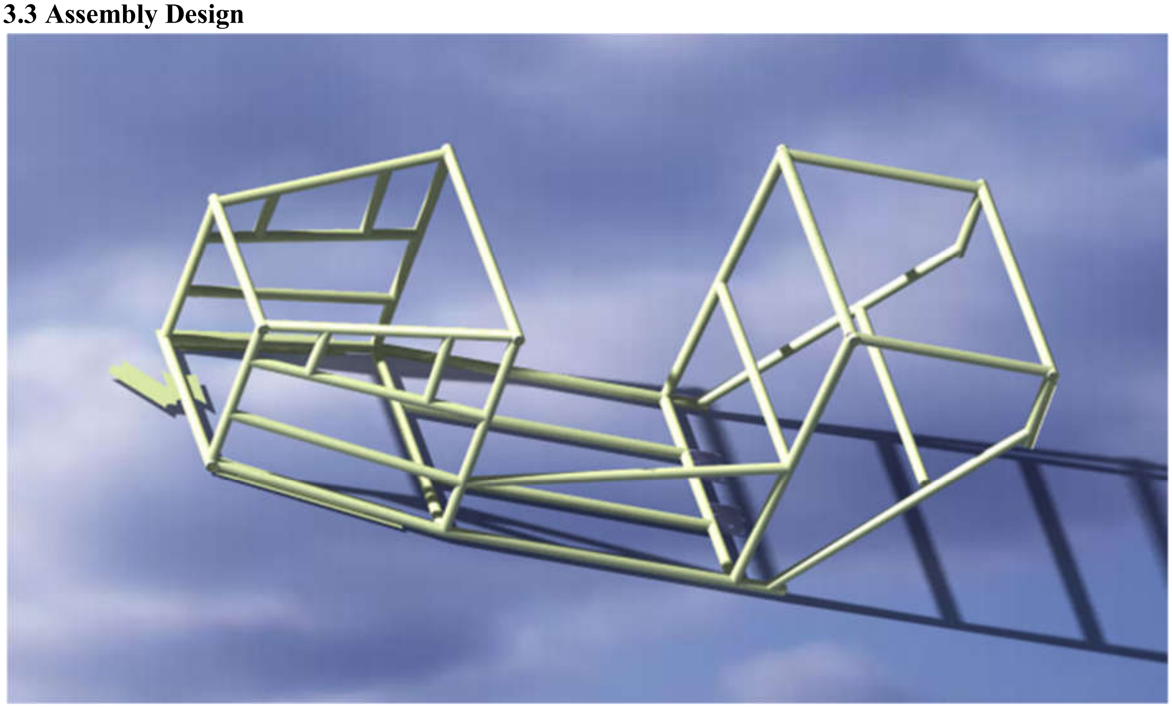

Fig:-2 wire frame model of roll cage or chassis

The Fig:-2 show the assembly of some parts of the solar vehicle. Assembly design provides us more convenient and more accurate way of positioning all the parts made by part modeling Surface Modeling. Constraints allows to position mechanical components in relation to other components of assembly. It just needs to specify the type of constraint to be setup between two components and the system will plays the components exactly the way it is required. Constraint can also be used to indicate the mechanical relationship between the components. Assembling process is similar to the general manufacturing process any one part is made fixed as the base component and the other components are constrained with respect to the base components.

4. FINITE ELEMENT ANALYSIS OF SOLAR VEHICLE STRUCTURE

4.1 Analysis of Solar Vehicle Structure

The finite element analysis of the model is carried out by using ANSYS. The model is imported from CATIA to ANSYS and then stress and deflection analysis is carried out on it. For this the whole of the model is divided into finite number of elements or nodes and by using proper meshing techniques these nodes are then analyzed by applying proper boundary conditions. Below figure 3 shows the geometry of the imported model along with attached table 1 for geometric detail of the model

