" SIMULATION OF CRASH TEST OF A SALOON CAR WITH SKIN PANELS MADE OF IF AND AHS STEEL"

A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE AWARD OF DEGREE
OF
MASTER OF TECHNOLOGY
IN
COMPUTATIONAL DESIGN

Submitted by:

ASHWANI KR. SINGH
2K18/CDN/01

Under the supervision of

PROF. VIJAY GAUTAM

DEPARTMENT OF MECHANICAL ENGINEERING
DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Bawana Road, Delhi-110042

AUGUST, 2020

M.Tech (Computational Design)

ASHWANI KR. SINGH

2020

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi – 110042

CANDIDATE'S DECLARATION

I, Ashwani Kr. Singh , Roll No. 2K18/CDN/01 student of M.Tech (Computational Design), hereby declare that the project report titled **"Simulation of Crash test of a Saloon car with skin panels made of IF and AHS steel"** which is submitted by me to the Department of Mechanical Engineering, Delhi Technological University, Delhi, in partial fulfilment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without a proper citation. This work has not previously formed the basis for the award of a Degree, Diploma Associateship, Fellowship or other similar title or recognition.

Place: Delhi   Ashwani Kr. Singh

Date:

DEPARTMENT OF MECHANICAL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi – 110042

CERTIFICATE

I hereby certify that the Project report titled **"Simulation of Crash test of a Saloon car with skin panels made of IF and AHS steel"** which is submitted by Ashwani Kr. Singh, 2K18/CDN/01 to the Department of Mechanical Engineering, Delhi Technological University, Delhi, in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi **PROF. VIJAY GAUTAM**

Date: **SUPERVISOR**

ACKNOWLEDGEMENT

The successful completion of a Major project needs support and effort from numerous individuals and the organization. Writing the report of this project work gives me an opportunity to express my gratitude to everyone who has helped in shaping up the outcome of this project.

I express my sincere gratitude to my project guide **Prof. Vijay Gautam** for providing me an opportunity to do my Major project work under his guidance. His guidance, support and encouragement in completion of this project has been highly invaluable. I would also like to express my gratitude to Mr. Devendra Kumar, my senior, who helped me in understanding the software and its concepts. I am highly grateful to the faculties during all the progress evaluations, for their constructive guidance, careful supervision and for motivating me to efficiently complete my work. They have helped me throughout by giving new suggestions, providing necessary information and inspiring me to move forward towards completion of the work.

I express my sincere thanks to all the friends who have helped me in this project including my classmates and also my family.

Ashwani Kr. Singh

ABSTRACT

Car crash test analysis is widely performed to determine the level of safety provided by the car to its passengers. This thesis focusses on the similar study. There are several factors which contribute to the safety of passengers, specially front seat travellers based on which the star ratings are provided to every car by the standard testing organisations.

The study involves all the standards as set by NCAP and also uses the model of Toyota Yaris with the conditions and specifications assigned to it by NCAP officially. The FE model was observed on the software LS-Dyna. The study of the car involves material change for the skin and frame of the car on software. The new material whose specifications were used on the software were IF (Interstitial Free) steel for the skin material and AHSS(Advanced High Strength Steel) for the frame which require comparatively higher strength. The tensile testing results were obtained which were helpful in defining the Load Curves for the respective materials. The load curves were used in the software simulation for definition of material deformation in its plastic state.

The simulation in full frontal orientation which is one of the standard tests involved in Crash analysis was performed with changed material. The results and observations have been limited to the materials' properties during impacts. Although there are numerous factors which involve the safety of a vehicle, the focus was primarily on the skin and frame material change which can increase the crashworthiness and make vehicle safer. The crash pulse and energy absorption was primarily focussed directly

determining the materials' effectiveness in crash. Also, the deceleration curve and velocity curve for the driver's seat was drawn with respect to time in order to determine effect of the change of material on the shock propagation through the car body.

The net increase in the energy absorption was slightly less than 2 percent which is small but significant taking into the account of others parameters which have been excluded like the change in parameters for the Cowper-Symonds material model. Also, the average decrease in acceleration and velocity of the driver's seat was less than 2 percent too. Along the thesis, the reason can be discerned behind this increase and decrease which is primarily based on the limitations and assumptions.

