ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF MECHANICAL, CHEMICAL AND MATERIALS ENGINEERING

Modification and Analysis of Frontal Frame Structure of a Small Car with Different Composite Materials for Improving Self Protection in a Frontal Crash

Thesis

A thesis submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in Automotive Engineering

By

Kebede Zegeye

Major Advisor: - N. Ramesh Babu (Associate Professor)

DEPARTMENT OF MECHANICAL AND VEHICLE ENGINEERING

September, 2015

Adama

CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in the thesis entitled "**Modification and Analysis of Frontal Frame Structure of a Small Car with Different Composite Materials for Improving Self Protection in a Frontal Crash**" in partial fulfillment of the requirements for the award of the degree of Master of Science in Automotive Engineering is an authentic record of my own work carried out from February,2015 to September,2015 under the supervision of N.Ramesh Babu, Associate Professor, Department of Mechanical and Vehicle Engineering, Adama Science and Technology University, Ethiopia.

The matter embodied in this thesis has not been submitted by me for the award of any other degree or diploma. All relevant resources of information used in this thesis have been duly acknowledged.

Name	Signature	Date
Kebede Zegeye	____________	2015-10-29-GC

Student

This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief. This thesis has been submitted for examination with my approval.

Name	Signature	Date
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Advisor

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Approved by board of Examiners

____________________________________ _____________

Chairman, Department graduate committee

____________________________________ _____________

Advisor

____________________________________ _____________

Internal Examiner

____________________________________ _____________

External Examiner

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ACRONYMS AND ABBREVIATIONS

SUV	Sport Utility Vehicle
FEA	Finite Element Analysis
SRIM	Structural Reinforcement Injection Molding
PAN	Polyacryonitride
FRP	Fiber Reinforced Polymer
CAD	Computer Aided Design
CATIA	Computer Aided Three Dimensional Interactive Applications
3D	Three Dimensional
FS	Factor of Safety
PMCs	Polymer Matrix Composites
MMCs	Metal Matrix Composites
CMCs	Ceramic Matrix Composites
CCCs	Carbon/Carbon Matrixes
FEM	Finite Element Method
CAE	Computer aided engineering
A/SP	Auto/Steel Partnership
CTE	Coefficient of Thermal Expansion
Euro-NCAP	Euro New Car Assessment Program
US NCAP	US New Car Assessment Program
NCAP	New Car Assessment Program
IIHS	Insurance Institute of Highway Safety
OEM	Original Equipment Manufacturer
ODB	Offset Deformable Barrier
IE	Impact Energy

Pm	Mean Crush Load
VARI	Vacuum Assisted Resin Injection
ABS	Acrylonitrile-butadiene-styrene
SMC	Sheet Molding Compound
DAF	Dynamic amplification factor
SEA	Specific energy absorption
NL	Non linear
DP	Dual phase
HSS	High strength steel
YS	Yield Strength
UTS	Ultimate Tensile Strength
RTI	Road Traffic Injuries
TRIP	Transformation-Induced Plasticity
fn	Natural frequency
δ_{max}	Maximum deformation
σ_{max}	Maximum stress

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ABSTRACT

Now a day's vehicle accident is becoming critical issue all over the world particularly in Ethiopia that demands engineer's endeavor to find ways to minimize the incidence. Preservation of passenger compartment space during a frontal vehicle collision is extremely significant for the self-protection of small cars. It is well known that crash speed, mass, stiffness and geometric interaction all have an influence on the intrusion of the passenger compartment in a frontal impact between vehicles. Ladder chassis is considered to be one of the oldest forms of automotive chassis or automobile chassis that is still used by most of the SUVs till today. As its name connotes, ladder chassis resembles a shape of a ladder having two longitudinal rails inter linked by several lateral and cross braces Crash guards used in Sports Utility Vehicle (SUV) serves as a platform for avoiding frontal collisions and ensures occupant safety . This paper proposed on modification and analysis of frame structure for the front end of Haunghai Sports Utility Vehicle (SUV) expected to achieve a previously unavailable level of efficiency of energy absorption, strength and weight reduction in order to reduce front SUV component and passenger compartment intrusion during crash by focusing on analyzing the static and dynamic behavior of the frontal upper cross beam modified from frame rail during full frontal impact against a rigid barrier in order to predict the Von misses stresses , deformation ,natural frequencies and strain energy in the components, with the help of CATIA V5 for geometric modeling and ANSYS 14.5 for analysis. The simulation predicted that the modified shape and material which have less deform, less weight, less stress (which is less than the yield strength of the material) and better energy absorbing capacity from comparison of different material is selected at the end of simulation. Depend on the analysis, thus results can be effectively utilized in modeling the frontal frame structure behavior for crash loads and successfully identify the safe performance.

Key words: frame structure, vehicle crash, frontal impact, energy absorption, crush worthiness

1. INTRODUCTION

1.1 Background of the study

A car accident is a road traffic incident which usually involves one road vehicle being in collision with, either another vehicle, or another road user, or a stationary road side object, and this may result in death, injury or property damage. The 2004 World Health Report shows that of the 1.2 million people killed in road crashes worldwide, 85% are in developing countries. Sub-Saharan Africa alone with only 4% of the global vehicle registered accounts for 10% of the total road fatalities, and the economic, social and health consequences are grave. Conversely, the high income nations, with 60% of the total global vehicle fleet contribute only 14% of the annual road deaths. Human error, road environment and vehicle factors are reported by the traffic police as the main causes of road crashes. Ethiopia is a country with the largest number of traffic accidents and fatality rate, and the share of the city of Addis Ababa is quite big (more than 60%), the death rate is 136 per 10,000 vehicles and Ethiopia is losing over 400 million birr yearly as a result of road accidents. Generally By 2020, Road Traffic Injuries (RTIs) are expected to be the third leading cause of death and disability worldwide [14].

There are two main areas of interest when discussing accidents: Single vehicle accidents and vehicle-to-vehicle accidents. In single vehicle accidents, the object is mainly rigid and all deformation energy has to be provided by the vehicle itself. In car-to-car accidents, both components provide deformation energy and the technical challenge is to enhance the interaction of both objects so that all available deformation energy is dissipated in a collision. There is a clear finding in Europe and in the U.S regarding the distribution of single vehicle accidents and vehicle-to-vehicle accidents. Single vehicle accidents are of very high statistical significance and have to be taken into account when discussing partner protection and compatibility [15].

Self protection is generally evaluated in crash tests; In case of a crash between actual vehicles, crash members, like front rails, do not always have a good interaction with each other because of their mismatch in design layout or if the tree may strike one longitudinal and miss the other, or the tree may strike the vehicle between the longitudinal. The deformation energy available within the longitudinal would not be available in this case as it is unlikely the cross modified frame could transmit the loading to both longitudinal. Therefore modification of frontal frame structure is important in order to save passenger and car components, for this thesis Haungahi SUV is preferred depend on this car frontal structure and the upper cross beam is modified from main longitudinal rail and the area is included in crumble zone due to that the newly modified upper cross compared with the criteria of bumper beam which is include in crumble zone in order decrease the aggressiveness of the designed beam. In automobile design, crash and structural analysis are the two most important engineering processes in developing a high quality vehicle. Computer simulation technologies have greatly enhanced the safety, reliability, comfort, environmental and manufacturing efficiency of today's automobiles.

The primary concern for drivers and passengers is safety. Governments have responded to this key concern and expectation with an increasing number of regulations. Although the details may vary slightly from country to country, the fundamental requirements are almost similar. A vehicle is expected to provide adequate protection to drivers and passengers in a not so serious accident, while designing and modifying the beam important considerations during the materials selection process include: yield strength (YS), ultimate tensile strength (UTS), ductility (sustaining plastic deformation before fracture), toughness (absorbing energy before fracture, indicated by the total area under the tensile stress-strain curve), and hardness (resisting deformation on the surface) depend on this criteria the material from Advanced High Strength Steel, aluminum alloy and composite materials are selected for comparison. In recent years the use of stationary barrier crash tests as a method of evaluation of crash safety performance has increased internationally. This has been very effective in improving vehicle crash safety performance and reducing the number of casualties in traffic accidents.

Modern passenger vehicles are being extensively tested for the ability to protect vehicle occupants in the event of a crash. Regulatory as well as rating tests are carried out all over the world. The results from these tests are publicly available and receive great attention. For the consumer the results from these tests are an important factor that influences the choice of vehicle when buying a new passenger vehicle. The impact velocities at which these tests are run have been increasing over time. The rating tests carried out at present in the US and in EUROPE (USNCAP and EUNCAP) are run at impact velocities of 56 km/h (35 mph) and 64 km/h (40 mph) [16].

For optimal frontal crash behavior, all kinetic energy should be dissipated by the front structure. The stiffness of the obstacle has a large influence on the crash behavior of a car two-thirds of the collisions in which car occupants have been injured are frontal impacts, two-thirds of the frontal collisions use only part of the front structure. Defining the proper design requirement for a considered crash velocity is very important. Crashes at speeds above this design velocity lead to a higher number of fatal injuries. On the other hand, crashes at lower speeds lead to a higher number of minor injuries. Setting the design speed at 56 km/h is sufficient for more than 90 per cent of the frontal collisions. This speed is compatible with current restraint systems [17].

As it is known that our country is in the stage of developing automotive industry, and believed that the industry is playing crucial role in the development of the country. However, most of the existing automotive industries except some import the components of the car and assemble it. This will increase the initial cost of the car and intelligence dependency will not be eradicated unless the company starts analyzing and designing the existing material or produce new alternative from other different material which is available nearby. Therefore, in order to improve the development of industry it is important to give emphasis towards replacing components which can easily produced locally having the same or more strength and stiffness. One of the methods to reduce the weight and cost of the car can be done thoroughly analyzing and optimizing the existing component or by replacing the existing material.

Since the composite materials have more energy storage capacity and high strength to weight ratio as compared with those of steel, the composite material offer opportunities for substantial weight saving but not always are cost- effective over their steel counter parts. Automotive chassis is considered to be one of the significant structures of an automobile. It is usually made of a steel frame, which holds the body and motor of an automotive vehicle. More precisely, automotive chassis or automobile chassis is a skeletal frame on which various mechanical parts like engine, tires, axle assemblies, brakes, steering etc are bolted. At the time of manufacturing, the body of a vehicle is flexibly molded according to the structure of chassis. Automobile chassis is usually made of light sheet metal or composite plastics. It provides strength needed for supporting vehicular components and payload placed upon it. Automotive chassis or automobile chassis helps keep an automobile rigid, stiff and unbending. Auto chassis ensures low levels of noise, vibrations and harshness throughout the automobile. Ladder chassis is considered to be one of the oldest forms of automotive chassis or automobile chassis that is still used by most of the SUVs till today. As its name connotes, ladder chassis resembles a shape of a ladder having two longitudinal rails inter linked by several lateral and cross braces. Since the modified front frame of Haunghai F1 landscape SUV used as crash guard (or included in crash zone) , it is compared with the criteria of front SUV bumper designed from different material and different standard of frontal crash zone . Hence, improvement in the safety of automobiles is prerequisite to decrease the numbers of accidents. Automotive bumper system is one of the key systems in passenger cars. Bumper systems are designed to prevent or reduce physical damage to the front or rear ends of passenger motor vehicles in collision condition. It protects the fuel, engine part and cooling system as well headlamps etc and a good design of car bumper must provide safety for passengers and should have low weight .

Different countries have different performance standards for bumpers. Under the International safety regulations originally developed as European standards and now adopted by most countries outside North America, a car's safety systems still function normally after a straight moving-barrier impact of 4 km/h (2.5 mph) to the front and the rear . The later performance is achieved by a combination of careful design, material selection to obtain a particular balance of stiffness, strength and energy absorption. Stiffness and Energy absorption are essential criterion. Stiffness is important because vehicle design consideration limits the packaging space for the bumper design to deform under load and Energy absorption is important because bumper must limit the amount of the impact force transmitted to the surrounding rails and vehicle frame. Automotive bumper plays a very important role in absorbing impact energy (original purpose of safety) and styling stand [4].

Therefore, this paper focus on modification and analysis of frontal frame structures(upper cross beam)with different material which used as a safety guard for Haunghai SUV based on new design concepts and optimization with the help of frame structure and front bumper design literature and analyzing the frontal crash for dynamic and static behavior subjected to impact loads. Geometric modeling of a frontal frame structure for Hangauhi SUV (Sports Utility Vehicle) was carried out using CATIA V5 package and further geometric model was imported into ANSYS Workbench to carry out static and crash analysis to find the stress distribution ,energy absorption and deformation . Modal analysis to understand the system behavior and calculate natural frequencies for different modes. Therefore, this research reports on the possibility to improve the self and part protections which are discussed in the society by modifying the frontal frame structure by using the CATIA V5 for modeling and ANSYS 14.5 for analyzing of frontal frame structure.

1.2 Justification of the study

The automobile accidents affecting lives and property are becoming very critical issue especially in Ethiopia. As time goes on, the number of vehicles operated by the public is increasing resulting in a greater number of highway tragedies. It is assumed that large number of such accidents occurs due to lack of the drivers' ability and road condition, and the other which cause for car frontal damage and passenger injury during crash is stiffness, mass and geometric incompatibility of the vehicle . The writer of this research , as a citizen of this country, has planned to modify and analyze a frontal frame structure (upper cross beam) of Haungahi SUV(sport utility vehicle) which is assembled in Bishoftu car industry by analyzing the exist one and optimizing it by changing the beam geometry with the help of proper software and using material more stiffer ,less deformed ,less weight and can absorb more energy during impact which improve the self and partner protection for frontal car collision which happened due to driver failure or road condition .This design modification of frontal frame structure is proposed for small car (Haungahi SUV) because, the risk of injuries in this car is higher during frontal crash depend on the data of already frontal damaged car due to frontal stiffness , material property they use for design .

1.3 Statement of the problem

The worsening situations in the rate of car crash calls for hand to hand efforts of all concerned bodies and the society in general. It is a well known fact that the socio economic, physical and psychological crisis caused by vehicle accidents need to be dealt with seriously. Various research and studies should be conducted to overcome these problems. The ever growing of interest of problem finding and solving will bring many changes in the future that we think it would be possible to improve the present technologies we are using every day in our life . In automotive industries also many improvements have been done so far and will in the future. The researches done to date and the measures taken accordingly in Ethiopia to alleviate this problem focused on improving drivers' skill, making awareness of road users, strengthening road regulation and control of issuance of driving license. Though these all have their contribution to minimize vehicle accidents, still the problem exists demanding other approaches of solution. This research is attempting a different approach to this problem (vehicle accident) particularly front end collision by modifying frontal frame structure for the self protection of small car in frontal vehicle crash. It appears that current road small cars are generally without frontal self protection (safety guard). As a result especially Ethiopia is facing a challenge not only due to increased number of death but also economic damage. The system intended to be innovative in this research will save the life and cars during frontal car crash.

As we can see on the literature review all researchers have done their research on other different parts like bumper and cross member for self protection for different types of vehicle rather than Haunghai SUV and this will make this work unique . This research is dedicated to find solution for this known problem by modifying and analyzing front frame structure (upper cross beam) which protect life and part from injuries during frontal collision of SUV by using TRIP steel, aluminum alloy and composite materials (carbon, E-glass and S-glass) for comparison in order to get lowest in weight, higher energy absorbing capability and lowest in deformation material. A virtual model of frontal frame structure is created in CATIA V5 and ANSYS 14.5 is used for analysis.

1.4 Significance of the study

Since Sufficient studies have not been conducted to alleviate the negative impacts of vehicle crash in Ethiopia. Thus, this study is an attempt to introduce a new approach to minimize the interior in particularly front end collision by modifying frontal frame structure. Therefore, this study will help the country at large and the public in particular when the outcome from the study becomes evaluated and implemented.

- ✓ Economical benefit: Saving costs of accident losses, Optimization of Automotive industry usage, and improving market share of the experiment vehicle type.
- ✓ Social benefits: Improve safety of the society and minimization of death rate
- ✓ Environmental benefits :Safe and convenient living environment

Beneficiaries of the study:-The researcher, high institute, industries, insurance companies, dealer companies, vehicle owners, the public and the country.

1.5 Scope of the study

This research work covers modification and analysis of upper cross beam modified from front frame structure and the comparison of existing frontal upper cross beam with upper cross modified from frame rail is done . Static impact and crash analysis of the preferred shape of frontal frame structure is done with the help of ANSYS work bench by using different material for comparison in order to get the material which best met the design criteria of vehicle frontal structure.

1.6 Limitations of the study

Problems encountered while doing this thesis work are the following:

- Finding the exact dimensions of the existing frame and upper cross beam was challenging because, the right measuring tools by which measurements can be done is not available.
- Getting existing frame structure and upper cross beam material composition was also the real problem using the standard instruments because the manufacturer hides from being seen and this helps them to keep their technology away from illegal duplication.

1.7 Objectives of the study

1.7.1 General objective

The main objective of this thesis work is to modify and analyze frontal frame structure with different materials for improving self protection of small car in a frontal vehicle crash.

1.7.2 Specific objectives

- ✓ To study the existing frontal upper cross beam of small cars.
- ✓ To identify the parameters of the structure which play important role in frontal collision.
- ✓ To develop model of modified frontal frame structure of a car by CATIA.
- ✓ To analyze the existing frontal upper cross beam and a newly modified upper cross beam behavior in frontal collision using FEM software by changing the material for comparison.

2. LITERATURE REVIEW

In order to have deep understanding on the problem of this study, it is vital to review several literatures and exercising different software that have been used in the field so far. For this reason, related literature such as books, accident data, articles, proceeding papers and some other sources that are retrieved from the internet will be consulted so as to understand the domain knowledge, concepts, principles and methods that are important for developing knowledge-based systems.

2.1 Terminology

2.1.1 Chassis Frames

Chassis frames can also be considered as the structures. Safety engineers design and manufacture vehicle body structures to withstand static and dynamic service loads encountered during the vehicle life cycle. The vehicle body provides most of the vehicle rigidity in bending and in torsion. In addition, it provides a specifically designed occupant cell to minimize injury in the event of crash. The vehicle body together with the suspension is designed to minimize road vibrations and aerodynamic noise transfer to the occupants. In addition, the vehicle structure is designed to maintain its integrity and provide adequate protection in survivable crashes. The automobile structure has evolved over the last ten decades to satisfy consumer needs and demands subject to many constraints. Among these constraints are materials and energy availability, safety regulations, economics, competition, engineering technology and manufacturing capabilities. The different types of chassis that are available in the market are :- Ladder chassis ,Back bone chassis and Monocoque chassis.

2.1.1.1 Ladder Chassis

This is the earliest kind of chassis. It looks like a ladder, so for that sake it is called a ladder chassis. The construction of this chassis is two longitudinal rail interconnected by many lateral braces. The rigidity to the structure is provided by the cross members and lateral. Most SUV’s are still built up on them. Hanghaui SUV is the one which use ladder type chassis. Ladder chassis is taken into account to be one of the oldest styles of automotive chassis. As the ladder chassis posses superior load carrying capacity, they are employed in most of the SUVs as well as in heavy commercial vehicles. Higher load carrying capacity of the chassis provides good driving dynamics and high ride comfort. Hence, ladder chassis are widely preferred over unibody and backbone frames.

2.1.1.2 Back Bone Chassis

It is simple in structure with a study tubular backbone which joins the front and rear axle and is responsible for most of the mechanical strength of the frame work. At the end of the chassis, the suspension and the drive train are connected. From inside, it resembles the drive shaft tunnel or more conventional front engine vehicles, but the difference is that it was closed in the bottom surface to provide a true tubular section. Still when the torsional stiffness of a chassis is derived from one large central tube running the length of the car, the resistance to twist depends mostly on the cross sectional area of that tube, and it is clearly possible from that cross section to be much larger than that of a typical drive shaft tunnel.

2.1.1.3 Monocoque chassis

This type of chassis is used by most of the modern vehicles, as it is a single piece frame work which gives the perfect shape to the car. It is very much different from the ladder and the back bone type chassis. Study of different parameters on the chassis space frame for the sports car by using FEA when several pieces are welded together, a one-piece chassis is built up. Unlike the above two types of chassis, it is incorporated with the body in a single piece, where as the former only supports the stress members.

2.1.2 Purpose of Chassis Frames in a Vehicle

The main purpose of the chassis frame is that, it carries all the mechanical parts of a vehicle like tires, engine, axle assemblies, steering and brakes and all these mechanical parts are supported by frame and also longitudinal main frame was designed for stiffness and energy absorption during crash and the various loads acting on the structure. It is essential that the best one is chosen to ensure acceptable structural performance within other design constraints such as cost, volume and method of production, product application and many more and assessments of the performance of a vehicle structure are related to its strength and stiffness. A design aim is to achieve sufficient levels of these with as little mass as possible. The main deformation modes occurring on the chassis is as follows:

2.1.2.1 Longitudinal Torsion

At the point when the connected burdens following up on one or two oppositely contradicted corners of the auto torsion happens. This will encounter while moving an auto on street subjected to compels of distinctive sizes. The edge could be thought as a torsion spring interfacing the two finishes where suspension burdens act. Torsional stacking and undesirable redirections of suspension springs can influence the taking care of and additionally execution of the auto. The imperviousness to tensional miss happening is called solidness spoke to in name. In the execution of a FSAE race auto this is the essential determinant.

2.1.2.2 Vertical Bending

In this case the frame is act as a simply supported beam and the four wheels as supports and the weight of the driver and components mounted to the frame, such as the engine and other parts are acting at the centre of the frame. Under the effect of gravity produce sag in the frame. Hence the vertical damping force due acceleration or deceleration can increase the vertical deflections.

2.1.2.3 Lateral Bending

Lateral bending loads are induced in the frame for various reasons, such as road camber, side wind loads and centrifugal forces caused by cornering. The sideways forces will act along the length of the car and will be resisted by the axles, tires and structural members.

2.1.2.4 Horizontal Lozenging

This deformation is caused when the forward and backward forces applied at opposite wheels. These forces tend to distort the frame into a parallelogram shape. If torsional and vertical bending stiffness are satisfactory, then the structure will generally be satisfactory. The magnitude of these load changes with the operating mode of the car.

2.1.3 Bumper

Automotive bumper system is one of the key systems in passenger cars. Bumper systems are designed to prevent or reduce physical damage to the front or rear ends of passenger motor vehicles in collision condition. It protects the hood, trunk, grill, fuel, exhaust and cooling system as well as safety related equipment such as parking lights, headlamps and taillights, etc . A good design of car bumper must provide safety for passengers and should have low weight. The later performance is achieved by a combination of careful design, material selection to obtain a particular balance of stiffness, strength and energy absorption. Stiffness and Energy absorption are essential criterion. Stiffness is important because, vehicle design consideration limits the packaging space for the bumper design to deform under load and Energy absorption is important because bumper must limit the amount of the impact force transmitted to the surrounding rails and vehicle frame. Automotive bumper plays a very important role in absorbing impact energy (original purpose of safety) [4]. The bumper converts the kinetic energy of the system to strain energy due to elastic and plastic deformation of the material. Internal Energy is phenomenal as it decides the plastic deformation after the collision of the vehicle [19] .

Now a days, automotive industry concentrates on optimization of weight and safety [4]. Front bumper, is an important structural member located at the front of the vehicle designed to protect the vehicle from damage due to collision, bumpers should protect car bodies from damage in low speed collisions [20].

2.2 Design Concept

M. Saito, T.Gomi, Y.Taguchi, T. Yoshimoto and T.Sugimo[21]: To improve the offset and full lap frontal crash performance, conventional body structures are generally designed with two main frames located on each side of the engine compartment to absorb vehicle energy and to control vehicle deceleration. The design concept will be expected not only to achieve progress for self-protection but also the effect of partner-protection for compatibility. It is predicted that this structure will be effective in reducing passenger compartment intrusion for various overlap distances in the direction of vehicle width for the difference of bumper height and for angle of approach.