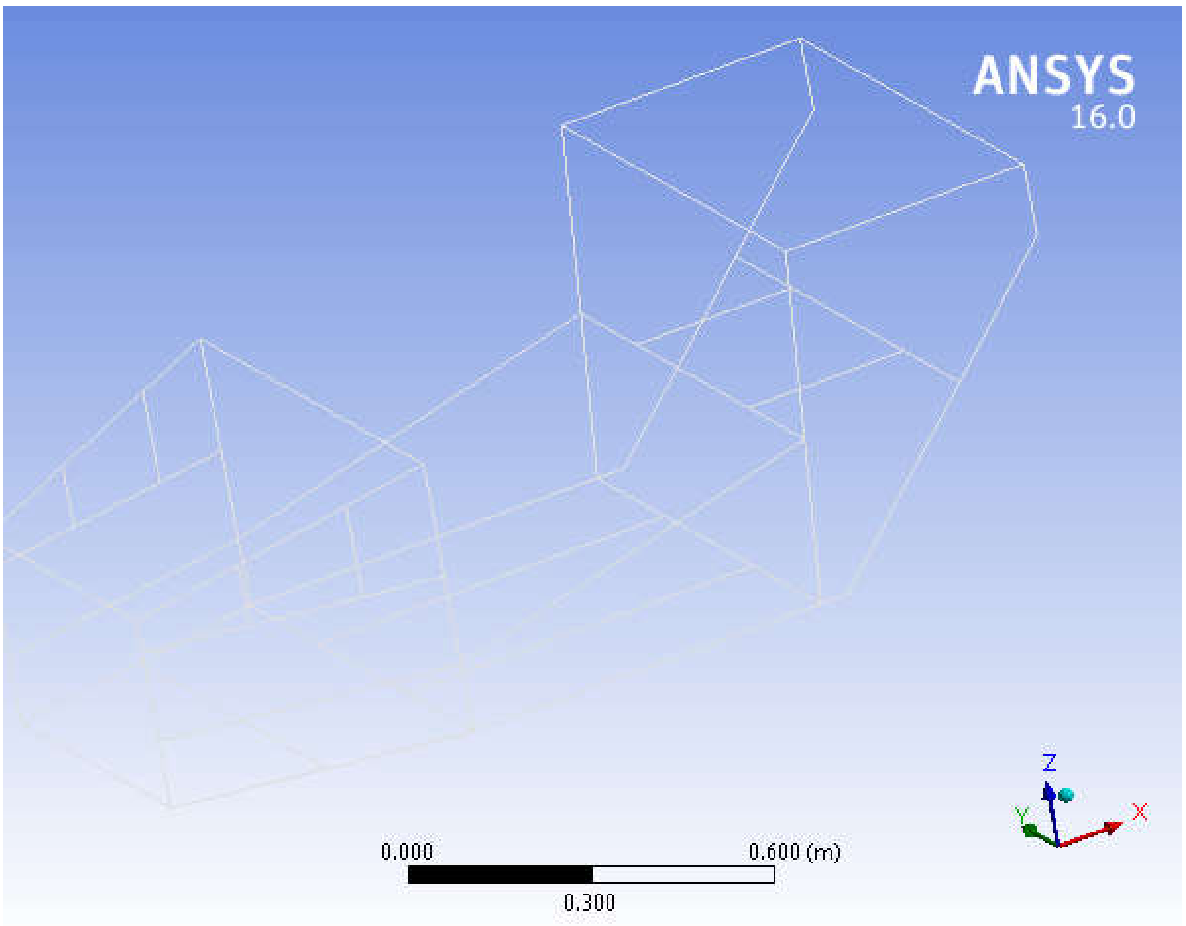

Figure 3:- Geometry of Imported Model

This model is having different types of contacts with different parts. All the contacts are welded joints, which are rigidly attached to each other. For making the roll cage of solar vehicle structural steel rod tube is used. The table below shows the different geometric details of model.

Table 1: Geometric Details of the Model

Object Name	*Geometry*
State	Fully Defined

Definition	
Source	E:\project\final ANALYSIS ROLL CAGE files\dp0\SYS\DM\SYS.agdb
Type	Design Modeler
Length Unit	Meters
Element Control	Program Controlled
Display Style	Body Color
Bounding Box	
Length X	1.6768 m
Length Y	0.76 m
Length Z	0.65 m
Properties	
Volume	2.4891e-003 m³
Mass	19.539 kg
Statistics	
Active Bodies	1
Nodes	4458
Elements	2242

The roll cage of the solar vehicle is made by rod of material of structural steel. The values of different constants of structural steel like density, coefficient of thermal expansion, specific Heat, thermal conductivity and resistivity are shown in below table 2

Table 2: Structural Steel Constants

Density	7850 kg m^-3
Coefficient of Thermal Expansion	1.2e-005 C^-1
Specific Heat	434 J kg^-1 C^-1
Thermal Conductivity	60.5 W m^-1 C^-1
Resistivity	1.7e-007 ohm m

The figure 4 below shows the Meshing in the structure along with all the details of the meshing in table 3:

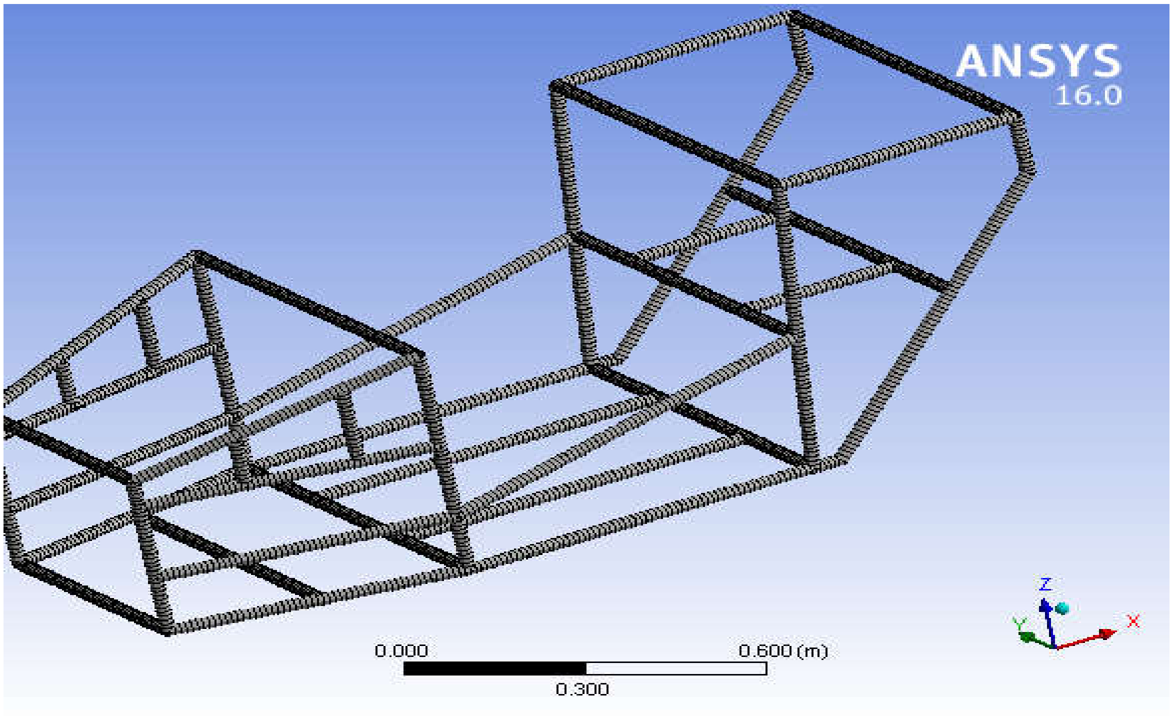

Fig:-4 Meshing in the Model

Table 3: Meshing details

Object Name	*Mesh*
State	Solved
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	Off
Relevance Center	Coarse
Element Size	1.e-002 m
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast
Span Angle Center	Coarse
Minimum Edge Length	1.83e-002 m
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No

Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Shape Checking	Standard Mechanical
Element Midside Nodes	Program Controlled
Straight Sided Elements	No
Number of Retries	Default (4)
Extra Retries For Assembly	Yes
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled

4.2.1 Front Impact Details

Various boundary conditions are applied on the model to generate the actual environment for analysis of the vehicle chassis. The table 4 below shows the boundary conditions of the model when impact on the front part of the chassis.