Based on those results, the thesis concludes the study with the scope of work that can be done in future with relaxation in the limitations.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 General

Car crash test analysis is widely performed to determine the level of safety provided by the car to its passengers. The behaviour of the vehicles in the full frontal and sideways collision is the main motive of the crash test analysis. So, while testing these vehicles for crash there are many important factors which affect the safety of these vehicles. One of them is light weighting and other is crashworthiness. Both are two of the most important factors considered while designing a vehicle with safety measures. The chassis frame is the backbone of the vehicle. Carrying the major part of the weight of the vehicle is its main function in all operating conditions. So, in the designing part, it is important to consider the characteristics like crashworthiness to safeguard the occupant in crash. Also, there needs to be some measures considered while designing so that the destructive part of the testing can be reduced. This method of testing the crash and analysing on software is gaining popularity because of its low cost and safety. That is why, it has a great potential to flourish in all the automobile industry because of one simple advantage of low cost. In the competitive automobile industry, due to large number of options, customers have variety to choose from. Hence, all companies are adopting this method because customers are choosing lightweight and safer vehicles now.

Since, Crash-testing involves a number of the test vehicle to be destroyed during the operation of the tests, the procedure becomes time consuming and highly uneconomical. A contemporary trend that is gaining a quick popularity is computer simulated crash-testing. In this computer simulated testing, FE i.e., finite element model of the vehicle is produced to be tested in computer having same boundary conditions as used in an actual vehicle crash test. There are several software packages which allow this simulation to be conducted and provide the necessary models to aid the process and one of the most popular in them is LS-DYNA. The car crash test analyses the performance of air bags, the shock absorption by the material or to be exact, the crashworthiness of the material. There are several factors which contribute to the safety of passengers, specially front seat travellers based on which the star ratings are provided to every car by the standard testing organisations. For such tests, the renowned organisation is NCAP- New Car Assessment Programme. The guidelines and standard operating procedure for testing has been duly adopted by many countries, namely Japan, China, Latin American countries and many others. Global-NCAP is the most famous one which provides ratings for the cars which are used all across the world.

1.2 Types of Car Crash Testing

- Frontal Impact test :- This test involves the car crashing to a concrete wall with full frontal face. Oblique tests are also frontal impacts but only a portion of car gets impacted namely left or right which results in a different kind of force generation than full frontal impact.

- Rear Impact test :- Rear Impact test is done for checking the neck and minor injuries due to jerk and vehicle's stability when a there is a chain of crashes.

- Side Impact test :- A crash test for vehicle safety when a car/vehicle impacted from a side by a vehicle or any other object. The situation also arises when an object which is stationary like pole/wall gets hit by a car sideways resulting in fatality.

- Roll-over tests :- Vehicle rollovers are broadly classified into two categories: tripped and un-tripped. External objects, like crash or impact of collision generates forces which are the amin cause of a Tripped rollover. While Un-tripped crashes are caused by steering input, speed, and friction with the ground. So, the tests involving these conditions are also done.

1.3 Software LS-Dyna

Finite element analysis methods are used exclusively by almost every industry manufacturing mechanical parts. They use the software and simulated testing to examine the forces and operation of the parts in a simulated environment. Automobile industry does the same. Their engineers and researchers simulate and analyse the vehicle crashes to design safety systems for their customers and to develop the future vehicles based in the test results through the software simulation. LS-DYNA is a software involving finite element analysis primarily made for simulating the crash testing. It is an industry standard software originally developed by Lawrence Livermore National Laboratory for impact and defence applications. The software is created to solve large deformation problems through explicit finite element formulations which are non-linear. This can be seen in the vehicle undergoing crash (full frontal single, oblique/ vehicle-to-vehicle etc.) resulting in typical crashed structures.

The advent of fast, large memory capacity, graphically enhanced computers in the early 1990s helped in visualization (simulation) of vehicle crashes in computers. The advanced technology which improved the visualization also permitted to have a better understanding of vehicle crashes by fast analysis through videos of car crash in actual scenario. Moreover, in LS-DYNA FE simulations other than vehicle crashes can also be observed. The static problems can also be solved in this software. The acceleration, forces, displacement, velocity, stresses, strain can also be calculated for dynamic problems for vehicle and normal parts also. There is a large amount of data analysis required in actual testing so this becomes comparatively easy as choosing the required output in impact simulations is quite easier. Thus, the simulation analysed through non-linear finite element analysis for rigid body dynamics has become an important tool in optimizing and examining safety systems for vehicle undergoing crash.[10]

1.4 Material Model

There are many material models which can be used while simulating an experiment in the software LS-Dyna. The skill lies in selecting the most appropriate material model which closely matches the conditions and properties owned by original material in the real world. The material model in which we have incurred changes is MAT_024 of the software which works on the principle and stress-strain equation as governed by Cowper-Symonds material model in LS-Dyna.