Matthew L. Brumbelow and David S. Zuby[9] : Crash Configurations Study vehicles were assigned a crash configuration based on photographs of damaged vehicle components and the struck object.

Center impact – major load path was between the two main longitudinal; all case vehicles in this configuration struck a pole, post, or tree, but this was not a specific requirement. **Small overlap** – major load path was outboard of all major longitudinal structure; deformation of this structure may have occurred but was judged not a major source of energy absorption. **Moderate overlap** – major load path was along one longitudinal member and associated structures; offside member may have been loaded, but this either was less substantial, was induced by cross beams connecting the two members, or occurred separate from the initial engagement with the struck object or partner vehicle.

Full width – major load paths were along both longitudinal structural members. **Underride** – major load paths were along components vertically above the bumper bar and longitudinal.

Override – major load paths were along components vertically below the bumper bar and longitudinal.

Low severity:minor loading to all structural components; insignificant longitudinal crush, if any.

Nonfrontal/unreproducible – miscoded primary deformation location or extreme crash scenario with limited relevance to general crashworthiness.

The first four crash configurations, illustrated in Figure 1, describe lateral locations of vehicle structures loaded during the crash. In some instances, one of these configurations seemed applicable in addition to either under ride or override, so a judgment was made about which configuration was most significant to crash outcome. However, in two cases, a vehicle was assigned the under ride configuration in addition to one of the lateral configurations because both appeared to be major factors in producing occupant injury.

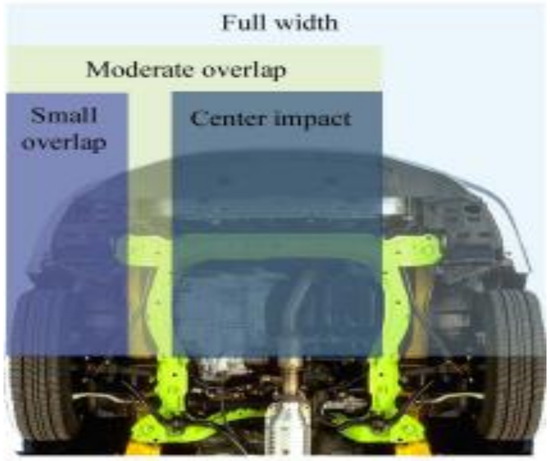


Figure 2.1 Locations of crash loading for various Configurations [9]

To summarize the major factors producing injuries in the crashes being studied, each occupant was assigned to one of four injury categories, as described below:-

Intrusion – injuries attributed mainly to compromise of occupant survival space.
Restraint factor – injuries attributed to inability of restraint system to sufficiently control occupant motion or loading; occupant compartment integrity was maintained, but occupant sustained injury either from loading by restraint system itself or from impact with interior component not prevented by restraints.

Occupant factor – occupant behavior or characteristic (e.g., misuse of restraint, loading by another occupant, extreme obesity with use of seat belt extender) likely contributed to injury more than any intrusion or restraint factor; age alone was not considered an occupant factor, but some fatally injured occupants were assigned to this category because they developed post crash complications that may have been age related, or they had pre-existing health conditions.
Unknown: occupant/restraint – occupant behavior or other characteristic may have contributed to injury, but evidence was unclear; structural integrity was good, but injury still occurred due to restraint factor, occupant factor, or some combination of factors.

2.3 Material selection

Important considerations during the materials selection process include: yield strength (YS), ultimate tensile strength (UTS), ductility (sustaining plastic deformation before fracture), toughness (absorbing energy before fracture, indicated by the total area under the tensile stress-strain curve), and hardness (resisting deformation on the surface).

2.3.1 Mechanical Properties of Metals

The mechanical properties of the metals are those which are associated with the ability of the material to resist mechanical forces and load. These mechanical properties of the metal include strength, stiffness, elasticity, plasticity, ductility, brittleness, malleability, toughness, resilience, creep and hardness. We shall now discuss these properties as follows: [8]

1. Strength: It is the ability of a material to resist the externally applied forces without breaking or yielding. The internal resistance offered by a part to an externally applied force is called stress.

2. Stiffness: It is the ability of a material to resist deformation under stress. The modulus of elasticity is the measure of stiffness.

3. Elasticity: It is the property of a material to regain its original shape after deformation when the external forces are removed. This property is desirable for materials used in tools and machines. It may be noted that steel is more elastic than rubber.

4. Plasticity: It is property of a material which retains the deformation produced under load permanently. This property of the material is necessary for forgings, in stamping images on coins and in ornamental work.

5. Ductility: It is the property of a material enabling it to be drawn into wire with the application of a tensile force. A ductile material must be both strong and plastic. The ductility is usually measured by the terms, percentage elongation and percentage reduction in area. The ductile material commonly used in engineering practice (in order of diminishing ductility) are mild steel, copper, aluminium, nickel, zinc, tin and lead.

8.Toughness: It is the property of a material to resist fracture due to high impact loads like hammer blows. The toughness of the material decreases when it is heated. It is measured by the amount of energy that a unit volume of the material has absorbed after being stressed up to the point of fracture. This property is desirable in parts subjected to shock and impact loads.

10. Resilience: It is the property of a material to absorb energy and to resist shock and impact loads. It is measured by the amount of energy absorbed per unit volume within elastic limit. This property is essential for spring materials.

12. Fatigue: When a material is subjected to repeated stresses, it fails at stresses below the yield point stresses. Such type of failure of a material is known as fatigue. The failure is caused by means of a progressive crack formation which are usually fine and of microscopic size. This property is considered in designing shafts, connecting rods, springs, gears, etc.

13. Hardness: It is a very important property of the metals and has a wide variety of meanings. It embraces many different properties such as resistance to wear, scratching, deformation and machinability etc. It also means the ability of a metal to cut another metal.
The various properties of the material are discussed below :

2.3.1.1 Proportional limit

We see from the diagram that from point O to A is a straight line, which represents that the stress is proportional to strain. Beyond point A, the curve slightly deviates from the straight line. It is thus obvious, that Hooke's law holds good up to point A and it is known as proportional limit. It is defined as that stress at which the stress-strain curve begins to deviate from the straight line.

2.3.1.2 Elastic limit

It may be noted that even if the load is increased beyond point A upto the point B, the material will regain its shape and size when the load is removed. This means that the material has elastic properties up to the point B. This point is known as elastic limit. It is defined as the stress developed in the material without any permanent set.

Note: Since the above two limits are very close to each other, therefore, for all practical purposes these are taken to be equal.

2.3.1.3 Yield point

If the material is stressed beyond point B, the plastic stage will reach i.e. on the removal of the load, the material will not be able to recover its original size and shape. A little consideration will show that beyond point B, the strain increases at a faster rate with any increase in the stress until the point C is reached. At this point, the material yields before the load and there is an appreciable strain without any increase in stress. In case of mild steel, it will be seen that a small load drops to D, immediately after yielding commences. Hence there are two yield points C and D. The points C and D are called the upper and lower yield points respectively. The stress corresponding to yield point is known as yield point stress.

2.3.1.4 Ultimate stress

At D, the specimen regains some strength and higher values of stresses are required for higher strains, than those between A and D. The stress (or load) goes on increasing till the point E is reached. The gradual increase in the strain (or length) of the specimen is followed with the uniform reduction of its cross-sectional area. The work done, during stretching the specimen, is transformed largely into heat and the specimen becomes hot. At E, the stress, which attains its maximum value is known as ultimate stress. It is defined as the largest stress obtained by dividing the largest value of the load reached in a test to the original cross-sectional area of the test piece.

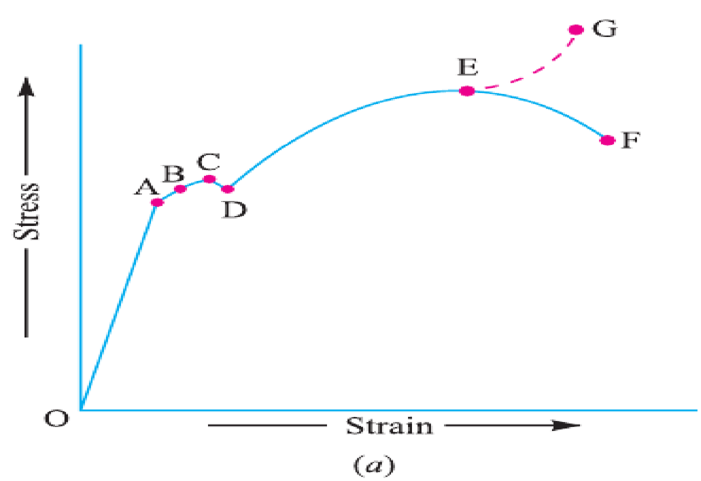
2.3.1.5 Breaking stress

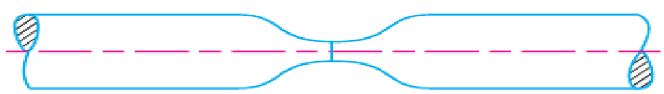
After the specimen has reached the ultimate stress, a neck is formed, which decreases the cross-sectional area of the specimen, as shown in Fig. 2.2(b). A little consideration will show that the stress (or load) necessary to break away the specimen, is less than the maximum stress. The stress is, therefore, reduced until the specimen breaks away at point F. The stress corresponding to point F is known as breaking stress.

Note : The breaking stress (i.e. stress at F which is less than at E) appears to be somewhat misleading. As the formation of a neck takes place at E which reduces the cross-sectional area, it causes the specimen suddenly to fail at F. If for each value of the strain between E and F, the tensile load is divided by the reduced cross-sectional area at the narrowest part of the neck, then the true stress-strain curve will follow the dotted line EG. However, it is an established practice, to calculate strains on the basis of original cross-sectional area of the specimen.

2.3.1.6 Percentage reduction in area

It is the difference between the original cross-sectional area and cross-sectional area at the neck (i.e. where the fracture takes place). This difference is expressed as percentage of the original cross-sectional area.





(b) Shape of specimen after elongation.

Figure 2.2 : Stress-strain diagram of mild steel [8]

2.3.2 Young's Modulus (E) versus Density (ρ)

The stress-strain relationship (in its linear part) is usually described by Young's modulus: $E = \sigma/\varepsilon$, where σ is the "true stress" and ε is the "true strain". Specific stiffness E/ρ is a reliable indicator of material performance in bending. A simple comparison of specific stiffness gives a good indication of stiffness resistance of different materials [6].

2.3.3 Strength (s) versus Density (ρ)

Specific strength i.e. the ratio between yield stress (σo) and density (ρ) is another relationship characterizing the engineering properties of different materials. As it can be seen in Figure 2.2, the specific strength ($\sigma o/\rho$), the specific strength of the austenitic Stainless Steel in the cold worked condition, is much higher than the one for the other materials [6].

2.3.4 Yield Strength vs. Yield Stress

After elongating by elastic deformation, regions of the metal will begin adding plastic (permanent) deformation to sheet metal. Instead of a sharp change from elastic to plastic deformation, a gradual transition occurs. Deformation in the plastic region causes the metal to work harden, which has both advantages and disadvantages. The metal in the area of greater deformation is strengthened by work hardening to reduce the formation of strain gradients .

DP and TRIP steels have increased energy absorption in a crash event compared to conventional HSS because of their high tensile strength, high work hardening rate, and large BH effect. The greater ductility of DP and TRIP steels permit use of higher strength, greater energy absorbing capacity material in a complex geometry that could not be formed from conventional HSS. DP and TRIP steels have better fatigue capabilities compared to conventional HSS of similar yield strength.

For improved frontal car safety it is necessary to design a structure that absorbs enough energy in each realistic crash situation. To protect the occupants, the passenger compartment should not be deformed and intrusion must be avoided too. To prevent excessive deceleration levels, the available deformation distance in front of the passenger compartment must be used completely for a predetermined crash velocity. This implies that in a given vehicle concept the structure must have a specific stiffness. Normally, the two main longitudinal members will absorb most of the crash energy with a progressive folding deformation of a steel column. The later performance is achieved by a combination of careful design, material selection to obtain a particular balance of stiffness, strength and energy absorption. Stiffness and Energy absorption are essential criterion. Stiffness is important because vehicle design consideration limits the packaging space for the bumper design to deform under load and Energy absorption is important because bumper must limit the amount of the impact force transmitted to the surrounding rails and vehicle frame.

Automotive bumper plays a very important role in absorbing impact energy (original purpose of safety) and styling standpoint/aesthetic purpose. Now a days ,automotive industry concentrates on optimization of weight and safety [3].

2.4 Transformation-Induced Plasticity (TRIP) Steels

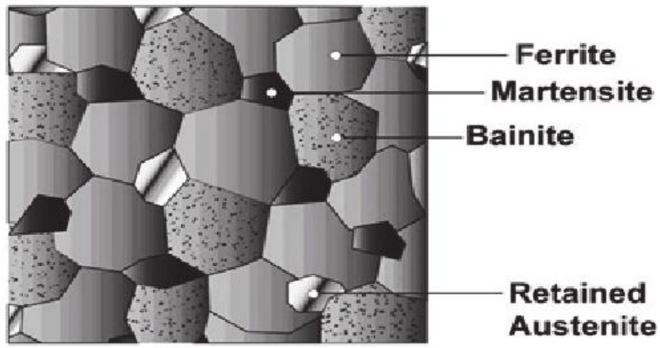


Figure 2.3: Schematic of a typical TRIP microstructure [3]

Another multi-phase steel with complex metallurgy and production processing, TRIP steels use higher quantities of carbon and other alloying elements than DP steels to achieve uncommon micro-structural phases at or below ambient temperature. TRIP steels contain metastable Austenite, that transforms to the hard phase Martensite during plastic strain of metal forming or crash. During deformation, the TRIP steel micro structure results in higher work hardening rates at higher strain levels, beyond that of DP steels, providing a slight advantage over DP in the most severe stretch forming applications. TRIP steels therefore can be engineered or tailored to provide excellent formability for the manufacturing of complex part shapes, and exhibit high work hardening during crash deformation for excellent crash energy absorption. The additional alloying requirements of TRIP steels degrade their resistance spot-welding behavior.

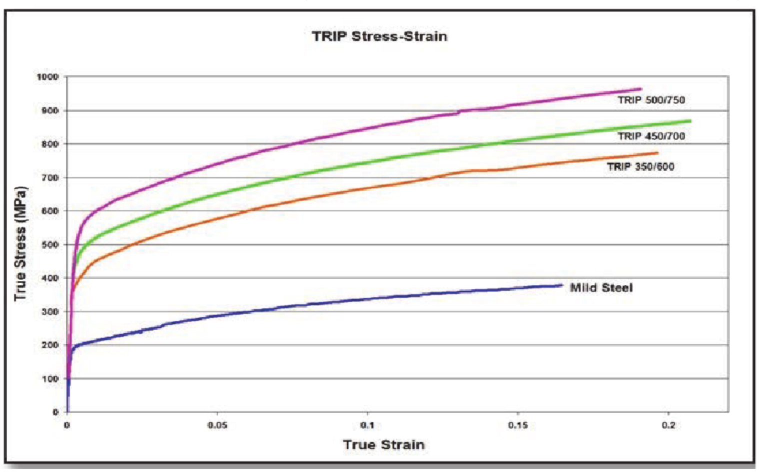


Figure 2.4: True stress –strain diagram for TRIP grades compared to mild steel. Note the high strain hardening rate maintained even at high strain [3].

TRIP, as a result of its high work hardening rates, has excellent formability and a high capacity for stretch. Complex shapes are possible because TRIP exhibits good bend ability and resists the onset of necking. TRIP also has excellent bake-hardening capacity. TRIP steels are some of the newest in development, but steel companies are quickly offering a greater variety of TRIP steels for automotive applications. They boast of its wide applicability, especially in complicated parts, and its high potential for mass savings. It can now be obtained in a variety of grades. Automotive applications of TRIP include body structure and ancillary parts. With high energy absorption and strengthening under strain, it is often selected for components that require high crash energy management, such as cross members, longitudinal beams, A- and B- pillar reinforcements, sills and bumper reinforcements [3].

Table 2.1 Comparative mechanical properties of aluminum alloy and steel [23]

material	density ρ (g/cm^3)	tensile modulus E (GPa)	yield strength (MPa)	tensile strength (MPa)
DQ low carbon steel	7.87	207	186	317
TRIP 450/800 steel	7.87	207	400	700
5182 H24 Al alloy	2.7	70	235	310
6111-T62 Al alloy	2.7	70	320	360

2.5 Aluminium

Aluminum is a nonferrous material with very high corrosion resistance and very light material compared to steels. Aluminum cannot match the strength of steel but its strength-to-weight ratio can make it competitive in certain stress application. Aluminum can also be alloyed and heat treated to improve it mechanical properties, which then makes it much more competitive with steels however the cost increases dramatically. Pure aluminum is also a possible material and is reasonably affordable and very light but it is the weakest and requires extra reinforcement to produce a rigid chassis. Aluminum is very hard to work with as it requires very skilled welding and is an overall softer metal. Basically there are several types of aluminum [24].

For this project, test with Aluminium Alloy preferred . The reason is that the material which in the area of crush zone is designed from non linear material. It has most of the good qualities of aluminium of non linear. It offers a range of good mechanical properties and good corrosion resistance. It can be fabricated by most of the commonly used techniques. In the annealed condition it has good workability. The typical properties of aluminium alloy include medium to high strength, good toughness, good surface finishing, excellent corrosion resistance to atmospheric conditions, good workability and widely [55 56].

Properties	Value and unit
Density	$2.77 g/cm^3$
Poisonous ratio	0.33
Modulus of elasticity	71Gpa
Shear Modulus	26.692Gpa
Bulk Modulus	69.608Gpa
Yield strength	280Mpa

Table 2.2: mechanical properties of Aluminum Alloy NL

2.6 Composite materials

A composite material is defined as a material composed of two or more constituents combined on a macroscopic scale by mechanical and chemical bonds. Composites are combinations of two materials in which one of the material is called the “matrix phase” is in the form of fibers, sheets, or particles and is embedded in the other material called the “reinforcing phase”. Another unique characteristic of many fiber reinforced composites is their high internal damping capacity. This leads to better vibration energy absorption within the material and results in reduced transmission of noise to neighboring structures. Many composite materials offer a combination of strength and modulus that are either comparable to or better than any traditional metallic metals. Because of their low specific gravities, the strength to weight-ratio and modulus to weight-ratios of these composite materials are markedly superior to those of metallic materials. The fatigue strength weight ratios as well as fatigue damage tolerances of many composite laminates are excellent. For these reasons, fiber composite have emerged as a major class of structural material and are either used or being considered as substitutions for metal in many weight-critical components in aerospace, automotive and other industries. High damping capacity of composite materials can be beneficial in many automotive applications in which noise, vibration, and hardness is a critical issue for passenger comfort [13]. Fibers factors contribute to the mechanical performance of a composite are; length, orientation, shape and material.

1. **Length**: - fibers can be made long or short. Long, continuous fibers are easy to orient and process, but short fibers cannot be controlled fully for proper orientation. Long fibers provide many benefits over short fibers; these include impact resistance, low shrinkage, improved surface finish, and dimensional stability. However, short fibers provide low cost, are easy to work with, and have fast cycle time fabrication procedures. Short fibers also have fewer flaws and therefore have higher strength.

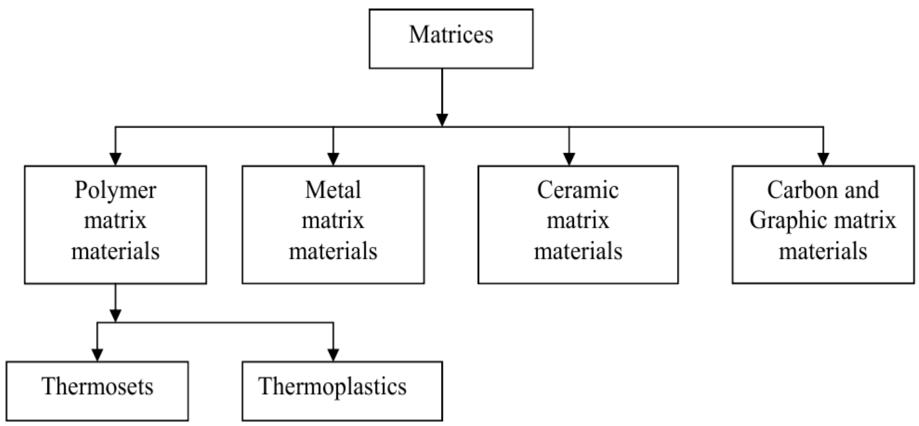
2. **Orientation**: fibers oriented in one direction give very high stiffness and strength in that direction. If the fibers are oriented in more than one direction, such as in a mat, there will be high stiffness and strength in the directions of the fiber orientations. However, for the same volume of fibers per unit volume of the composite, it cannot match the stiffness and strength of unidirectional composites.

3. Shape: the most common shape of fibers is circular because handling and manufacturing easiness. Hexagon and square shaped fibers are possible, but their advantages of strength and high packing factors do not outweigh the difficulty in handling and processing.

4. **Material**: The material of the fiber directly influences the mechanical performance of a composite. Fibers are generally expected to have high elastic modules and strengths. This expectation and cost have been key factors in the graphite, aramids, and glass dominating the fiber market for composites [25 2].

2.6.1 Classes and Characteristics of Composite Materials

Solid materials can be divided into four categories:



Both reinforcements and matrix materials are found in all four categories. Composites are usually classified by the type of material used for the matrix. The four primary categories of composites are polymer matrix composites (PMCs), metal matrix composites (MMCs), ceramic matrix composites (CMCs), and carbon/carbon composites (CCCs). The main types of reinforcements used in composite materials are, aligned continuous fibers, discontinuous fibers, whiskers (elongated single crystals), particles, and numerous forms of fibrous architectures produced by textile technology, such as fabrics and braids. Increasingly, designers are using hybrid composites that combine different types of reinforcements to achieve more efficiency and to reduce cost. A common way to represent fiber reinforced composites is to show the fiber and matrix separated by a slash. For example, carbon fiber reinforced epoxy is typically written "carbon/epoxy," or, "C/Ep." Composites are strongly heterogeneous materials; that is, the properties of a composite vary considerably from point to point in the material, depending on which material phase the point is located in. Many artificial composites, especially those reinforced with fibers, are anisotropic which means their properties vary with direction (the properties of isotropic materials are the same in every direction) [5].

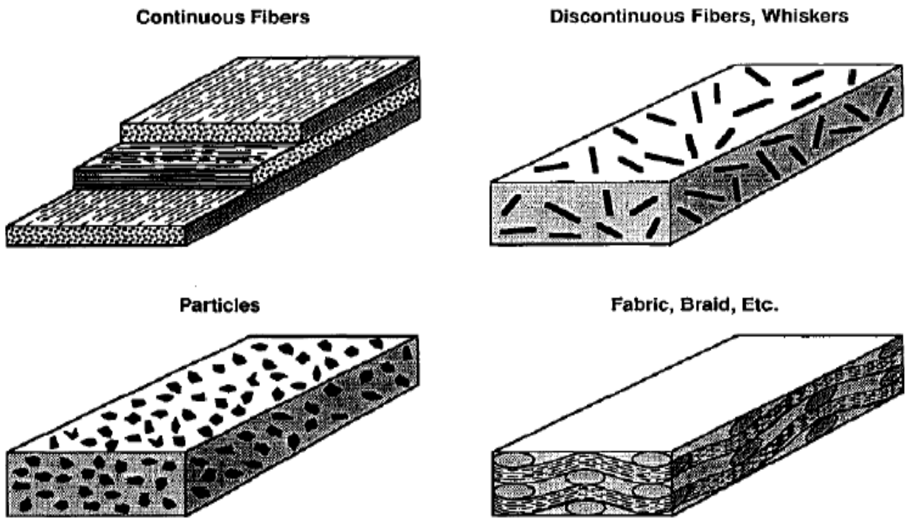


Figure 2.5: Reinforcement forms of composite [5]

2.6.2 Comparative Properties of Composite Materials

There are a large and increasing number of materials that fall in each of the four types of composites, making generalization difficult. However, as a class of materials, composites tend to have the following characteristics:

- ✓ High strength
- ✓ High modulus
- ✓ Low density

Excellent resistance to fatigue, creep, creep rupture, corrosion, and wear; and low coefficient of thermal expansion (CTE). For applications in which both mechanical properties and low weight are important, useful figures of merit are specific strength (strength divided by specific gravity or density) and specific stiffness (stiffness divided by specific gravity or density).