Table 4: Boundary Conditions of the Model

Object Name	*Nodal Displacement*	*Nodal Displacement 2*	*Nodal Force*	*Nodal Rotation*	*Nodal Rotation 2*
State	Fully Defined				
Scope					
Scoping Method	Named Selection				
Named Selection	front bumper	rear suspension	front impact	front bumper	rear suspension
Definition					
Type	Displacement		Force	Fixed Rotation	
Coordinate System	Nodal Coordinate System				
X Component	Free	0. m (ramped)	9611. N (ramped)		
Y Component	Free	0. m (ramped)	0. N (ramped)		
Z Component	0. m (ramped)		0. N (ramped)		
Suppressed	No				
Divide Load by Nodes			Yes		
Rotation X				Fixed	
Rotation Y				Fixed	
Rotation Z				Fixed	
Rotation X					Fixed
Rotation Y					Fixed
Rotation Z					Fixed

Now all the conditions for the model are set further the static structural analysis of the model is carried out by solving the model in the ANSYS and desired results are achieved. The resulting deflection observed in various parts of the chassis is shown by figure 5 below. Color variation shows the place of maximum deformation of the chassis model:

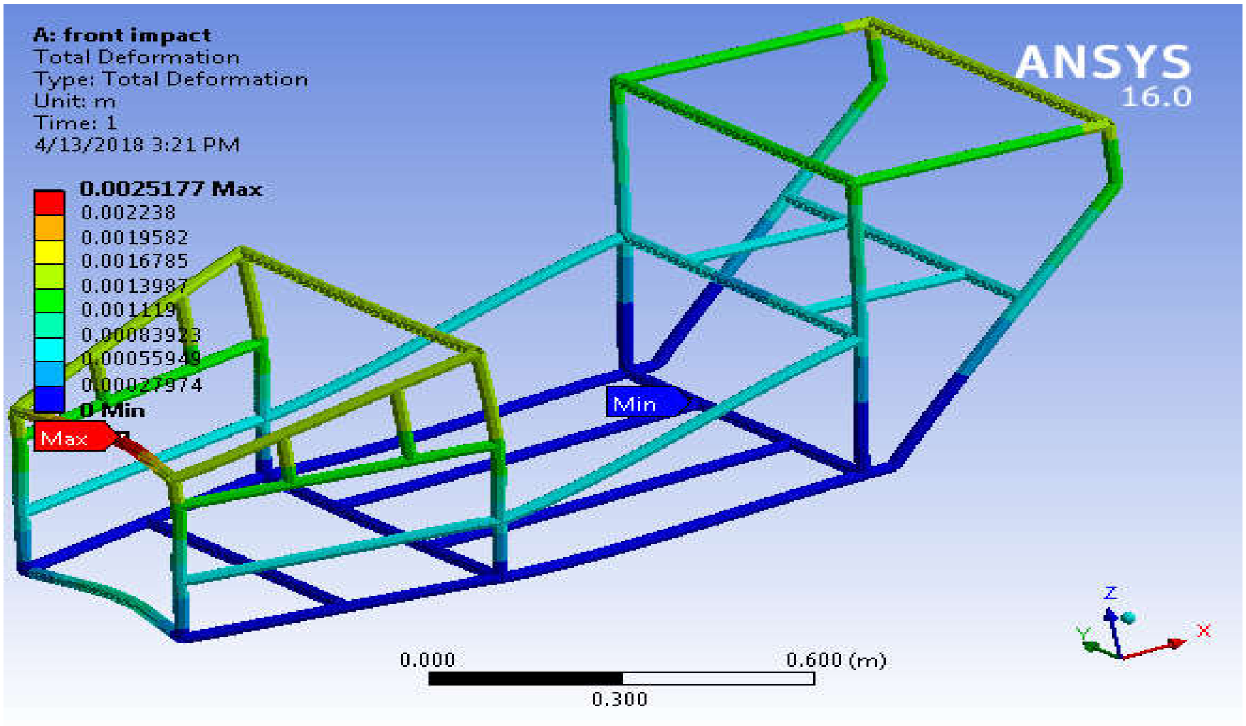

Fig:-5 Resulting Deformation

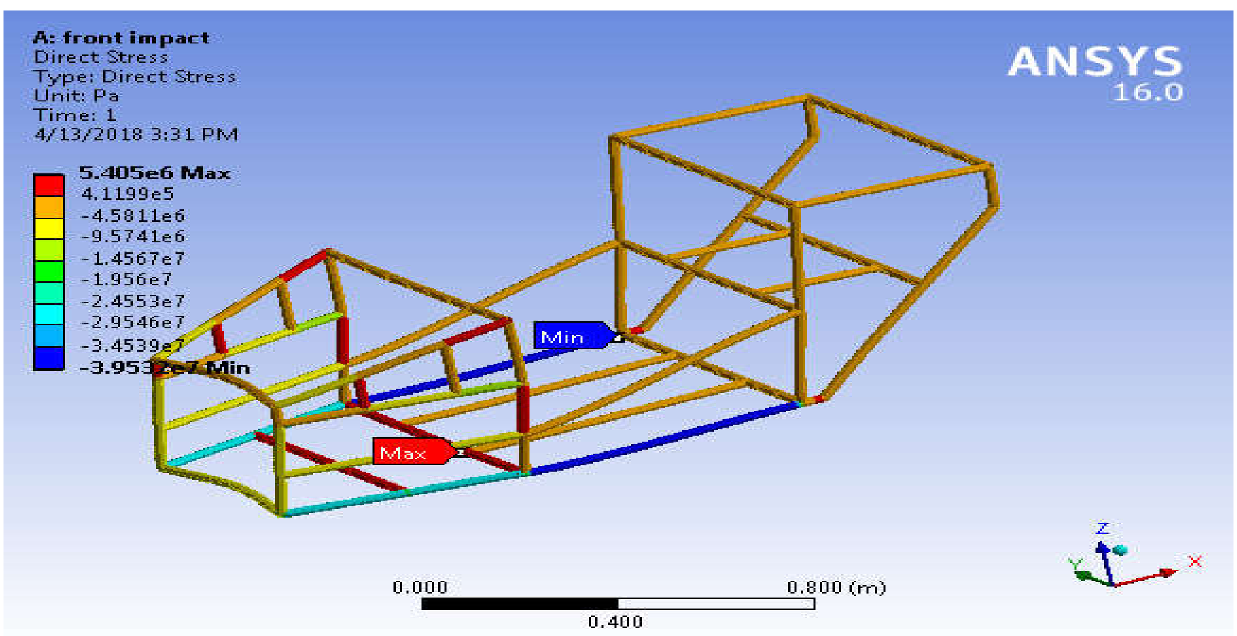

Fig:-6 Direct Stress

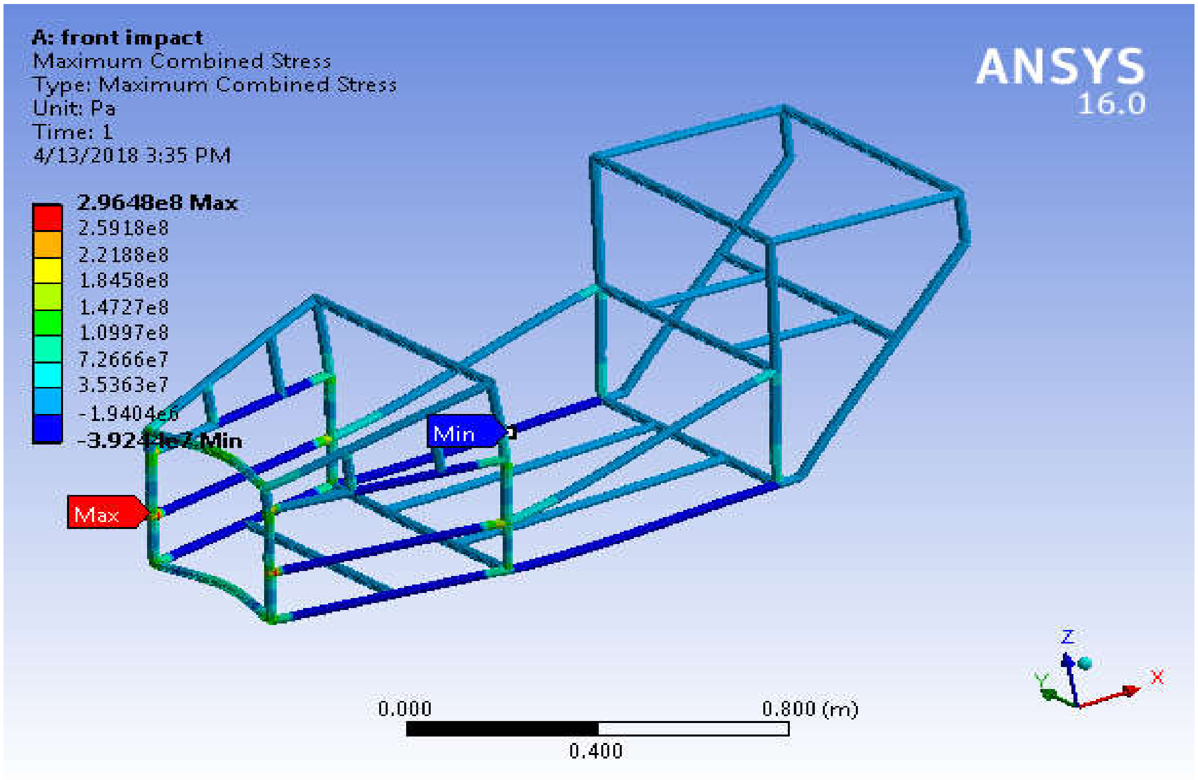

Fig:-7 Maximum Combined Stress

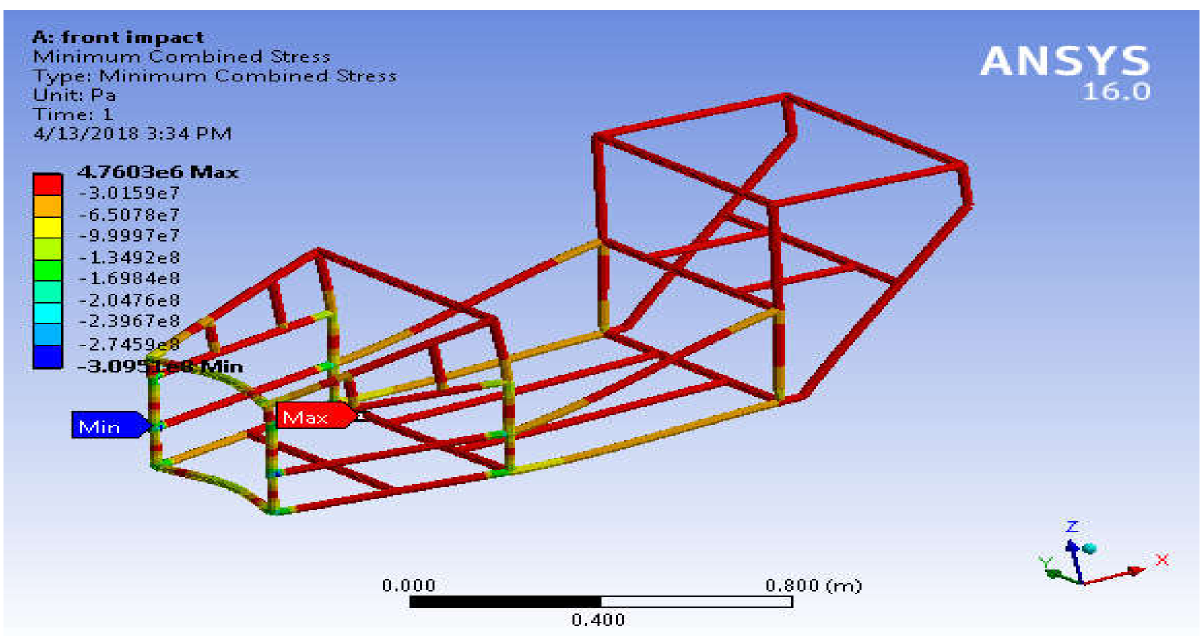

Fig:-8 Minimum Combined Stress

Table 5: Result Table