MAT_024, which is material model 24 is a type of material model which is defined by an arbitrary stress-strain curve behaving in a elasto-plastic manner and dependency on strain rate can also be defined. This material model in theory is defined as Cowper-Symonds material model which is a simple strain hardening and hardening by strain rate model which uses an empirical formula given by Ludwik. The material is defined by an equation as given below and it strengthens when the material is plastically deformed. This characteristics is known as work hardening or strain hardening. This material model calculates initial yield stress by two factors. In equation(1), C and P are the Cowper–Symonds strain rate parameters, σ is the initial yield stress, , $\dot{\varepsilon}$ is the strain rate, β is the strain hardening parameter, ε_p^{eff} is the effective plastic strain. In equation(2), E_p is the plastic hardening modulus which is given in terms of the elastic modulus E and the tangent elastic modulus E_{tan}. Strain hardening parameter modifies isotropic hardening and kinematic hardening.

$$\sigma_y = \left[1 + \left(\frac{\varepsilon.}{C}\right)^{\frac{1}{P}} . \left(\sigma_0 + \beta E_p \varepsilon_p^{eff}\right)\right] \quad (1)$$

$$E_p = E_{tan} \cdot \frac{E}{(E - E_{tan})} \quad (2)$$

1.5 Car FE model

This model is computer-sided design of the Toyota Yaris model of year 2010 designed to test and analyse crash simulations through FEA software. It was developed by a reverse engineering process by George Washington University National Crash Analysis Centre and incorporated in several programs researched by NHTSA.

Fig. 1.1 Image of the FEM model of the Toyota Yaris 2010 model[10]

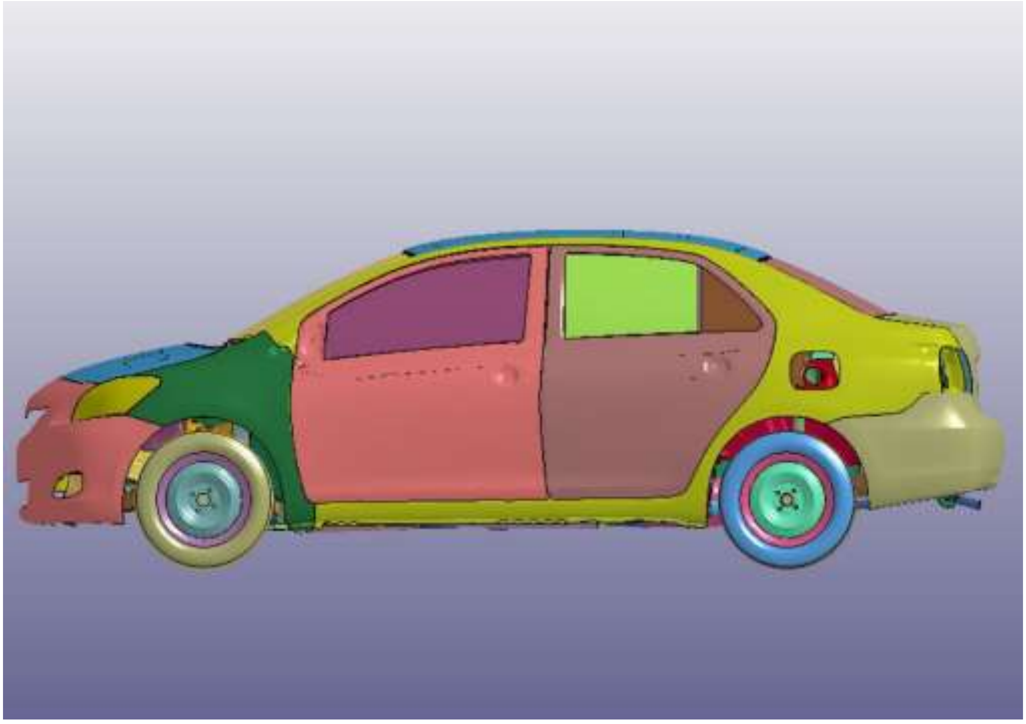


Table 1.1 Details of the FEM model of Toyota Yaris

Vehicle FEM model details	
Elements	1,519,587
Nodes	1,488,581
Parts	940
Attributes	Structural components, Interior component, Suspension system details, Uniform mesh throughout (multi-mode impacts)

This detailed finite element vehicle model of Toyota Yaris has over **1.5 million elements**. It includes details of the structural components, drivetrain, as well as the interior components, also accommodating occupant (dummy) models in the simulations. The model was developed to include full functional capabilities of the suspension and steering subsystems allowing for non-level terrain analyses.
Average size of the element of the model is 6–8 mm with a minimum size of 4 mm. Typical simulation time step is 1.0 µs. The model was generated for use with the *LS-DYNA* nonlinear explicit finite element code. Approximate computation time to run a 200 ms simulation using 8 cores is 12-13 hours.