2.6.3 Advantages of composite materials

Metals and their alloys cannot always meet the demands of today's advanced technologies. Only by combining several materials one can meet the performance requirements. Trusses and benches used in satellites need to be dimensionally stable in space during temperature changes between –256 (–160) and 200 (93.3). Metal materials cannot meet these requirements; this leaves composites, such as graphite/epoxy, as the only materials to satisfy them. In many cases, using composites is more efficient. For example, in the highly competitive airline market, one is continuously looking for ways to lower the overall mass of the aircraft without decreasing the stiffness and strength of its components. This is possible by replacing conventional metal alloys with composite materials. Even if the composite material costs may be higher, the reduction in the number of parts in an assembly and the savings in fuel costs make them more profitable. Reducing 0.453 kg of mass in a commercial aircraft can save up to 360 gal (1360 L) of fuel per year. It is known that fuel expenses accounts 25% of the total operating costs of a commercial airline. Composites also offer a number of significant manufacturing advantages over metals and ceramics. Fiber reinforced polymers and ceramics can be fabricated in large, complex shapes that would be difficult or impossible to make with other materials. The ability to fabricate complex shapes allows consolidation of parts, which reduces machining and assembly costs. Some processes allow fabrication of parts to their final shape (net shape) or close to their final shape which also produces manufacturing cost savings. The relative ease with which smooth shapes can be made is a significant factor in the use of composites in aircraft and other applications for which aerodynamic considerations are important. Generally, composites offer several other advantages over conventional materials. These may include improved:

- ✓ strength
- ✓ stiffness
- ✓ impact resistance
- ✓ fatigue resistance
- ✓ thermal conductivity
- ✓ Corrosion resistance, etc.

2.6.4 Limitations of composite materials

- ✓ High cost of fabrication of composites is a critical issue. Improvements in processing and manufacturing techniques will lower these costs in the future. Already, manufacturing techniques such as SMC (sheet molding compound) and SRIM (structural reinforcement injection molding) are lowering the cost and production time in manufacturing automobile parts.
- ✓ Mechanical characterization of a composite structure is more complex than that of a metal structure. Unlike metals, composite materials are not isotropic, that is, their properties are not the same in all directions Such complexity makes structural analysis computationally and experimentally more complicated and intensive. In addition, evaluation and measuring techniques of some composite properties, such as compressive strengths are still being debated.
- ✓ Repair of composites is not a simple process compared to that of metals. Sometimes critical flaws and cracks in composite structures may go undetected.
- ✓ Composites do not have a high combination of strength and fracture toughness compared to metals [2].

2.6.5 Reinforcements and matrix materials

2.6.5.1 Reinforcements

The four key types of reinforcements used in composites are continuous fibers, discontinuous fibers, whiskers (elongated single crystals) and particles continuous aligned fibers are the most efficient reinforcement form and are widely used, especially in high performance applications. However, for ease of fabrication and to achieve specific properties, such as improved through thickness strength, continuous fibers are converted into a wide variety of reinforcement forms using textile technology.

2.6.5.1.1 Fibers

Fibers or particles embedded in matrix of another material would be the best example of modern-day composite materials, which are mostly structural. Laminates are composite material where different layers of materials give them the specific character of a composite material having a specific function to perform. Fabrics have no matrix to fall back on, but in them, fibers of different compositions combine to give them a specific character. Reinforcing materials generally withstand maximum load and serve the desirable properties [25]. The key fibers for mechanical engineering applications are glasses, carbons (graphite), several types of ceramics, and high modulus organics. Most fibers are produced in the form of multifilament bundles called strands or end in their untwisted forms, and yarns when twisted. Some fibers are produced as monofilaments, which generally have much larger diameters than strand filaments. Most of the key fibrous reinforcements are made of brittle ceramics or carbon. It is well known that the strengths of monolithic ceramics decrease with increasing material volume because of the increasing probability of finding strength limiting flaws. This is called size effect. As a result of size effect, fiber strength typically decreases monotonically with increasing gage length (and diameter). Flaw sensitivity also results in considerable strength scatter at a fixed test length. Consequently, there is no single value that characterizes fiber strength. The main functions of the fibers in a composite are:

- To carry the load, in a structural composite 70 to 90% of the load is carried by fibers.
- To provide stiffness, strength, thermal stability, and other structural properties in the composites.
- To provide electrical conductivity or insulation, depending on the type of fiber used.

2.6.5.1.1.1 Glass Fibers

Glass fibers are prepared by mixing ingredients such as silica sand, limestone, folic acid and other compounds. The mixture is heated to melting temperature of about 1260°C and the molten glass is made to pass through fine holes of platinum plate. The glass strands thus formed are gathered, cooled and wound. The fibers are drawn and woven into various forms to increase the directional strength of composite materials. Glass fibers are predominantly used fibers in reinforced polymers as they are economical, easy to produce, have high strength, stiffness and easily moldable with plastics. Different types of glass fibers like E, S, C and D, can be manufactured by adding varied chemicals to silica sand Glass fibers are widely used as the reinforcing material for the following reasons: [5 , 26]

- Inexpensive and easily available
- Manufacturing using simple and economical method
- Possess high tensile strength and high resistance to corrosion .

2.6.5.1.1.2 Carbon (Graphite) Fibers

While use of the term carbon for graphite is permissible, there is one basic difference between the two. Element analysis of poly-acrylo-nitrile (PAN) base carbon fibers show that they consist of 91 to 94% carbon. But graphite fibers are over 99% carbon. The difference arises from the fact that the fibers are made at different temperatures. PAN-based carbon cloth or fiber is produced at about 1320ºC, while graphite fibers and cloth are graphitised at 1950 to 3000ºC. The properties of graphite remain unchanged even at high temperatures [25] . There are dozens of commercial carbon fibers, with a wide range of strengths and modules. PAN-based materials are the most widely used carbon fibers .As a class of reinforcements, carbon fibers are characterized by high stiffness, strength, low density. Carbon fibers have excellent resistance to creep, stress rupture, fatigue and corrosive environments, although they oxidize at high temperatures. Carbon fibers are the workhorse reinforcements in high performance aerospace and commercial PMCs and some CMCs. Of course, as the name suggests, carbon fibers are also the reinforcements in carbon/carbon composites. Most carbon fibers are highly anisotropic. Carbon fiber stress-strain curves tend to be nonlinear. Modulus increases under increasing tensile stress and decreases under increasing compressive stress. Carbon fibers are made primarily from three key precursor materials: polyacrylonitrile (PAN), petroleum pitch, and coal tar pitch. Rayon based fibers, once the primary CCC reinforcement, are far less common in new applications. Experimental fibers also have been made by chemical vapor deposition. Carbon fibered composites are ideally suited for applications where strength, chemical inertness, stiffness, weightlessness, high damping and fatigue characteristics are the inevitable requirements. They can also be used at elevated temperatures without many consequences. Their properties make it an ideal choice of reinforcing materials used in aerospace, automobiles, civil engineering, military and various competitive sport applications. Carbon fibers are used as a reinforcing material due to: [5]

- Good physical strength, toughness and impact resistance.
- Good vibration damping strength, lightweight, dimensional stability
- Low abrasion rate, low coefficient of thermal expansion.

Fuel efficiency of the vehicle directly depends on the weight of the vehicle. The carbon fiber composite body structure is 57% lighter than steel structure of the same size and providing the superior crash protection, improved stiffness and favorable thermal and acoustic properties. carbon fibers have high specific energy absorption because of the low density and high strength of the constituent carbon fibers. To obtain the maximum energy absorption from a particular fiber, the matrix material in the composite must have a greater strain at failure than the fiber''. The graphite/epoxy tubes had specific energy absorption values greater than that of Kevlar/epoxy and glass/epoxy tubes having similar ply constructions. On comparable specimens, carbon fiber reinforced tubes absorb higher energy than those of glass or aramid fibers [12].

2.6.5.1.1.3 Boron Fibers

Boron fibers are primarily used to reinforce polymers and metals. Boron fibers are produced as monofilaments (single filaments) by chemical vapor deposition of boron on a tungsten wire or carbon filament, the former being the most widely used. They have relatively large diameters, 100-140 micrometers (4000-5600 micro-inches), and compared to most other reinforcements. The properties of boron fibers are influenced by the ratio of overall fiber diameter to that of the tungsten core. For example, fiber specific gravity is 2.57 for 100 micrometer fibers and 2.49 for 140 micrometer fibers.

2.6.5.1.1.4 Fibers Based on Silicon Carbide

Silicon carbide based fibers are primarily used to reinforce metals and ceramics. There are a number of commercial fibers based on silicon carbide. One type, a monofilament, is produced by chemical vapor deposition of high purity silicon carbide on a carbon monofilament core. Some versions use a carbon rich surface layer that serves as a reaction barrier. There are a number of multifilament silicon carbide based fibers which are made by pyrolysis of polymers. Some of these contain varying amounts of silicon, carbon and oxygen, titanium, nitrogen, zirconium, and hydrogen.

2.6.5.1.1.5 Alumina based fibers

Alumina based fibers are primarily used to reinforce metals and ceramics. Like silicon carbide based fibers, they have a number of different chemical formulations. The primary constituents, in addition to alumina, are boron, silica, and zirconia.

2.6.5.1.1.6 Aramid Fibers

Aramid, or aromatic, poly amide fibers are high-modulus organic reinforcements primarily used to reinforce polymers and for ballistic protection. There are a number of commercial aramid fibers produced by several manufacturers. Like other reinforcements, they are proprietary materials with different properties.

2.6.5.1.1.7 High Density Polyethylene Fibers

High density polyethylene fibers are primarily used to reinforce polymers and for ballistic protection. The properties of high density polyethylene tend to decrease significantly with increasing temperature and they tend to creep significantly under load even at low temperatures.

2.6.5.1.1.8 Filled Composites

Filled composites result from addition of filer materials to plastic matrices to replace a portion of the matrix, enhance or change the properties of the composites. The fillers also enhance strength and reduce weight. Another type of filled composite is the product of structure infiltrated with a second-phase filler material. The skeleton could be a group of cells, honeycomb structures, like a network of open pores. The infiltrant could also be independent of the matrix and yet bind the components like powders or fibers, or they could just be used to fill voids. Fillers produced from powders are also considered as particulate composite. The filler particles may be irregular structures, or have precise geometrical shapes like polyhedrons, short fibers or spheres. The benefits offered by fillers include increase stiffness, thermal resistance, stability, strength and abrasion resistance, porosity and a favorable coefficient of thermal expansion. However, the methods of fabrication are very limited and the curing of some resins is greatly inhibited [25].

2.6.5.2 Matrix Materials

The four classes of matrix materials are polymers, metals, ceramics, and carbon. A matrix material fulfills several functions in a composite structure, most of which are vital to the satisfactory performance of the structure. The important functions of a matrix material include the following: [5, 25]

- The matrix material binds the fibers together and transfers the load to the fibers. It provides rigidity and shape to the structure.
- The matrix isolates the fibers so that individual fibers can act separately. This stops or slows the propagation of a crack.
- The matrix provides good surface finish quality and aids in the production of net-shape or near net- shape parts.
- Through the quality of its grip on the fibers (the interfacial bond strength), the matrix can also be an important means of increasing the toughness of the composite .

- Distributes the loads evenly between fibers so that all fibers are subjected to the same amount of strain.
- Improves impact and fracture resistance of a component.
- The matrix provides protection to reinforcing fibers against chemical attack and mechanical damage .

2.6.5.2.1 Carbon Matrices

Carbon and graphite have a special place in composite materials options, both being highly superior, high temperature materials with strengths and rigidity that are not affected by temperature up to 2300ºC. This carbon-carbon composite is fabricated through compaction of carbon or multiple impregnations of porous frames with liquid carboniser precursors and subsequent pyrolization.

They can also be manufactured through chemical vapour deposition of pyrolytic carbon. Carbon-carbon composites are not be applied in elevated temperatures, as many composites have proved to be far superior at these temperatures. However, their capacity to retain their properties at room temperature as well as at temperature in the range of 2400ºC and their dimensional stability make them the oblivious choice in a garnut of applications related to aeronautics, military, industry and space. Components, that are exposed to higher temperature and on which the demands for high standard performance are many, are most likely to have carbon-carbon composites used in them [25].

2.6.5.2.2 Polymer Matrix Materials

Polymer matrix composites are the most commonly used, advanced composite materials comprising of a fibrous material of thin diameter (e.g., fiberglass, graphite, carbon, Kevlar, boron etc.) reinforced into polymerized resin (e.g., epoxy, polyester etc.) to enhance the required properties of composites to desired levels for specific applications. Polymer matrix composites have widespread usage due to their low cost, high strength and simple fabrication methods. Polymer matrix composites are advantageous, mainly due to the following properties: [25]

- Possess high tensile strength, stiffness and fracture toughness
- Possess good abrasive resistance

The major disadvantages are:

- Thermal resistance is low
- Coefficient of thermal expansion is high

Properties of polymer matrix composites are determined by properties of the fibers, orientation of the fibers, concentration of the fibers, stacking sequence of fibers, aspect- ratio of fibers and properties of the matrix .There are two major classes of polymers used as matrix materials:

thermosets and thermoplastics. Thermosets are materials that undergo a curing process during part fabrication, after which they are rigid and cannot be reformed. Thermoplastics, on the other hand, can be repeatedly softened and reformed by application of heat. Thermoplastics are often subdivided into several types:

- Amorphous
- Crystalline
- Liquid crystal

There are numerous types of polymers in both classes. Thermo-sets tend to be more resistant to solvents and corrosive environments than thermoplastics, but there are exceptions to this rule. Resin selection is based on design requirements, as well as manufacturing and cost considerations.

2.6.5.2.2.1 Thermosetting Resins

The key types of thermosetting resins used in composites are epoxies, bismaleimides, thermosetting polyimides, cyanate esters, thermosetting polyesters, vinyl esters, and phenolics. Epoxies are the workhorse materials for airframe structures and other aerospace applications, with decades of successful flight experience to their credit. They produce composites with excellent structural properties. Epoxies tend to be rather brittle materials, but toughened formulations with greatly improved impact resistance are available. The maximum service temperature is affected by reduced elevated temperature structural properties resulting from water absorption. A typical airframe limit is about 1200C (2500F) [2 , 5].

Table 2.3: properties of matrix materials [5]

Material	Class	Density g/cm³ (Pci)	Modulus GPa (Msi)	Tensile Strength MPa (Ksi)	Tensile Failure Strain %	Thermal Conductivity W/mK (BTU/h · ft · F)	Coefficient of Thermal Expansion ppm/K (ppm/F)
Epoxy	Polymer	1.8 (0.065)	3.5 (0.5)	70 (10)	3	0.1 (0.06)	60 (33)
Aluminum (6061)	Metal	2.7 (0.098)	69 (10)	300 (43)	10	180 (104)	23 (13)
Titanium (6Al-4V)	Metal	4.4 (0.16)	105 (15.2)	1100 (160)	10	16 (9.5)	9.5 (5.3)
Silicon Carbide	Ceramic	2.9 (0.106)	520 (75)	—	< 0.1	81 (47)	4.9 (2.7)
Alumina	Ceramic	3.9 (0.141)	380 (55)	—	< 0.1	20 (120)	6.7 (3.7)
Glass (borosilicate)	Ceramic	2.2 (0.079)	63 (9)	—	< 0.1	2 (1)	5 (3)
Carbon	Carbon	1.8 (0.065)	20 (3)	—	< 0.1	5–90 (3–50)	2 (1)

2.6.5.2.2.2 Thermoplastic Resins

Thermoplastics are divided into three main classes: amorphous, crystalline, and liquid crystal. Polycarbonate, acrylonitrile-butadiene-styrene (ABS), polystyrene, polysulfone, and polyetherimide are amorphous materials. Crystalline thermoplastics include nylon, polyethylene, polyphenylene sulfide, polypropylene, acetal, polyethersulfone, and polyether etherketone. Amorphous thermoplastics tend to have poor solvent resistance. Crystalline materials tend to be better in this respect. Relatively inexpensive thermoplastics such as nylon are extensively used with chopped E-glass fiber reinforcements in countless injection molded parts. There are many numbers of applications using continuous fiber reinforced thermoplastics.

2.6.6 Material selections

Selection of the suitable material is a key aspect. Even a small amount in weight reduction of the vehicle, may have a wider economic impact. Composite materials are proved as suitable substitutes for steel in connection with weight reduction of the vehicle. The material which is capable of absorbing more energy in the form of plastic deformation would be preferred for upper cross beam. Composite materials have higher strain energy (energy storing capacity) as compared with metals hence, the composite materials can be selected for beam design. Fiber reinforced polymer (FRP) composite materials consisting of fibers of high strength and modulus embedded in or bonded to resins with distinct interfaces between them. In general, fibers are the principal load carrying members, while the surrounding resins keep them in preferred location and orientation [27]. The commonly used fibers are carbon, glass, keviar, etc. Among these, fiber has been selected based on the energy storing capacity and strength. The types of glass fibers are C-glass, D-glass, S-glass and E-glass. The C-glass fiber is designed to give improved surface finish. D-glass is used when permeability to electromagnet wave is required. S-glass fiber is design to give very high modular, which is used particularly in aeronautic industries [15]. Carbon fiber behavior is due to the properties like high stiffness, high tensile strength, low weight and less deform it is selected for bumper [28].

2.6.7 Resin selection

In a fiber reinforced plastics (FRP) beam, the inter laminar shear strengths are controlled by the matrix system used. Since these are reinforcement fibers in the thickness direction fiber do not influences inter laminar shear strength. Therefore, the matrix system should have good inter laminar shear strength characteristics compatibility to the selected reinforcement fiber. Many thermo-set resins such as polyester, vinyl ester, and Epoxy resins are being used for fiber reinforcement fabrication. Among these resin systems, epoxies show better inter laminar shear strength and good mechanical properties. Hence, epoxide is found to be the best resins that would suit this application. Different grades of epoxy resins and hardener combinations are classified, based on the mechanical properties [26].

Table 2.4: Mechanical properties of matrices with different direction [2]

Property	Units	Epoxy	Aluminum	Polyamide
Axial modulus	GPa	3.4	71	3.5
Transverse modulus	GPa	3.4	71	3.5
Axial Poisson's ratio	—	0.30	0.30	0.35
Transverse Poisson's ratio	—	0.30	0.30	0.35
Axial shear modulus	GPa	1.308	27	1.3
Coefficient of thermal expansion	μm/m/°C	63	23	90
Coefficient of moisture expansion	m/m/kg/kg	0.33	0.00	0.33
Axial tensile strength	MPa	72	276	54
Axial compressive strength	MPa	102	276	108
Transverse tensile strength	MPa	72	276	54
Transverse compressive strength	MPa	102	276	108
Shear strength	MPa	34	138	54
Specific gravity	—	1.2	2.7	1.2

2.6.8 Laminar Composites

Laminar composites are found in as many combinations as the number of materials. They can be described as materials comprising of layers of materials bonded together. These may be of several layers of two or more metal materials occurring alternately or in a determined order more than once, and in as many numbers as required for a specific purpose. Clad and sandwich laminates have many areas as it ought to be, although they are known to follow the rule of mixtures from the modulus and strength point of view. Other intrinsic values pertaining to metal-matrix, metal-reinforced composites are also fairly well known. Powder metallurgical processes like roll bonding, hot pressing, diffusion bonding, brazing and so on can be employed for the fabrication of different alloys of sheet, foil, powder or sprayed materials. It is not possible to achieve high strength materials unlike the fiber version. But sheets and foils can be made isotropic in two dimensions more easily than fibers. Foils and sheets are also made to exhibit high percentages of which they are put. For instance, a strong sheet may use over 92% in laminar structure, while it is difficult to make fibers of such compositions. Fiber laminates cannot over 75% strong fibers. The main functional types of metal-metal laminates that do not posses high strength or stiffness are single layered ones that endow the composites with special properties, apart from being cost-effective. They are usually made by pre-coating or cladding methods.

Pre-coated metals are formed by forming by forming a layer on a substrate, in the form of a thin continuous film. This is achieved by hot dipping and occasionally by chemical plating and electroplating. Clad metals are found to be suitable for more intensive environments where denser faces are required. There are many combinations of sheet and foil which function as adhesives at low temperatures. Such materials, plastics or metals, may be clubbed together with a third constituent. Pre-painted or pre-finished metal whose primary advantage is elimination of final finishing by the user is the best known metal-organic laminate. Several combinations of metal-plastic, vinyl-metal laminates, organic films and metals, account for up to 95% of metal-plastic laminates known. They are made by adhesive bonding processes [25].

2.6.9 Manufacturing Process Selection

Apart from the selection of material and design procedure, the selection of manufacturing process also determines the quality and cost of the product. Hence, the composite frontal frame structure manufacturing process should fulfill the following criteria:

- The process should be amenable to mass production.
- The process should be capable of producing continuous reinforcement fiber

A number of processes have been developed to produce and shape the fiber reinforced composites. Variations are based primarily on the orientation of the fibers, the length of continuous filaments and the property of the final product. Each seeks to embed the fibers in a selected matrix with the proper alignment is necessary to produce the desired properties. Discontinuous fibers can be combined with a matrix to produce either a random or preferred orientation. Continuous fibers are normally aligned in a unidirectional fashion in rods or tapes, woven into fabric layers. There are different types of manufacturing processes:

- Hand Layup
- Prepreg forming
- Pressure molding
- Vacuum bagging
- Filament winding
- Pultrusion
- Spray method
- Sheet molding
- Bulk molding
- Resin transfer molding

2.6.9.1 Hand Lay-up Technique

The hand layup is one of the oldest and most commonly used methods to manufacture the composite. The work is carried out in a female mold polished with gel coat on the inside surface. Having the required materials and setting up the mold at a convenient working height in the workshop, the following procedure is adopted:

- Wash the mould carefully with warm water and soft soap to remove dust, grease, finger marks, etc.
- Dry the mould thoroughly.

- Check the mould surface for chips or blemishes. These should be repaired by filling with polyester filler and cutting back with wet/dry paper. The odd small chip can be temporarily repaired by filling with filler material.
- If the mold surface is in good condition the mold release wax is now applied, using a small piece of cloth. Three coats of wax are sufficient for a mould surface which has been previously used but a new mold surface will require at least six applications. Care must be taken to remove all streaks of wax. Make sure that the wax is polished and not removed by aggressive buffing. Failure to take care at this stage can result in stick up.
- Cut the fiber to the desired length, so that they can be deposited on mold layer by layer during fabrication.
- Prepare the solution of resin and place the first layer of fiber chopped mat on mould followed by epoxy resin solution over material.
- Wait for 5-10 minutes; repeat the procedure till the desired thickness is obtained. Finally remove the composite material from the mould.

The most common precursor is polyacrylonitrile (PAN), because it gives the best carbon fibre properties [26].