Object Name	*Direct Stress*	*Minimum Combined Stress*	*Maximum Combined Stress*
State	Solved		
Definition			
Type	Direct Stress	Minimum Combined Stress	Maximum Combined Stress
By	Time		
Display Time	Last		
Calculate Time History	Yes		
Identifier			
Suppressed	No		
Integration Point Results			
Display Option	Averaged		
Results			
Minimum	-3.9532e+007 Pa	-3.0951e+008 Pa	-3.9244e+007 Pa
Maximum	5.405e+006 Pa	4.7603e+006 Pa	2.9648e+008 Pa

4.1.2 Side Impact Details

Various boundary conditions are applied on the model to generate the actual environment for analysis of the vehicle chassis. The table 6 below shows the boundary conditions of the model when impact on the side part of the chassis.

Table 6: Boundary Condition of the Model

Object Name	*Nodal Force*	*Nodal Displacement*	*Nodal Displacement 2*	*Nodal Rotation*	*Nodal Rotation 2*
State	Fully Defined				
Scope					
Scoping Method	Named Selection				
Named Selection	side impact	side impact front bu	rear suspension(front impact)	side impact front bu	rear suspension(front impact)
Definition					
Type	Force	Displacement		Fixed Rotation	
Coordinate System	Nodal Coordinate System				
X Component	0. N (ramped)	0. m (ramped)			
Y Component	2605. N (ramped)	0. m (ramped)			
Z Component	0. N (ramped)	0. m (ramped)			
Divide Load by Nodes	Yes				

Suppressed	No		
Rotation X		Fixed	
Rotation Y		Fixed	
Rotation Z		Fixed	
Rotation X			Fixed
Rotation Y			Fixed
Rotation Z			Fixed