The detailed model with all the constraints, wall and floor was obtained from website of NHTSA. The instantly usable model is readily available which can be downloaded and directly run without any changes which will give the results for original car in full-frontal car crash orientation. The model follows all the specifications and regulations of NCAP crashing at 56.33 Kmph.[10]

Various aspects which have been taken in to consideration are computational models for various materials and used traditional and innovative materials in the development of hardware for the reduction of collision forces. These have included modelling windshield glass and characterizing the metals used in vehicles based upon tests in reverse engineering. This FE model incorporates various material models while defining the parts of the car like piecewise_linear_plasticity model based on Cowper-Symonds model, low_density_foam, spring_elastic, damper_viscous.

1.6 Methodology

The project involves all the standards as set by NCAP and also uses the FE model of Toyota Yaris with the conditions and specifications assigned to it by NCAP officially. The CAD model was observed on the software LS-Dyna by Livermore Software Technology Corporation (LSTC). The study of the car involves material change for the skin and frame of the car on software. The new material whose specifications were used on the software were IF (Interstitial Free) steel for the skin material and AHSS(Advanced High Strength Steel) for the frame and pillars which require comparatively higher strength. Also, the material compositions were observed by Spectrometry which is highlighted in one of the chapters and its tensile testing was also done. The tensile testing results were obtained which were helpful in defining the Load Curves for the respective materials. The load curves were used in the software simulation for definition of material deformation in its plastic state.

The simulations were performed in full frontal orientation which is one of the standard tests involved in Crash analysis.

For full frontal crash, the material for hood, rail-liners, radiator covers, frame supports and various other parts with comparable strength to the new material were changed on the software and simulation was performed.

The results and observations have been limited to the materials' properties during impacts. Although there are numerous factors which involve the safety of a vehicle, the focus was primarily on the skin and frame material change which can increase the crashworthiness and make vehicle safer. The crash pulse and energy absorption was primarily focussed directly determining the materials' effectiveness in crash. Also, the deceleration curve and velocity curve for the driver's seat was drawn with respect to time in order to determine effect of the change of material on the shock propagation through the car body.

CHAPTER 2

LITERATURE REVIEW

This chapter highlights the literature studied and reviewed which has been used in this project.

Erika Fechová, Jozef Kmec, et al**.** : The paper stipulates the importance of material properties of different types of steel when they are used for a barrier in the frontal crash orientation. The biomechanical limits of occupants was tested especially for head injuries. Also, deformation work has been calculated after which a suitable member was proposed with most suitable type of steel based on the various experimental and theoretical results. Paper also talks about a deformation member which helps in protecting solid parts of the structure at the time of crash and also aids in setting the biomechanical criteria simultaneously. Since, head injury is the one of the most critical type body damage for human beings so through various tests and analysis of the crash an estimation of super-critical acceleration on human body was discerned so that it can be improved for better results. [1]

K. T. Gursel, S. N. Nane : This paper talks about the use of data models of different vehicles to analyse crashes using explicit method algorithm with in the Ansys/Ls-dyna program. The results were drawn with a comparison to the test results as compared to the actual vehicles in for their corresponding test vehicles. These observations stipulate that the algorithm can be used to study and analyse the crash simulations and proved to be a reliable tool. With the success of this comparison, the number of vehicles to be tested for crash have been reduced considerably for a safe design of automobiles.