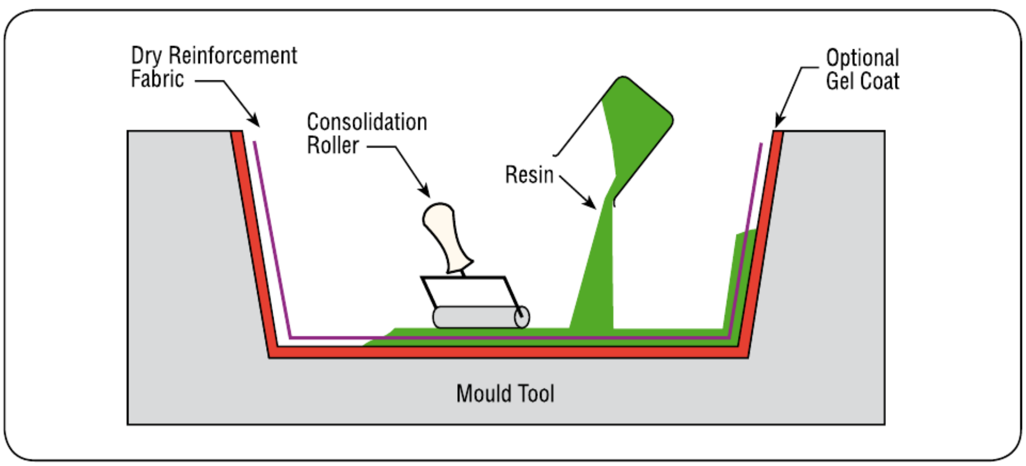


Figure 2.6: Hand layup technique [29]

2.6.9.2 Spray layup

Fibre is chopped in a hand-held gun and fed into a spray of catalyzed resin directed at themould. The deposited materials are left to cure under standard atmospheric conditions [29].

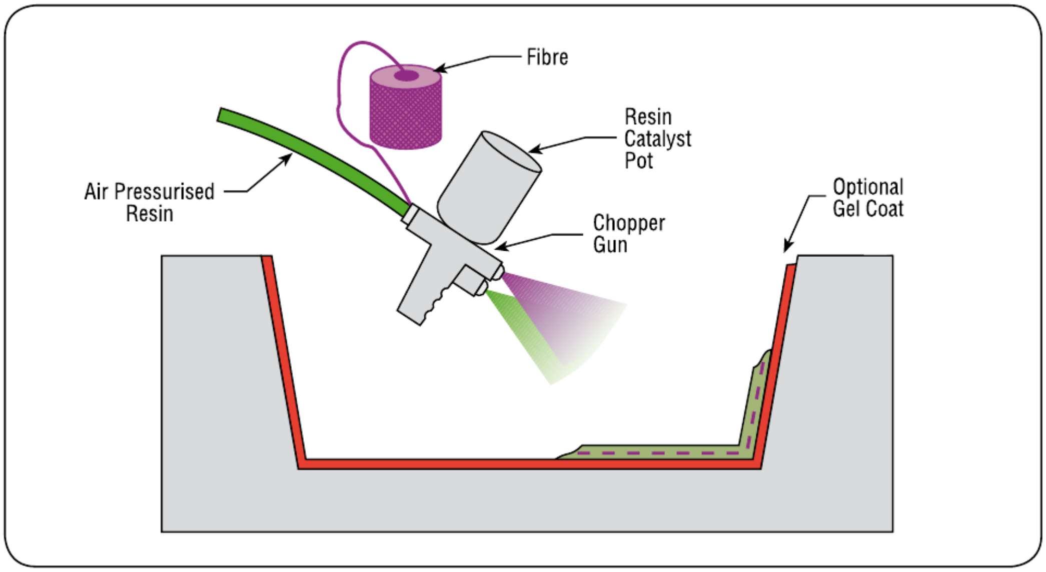


Figure 2.7: Spray layup technique [29]

2.6.9.3 Resin transfer molding

Fabricsare laidup as a dry stack of materials. These fabrics are sometimes pre-pressed to the mould shape, and heldtogether by a binder. These 'preforms' are then more easily laid into the mould tool. A second mould tool is then clamped over the first, and resin is injected into the cavity. Vacuum can also be applied to the mould cavity to assist resin in being drawn into the fabrics. This isknown as Vacuum Assisted Resin Injection (VARI). Once all the fabric is wet out, the resin inlets are closed, and the laminate is allowed to cure. Both injection and cure can take place at either ambient or elevated temperature [29].

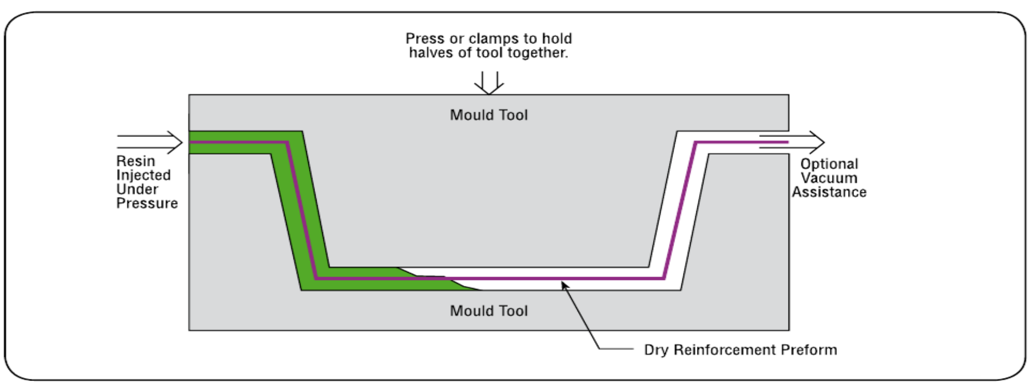


Figure 2.8: Resin transfer molding technique [29]

Advantages:

- low cost tools (low production cost)
- versatile wide range of products

Disadvantages:

- time consuming
- easy to form air bubbles and disorientation of fibers
- inconsistency

Table 2.5: Mechanical properties of reinforcement fibers [30]

Fiber	Density		Tensile Strength		Tensile Modulus		Ultimate
	lb/in^3	gms/cm^3	psi x 10^3	Mpa	psi x 10^6	Gpa	Elongation
E-Glass	.094	2.60	500	3450	10.5	72	4.8%
S-Glass	.090	2.49	665	4590	12.6	87	5.7%
Aramid-Kevlar® 49	.052	1.44	525	3620	18	124	2.9%
Polyester-COMPET®	.049	1.36	150	1030	1.4	10	22.0%
Carbon-PAN	.062-.065	1.72-1.80	350-700	2400-4800	33-57	228-393	0.38-2.0%

Sr. no.	Properties	E-glass/epoxy	Carbon epoxy	Graphite epoxy
1	EX(MPa)	43000	177000	294000
2	EY(MPa)	6500	10600	6400
3	EZ(MPa)	6500	10600	6400
4	PRXY	.27	.27	.023
5	PRYZ	.06	.02	.01
6	PRZX	.06	.02	.01
7	GX (MPa)	4500	7600	4900
8	GY(MPa)	2500	2500	3000
9	GY(MPa)	2500	2500	3000
10	ρ (kg/mm^3)	.000002	.0000016	.00000159

Table 2.6: mechanical properties of composite material [31]

Material	Tensile strength (Mpa)	Tensile Modulus (Gpa)	Density (g/cm^3)
E-glass fiber	3448	72	2.54
S-glass fiber	4482	86	2.49
Carbon fiber(PAN)			
• AS-4	4000	228	1.8
• IM-7	5413	276	1.77
• T-300	3654	231	1.77
• T-650/42	5033	290	1.77
Carbon fiber (Pitch)			
• P-55	1724	379	1.99
• P-75	2068	517	1.99
• P-100	2241	690	2.16

Table 2.7 Mechanical properties of Fibers [2]

Property	Units	Graphite	Glass	Aramid
Axial modulus	GPa	230	85	124
Transverse modulus	GPa	22	85	8
Axial Poisson's ratio	—	0.30	0.20	0.36
Transverse Poisson's ratio	—	0.35	0.20	0.37
Axial shear modulus	GPa	22	35.42	3
Axial coefficient of thermal expansion	µm/m/°C	–1.3	5	–5.0
Transverse coefficient of thermal expansion	µm/m/°C	7.0	5	4.1
Axial tensile strength	MPa	2067	1550	1379
Axial compressive strength	MPa	1999	1550	276
Transverse tensile strength	MPa	77	1550	7
Transverse compressive strength	MPa	42	1550	7
Shear strength	MPa	36	35	21
Specific gravity	—	1.8	2.5	1.4

2.7 Impact

2.7.1 Frontal impact

For cases of frontal impact, there has to be a frontal crush zone that will absorb and distribute the forces when the car crashes head-on, whether into another car, a large tree, or a bridge abutment. Structurally, the frontal shroud should not be shoved rearward and impinge into the front-door hinges and door-latch system.

2.7.2 Side impact

For side impacts, the car must have strong frame members and rocker sections that are at the outermost periphery of the vehicle body, or if the main structural frame members are further inboard, serve as extensions. These members should be internally reinforced with a baffle plate, or with rigid-foam filling, or both. Such reinforcement measures will typically triple the compressive and bending strength of the hollow member that it is filling. The doors should have internal reinforcement beams, with strong hinges and door-latch system.

2.7.3 Rear impact

For cases of rear impact, the seats should be designed with high backrests and integrated head restraints to help keep the head, neck, and upper torso in safe alignment during the dynamics of a crash.

2.7.4 Rollover

For incidences of rollover accidents, the cab needs to incorporate a strong safety-cage construction with roof pillars, windshield header, side rails, and cross-members, all internally reinforced with baffle plates and lightweight-rigid foam, thereby increasing each members compressive and bending strength by at least a factor of three. The roofs structural integrity should be capable of being maintained in a dynamic lateral rollover test, at a speed of at least 50mph. Side-curtain airbags should inflate when the sensors determine that a lateral rollover sequence is beginning, and should stay crash test Technology International Safe liner trucks, which provide under ride protection around the entire truck [32].

2.8 Crashworthiness

Crashworthiness can be defined as the capability of a vehicle structure to withstand and undergo an impact load in order to protect its survival space without any serious injury or death of its occupants. Inertia effects can influence impact response in different ways, depending on the nature of the structure the goal of crashworthiness is an optimized vehicle structure that can absorb the crash energy by controlled vehicle deformations while maintaining adequate space so that the residual crash energy can be managed by the restraint systems to minimize crash loads transfer to the vehicle occupants [33 34]. The goal of crashworthiness is an optimized vehicle structure that can absorb the crash energy by controlled vehicle deformations while maintaining adequate space so that the residual crash energy can be managed by the restraint systems to minimize crash loads transfer to the vehicle occupants [12].The novel design has to cope with the following crashworthiness problems:

1. Crash position: in the case of a full overlap crash (both longitudinal and engine involved) as in the case of an offset or oblique crash (at 40 per cent overlap only one longitudinal directly involved) a similar amount of energy must be absorbed by the front structure.

2. Crash velocity: With a not much longer deformation length, much more energy must be absorbed at high crash velocities (resulting in less fatal injuries) and a lower injury level must be obtained at lower crash velocities.

3. Crash pulse: A deceleration pulse must be obtained which is optimal (lowest injury level) for the concerning relative collision speed and the chosen dummy restraint parameters.

4. Crash compatibility: The structure stiffness must also be optimized for the mass and stiffness of the struck object.

5. Mean crushing load: It is the average force or load over which the energy absorber deforms in a stable manner, and is obtained for a given deflection by dividing the energy absorbed by the crush distance.

These equation is only used for the validation of analysis of rectangular tube.

$$\frac{\mathrm{Pm}}{Mo} = 52.22\left(\frac{\boldsymbol{c}}{\boldsymbol{h}}\right)^{1/3} \tag{1}$$

where Pm=mean crush load Mo=fully plastic bending moment per unit length $Mo = \frac{\boldsymbol{\sigma h^2}}{4}$ where $\boldsymbol{\sigma} =$ yield stress of the material , C= side length, h= thickness of tube

6. Peak force: It is the force at which first fold starts. It is higher than the mean load.

7. Crush Force Efficiency: It is the mean crushing force divided by the peak crushing force [35].

2.8.1 Crashworthiness requirements

The vehicle structure should be sufficiently stiff in bending and torsion for proper ride and handling. It should minimize high frequency fore-aft vibrations that give rise to harshness . In addition, the structure should yield a deceleration pulse that satisfies the following requirements for a range of occupant sizes, ages, and crash speeds for both genders: [33]

- Deformable, yet stiff, front structure with crumple zones to absorb the crash kinetic energy resulting from frontal collisions by plastic deformation and prevents intrusion into the occupant compartment, especially in case of offset crashes and collisions with narrow objects such as trees. Short vehicle front ends, driven by styling considerations, present a challenging task to the crashworthiness engineer.
- Deformable rear structure to maintain integrity of the rear passenger compartment and protect the fuel tank.
- Properly designed side structures and doors to minimize intrusion in side impact and prevent doors from opening due to crash loads.
- Strong roof structure for rollover protection.
- Properly designed restraint systems that work in harmony with the vehicle structure to provide the occupant with optimal ride down and protection in different interior spaces and trims.
- Accommodate various chassis designs for different power train locations and drive configurations.

The need for increased crashworthiness, and lighter compact design, demands the development of more efficient body-in-white, chassis, suspension and power train components. Sub-frame and underbody cross-members provide significant rigidity to the vehicle front-end allowing longitudinal member to crush efficiently. Crashworthiness is the ratio of the mean crush stress (S) to the density of the material (D).

ES = Mean Crush Stress/ Density of the material = S/D

Design Engineers of the vehicles should keep in mind while designing that, the structures in the vehicles should absorb the maximum energy during the impact. In the force v/s deflection curve, the area under the curve shows the energy absorption. The structure should be designed in such way that the area under the curve should be maximum during the vehicle impact which in turn reduces the injury of the occupants. In the present day accidents happen every hour around the world and most of these are very dangerous. Frontal-Impact crash is the one of the most severe crash scenario. Figure 1 shows the comparison of different crash scenarios involved. It can be observed that the frontal impact is higher than all other impacts [12].

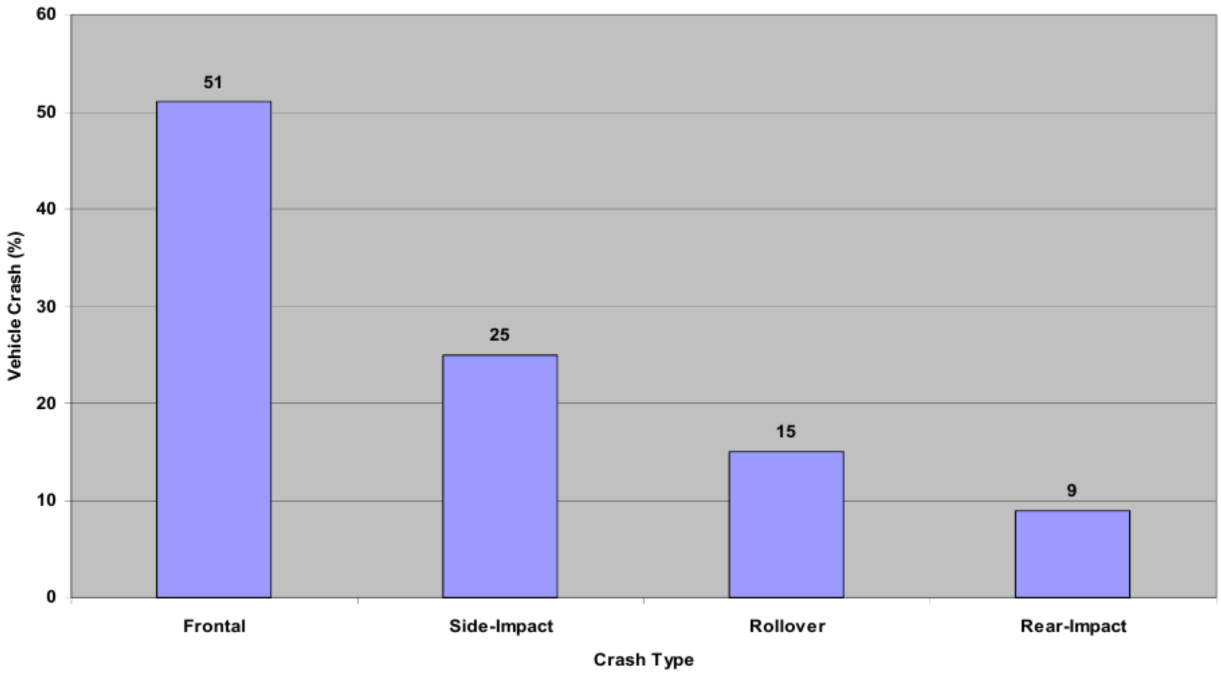


Figure2.9: Vehicle crashes by crash type [12]

2.8.2 Crashworthiness Metrics

Crashworthiness is measured by deferent metrics depending on the type of analysis being conducted.

- Structural analysis, in which the structure response under impact is of engineering concern. In this type of analysis, the amount of Impact Energy (IE) absorbed is of paramount importance as the larger the value, the safer the design. The main objective of the design process is to increase IE. Dividing IE by the structural mass is called the Specific Energy Absorbed (SEA), which represents the amount of energy absorbed with respect to the structural mass. It is basically used to compare the efficiency of different structures. Another important quantity is the peak reaction force achieved during impact. The objective of the design process is to limit peak values since higher peak values can induce large deceleration values which may cause irrecoverable brain damage.
- Injury analysis, in which the effect of impact on the occupants is considered. This effect is determined by the injury tolerance limits determined from bio-mechanics. This type of analysis also studies the interaction between occupants and vehicle interior under crash situations, and how restraint systems can limit the level of injury severity [11].

2.9 Energy absorption

2.9.1 Internal energy

The law of conservation of energy explains that energy inside a system cannot be created or destroyed, and it can be transferred from one form into another without changing the Total amount of energy. Considering mechanical systems, such as the vehicle systems, the absorbed work or internal energy of a system cannot exceed the work input. In theory, internal energy is equal to the work (E) done by external Forces on the system, which is equal to the product of the exerted force (F) and the distance (d) through which the force moves. During the impact of a vehicle, its kinetic energy is predominantly transformed into plastic deformation of the respective structures, for which the internal energy can be calculated. To simplify the concept, the energy of a head-on vehicle impact against a rigid barrier is provided. The rigid barrier is fixed during the impact so its kinetic energy is constantly zero. Due to the rigid body definition, it does not deform and absorb energy. Therefore, the energy of the vehicle is equal to the energy of whole system. This means that the kinetic energy of vehicle is absorbed by itself during impact time. The total amount of internal energy to be absorbed by the chosen vehicle models is calculated using ANSYS LS-DYNA [37].

2.9.2 Total energy

The total absorbed energy is the amount of energy that the specimen absorbed during the entire impact test from start to end. This value may be the same as energy to maximum load when the specimen abruptly fails at the maximum load point. The value is calculated from the time the load begins to rise until the first occurrence of zero loads after the maximum point. This value can be used as an indicator to a materials ductility or toughness the higher the value the stronger the material. However, care needs to be taken to ensure that when the data collection ends, the load has fallen below the zero thresholds. If it hasn't, this value is no longer a valid number to be used. The total energy is calculated by the summation of energy before crash and after crash of the different materials.

2.9.3 Specific energy

Fundamentally, the key requirement of crash protection is to absorb and dissipate energy. In an impact, the crash structure must dissipate the energy of the impact whilst ensuring that the occupants of the vehicle are not subjected to excessive accelerations/forces, and that the "survivable" zone within the car remains intact (i.e. the crash structure does not ingress too far into the vehicle). This energy dissipation is achieved through plastic work done in deforming the material in the crash structure. Therefore, by comparing the capacity for energy dissipation of different materials, and considering their density, it is possible to assess which materials provide optimal energy dissipation per unit mass "specific energy absorption". Composites have dramatically higher specific energy absorption than steel or aluminum.

Energy absorption is the concept of absorbing energy by converting the kinetic energy into another form of energy. Energy converted is either reversible like pressure energy in compressible fluids or elastic strain energy in solids or irreversible plastic deformation energy. When designing a collapsible energy absorber, one aims at absorbing the majority of kinetic energy of impact within device itself in an irreversible manner, thus ensuring that human injuries and equipment damages are minimal. The conversion of kinetic energy into plastic deformation depend on the magnitude and method of application of loads, transmission rates, deformation or displacement patterns and material properties . The component of deformable energy absorbers such as circular tubes, square tubes, multi corner tubes, frusta and honey comb cells. The study of deformation in energy absorber accounts geometrical changes and interaction between various modes of deformation such as axisymetric mode of collapse and diamond (non-axisymetric) mode of collapse for axial loaded tubes.

Increasing the amount of energy absorption of front structures can help reduce the cabin intrusion in turn. But In case of a crash between actual vehicles, crash members, like front rails, do not always have a good interaction with each other because of their mismatch in design layout. When crash members miss each other, not enough crash load for energy absorption is generated and could cause a severe deformation of the passenger compartment. Front body parts start to absorb the energy from the beginning of the crash and continue to the third stage. As for the cabin parts, strain energy starts to be absorbed after 30 ms. In case of the small car in this study, some 70 % of the strain energy of body structures was shared by the front structures, and 30 % by the cabin structures. The EA amount of the small car cabin absorbed is 1.4 times as much as that of the cabin structures absorbed in an Euro NCAP 64km/h ODB crash. On the contrary, in case of the SUVs, most energy was absorbed by front structures only [38].

2.9.4 Energy absorber characteristics

Fundamentally, the load-displacement response of energy absorbing devices can primarily measure their energy absorption performance. Energy absorption, Ea is defined as an integration of a load-displacement curve as follows.

$$E_a = \int_0^{\delta \max} P \delta d\delta \tag{2.1}$$

where P is an instantaneous crushing load, δ and δmax are the current and maximum attainable crush distance, respectively. From Equation (2.1), the mean crush load can be determined using the following equation.

$$P_m = \frac{1}{\delta} \int_0^{\delta} P \delta d\delta \tag{2.2}$$

In general, a collapse load can be defined as the required load to cause a permanent deflection, and the deflection increases as the crush progresses. An ideal energy absorber can be represented with a constant crushing load, P_{max} from the onset of the crushing process up to the maximum deflection, δmax. Energy absorption capacity can then simply be calculated as the rectangular area of a load deflection curve.

The most important characteristic of energy absorbers is the specific energy absorption capacity, SEA. The specific energy absorption, SEA is defined by energy absorbed per unit mass where Eabs is the absorbed energy and m is the original un deformed mass.

$$SEA = \frac{E_{abs}}{m} \tag{2.3}$$

The SEA is the most common performance parameter for energy absorbing components to assess the energy absorbing capacity particularly when weight reduction is vitally important. Moreover, the specific energy absorption is usually used as an indicator of the weight efficiency of an energy absorber. For a given absorbed energy, a higher SEA indicates a more efficient crash absorber in terms of its weight.

2.9.4.1Mean crush load

The mean crush load, Pmean for a given deformation is defined as the total energy absorbed energy, Et divided by the total deformation, δ.

$$P_{mean} = \frac{E_t}{\delta} \tag{2.4}$$

2.9.4.2 Dynamic amplification factor

The dynamic amplification factor, DAF is an additional crush criterion when comparing the energy absorption capacity of structures under quasi static and dynamic loading conditions. This parameter is a simple means of determining the effect of loading conditions . The dynamic amplification factor is defined by the ratio of energy absorbed under dynamic loading, Ed and energy absorbed under static loading, Es: [34]

$$DAF = \frac{E_d}{E_s} \tag{2.5}$$

2.10 Crash Analysis

Vehicle crash is a highly nonlinear transient dynamics phenomenon. The purpose of a crash analysis is to see how the car will behave in a frontal or sideways collision. Crashworthiness simulation is one typical area of application of Finite-Element Analysis (FEA). This is an area in which non-linear Finite Element simulations are particularly effective. In this project impacts and collisions involving a car frontal frame model are simulated and analyzed using ANSYS software. The crash analysis simulation and results can be used to assess both the crashworthiness of current frame and to investigate ways to improve the design. To minimize the injury of car occupants during a frontal crash, the car structure must generate a predetermined optimal deceleration pulse (specific curve) on the assumed undeformable passenger compartment to absorb all the kinetic energy [39].