Now all the conditions for the model are set further the static structural analysis of the model is carried out by solving the model in the ANSYS and desired results are achieved. The resulting deflection observed in various parts of the chassis is shown by figure 9 below. Color variation shows the place of maximum deformation of the chassis model:

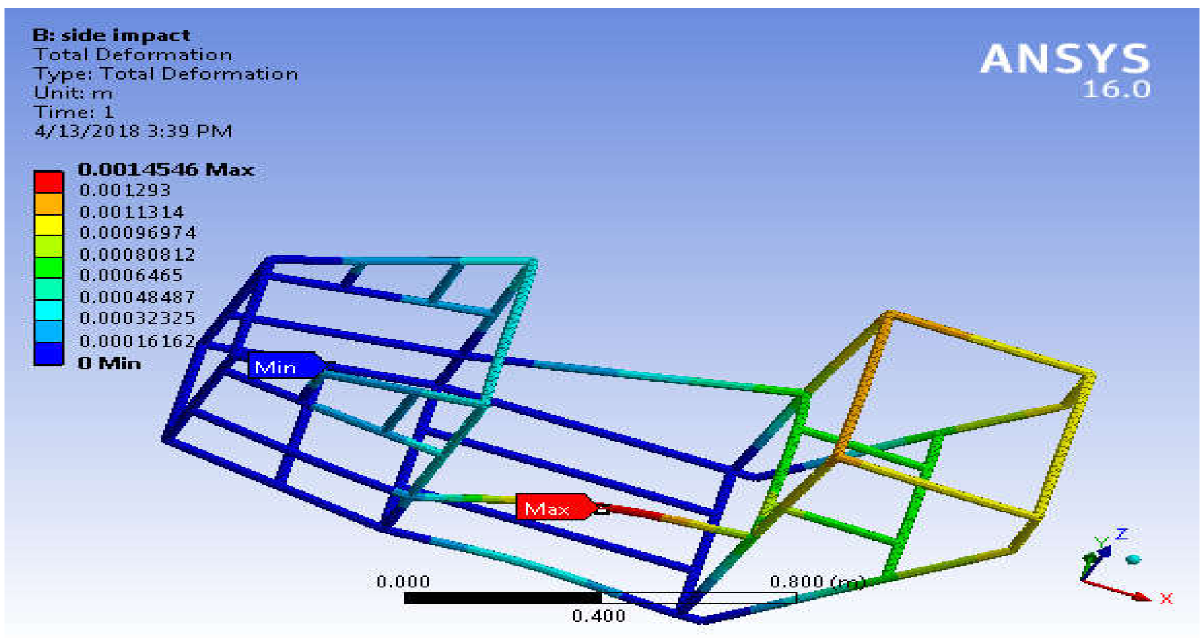

Fig:-9 Resulting Deformation

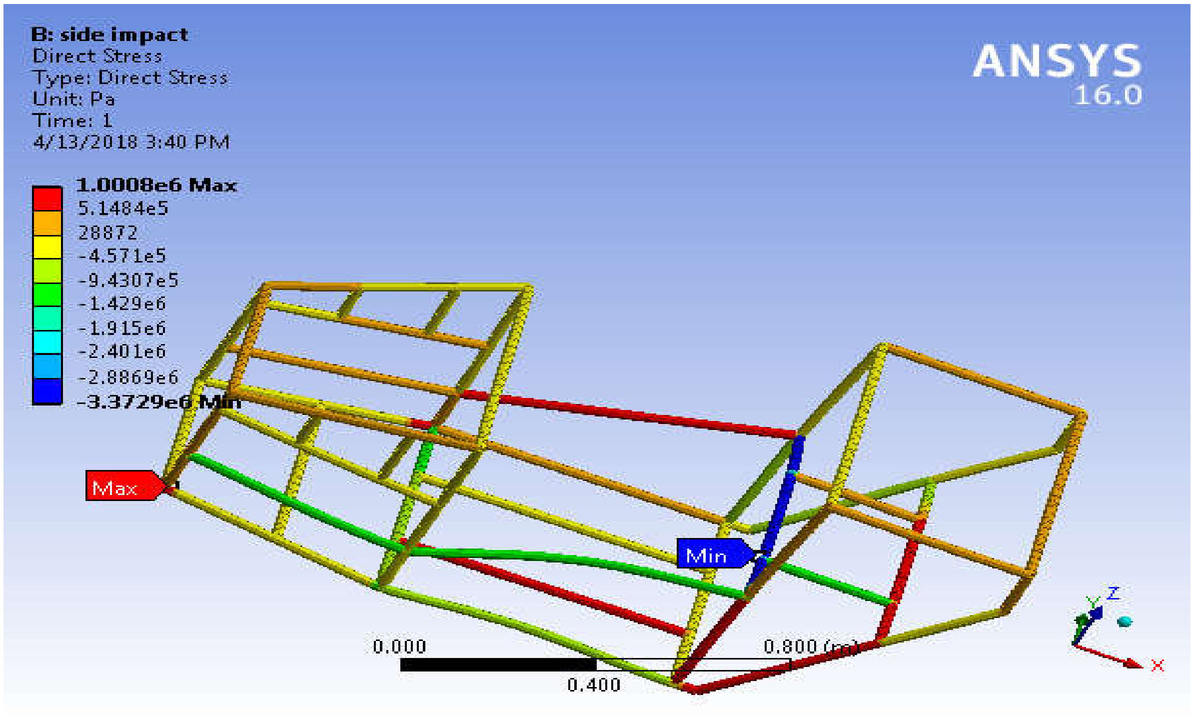

Fig:-10 Direct Stress

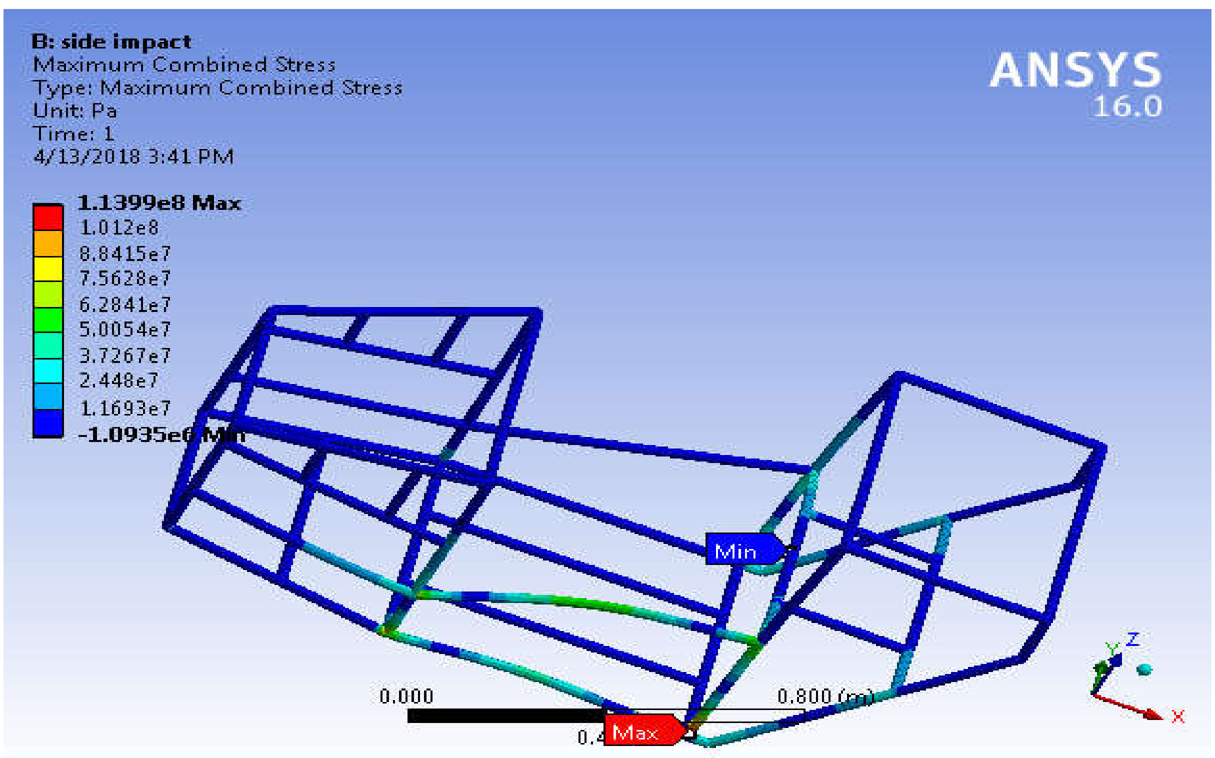

Fig:-11 Maximum Combined Stress

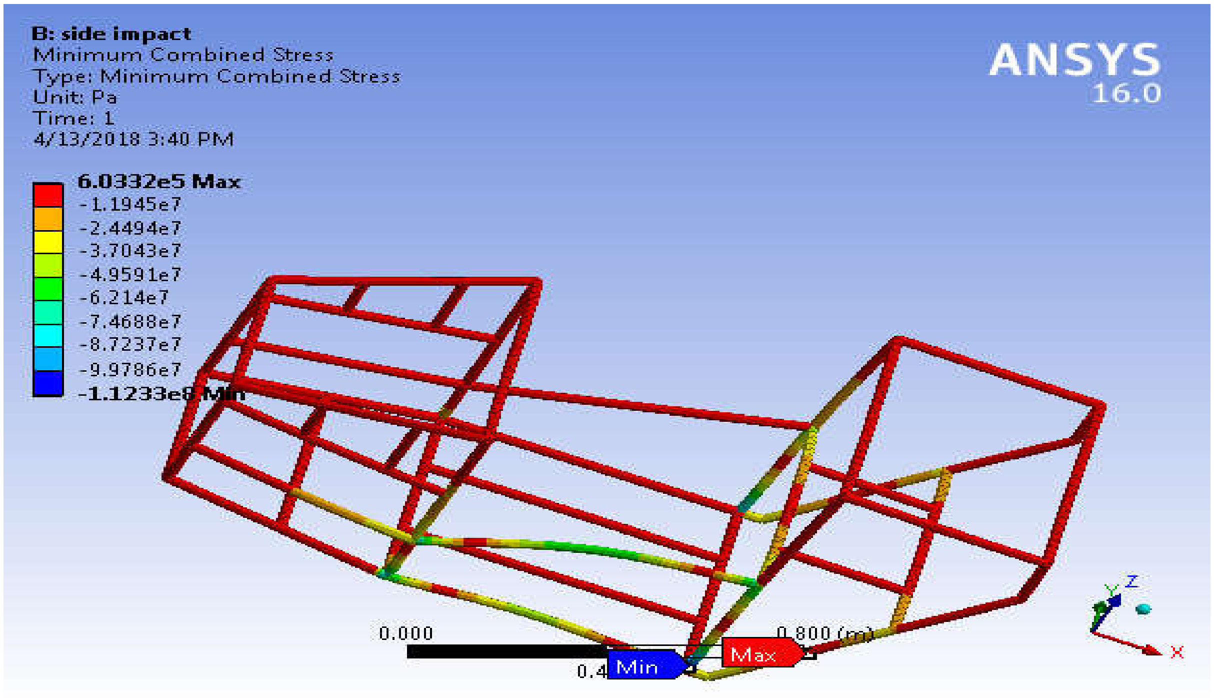

Fig:-12 Minimum Combined Stress

Table 7: Result Table

Object Name	*Direct Stress*	*Minimum Combined Stress*	*Maximum Combined Stress*
State	Solved		
Definition			
Type	Direct Stress	Minimum Combined Stress	Maximum Combined Stress
By	Time		
Display Time	Last		
Calculate Time History	Yes		
Identifier			
Suppressed	No		
Integration Point Results			
Display Option	Averaged		
Results			
Minimum	-3.3729e+006 Pa	-1.1233e+008 Pa	-1.0935e+006 Pa
Maximum	1.0008e+006 Pa	6.0332e+005 Pa	1.1399e+008 Pa

4.1.3 Rear Impact Details

Various boundary conditions are applied on the model to generate the actual environment for analysis of the vehicle chassis. The table 8 below shows the boundary conditions of the model when impact on the rear part of the chassis.