In the test case of a Ford Taurus model, the safety cage remained intact and did not get destroyed during the full frontal crash as the major portion of the crash shock and energy was absorbed the front part using its full width. This was also observed in the case of offset frontal crash simulations. Tests performed by the NHTSA were compared with the results of crash simulation for deformations and accelerations and they happen to be in full agreement. .[2]

Gauri B. Mahajan, Dinesh. N. Kamble **:** The paper discusses the car's performance of BIW when it is impacted on the side. Interdependence of performance of Body-in-white frame (when vehicle undergoes crash in different angles with the rigid pole) and well-being of the occupants after the crash was the main intention. Initially, finite element model of body-in-white (BIW) frame as developed based on logical method to solve the problem. Then, procedure of design and manufacturing processes, analysis and evaluation of the side impact safety and the outcome of the side impact orientation were discussed. Then, in accordance with the regulation FMVSS No.214 or EURO NCAP analysis of the intrusion level standards towards the occupant (boot) space and of the occupant injury levels was discussed. The test results are compared with the FMVSS No.214 or EURO NCAP standards in the form of intrusion (mm). [3]

NHTSA, "Structural Countermeasure/ Research Program : Mass and Cost Increase Due to Oblique Offset Moving Deformable Barrier Impact Test" : This paper elucidates the importance of strengthening the structure of the vehicle for both driver and the front seat passenger through reinforcements. The proposal of the idea is based on the test results based on the side oblique offset impacts.
The designs which were recommended and verified through CAE modelling met all the performance requirements of all relevant tests in crash analysis. Test model taken were a finite element model of Honda Accord and Silverado 1500 and all modelled test results were comparable to the actual tests performed in crashing. The EDAG team used LS-DYNA software which is equipped with the tools aiding the ease of testing and analysis. The models developed through LS-DYNA may prove to be useful in analysing the vehicle to vehicle crashes in the coming future. Also, these CAE models are helpful in checking the safety of the interiors and passenger restraint systems and updating them accordingly for a better performance. [4]

NHTSA, "Vehicle interior and restraints modelling Development of full vehicle Finite Element Model including vehicle interior and occupant restraints systems for occupant safety analysis using THOR dummies" : The National Highway Traffic Safety Administration works for the safety of the vehicles and in the direction of this aim, they issued a contract to the EDAG Inc., which is an automotive design and engineering company.

The assignment was to create a finite element model for a full vehicle with all the interiors and restrain systems for occupant safety for driver and front seat passenger. A saloon car 2014 Honda Accord was developed to honour this contract. IIHS (Insurance Institute for Highway Safety) awarded "Good" or "Acceptable" rating for structural and interiors as vehicle met the requirements during the small overlap test. A "Good" rating in IIHS moderate overlap and NHTSA New Car Assessment Program (NCAP) also provided it a 5-star rating. [5]

Timothy Keon, **"**Alternative Approaches to Occupant Response Evaluation in Frontal Impact Crash Testing", This paper investigates the response of the test device or test dummy known as THOR-50M which expands as a test device for human occupant restraint 50th male. This investigation was done by The National Highway Traffic Safety Administration for oblique crash tests. The dummy was placed in the driver's position and response were recorded for frontal impact crash with a vehicle speed of 56 kmph.

There were many test devices used for analyses positioned along the seats of both the front seat passenger and driver. The NCAP procedures and regulations were considered for the right seat front the passenger that is the seat beside the driver's. FMVSS No. 214 was the procedure used for the right back seat occupant following the side impact compliance. Results describe that dummy THOR predicted a higher risk of chest injury and the results were compared with crash tests carried out previously following the NCAP regulations. The AF05 speculates a considerably higher probability of head, neck and chest injury for rear seat passengers than the front seat passenger.

Volker Sandner , et.al ,"EURO NCAP FRONTAL IMPACT WORKING GROUP REPORT" The data of the accidents occurring in the real world and prevailing research on the frontal crashes with some overlap have been covered by this group which has been detailed in this paper.

The testing measure’s development for a full frontal crash consists of a barrier which can move to car with a deformable face that is progressive honeycomb structured was guided using important factors including speed, mass and impact overlap which were highlighted by analysing accidents. The build level and response to the injuries defined the Thor-M ATD and also procedures for certification were researched into and are also included with the proposed criteria of assessment. Programmes to evaluate the tests and assessment on full scale will be the final phase of work before implementing it into the official assessment in 2020. [7]

Andrew Hickey, Shaoping Xiao : Via finite element method, quasi static car crash simulations were conducted in this paper. The model of the car 2002 ford explorer was produced using software CREA and then it was imported to ANSYS for meshing and finite element analysis. Different travelling speeds were considered when car was simulated to crash in the wall. The car was totalled when an incoming speed of around 100 mph was given to the car. The observations from a real life testing were in agreement with the maximum deformation in the numerical simulation. [8]

CHAPTER 3

MATERIAL CHARACTERIZATION

Crashworthiness is the measure of the ability of the material to absorb the energy by plastically deforming resulting in the protection and safety of the occupants from the crash.. Research on crashworthiness incorporates vehicle design improvement and modification, countermeasures for safer vehicle and instruments to upgrade the safety of the passengers. This research program will be evaluating motor vehicle safety by using different material. The two developing materials which are being used in automobiles and various other applications are Interstitial Free steel and Advanced High Strength Steel. So, further in this thesis, the advantages and properties of both the types of steel has been highlighted and the study will include the stress-strain graphs for both the material. The study will conclude with acceleration-time graphs also known as crash pulse and energy absorption graphs for the materials to be tested in crashing condition. The materials detailed below are the experimental materials which were used in crash testing analysis.