The objective of the research project presented here was to design a concept structure that substitutes the conventional energy absorbing members in a frontal vehicle structure and that yields optimized deceleration pulses for different crash velocities, overlap percentages and collision partners. A crossbeam improves the distribution of forces exhibited by the front-end of a car and therefore the homogeneity, at least on the level of the longitudinal. This offered the opportunity to check how test procedures under consideration evaluated this change in front-end design [15].

2.10.1 Linear and Nonlinear FE Analyses

There are mainly two types of FE analyses: linear and nonlinear. The two major differences between them can be summarized as:

- In linear FE analysis, the displacements are assumed to be infinitesimally small, where nonlinear FE analysis involves large displacements. The term displacements refers to both linear and rotational motions.
- In linear FE analysis, the material behavior is assumed to be linearly elastic, whereas in nonlinear FE analysis, the material exceeds the elastic limit and/or its behavior in the elastic region is not necessarily linear.
- Linear FE problems are considerably easy to solve at a low computational cost compared to nonlinear FE problems.
- Also, deferent load cases and boundary conditions can be scaled and superimposed in linear analysis which are not applicable to nonlinear FE analysis.
- The nonlinear FE analysis can be considered as the modeling of real world systems, while linear FE is the idealization. This idealization can be reasonably satisfactory in some cases, but for special cases nonlinear FE modeling is the only option such as in crashworthiness simulations.

Sources of Nonlinearity

- Geometric nonlinearity; in which the change in geometry is taken into consideration in setting the strain-displacement relations.
- Material nonlinearity; in which the material response depends on the current deformation state and possibly past deformation history[11]

2.10.2 Material Nonlinearities

Material nonlinearities refer to the nonlinear relationship in the stress-strain curve for the given material where plasticity, or permanent deformation, is involved. In an elastic-plastic model, material yielding and strain hardening become factors that must be accounted for. In this research, it is assumed that material does not reach the ultimate stress. The stress-strain relationship for a material, as shown in Fig. 2.10, characterizes the deformation behavior of the material. This curve is often plotted using engineering stress and strain measures, where the change in the cross-sectional change in area is neglected. Plasticity is a property of a material to undergo a non-reversible change of shape in response to an external force. The total strain is expressed as

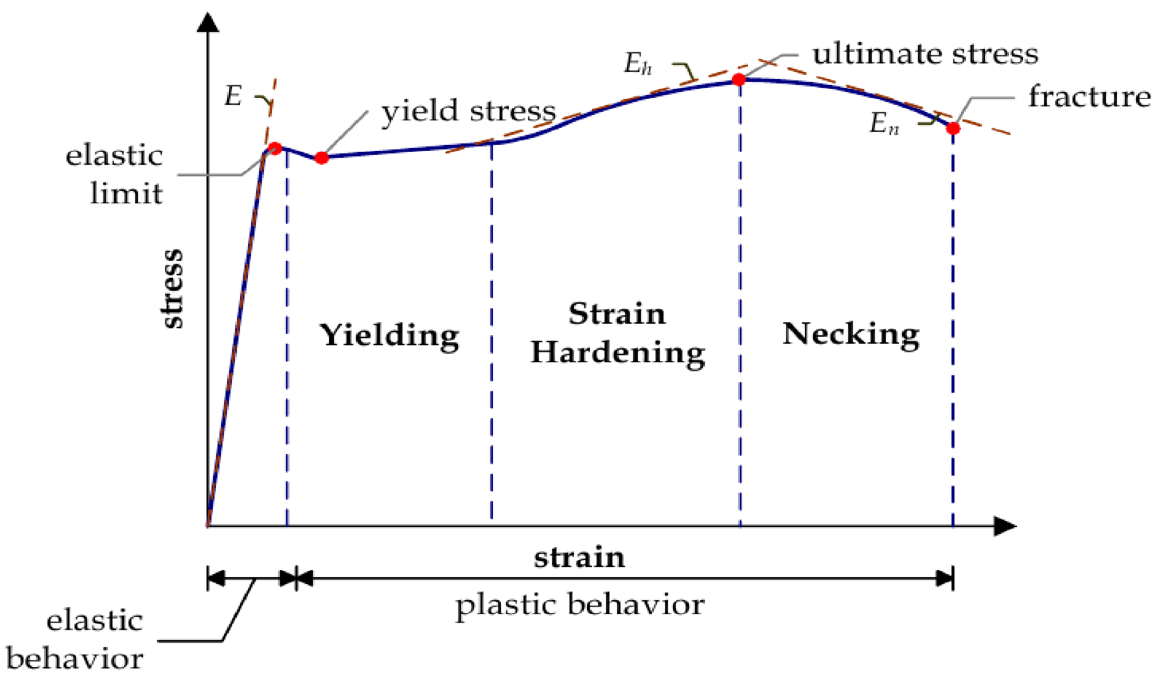


Figure 2.10: The stress-strain curve:the linear elastic behavior holds for small displacements, but most materials exhibit nonlinear phenomena as illustrated past the elastic limit. Parameters E,E_h,and E_n represent the elastic modulus ,the strain hardening tangent modulus and the necking tangent modulus respectively.

The yield function defines the criterion in terms of the multi axial stress for which yielding begins, or transition from elastic to plastic deformation. In one dimension, yielding occurs when the uniaxial stress reaches the value of the yield stress (σ_Y)in tension, i.e., when $\sigma = \sigma_Y$. For multiaxial stress states, more complex criterion are required. For example, the Tresca, or maximum shear stress, criterion requires that the largest principal stress deference be less than the yield shear stress. The von Mises criterion states that failure occurs when the energy of distortion reaches the same energy for yield/failure in uniaxial tension. The criterion defines a yield surface. During loading, once the yield criterion is reached, plastic straining, or strain hardening, occurs. The flow rule defines the relationship between the strain increments and the current stress and the stress increments and hardening rule define show the yield function changes during strain hardening. Strain hardening is an increase in mechanical strength due to plastic deformation. The simplest method to model strain hardening is to have the yield surface increase in size, but maintain its shape, as a result of plastic straining. This is referred to as isotropic hardening. An isotropic hardening law is typically not useful when cyclic loading occur [40].

2.10.3 Plastic deformation

A useful idealization in modeling plastic behavior takes the material to be linearly elastic up to the yield point and then “perfectly plastic” at strains beyond yield. Strains up to yield are recoverable, and the material unloads along the same elastic line it followed during loading; this is conventional elastic response. But if the material is strained beyond yield point , the “plastic” straining beyond yield point takes place at constant stress and is unrecoverable. Plastic deformation can generate “ residual” stresses in structures, internal stresses that remain even after the external loads are removed [41].

2.10.4 Nonlinear FE for Crashworthiness

Simulation of vehicle accidents is one of the most challenging nonlinear problems in mechanical design as it includes all sources of nonlinearity. A vehicle structure consists of multiple parts with complex geometry and is made of different materials. During crash, these parts experience high impact loads resulting in high stresses. Once these stresses exceed the material yield load and/or the buckling critical limit, the structural components undergo large progressive elastic-plastic deformation and/or buckling. The whole process occurs within very short time durations. Since closed form analytical solutions are not available, using numerical approach specially the nonlinear FE method becomes unavoidable. There are few computer softwares dedicated to nonlinear FE analysis such as ABAQUS, RADIOSS, PAM-CRASH and LS-DYNA. LS-DYNA has been proved to be best suited for modeling nonlinear problems such as crashworthiness problems. In the following section, the theoretical foundation of the nonlinear FE analysis is presented [11].

2.10.5 Crash test

Euro-NCAP organizes crash test using frontal and side collisions and publish test results that provide accurate information to motoring consumers based-on a realistic and independent assessment of safety performance for most popular cars sold in Europe.

US NCAP(New Car Assessment Program) - 56 km/h Frontal Impact is a frontal impact for the US New Car Assessment Program (NCAP), and due to its high velocity impact into a rigid barrier (100% overlap), is one of the critical regulations to meet for frontal impact. This test needs the vehicle front-end structure to absorb very high kinetic energy while decelerating the car at an optimal rate (as close to a square pulse as possible) [3 10].

In the European New Car Assessment Program for frontal impact, a vehicle moving at 65khm (40 hm)strikes a deformable barrier that is offset to 40% of vehicle width .This test is very severe on the vehicle front-end structure as only one-half of the structure absorbs most of the energy of impact [3].

Crash incompatibility arises due to: Mass, Stiffness and Geometric Incompatibility; stiffness may not prove to be as dominant an aggressiveness factor as mass for example, for a Ford Taurus and a Ford Ranger pickup, Both vehicles had approximately the same crash test weight (1750-kg), but note that the Ranger pickup was significantly stiffer than the Taurus and geometric incompatibility creates a mismatch in the structural load paths in frontal impacts [42].

The conditions for the impact simulations are like velocity of the impact barrier was given as 15 kmph as per FMVS standard, Crash type as frontal impact, Obstruction as rigid barrier and Simulation time as 50 ms. . After all the boundary conditions were applied the meshed model is exported to LSDYNA. During the process the properties of the bumper materials like young's modulus, yield strength, Poisson ratio and density should be considered for the pre-processing. The bumper converts the kinetic energy of the system to strain energy due to elastic and plastic deformation of the material. Internal Energy is phenomenal as it decides the plastic deformation after the collision of the vehicle. Kinetic energy is absorbed by the bumper as it undergoes plastic deformation during collision. The impact analysis between the pole and frontal bumper during high speed crash involves transient and non-linear conditions which lead to an elasto-plastic impact. During this collision, the bumper system should not have any crash or failure to prove the FMVSS [19].

2.10.5.1 Standard of bumper crush test

Under the International safety regulations originally developed as European standards and now adopted by most countries outside North America, a car's safety systems must still function normally after a straight-on pendulum or moving-barrier impact of 4 km/h (2.5 mph) to the front and the rear, and to the front and rear corners of 2.5 km/h (1.6 mph) at 45.5 cm (18 in) above the ground with the vehicle loaded or unloaded [4].

The Auto/Steel Partnership (A/SP) commissioned Quantech Global Services to conduct a study on the front-end of a four-door, mid-size sedan. The objective was to reduce the cost and mass of the front end structure through the use of advanced high-strength steels. The study included the development of a high speed bumper system.Current North American passenger cars have low speed bumper systems. Thus, Quantech's first task for the high speed bumper system was to establish design criteria and a design process. Quantech, in consultation with A/SP, established the design criteria for a high speed bumper system as:

- No bumper damage or yielding after a 5mph (8km/h) frontal impact into a flat, rigid barrier. Note: This criterion does not apply to low speed bumpers, where controlled yielding and deformation are beneficial.
- No intrusion by the bumper system rearward of the engine compartment rails for all impact speeds less than 9mph (15km/h).
- Minimize the lateral loads during impacts in order to reduce the possibility of lateral buckling of the rails [43].

At low velocity impacts up to 4 km/h the bumper beam system should absorb the impact energy entirely elastically, i.e. without any plastic deformation whatsoever. Up to 8 km/h the energy should be absorbed through plastic deformation confined to the bumper beam itself. Up to 15 km/h all the impact energy should be absorbed in the bumper beam and crash boxes while as for higher impact velocity all components in the system should absorb an optimized part of the energy in interaction with connected units, thus contributing significantly to the safety of the vehicle's occupants [6].

3. METHODOLOGY AND SOFTWARE USED

Points below depict the methodology carried out in this research

- This study starts with modifying the design of upper cross beam of frontal frame structure of SUV by using different material in order to identify material which have better energy absorbing capability , high strength and crushing stability.
- First 3D was prepared using CATIA V5 with available dimensions. There was a significant advantage in creating a model with the help of CATIAV5 that could be used for Impact Analysis.
- Analytical formulation(Calculations)for existing and newly modified structure was done
- Then the model was meshed using FEA mesh. In order to reduce the complexity of the model, discrete element approximations were used where possible.
- Structural finite element analysis was done in ANSYS 14.5 work bench for different materials in order identify the material which meets best for design.
- Parametric study is carried out on the frontal frame structure, which included changing the material, orientation and thickness.
- Crash analysis was done by Explicit dynamics in ANSYS 14.5 for newly modified frontal structure and results were compared.

3.1 ANSYS

ANSYS is being used by designers across a broad spectrum of industries such as aerospace, automotive, manufacturing, nuclear, electronics, biomedical, and many more. ANSYS provides simulation solutions that enable designers to simulate design performance directly on desktop. In this way, it provides fast, efficient and cost effective product development from design concept stage to performance validation stage of the product development cycle. ANSYS package help to accelerate and streamline the product development process by helping designers to resolve issues related to structural deformation, heat transfer, fluid flow, electromagnetic effects, a combination of these phenomena acting together, and so on [11 26].

Table 3.1: Huanghai landscape F1 SUV (DD6460K) model specification

Parameters	Value and unit
Length	4620mm
Width	1860mm
Height	1830mm
Wheel base	2730mm
Ground clearance	220mm
Number of passenger	5
Curb mass	1830kg

Figure3.1: Huanghai landscape F1sport utility vehicle

Figure 3.1 shows huanghai Landscape F1 SUV on which is assembled in Bishoftu Automotive Industry and the study is carried out.

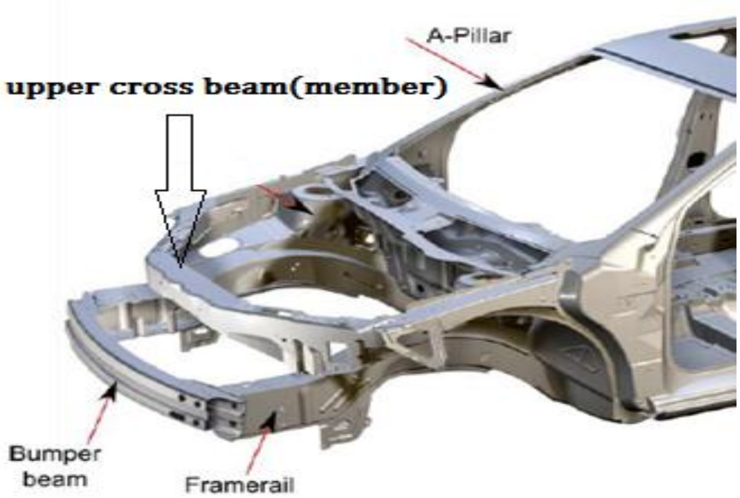
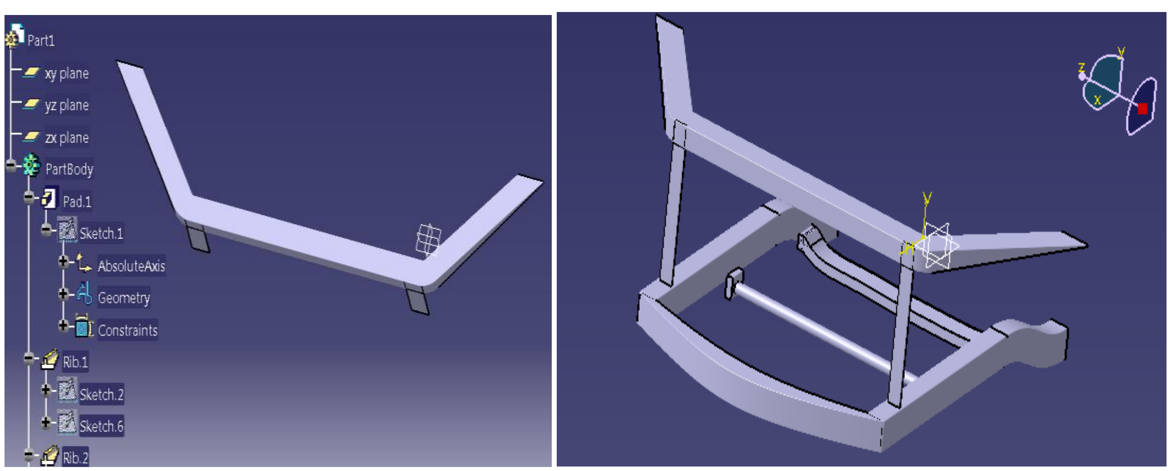


Figure 3.2: shows frontal structure of small vehicle (including upper cross beam, bumper beam and frame rail)

3.2 Modeling frontal frame structure (CAD Modeling)

Development of a different type of frontal beam is a long process which requires number of tests to validate the design and manufacturing. Computer aided engineering (CAE) is used to shorten this development thereby reducing the tests. CAE tools are widely used in the automotive industries; because of it enables them to reduce product development cost and time while improving safety, comfort and durability of the vehicles. Existing front cross beam and designed frontal frame structure (including front upper cross beam modified from frontal frame) is modeled in CATIA V5 in part design. The computer model is shown in figure below based on the measured values.



(a) existing frontal uppercross beam (b)Newly modified fontal frame structure

Figure3.3: (a) shows the frontal upper cross beam of existing haunghai SUV and (b) shows the newly modified frontal frame structure (i.e frontal upper cross beam which is modified from front frame rail is included as frame structure)

3.2.1 Existing upper cross beam dimension

This frontal upper cross beam is hollow rectangular with thickness of 2mm and the other dimensions are given in the figure 3.4.

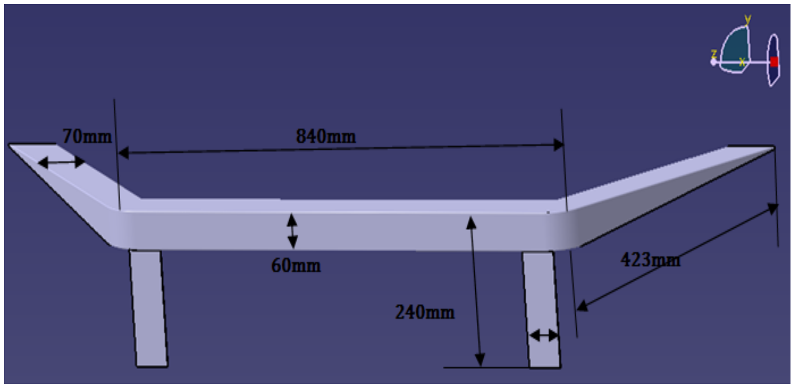


Figure 3.4: existing frontal upper cross beam dimension

The dimension of newly modified frontal upper cross beam is similar with the existing one except the leg of the beam with height of 435 mm from frame rail and the thickness of modified leg is 3mm and also a little shape modification was done. The basic requirements of the existing frontal upper cross beam is that the selected grade of steel(non linear material) must have sufficient energy absorbing capability for the size involved to ensure a full reliable frontal structure especially during crash. In general terms higher alloy content is mandatory to ensure adequate energy absorbing in order to save the life and component. The frontal upper cross beam is taken to be analyzed, which is made of Aluminum alloy. Because, different research and manual shows frontal collision zone like frame rail and bumper beam are done from aluminum alloy [55 56]. All the necessary parameters required for design and analysis are taken from its manual and also by measuring directly.

3.3 Static analysis of frontal upper cross beam

3.3.1 Analytical Formulation

The analytical formulation for a problem involves reference to the empirical and pure Engineering practices for arriving at a solution. Typically, empirical formulae that are historically developed for the application can offer a solution for the given problem. Considering the upper cross beam as two end fixed beam, load is applied throughout uniformly, as shown in the figure3.5 below.

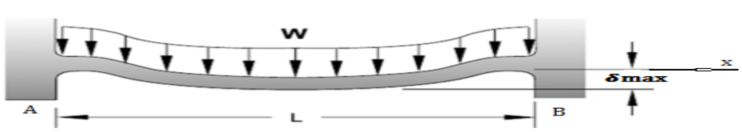


Figure 3.5 two end fixed support with uniformly distributed load

1.Mass

Curb mass of the SUV vehicle is 1830kg and passenger seat capacity is five ,an average mass of each person is 75kg, mass of the passenger comes to 375kgs.
Total mass of the SUV is 1830+375 =2205kg
Then $Weight = mg$ =2205kg x 9.8 m/s^2=21609N

2.Bending moment (M)

Bending moment of uniformly distributed load of two end fixed beam is given by:

$$\boldsymbol{M_A = M_B = -\frac{WL}{12}}$$

at x= $\boldsymbol{\frac{L}{2}}$ $\boldsymbol{M = \frac{WL}{24}}$ (3.1)

3.Moment of inertia(I)

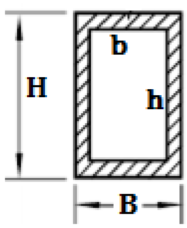


Figure 3.6: Hollow rectangular section

Moment of inertia of hollow rectangular section (I) is given by:

$$I=\frac{BH^3-bh^3}{12} \tag{3.2}$$

4.Section Modulus

Section modulus (Z) of the hollow rectangular section is given by:

$$Z= \frac{2I}{H} \tag{3.3}$$

5.Area

Area(A) of the hollow rectangular section is given by:

$$A = BH - bh \tag{3.4}$$

6. Impact force

Since the frontal upper cross beam is included in crumble zone (collision zone) ,this zone is compared with the criteria of the bumper beam and front end collision standard because if the frontal structure is more strengthened aggressiveness also increase due to that we have to consider the criteria of crush zone. To properly analyze the impact force, we need to find the deceleration of the vehicle after impact. Therefore impact force analysis of the front bumper beam is calculated with the deceleration value of 3g [45 46] .

$$F = ma \tag{3.5}$$

$a = 3G = 3x9.81 = 29.43$ m/s^2

Mass of the vehicle is 2205kg $F = ma = 2205x29.43 = 64893.15$N

Distributed force (w) is given by : $W = \frac{F}{L} = \frac{64893.15N}{1.686} = 38489.413\text{N/m}$

7.Maximum Stress(σ_{max})

Stress analysis is used to calculate relative stress levels in components under static or dynamic loads. For Uniformly distributed load of fixed beam (W) maximum stress is given by

$$\sigma_{max} = \frac{WL^2}{12Z} \tag{3.6}$$

8. Maximum deformation (δ_{max})

Deflection Analysis - used to examine how a component will deform under various loading conditions. For uniformly distributed load the maximum deflection is given by:

$$\delta_{max} = \frac{WL^4}{384EI} \tag{3.7}$$

Where W is distributed load, E modulus of elasticity of the selected material, L length of the beam and I is moment of inertia.

9. Strain energy

When a body is loaded, it deforms and some work is done which is stored within the body in the form of internal energy. This stored energy in the deformed body is known as Strain energy.

Strain energy Density (Resilience) The ability of the material to regain its original shape on removal of the applied load is known as Strain energy Density (Resilience) [7].

$$U = \int \frac{M^2 \boldsymbol{dx}}{2EI} = \int \frac{\boldsymbol{\sigma}^2}{2E}\ \mathrm{dV} \tag{3.8}$$

From bending theory $\boldsymbol{\sigma} = \frac{\mathrm{My}}{I}$

$$U = \frac{(\boldsymbol{M})^2}{2E(\boldsymbol{I})^2} dx \int \boldsymbol{y}^2\, dA \qquad \text{and by definition} \qquad I = \int \boldsymbol{y}^2\, dA$$

$$\therefore\ U = \frac{\boldsymbol{M}^2\boldsymbol{L}}{2EI} \text{ for finite length of the beam.}$$

Where U=strain energy, M=bending moment at L/2, I moment of inertia, y deformation at the center of beam.

10. Mass of the frontal upper cross beam

The mass of the beam, mass of two legs are included in the calculation of upper cross beam, but mass of the frame is not included.

$$m = \rho V = AL\rho \tag{3.9}$$

11. Stiffness of the beam

Stiffness of the upper cross beam is give by: K= impact force/deflection [54].

$$K = \frac{F}{\delta max} \tag{3.10}$$

12 Factor of safety

Factor of safety is given by: $f\mathrm{s} = \frac{\text{tensile yield strength}}{\boldsymbol{designing\ stress}}$

$$f\mathrm{s} = \frac{\sigma_y}{\sigma_{max}} \tag{3.11}$$

3.3.2 Natural frequency

The natural frequency of body or a system depends upon the geometrical parameters and mass properties of the body. It is independent of the forces acting on the body or a system. When the frequency of external excitation force acting on the body is equal to the natural frequency of a vibrating body, the amplitude of vibration become excessively large such state is known as resonance. Resonance is dangerous condition and it may lead to failure of the part. Therefore to avoid the resonance condition, the natural frequency of the machine parts that are subjected to vibration or external excitation should be known. Hence it is of prime importance to calculate the natural frequency. There are various methods for calculating natural frequency of a given vibratory system.