Table 8: Boundary Condition of the Model

Object Name	*Nodal Force*	*Nodal Displacement*	*Nodal Displacement 2*	*Nodal Rotation*	*Nodal Rotation 2*
State	Fully Defined				
Scope					
Scoping Method	Named Selection				
Named Selection	rear impact	front bumper(front impact)(side impact)	rear suspension(front impact)(side impact)	front bumper(front impact)(side impact)	rear suspension(front impact)(side impact)
Definition					
Type	Force	Displacement		Fixed Rotation	
Coordinate System	Nodal Coordinate System				
X Component	-1605. N (ramped)	0. m (ramped)	Free		
Y Component	0. N (ramped)	0. m (ramped)	Free		
Z Component	0. N (ramped)	0. m (ramped)			
Divide Load by Nodes	Yes				
Suppressed	No				
Rotation X				Fixed	
Rotation Y				Fixed	
Rotation Z				Fixed	
Rotation X					Fixed
Rotation Y					Fixed
Rotation Z					Fixed

Now all the conditions for the model are set further the static structural analysis of the model is carried out by solving the model in the ANSYS and desired results are achieved. The resulting deflection observed in various parts of the chassis is shown by figure 11 below. Color variation shows the place of maximum deformation of the chassis model:

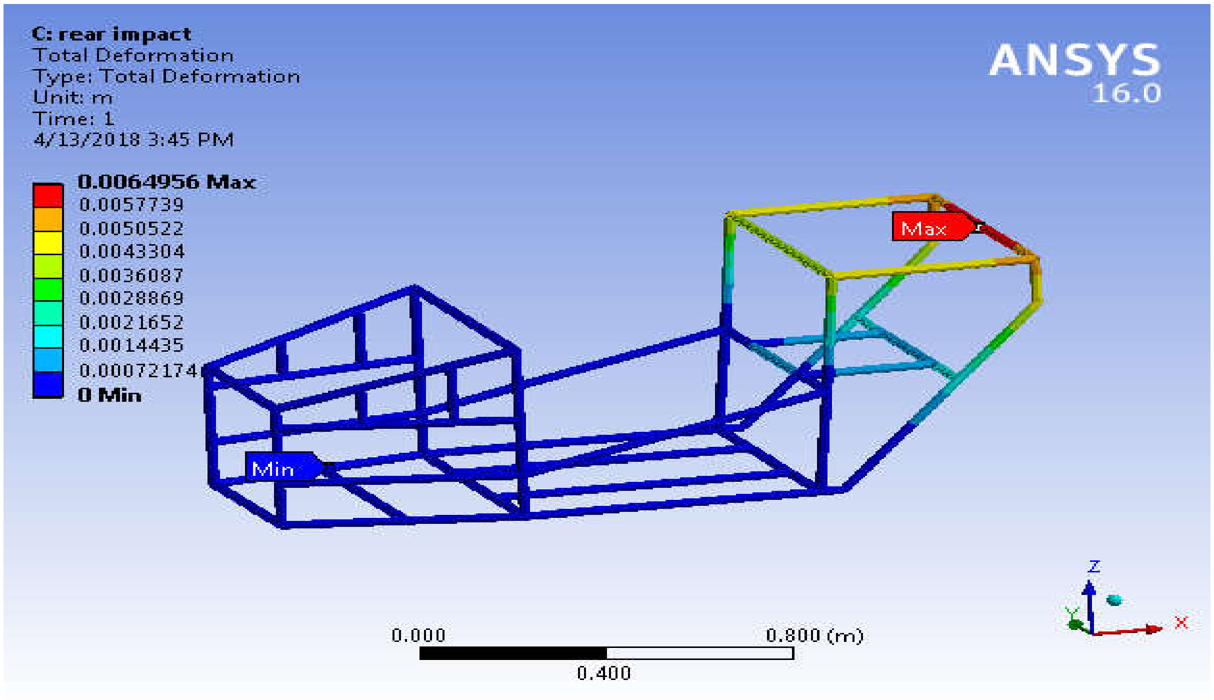

Fig:-11 Resulting Deformation

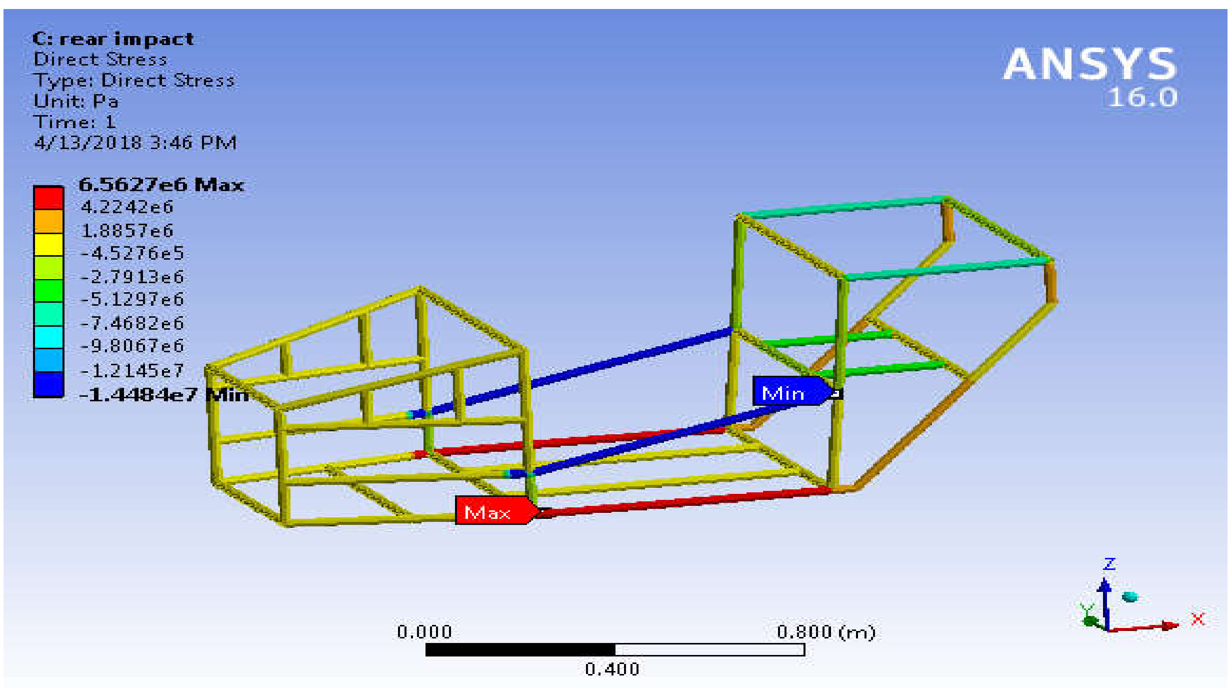

Fig:-12 Direct Stress

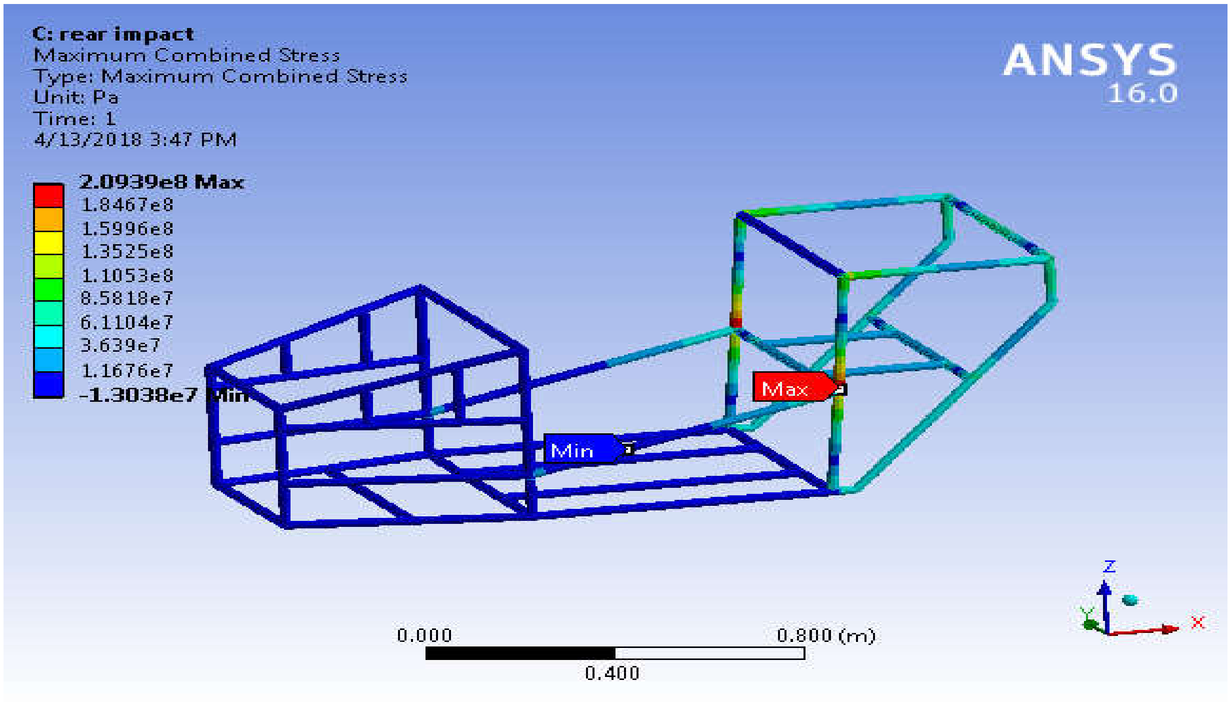

Fig:-13 Maximum Combined Stress

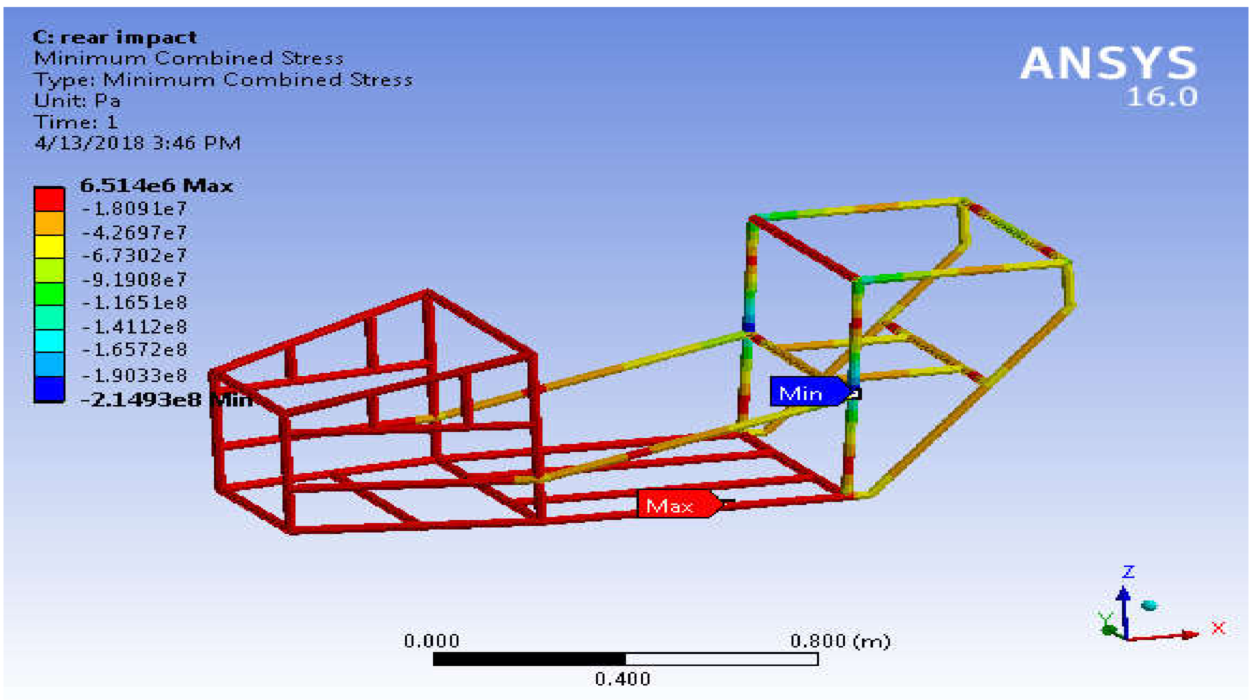

Fig:-14 Minimum Combined Stress

Table 7: Result Table

Object Name	*Direct Stress*	*Minimum Combined Stress*	*Maximum Combined Stress*
State	Solved		
Definition			
Type	Direct Stress	Minimum Combined Stress	Maximum Combined Stress
By	Time		
Display Time	Last		
Calculate Time History	Yes		
Suppressed	No		
Integration Point Results			
Display Option	Averaged		
Results			
Minimum	-1.4484e+007 Pa	-2.1493e+008 Pa	-1.3038e+007 Pa
Maximum	6.5627e+006 Pa	6.514e+006 Pa	2.0939e+008 Pa

CONCLUSION

The CAE analysis of a solar vehicle chassis structure has been done in this work. The modeling is done using CATIA while finite element analysis is carried out through ANSYS. In this work a tubular space frame type of chassis is modeling for solar vehicle structure. Different impact analysis i.e. front, rear and side test have been done using ANSYS. The outcomes of the all three impact analysis are found to be under safe conditions.

The total weight of the chassis is 19.53 Kg which is satisfactory to attain predefined performance parameters. On the basis of the kinetic energy of the vehicle, value of forces for different tests can be obtained. Using CAD methodology/technique following outcomes can be concluded;

- CAE results in saving of lots of time.
- Such kind of virtual design/development of a product helps us in saving lots of testing time and material too.
- Iteration process like optimization of prototype and their testing to check conformity to the design requirement can also be done.

FUTURE SCOPE

A lots of future work can also be extended with the aid of this work in which the component can be checked with different material type so as to reduce the weight of the model further and thus the material cost or with material having greater yield stress value.

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