1. Equilibrium method
2. Energy Method
3. Rayleigh's Method

All the above methods are reduced to a common and simple equation of motion which is compared with the standard simple harmonic motion given as:

$$\ddot{x} + \omega^2 x = 0$$

And $(\omega_n)^{\mathbf{2}} = \frac{k}{m} \rightarrow \omega_n = \sqrt{\left(\frac{\boldsymbol{k}}{\boldsymbol{m}}\right)}$ where k is the stiffness and m is the mass of beam [48]

Frequency (fn) = $\frac{\omega_n}{\boldsymbol{2\pi}}$ and let Carbon fiber is taken for this frequency.

$$f\text{n} = \frac{1}{\boldsymbol{2\pi}} * \sqrt{\left(\frac{\boldsymbol{k}}{\boldsymbol{m}}\right)} = \frac{1}{\boldsymbol{2\pi}} * \sqrt{\left(\frac{\mathbf{32504.27}}{\mathbf{1.3424}}\right)} = 24.778\text{Hz} \tag{3.12}$$

3.3.3 Laminate

A laminate is constructed from groups of individual unidirectional plies which are laid at various angles depending upon design requirements or from layers of woven cloth laid at various angles to the main stress axis.

$$\text{n}_l = \frac{\text{t}}{\text{t}_l} \tag{3.13}$$

where n_l is number of laminate (layer), t_l is laminate thickness=2.1mm [2], t is thickness of the beam

4. RESULT AND DISCUSSION

4.1 Finite Element Analysis

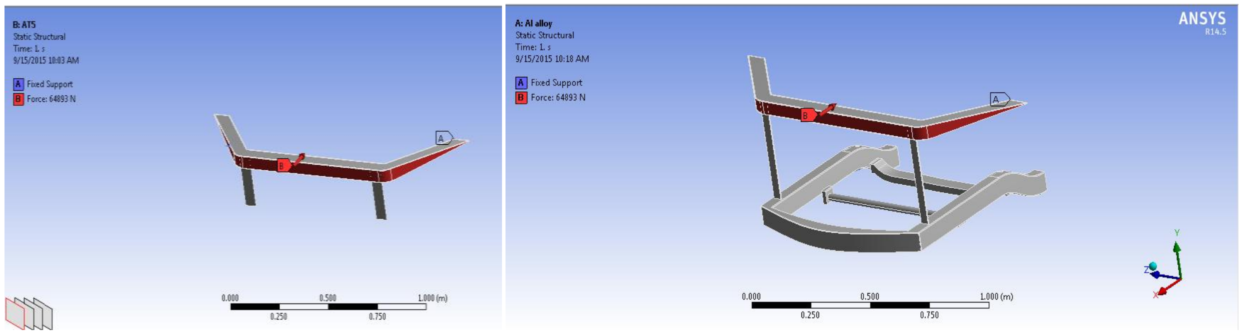
The Finite Element Analysis (FEA) is a numerical method for solving problems of manufacturing and mathematical physics. Design geometry is a lot more difficult and the accuracy requirement is a lot higher. We require:

- To understand the physical behaviors of a complex entity (strength, heat transfer capability, fluid flow, etc.)
- To predict the performance and behavior of the design.
- To calculate the safety margin.
- To identify the limitation of the design perfectly.
- To identify the optimal design with confidence.

Finite element analysis (FEA) is a computing technique that is used to obtain approximate solutions to the boundary value problems in engineering. It is used predict performance and behavior of the design. It uses a numerical technique called the finite element method (FEM) to solve boundary value problems. FEA involves a computer model of a design that is loaded and analyzed for specific results. Stress analysis is performed using quadrilateral/trihedral meshing element and plane strain finite element model. A plane strain solution is considered because of the high ratio of width to thickness of a beam [27]. Analysis for both existing frontal upper cross beam and upper cross beam which is modified from frontal frame structure is done by using ANSYS 14.5, and analysis results of stress, deflection and strain energy are done.

4.1.1 Boundary conditions

In finite element analysis 3D model of existing frontal upper cross beam and newly modified upper cross beam (frontal frame structure) which is developed in CATIA V5 is imported to ANSYS workbench to conduct the analysis. Boundary conditions are fixed support two end of the beam, and load is applied on the front face. Also material properties of aluminum alloy and TRIP(Transformation induced plasticity) steel as well as composite material properties i.e. modulus of elasticity, density etc are applied. From that material the one which have less deformation and good energy absorb capacity is selected for newly modified frontal upper beam.



a)existing frontal upper cross beam   b) and modified frontal frame structure

Figure 4.1: Boundary condition of existing frontal upper cross beam and modified frontal frame structure

4.1.2 Meshing

Meshing is basically the process of dividing the CAD model into very small elements which are then solved simultaneously to evaluate the behavior of the entire system. It is also known as piecewise approximation. The figure below shows meshed model which has 34631 nodes and 17603 elements.

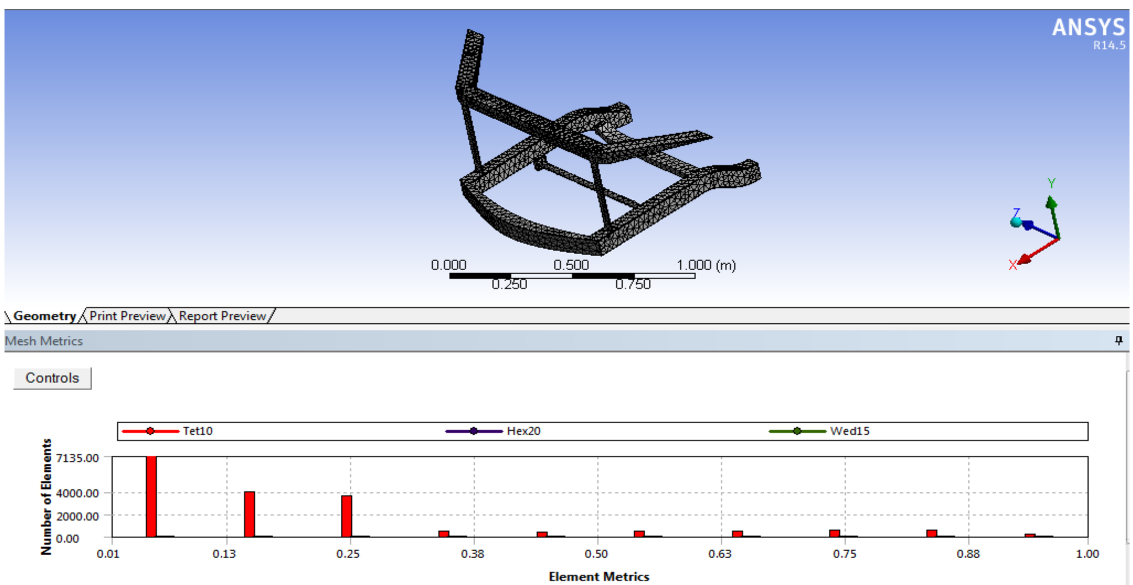


Figure 4.2 : Meshed model and element quality of modified frontal frame structure

4.1.3 Convergence

The analysis was carried out using progressively reducing elemental sizes. The elemental size having consecutive stress error less than 5% is generally considered as the optimum size of mesh. It means that any further decrease in size will only negligibly increase the accuracy of the results [49].

4.1.4 Equivalent stress

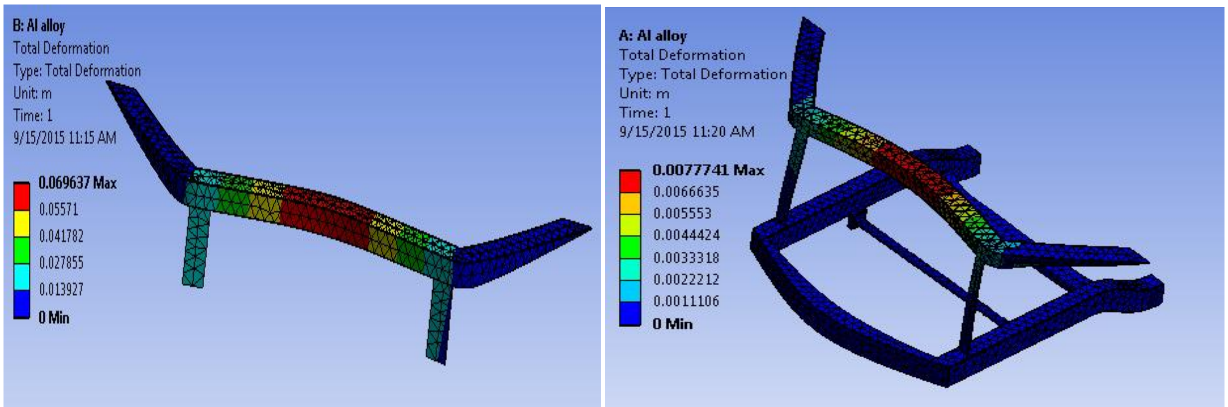
Failure of mechanical components subjected to bi-axial or tri-axial stresses occurs when the strain energy of distortion per unit volume at any point in the component, becomes equal to the strain energy of distortion per unit volume in a standard tension test specimen during yielding. According to this theory, the yield strength in shear is 0.577 times the yield strength in tension. Experiments have shown that the distortion energy theory is better in agreement for predicting the failure of ductile components than any other theory of failure [49]. Von - Mises stress is widely used by designers, to check whether their design will withstand given load condition [2].

4.1.5 Applying load (Impact force)

It has been mathematically calculated that the maximum impact load which the beam will be subjected to is 64.893kN during static impact. From the both existing and newly modified upper cross beam now by using similar material (aluminum alloy),the one which better quality, i.e. less deform and less stress is selected for detail analysis.

4.1.6 Stress and deformation results

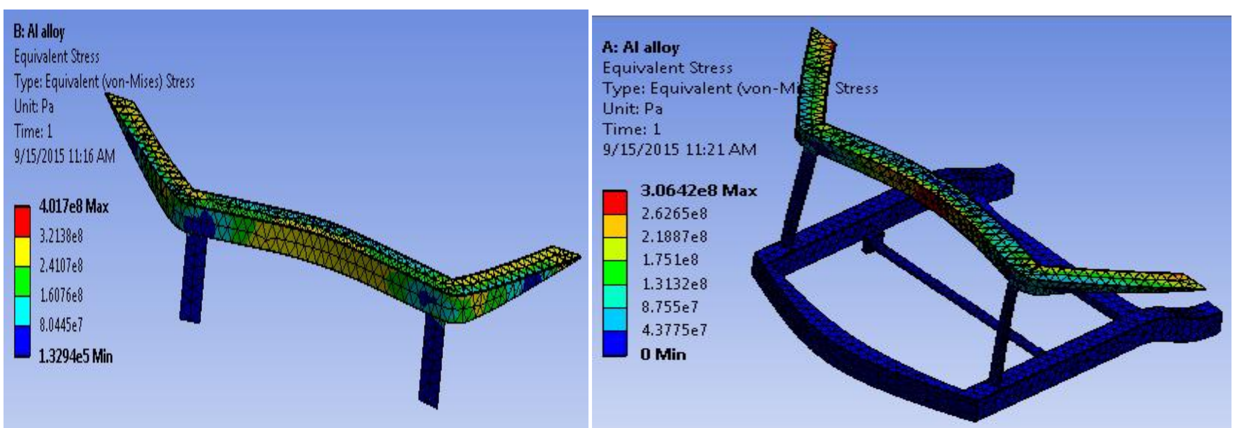
The total deformation (all directional displacement) and Equivalent stress of existing frontal upper cross beam and newly modified frontal upper cross beam is shown in figure 4.3(a and b) and figure 4.4(a and b) below respectively.



a)deformation analysis of existing upper cross beam

b)deformation analysis for newly modified frontal frame structure

Figure 4.3 (a and b) : Deformation analysis of existing upper cross beam and newly modified frontal frame structure



a)Stress analysis of existing upper cross beam

b)stress analysis for frontal frame structure

Figure 4.4 (a and b): Equivalent (von-misses) stress analysis of existing and newly modified frontal frame structure

The maximum value (maximum deformation) is indicated with red color which is at the center for both and 69.63 mm for existing one and 7.77 mm for newly modified frontal upper cross beam from frame rail and Figure 4.4(a and b) shows maximum and minimum value of equivalent (von - mises) stress when the existing and newly modified frontal upper cross beam with maximum impact load is applied. From the analysis Equivalent (von-misses) stress of the existing beam is 401.7Mpa and for newly designed beam 306.42Mpa.

The table below is tabulated on the bases of stress and deflection analysis results of frontal upper cross beam during frontal static impact from aluminum alloy in order to identify the existing and modified frontal upper cross beam to improve the frontal frame structure

Table 4.1 result of deformation, stress and strain energy analysis of exist and newly designed frontal upper cross beam from aluminum alloy

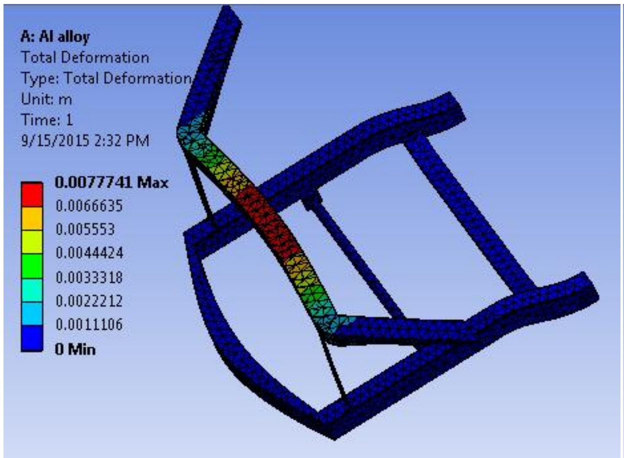
Parameter	Aluminum Alloy	
	Existing frontal upper cross beam	Newly modified frontal upper cross beam
Load(KN)	64.893	64.893
Deflection(m)	0.069637	0.0077741
Stress(Mpa)	401.7	306.42
Mass(kg)	1.973	2.1008

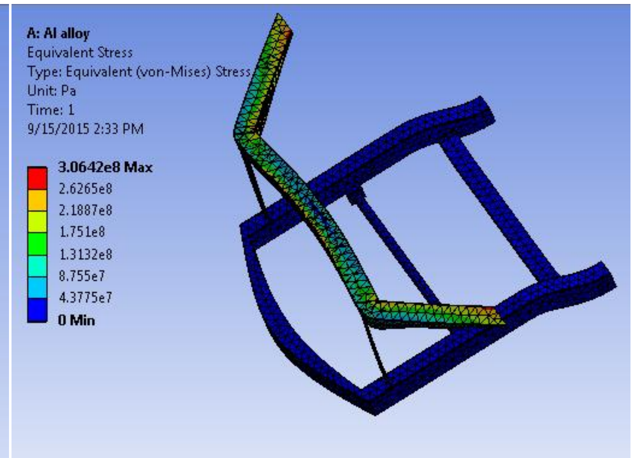
The results of this analysis are based on the design criteria called Von mises stress criteria, which arises from distortion energy failure theory. According to distortion energy theory failure occurs when the distortion energy in actual case is more than the distortion energy in a simple tension case at the time of failure. From table4.1 The results of this analysis is compared with the same material(aluminum alloy) and similar boundary condition the geometry of newly modified frontal upper cross beam which is modified from frontal frame rail is better than the existing one i.e. While analyzing the static impact by ANSYS work bench for the Aluminum alloy, the maximum stress value obtained for the existing beam is 401.7MPa, which is greater than the newly modified one and the deformation obtained in this case is 0.069637m, which is greater than the newly modified upper cross beam. Therefore depend on this analysis the newly modified frontal structure (upper cross beam modified from frontal frame rail) is selected for static, modal and crash analysis. But the weight of the beam is greater than the exist beam therefore comparison of different material is mandatory in order to get less weight less deform and better energy absorption. Incase if impact is applied from the top face the modified beam have more advantageous by sharing the impact load to the main rail.

4.2 Static impact analysis result of modified frontal frame structure

Static analysis was carried out for entire front upper cross beam model which was made of different type of steel grade. Main objective of the static analysis is to find the bending stress ,deformation and strain energy of the beam during static impact. Comparison of different material in analysis is done in order to get the material which best fit the design.

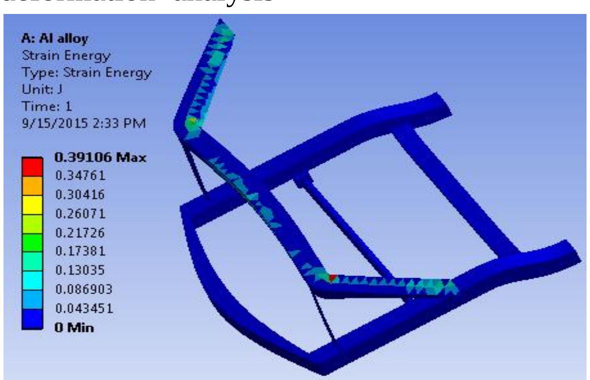
1. Now the material selected for analyze is aluminum alloy because the existing beam is designed from aluminum alloy and depending on that aluminum alloy is selected for beam analysis.





a) deformation analysis

b) stress analysis

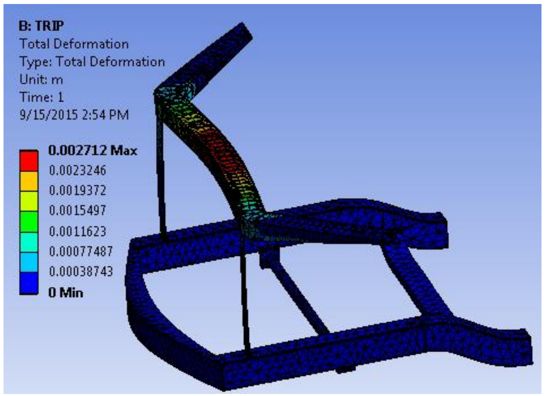


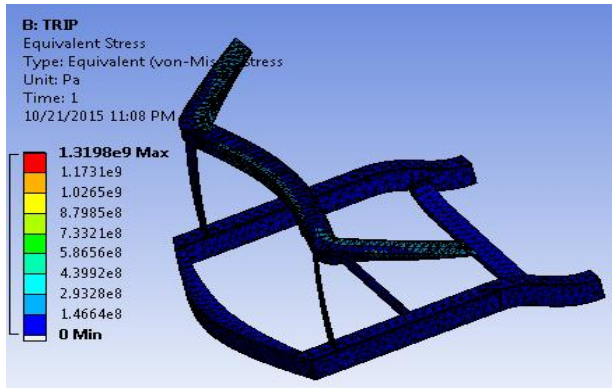
c) Strain energy analysis

Figure 4.5 (a, b and c): Deformation, Equivalent (von-misses) stress and strain energy analysis of modified frontal frame structure by aluminum alloy respectively

$$fs = \frac{\sigma_y}{\sigma_{max}} = \frac{280}{306.42} = 0.9137$$

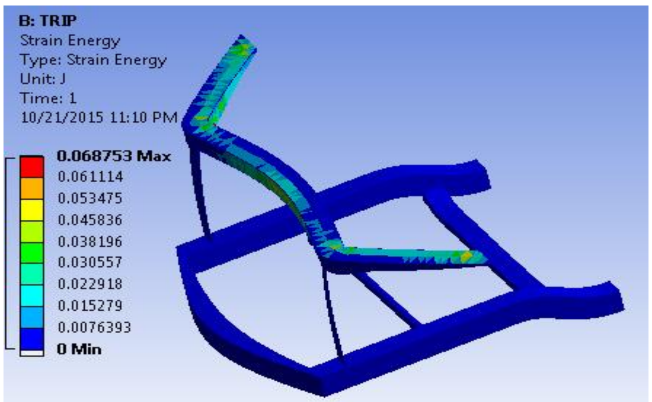
2. Now the material selected for analyze is TRIP steel because this type of steel is used for the design of the area which needs higher energy absorbing capability.





a)deformation analysis

b)stress analysis

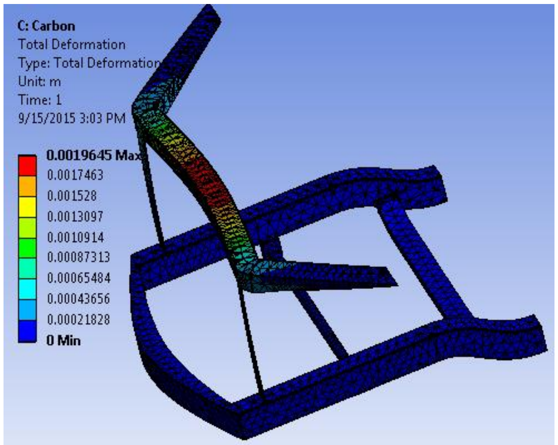


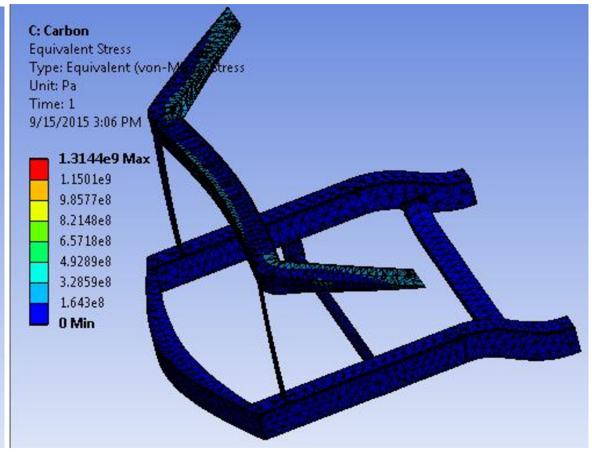
c)strain energy analysis

Figure 4.6 (a, b and c): Deformation, Equivalent (von-misses) stress and strain energy analysis of modified frontal frame structure by TRIP steel respectively

$$fs = \frac{\sigma_y}{\sigma_{max}} = \frac{700}{1319.8} = 0.53$$

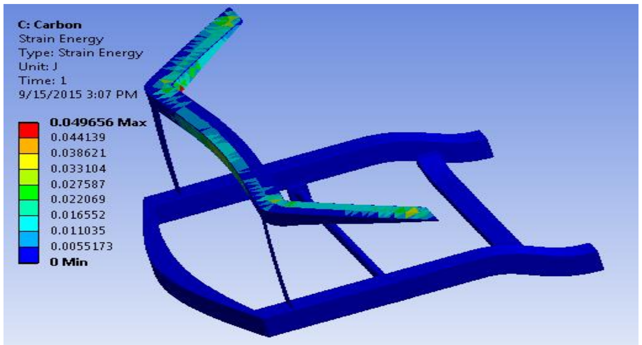
3. Now the material selected for analyze is carbon fiber because this type of composite material is used for the design of the area which need higher energy absorb capacity and less in weight.





a)deformation analysis

b)stress analysis

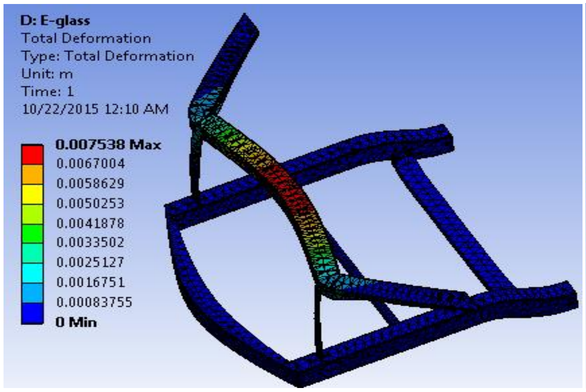


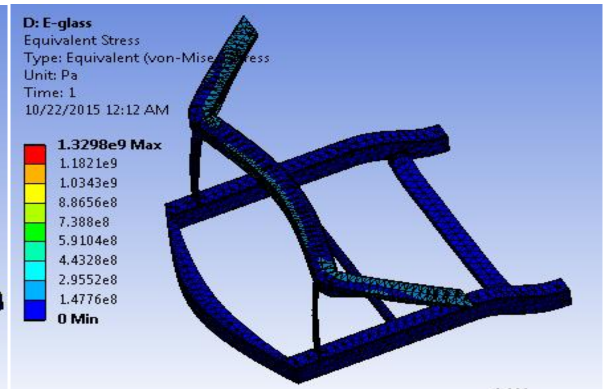
c) Strain energy analysis

Figure 4.7 (a, b and c): Deformation, Equivalent (von-misses) stress and strain energy analysis of modified frontal frame structure by carbon fiber respectively

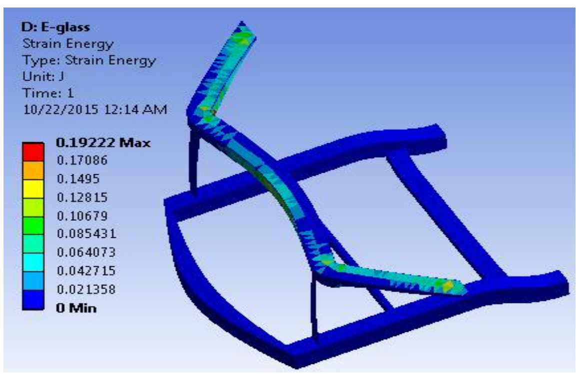
$fs = \frac{\sigma_y}{\sigma_{max}} = \frac{5413}{1314.4}$ =4.118 It satisfy the factor of safety criteria for design.

4. Now the material selected for analyze is E-glass fiber because this type of composite material is used for the design of the area which need higher energy absorption capacity and less in weight.





a)deformation analysis b)stress analysis

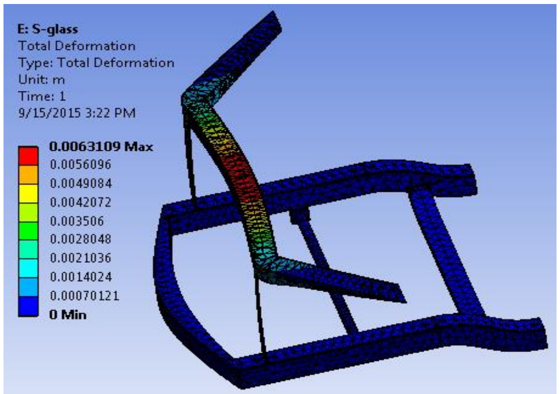


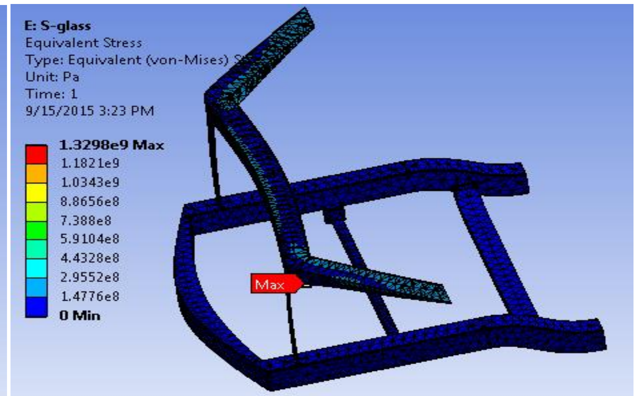
c) Strain energy analysis

Figure 4.8 (a, b and c): Deformation, Equivalent (von-misses) stress and strain energy analysis of modified frame structure by E-glass fiber respectively

$$fs = \frac{\sigma_y}{\sigma_{max}} = \frac{3448}{1329.8} = 2.59$$

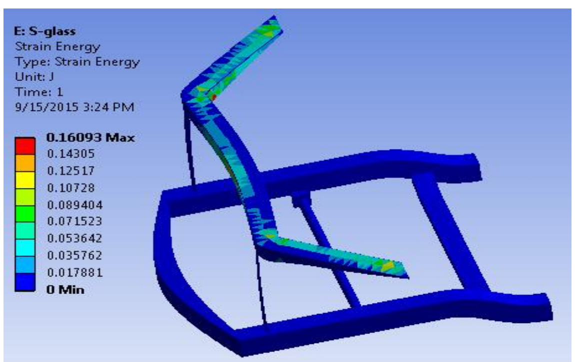
5. Now the material selected for analyze is S-glass fiber because this type of composite material is used for the design of the area which need higher energy absorb capacity and less in weight





a)deformation analysis

b)stress analysis



c) Strain energy analysis

Figure 4.9 (a, b and c): Deformation, Equivalent (von-misses) stress and strain energy analysis of modified frontal frame structure by S-glass fiber respectively

$$fs = \frac{\sigma_y}{\sigma_{max}} = \frac{4484}{1329.8} = 3.37$$

The table 4.2 is tabulated on the bases of stress, strain energy and deflection analysis results of modified frontal frame structure during frontal static impact from different material.

Table 4.2 result of deformation, stress and strain energy analysis of modified frontal frame structure from different material

Parameter	Materials				
	Aluminum alloy NL	TRIP steel	Carbon	E-glass	S-glass
Force(KN)	64.893	64.893	64.893	64.893	64.893
Deflection(mm)	7.774	2.712	1.99645	7.538	6.31109
Bending stress(Mpa)	306.42	1319.8	1314.4	1329.8	1329.8
Strain energy(J)	0.39106	0.068753	0.049656	0.19222	0.16093
Mass(kg)	2.1008	5.9686	1.3424	1.9263	1.8884

From the above static structural analysis of modified frontal frame structure deformation, stress and strain energy are done with the same impact force and boundary condition. Aluminum alloy, TRIP steel, Carbon fiber, E-glass fiber and S-glass fiber are the material selected on this analysis for comparison.

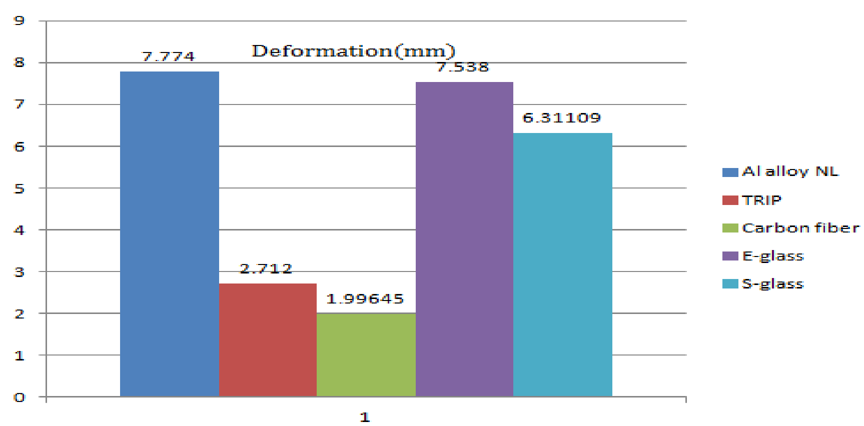


Figure 4.10 deformation comparisons of five different materials

The analysis of the aluminum alloy is done first. Among the five materials, this material shows the first maximum value for the deformation, which is 7.774mm and from composite material carbon fiber is the least deformed which is 1.99645 mm, Also TRIP steel is deformed by 2.712 mm which is the second least. In the case of the deformation, the material having the minimum value among the ductile materials used for design Even though this material is having the maximum density.

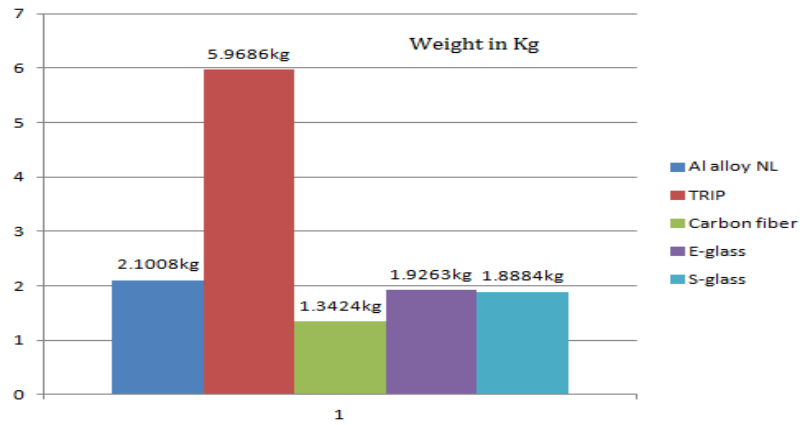


Figure 4.11 Weight comparisons of five different materials

During design weight reduction is one of the requirements, depending on this from the analysis weight reduction is observed between steel and composite, TRIP steel is the greatest in weight which is 5.9686kg and carbon fiber is 1.342kg which is least the material selected for comparison and also it is less than he mass of existing frontal upper cross beam.

The major barriers to the use of composite materials in automotive applications today is the raw materials cost, but production cost of glass fiber reinforced thermosets and carbon fiber reinforced have lower tooling costs, lower capital investment, and reduce the number of parallel fabrication lines for a given production volume as compared with steel [26]

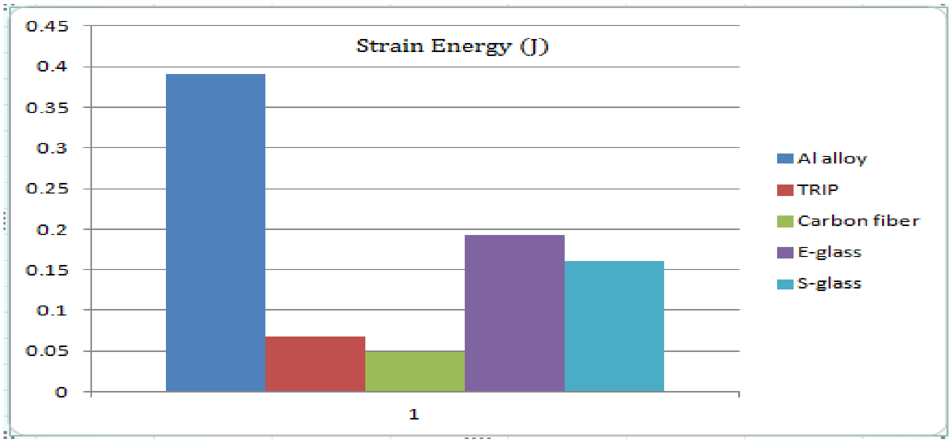


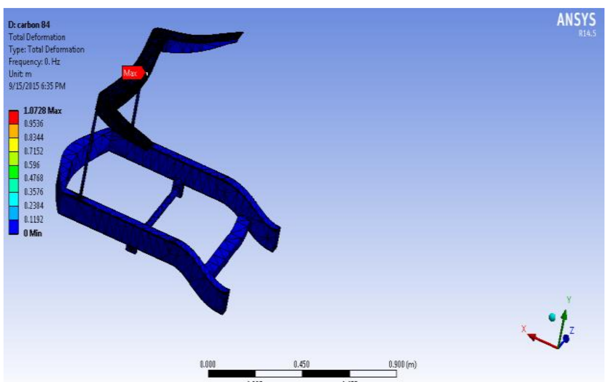
Figure 4.12 Strain comparisons of five different materials

The other criteria of design are energy absorption properties, the part which included in crumble zone or generally the frontal part of the vehicle must absorb more energy during impact. From the analysis the strain of carbon fiber is the lowest which 0.049656J and the second is TRIP steel Even though , this material is having the maximum density, it shows the second minimum strain energy which 0.068753J.

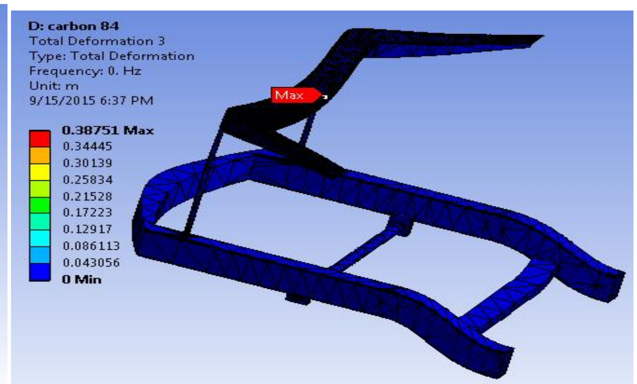
4.3 Modal Analysis

A modal analysis determines the vibration characteristics (natural frequencies and mode shapes) of a structure or a machine component. It can also serve as a starting point for another, more detailed, dynamic analysis, such as random vibration, transient dynamic analysis, a harmonic response analysis, or a spectrum analysis. The natural frequencies and mode shapes are important parameters in the design of a structure for dynamic loading conditions. Computer simulation, if applied properly, brings many benefits to the analysis of static and dynamic systems. It opens up opportunities to analyze behavior previously too complex to interpret, it can reduce the time required to investigate systems and it reduces some of the safety risks associated with prototype testing. All these factors contribute to reducing the cost of analysis, improving confidence in a design and achieving a higher added value to the analysis service and the products produced [51].

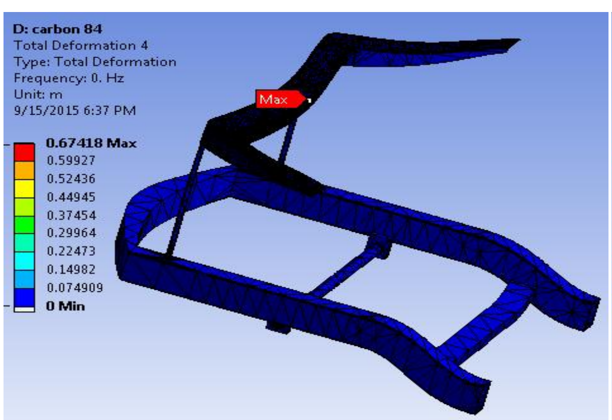
The natural frequency and the mode of deformation of modified frontal frame structure are shown in the figure below.



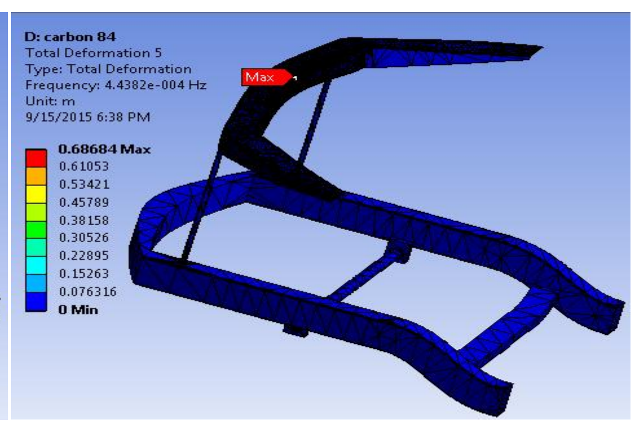
First natural frequency and mode shape



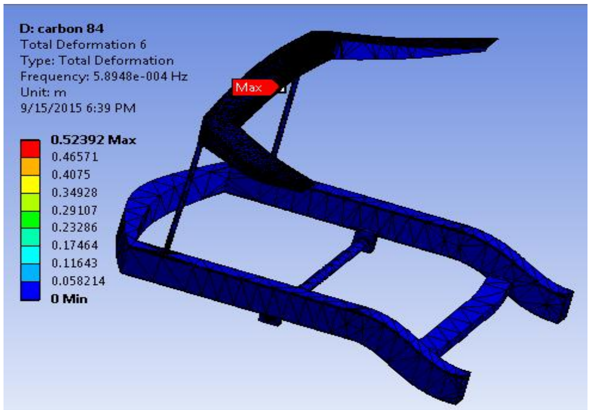
Second natural frequency and mode shape

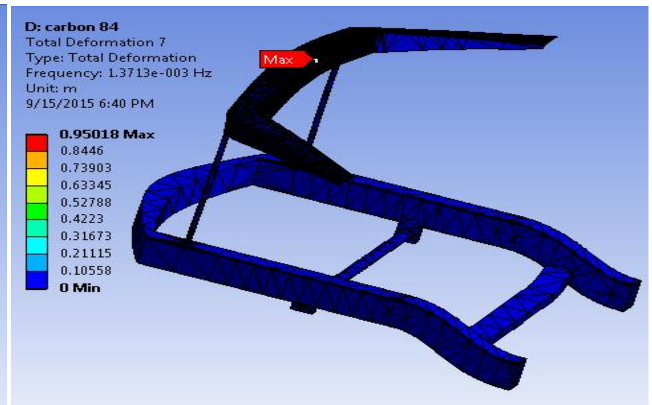


Third natural frequency and mode shape



Fourth natural frequency and mode shape





Fifth natural frequency and mode shape Sixth natural frequency and mode shape

Figure 4.13 (one to sixth): natural frequency and mode shape analysis of modified frontal frame structure respectively

Table 4.3 : Natural frequency analysis result of modified frontal frame structure

Mode	Frequency [Hz]
1.	0.
2.	
3.	
4.	4.4382e-004
5.	5.8948e-004
6.	1.3713e-003

From the above modal analysis the result of natural frequency is less up to six mode shape of frontal frame structure and it is used for simply understanding the behavior of frame structure for next crash analysis to avoid resonant with respect to vibration formed during externally applied force.

4.4 Dynamic (crash analysis)

In automobile design, crash analysis is the most important engineering processes in developing a high quality safety in the vehicle. With Explicit dynamics (LS-DYNA) application, automotive companies and their suppliers can test car designs without having to tool or experimentally test a prototype, thus saving time and expense . While the package continues to contain more and more possibilities for the calculation of many complex, real world problems, its origins and core-competency lie in highly nonlinear transient dynamic finite element analysis (FEA) using explicit time integration. The application of ANSYS covers a wide range of industries [52]. Vehicle crash is a highly nonlinear transient dynamics phenomenon. The purpose of a crash analysis is to see how the car will behave in a frontal or sideways collision. Crashworthiness simulation is one typical area of application of Finite-Element Analysis (FEA).This is an area in which non-linear Finite Element simulations are particularly effective [39].

4.4.1 Causes of Vehicle Crashes

Different factors contribute to the risk of vehicle collision that may include equipment failure, road-way design or poor roadway maintenance. A behavior of a driver, driver skill and/or impairment and speed of operation are another factor that could lead to vehicle accidents. The vehicle design and road environment are also factors in vehicle collisions [10]. Crash incompatibility arises due to: Mass, stiffness and geometric incompatibility. Stiffness may not prove to be as dominant an aggressivity factor as mass for example, for a Ford Taurus and a Ford Ranger pickup, Both vehicles had approximately the same crash test weight (1750-kg), but note that the Ranger pickup was significantly stiffer than the Taurus and geometric incompatibility creates a mismatch in the structural load paths in frontal impacts [42].

To minimize the injury of car occupants during a frontal crash, the car structure must generate a predetermined optimal deceleration pulse (specific curve) on the assumed undeformable passenger compartment to absorb all the kinetic energy. However, this optimal pulse is dependent on the final relative crash velocity and the occupant properties .The crash pulse must be independent on the struck car position. The absorbed energy must be dependent on the own accompanying mass (including passengers and luggage) and the relative final crash velocity, which is dependent on the original velocities of both crash partners and their mass relation (compatibility). Especially the structure stiffness can influence the deceleration level and the absorbed energy within the available deformation length. The crush zone is located in the front most part of the car, directly in front of the front bulkhead. The crush zone functions to absorb the energy of the impact if a frontal collision occurs [53].

A closed bulk head upper cross member to assist energy absorption in the upper part of the engine compartment. The innovative body structure proposed in this research reduces passenger compartment intrusion and occupant injury by restraining frame intrusion and enabling a high level of energy absorption in the engine compartment. The structure improves the level of self-protection in small cars, it is also expected to improve the level of partner-protection offered by large car. As a further step we are going to research the aggressiveness for large cars based on the proposed new structure in this report [1].

The objective of the research done here was to modify a concept structure that substitutes the conventional energy absorbing frontal upper cross members in a frontal vehicle structure and that yields optimized deceleration pulses for different crash velocities, overlap percentages and collision partners. The impacts and collisions involving a modified frontal frame structure model is simulated and analyzed using ANSYS software and the frontal upper cross beam(which is modified from frame rail) reduces passenger compartment intrusion and occupant injury by restraining frontal upper intrusion and enabling a high level of energy absorption than the existing one and it must also withstand static and dynamic loads without undue deflection or distortion depend on the standard of vehicle crush zone. The given model is tested under frontal collision conditions and the resultant deformation and stresses are determined with respect to a time calculated of different material by using ANSYS software. The crash analysis simulation and results can be used to assess the crashworthiness of different material in order to identify better material to improve the design.

4.4.2 Crash test

Euro-NCAP organizes crash test using frontal and side collisions and publish test results that provide accurate information to motoring consumers based on a realistic and independent assessment of safety performance for most popular cars sold in Europe . In the European New Car Assessment Program for frontal impact, a vehicle moving at 65khm strikes a deformable barrier that is offset to 40% of vehicle width .This test is very severe on the vehicle front-end structure as only one-half of the structure absorbs most of the energy of impact[3 38]. US-NCAP(New Car Assessment Program) conducts a frontal impact test and a side impact test to investigate occupant safety , A rigid barrier crash test is applied for full width frontal impact at 56km/h(35mph) [10 3].

The NHTSA New Car Assessment Program (NCAP) uses a rigid barrier and the full width of vehicle is crashed into the rigid barrier at 56km/hr and IIHS in the United States has standardized the procedure for frontal offset crash test that is adopted by The Euro NCAP which 40% offset impact test at 64km/h. All these tests are done using LS-DYNA [12].

4.4.3 Nonlinear Finite Element Modeling

The FE methods have been extensively used in simulating different dynamic problems through the discretization of the whole structure into finite elements, development of the equations of motion (EOM) for each element, assembly of all EOMs based on continuity, applying boundary conditions, and solving the set of governing equations of motion using the appropriate technique The generalized governing dynamic equations of motion of a structure in the finite element form can be represented as: [13]

$$[M]\{\ddot{X}\}+[C]\{\dot{X}\}+[K]\{X\}=\{F^{ext}\} \tag{3.14}$$

where [M], [K] and [C] are the system structural mass, stiffness and damping matrices respectively, [K]{X}, which equals $\{F^{int}\}$represents the internal forces resulting from the plastic deformation of a structural part,

$\{X\},\{\dot{X}\}$ **and** $\{\ddot{X}\}$ are the nodal displacement, velocity and deceleration vectors, respectively, and $\{F^{ext}\}$ is the external nodal load vector.

When we say implicit and explicit methods: An explicit method is more appropriate for impact problem or nonlinear transient dynamic problems with very short time durations as in the case of a crash simulation event. On the other hand, the implicit method is more suitable for dynamic problems in which the duration of the applied load is relatively large compared with the fundamental period of LS-DYNA is used to modify and simulate a full frontal vehicle impact test with a rigid barrier by assigning an initial velocity of 56.6 km/h to the whole model according to the New Car Assessment Program (NCAP) regulations for frontal impact[13].

4.4.4 Explicit Dynamics (LS-DYNA)

For an explicit time scheme, the displacements are solved for by direct numerical integration of the equation, meaning that prior to numerical integration, no transformation of the equations is required. This method is not accurate for modeling quasi-static processes that occur over a long period of time. The solution method is only stable when the time step (Δt) is very small. To be more specific, Δt must be smaller than the time required for an elastic wave to propagate from one side of an element to the other. An elastic wave is a type of mechanical wave that transmits energy which propagates in elastic or viscoelastic materials. The elasticity of the material provides the restoring force of the wave. The maximum time step is defined as:

$$\Delta t_{max} = L\sqrt{\frac{\rho(1-2\nu)}{2\mu(1-\nu)}} \tag{3.15}$$

Where μ and ν are the shear modulus and the Poisson's ratio of the material, respectively. $\boldsymbol{\rho}$ is the density of material. The primary benefit of the explicit integration is that it eliminates the requirement of solving for equilibrium at each time step [40].

- Explicit analysis typically requires a small time step.
- Implicit analysis requires matrix inversion. The solution of the nonlinear equations require iterative solution strategies,

- Explicit analysis requires no iteration and no matrix inversion, Explicit methods are well suited to solve dynamic problems
- Explicit analysis treats the structure as a dynamic problem and solves dynamic equations of motion in the time domain. It is especially efficient to solve crash, impact and similar dynamic problems, particularly if material non-linearity (plasticity), large deformations or contact occur.
- For explicit analysis all nodal and element quantities are given with respect to time [23].
- The distance between the vehicle and the barrier is kept to the minimum in order to minimize the simulation time [12].

4.4.5 Finite element analysis

Use of finite element vehicle model for crash analysis is increasing progressively in industry. The main reason being repeatability of tests and reduction in cost of production. With the increase in the use of FE models, the models are improving in terms of accuracy, robustness, fidelity and size [12]. The conditions for the impact simulations are like velocity of the impact barrier was given as 56 kmph as per NCAP standard, Crash type as frontal impact, Obstruction as rigid barrier and Simulation time is depend on material properties . After all the boundary conditions were applied the meshed model is exported to LS-DYNA. During the process the properties of the bumper materials like young's modulus, yield strength, Poisson ratio and density should be considered for the pre-processing which is used me as a reference in this analysis . The beam converts the kinetic energy of the system to strain energy due to elastic and plastic deformation of the material. Internal Energy is phenomenal as it decides the plastic deformation after the collision of the vehicle. Kinetic energy is absorbed by the beam as it undergoes plastic deformation during collision. The distance between the vehicle and the barrier is kept to the minimum in order to minimize the simulation time.

4.4.5.1 Result of crash analysis of modified frontal frame structure

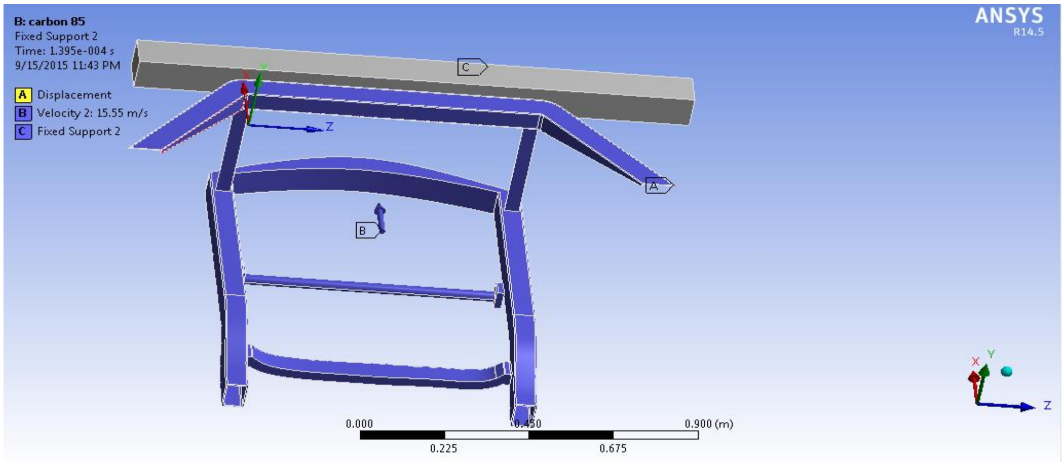


Figure 4.14: Boundary condition of modified frontal frame structure (upper cross beam) with rigid barrier

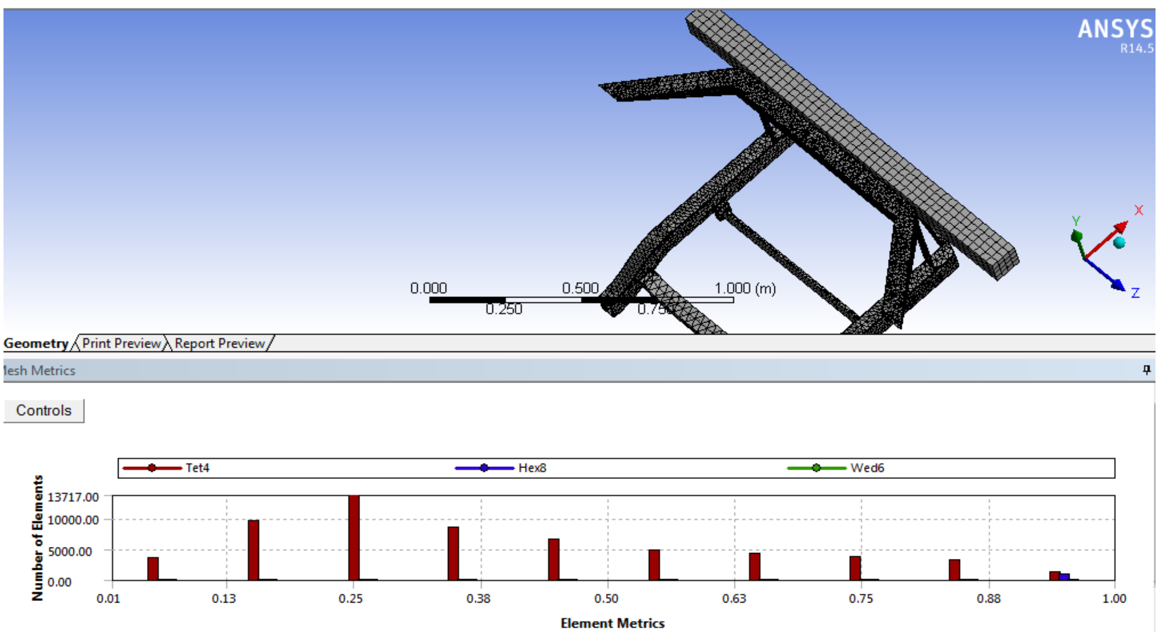


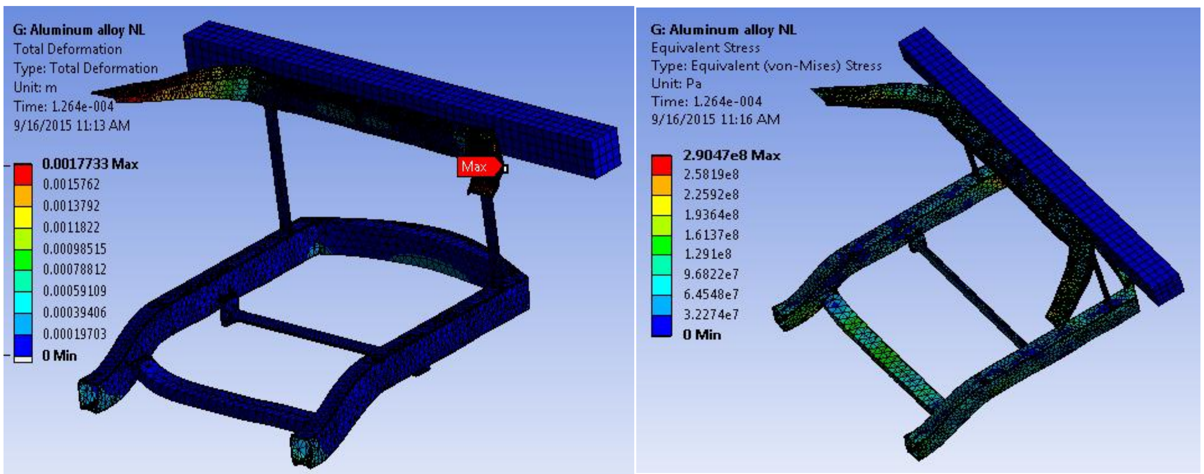
Figure 4.15: Meshed model and element quality of designed frontal frame structure and rigid barrier which is meshed by 19099 nodes and 59578 elements.

1. Aluminum alloy crash analysis in explicit dynamics

   The time of explicit dynamic analysis of aluminum alloy is given by:

   $t = L\sqrt{\frac{\rho(1-2\nu)}{2\mu(1-\nu)}}$ where μ is shear modulus , ν is poisson's ratio ρ is density of aluminum and L is effective length of beam

   $t = 0.84x\sqrt{\frac{2770(1-2x0.33)}{2x2.6692e10(1-0.33)}}$ = 0.000136s and the speed is 15.55m/s



a)deformation analysis b) Equivalent(von-mises)stress analysis

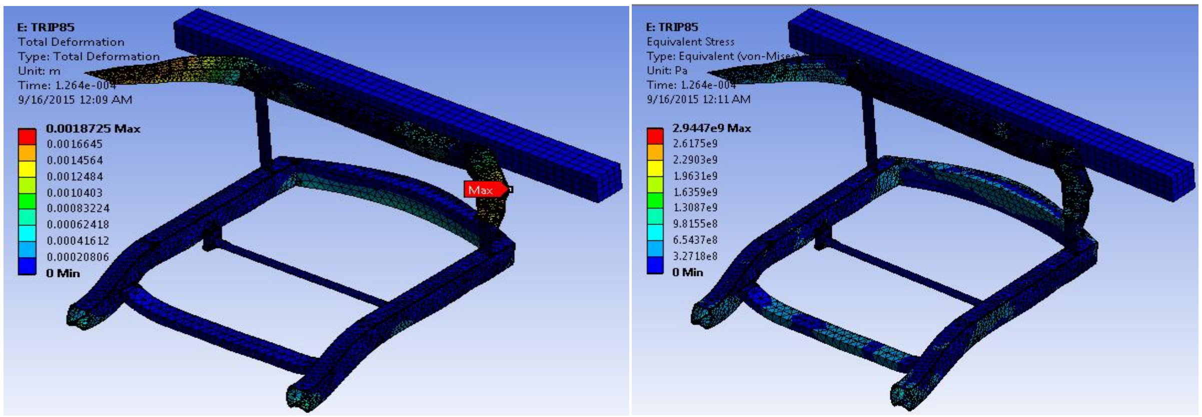
Figure 4.16 (a and b): Deformation and Equivalent (von-misses) stress analysis of modified frontal frame structure (upper cross beam) from Aluminum alloy respectively.

2. TRIP(transformed induced plasticity) steel crash analysis in explicit dynamics

   The time of explicit dynamic analysis of TRIP steel is given by:

   $t = L\sqrt{\frac{\rho(1-2\nu)}{2\mu(1-\nu)}}$ where μ is shear modulus , ν is poisson's ratio ρ is density of TRIP steel and L is effective length of beam

   $t = 0.84x\sqrt{\frac{7870(1-\mathbf{2x0.3})}{2x7.961e10(1-0.3)}}$ = 0.000141172s and the speed is 15.55m/s



a)deformation analysis b) Equevalent(von-mises)stress analysis

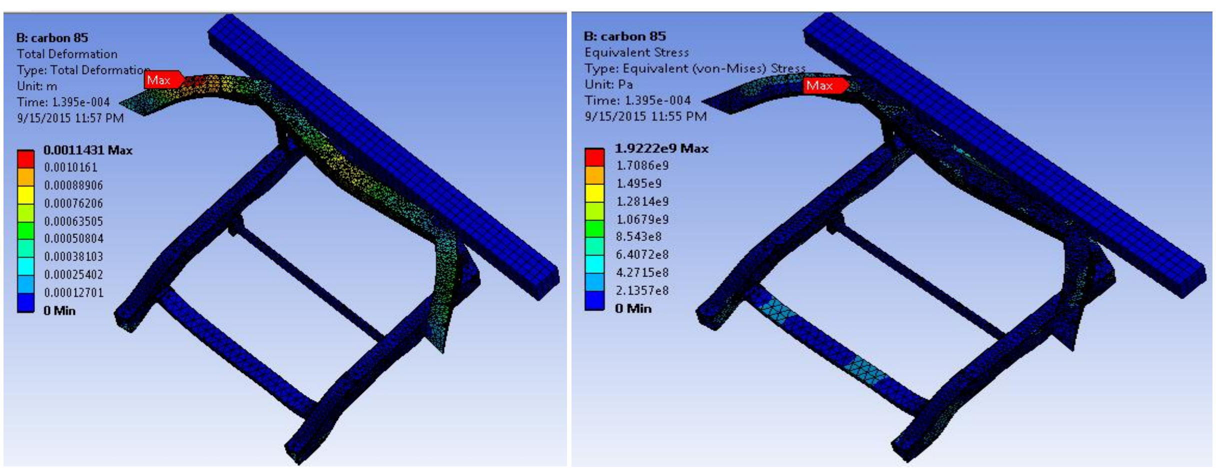
Figure 4.17(a and b): Deformation and Equivalent (von-misses) stress analysis of modified frontal frame structure(upper cross beam) from TRIP steel respectively

3. Carbon fiber crash analysis in explicit dynamics

   The time of explicit dynamic analysis of Carbon fiber is given by:

   $t = L\sqrt{\frac{\rho(1-2\nu)}{2\mu(1-\nu)}}$ where μ is shear modulus , ν is poisson's ratio ρ is density of Carbon fiber and L is effective length of beam

$$t = 0.84x\sqrt{\frac{1770(1-2x0.31)}{2x1.0534e11(1-0.31)}} = 0.0001395\text{s and the speed is } 15.55\text{m/s}$$



a) Deformation analysis b) Equivalent (von-mises) stress analysis

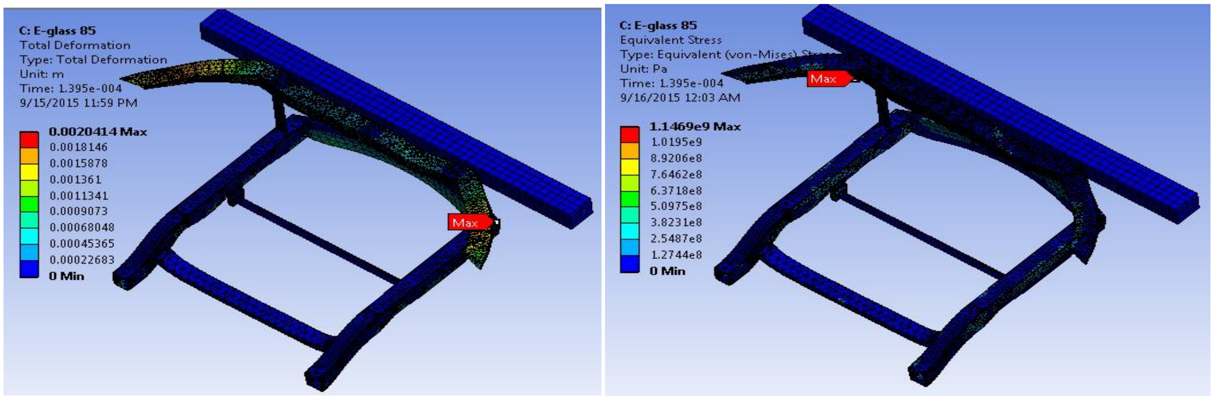
Figure 4.18 (a and b): Deformation and Equivalent (von-misses) stress analysis of modified frontal frame structure (upper cross beam) from carbon fiber respectively

4. E-glass fiber crash analysis in explicit dynamics

The time of explicit dynamic analysis of E-glass fiber is given by:

$t = L\sqrt{\frac{\rho(1-2\nu)}{2\mu(1-\nu)}}$ where μ is shear modulus , ν is poisson's ratio ρ is density of E-glass fiber and L is effective length of beam

$$t = 0.84x\sqrt{\frac{2540(1-\mathbf{2x0.28})}{2x2.8125e10(1-0.28)}} = 0.000129\text{s and the speed is } 15.55\text{m/s}$$



a) Deformation analysis b) Equivalent (von-mises) stress analysis

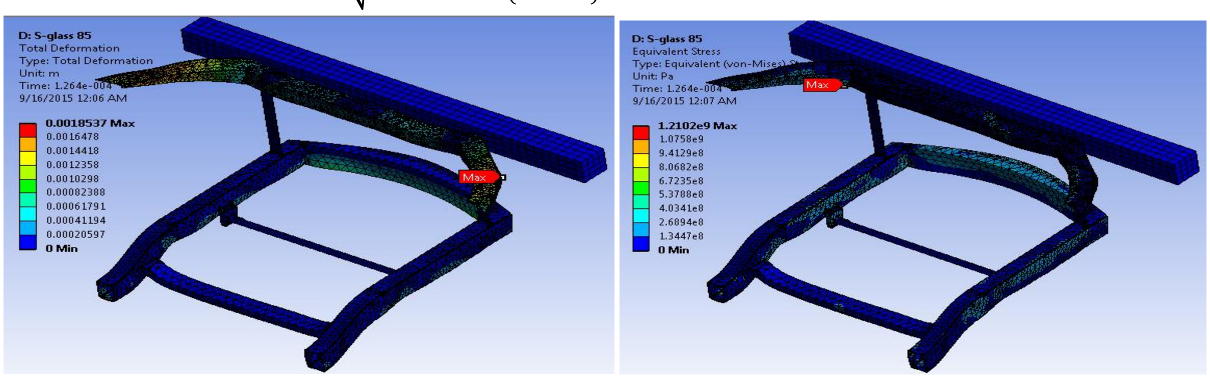
Figure 4.19 (a and b): Deformation and Equivalent (von-misses) stress analysis of modified frontal frame structure (upper cross beam) from E-glass fiber respectively.

5. S-glass fiber crash analysis in explicit dynamics

The time of explicit dynamic analysis of S-glass fiber is given by:

$t = L\sqrt{\frac{\rho(1-2\nu)}{2\mu(1-\nu)}}$ where μ is shear modulus , ν is poisson's ratio ρ is density of S-glass fiber and L is effective length of beam

$$t = 0.84x\sqrt{\frac{2490(1-\mathbf{2x0.28})}{2x3.3594e10(1-0.28)}} = 0.0001264\text{s and the speed is } 15.55\text{m/s}$$



a) deformation analysis b) Equevalent(von-mises)stress analysis

Figure 4.20 (a and b): Deformation and Equivalent (von-misses) stress analysis of modified frontal frame structure (upper cross beam) from S-glass fiber respectively.

The table 4.4 is tabulated on the bases of stress and deflection analysis results of modified frontal frame structure during frontal crash from different material.

Parameter	Materials				
	Al Alloy	TRIP steel	Carbon	E-glass	S-glass
Speed (m/s)	15.55	15.55	15.55	15.55	15.55
Deflection(mm)	1.733	1.8725	1.1431	2.0414	1.8538
Bending stress(Mpa)	290.47	2944.7	1922.2	1146.9	1210.2
Mass(kg)	2.1008	5.9686	1.3424	1.9263	1.8884

Table 4.3 crash analysis of modified frontal frame structure

Table 4.3 shows crash analysis of modified frontal frame structure by explicit dynamics at 56km/hr speed from different material:-Aluminum alloy, TRIP steel, Carbon, E-glass and S-glass fiber are carried out. While doing this analysis, carbon is the material which is shows lowest in deformation(1.1431mm) ,lowest in weight(1.3424kg) and the Equivalent (von-mises) stress of Carbon fiber is 1922.2Mpa which much less than its tensile strength (5413Mpa) when compared with the material which is selected for comparison .

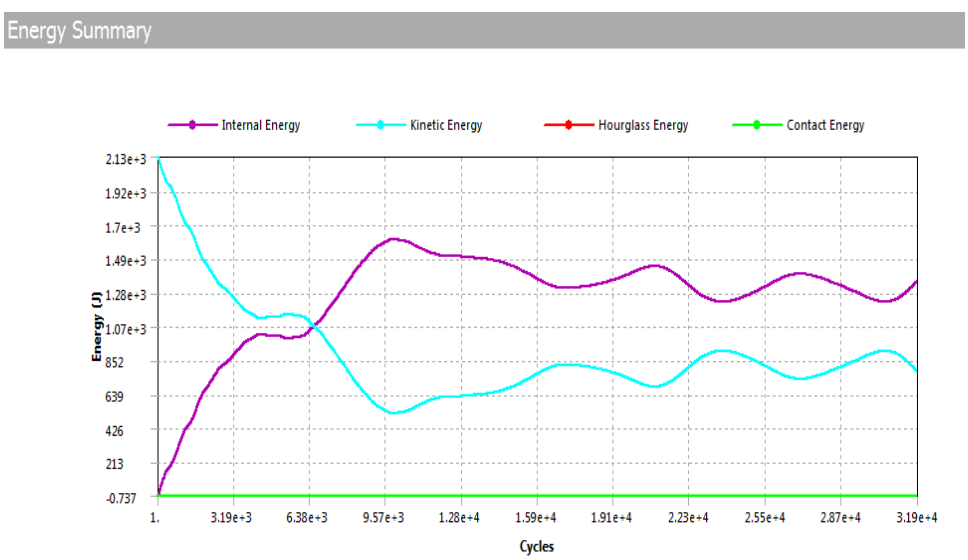


Figure 4.21 energy summary of crash analysis

This graph shows the energy summery i.e. Relation of internal energy and kinetic energy of the frontal frame structure during crash analysis (how the kinetic energy changed to internal energy in the form of deformation).

5. CONCLUSIONS AND RECOMMENDATION

The analysis of Huanghai F1 landscape SUV frontal upper cross beam done and based on the analysis results, newly frontal frame structure (upper cross beam which is modified from frame rail) is modified. Both the existing and newly modified frontal frame structure are modeled in CATIA V5 and imported into ANSYS workbench in the form of IGS file for detail analysis results. Then this IGS file is analyzed statically and finite element analysis on frontal crash by Explicit dynamics(LS-DYNA) is done successfully. The different analysis namely, stress analysis, deflection analysis, strain analysis, modal analysis and crash analysis were performed using ANSYS14.5. Analysis results of existing upper cross beam and newly modified frontal frame structure is compared on static analysis. Based on the results of analysis it is concluded that:

From static analysis the modified frontal frame structure is selected for detail analysis by considering the deformation and stress formed in the existing and new upper cross beam by using aluminum alloy. Then static analysis is done on ANSYS Workbench 14.5, Among the five materials (Aluminum alloy, TRIP steel ,carbon fiber ,E-glass and S-glass) used for the static analysis, carbon fiber composite possess the lowest in deformation, lowest in weight and strain value. Therefore carbon fiber is the one which suits the best among the five. And the TRIP steel possess the second lowest deformation and strain value but , this material is having the maximum density, therefore it is not suitable for this purpose because while considering the weight TRIP steel much greater than the others. With Explicit dynamics (LS-DYNA) application on ANSYS Workbench 14.5, crash analysis is done Among the five materials (Aluminum alloy, TRIP steel ,carbon fiber, E-glass and S-glass) used for the crash analysis, carbon fiber composite possess the lowest in deformation and lowest in weight value. From those various analysis, it is concluded that ,the modified frontal frame structure preferred and carbon fiber composite meets most of the requirements like high strength to weight ratio, crashworthiness and high stiffness to weight ratio.

Finally, I recommend department of mechanical engineering or automotive industries and any interested individual to take further research on front end collision of the vehicle structure that can be substituted by different material like composite materials and show the comparative advantages of composite to automobile industries and to the government since this will help the community in economical and environmental aspect and I also recommend the automotive industries to take some sort of research paper works and implement them .

Future work

One of the major limitation of the current work is that, analysis of the vehicle to vehicle crash is not done , therefore ,in the future analysis of frontal frame structure during vehicle to vehicle can be done and further reduction in weight is possible by means of shape optimization , also the joining method and cost analysis can be done.

6. REFERANCES

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