3.1 Advanced High Strength Steel (AHSS)

Advanced High-Strength Steels (AHSS) are intricate, refined materials. When a very precise controlled heating and cooling process in involved, it results in material which has a chemical composition which is carefully selected and multiphase microstructures. They are not the mild steels which were used earlier, instead they are advanced having a range of strength, ductility, toughness and fatigue which is brought about by several strengthening techniques. They are uniquely lightweight and are better than mild steels and HSS. They are manufactured to meet today’s fast challenges for very strict safety regulations, for reduction in the total emissions, for better solid performance and of course at costs which are economical.

Difference in microstructure is the distinctive criteria between AHSS and conventional HSS. With scope for some pearlite in C-Mn steels, HSS are single phase ferritic steels. Microstructure encompassing a phase different than ferrite, pearlite, or cementite come under AHSS – for example martensite, bainite, austenite, and/or retained austenite in quantities enough to produce mechanical properties which are unique. Some types of advanced high strength steel have a higher strain hardening capacity which results in a balance of strength and ductility better than conventional steels. Almost all types of advanced high strength steels are produced by controlling the constituents and chemistry and cooling rate is from austenite or the austenite-ferritic phase, which is controlled either on the hot mill runout table (for hot-rolled products) or in the cooling section of the continuous annealing surface furnace (continuously annealed or hot-dip coated products). By changing the chemical and processing combinations, many additional grades of AHSS can be created and for each type of AHSS properties can be improved as provided by research. [10]

3.1.1 Composition of AHSS

Before using any material, it is important to know its composition. The AHSS contains specific amount of alloying material which gives the steel its properties. The composition has been found by a process known as *Spectrometer analysis,* which uses a scientific instrument called *Spectrometer*, used to separate and measure the spectral components of a physical phenomenon.

The table 3.1 mentioned below gives the constituent materials and their percentage in the AHSS alloy for the thickness of 0.2 mm according to the spectrometer analysis conducted in a lab.

3.2 Interstitial Free Steel

Interstitial free (IF) steels are being extensively used for the fabrication of outer autobody components. These steels are characterized by high formability. The extremely low carbon content in the steel necessitates vacuum degassing and the use of low carbon mould powders. Addition of titanium and/or niobium is made for the elimination of solutes in the final steel after processing. Deep drawability for IF steel as compared to drawing quality of Aluminium killed steel has shown a significant increase according to the performance data. For intricate deep drawn parts, the breakage rates have been reduced in a dramatic fashion. With these attributes being in operation, anneals between the draws have been removed for one or more than one in number resulting in parts having better finishing. In multi-stage drawing steps, one or more steps can be removed for a complex part as shown by research trials in a laboratory. [10]

3.2.1 Composition of IF Steel

Before using any material, it is important to know its composition. The AHSS contains specific amount of alloying material which gives the steel its properties. The composition has been found by a process known as *Spectrometer analysis,* which uses a scientific instrument called *Spectrometer*, used to separate and measure the spectral components of a physical phenomenon.

Also, for the achievement of the required strength and formability properties in the final steel sheets, it is extremely important to produce a hot band with desirable microstructure, precipitate distribution and crystallographic texture. For this, careful control over processing parameters like reheating and finish rolling temperatures, cooling conditions and coiling temperature is necessary. Also, the cold rolling deformation and annealing parameters need to be monitored for the development of desirable properties in the final product.

The table 3.1 mentioned below gives the constituent materials and their percentage in the AHSS alloy for the thickness of 0.2 mm according to the spectrometer analysis conducted in a lab.

Apart from iron and carbon, which we know are the major elements in steel alloy, there are other elements involved to provide different properties to the steel. So, in the table below different elements along with their percentage in the alloy has been shown.

Table 3.1 Composition of AHSS and IF steel.

Steel / Element %	Si	Mn	S	P	Ni	Cr	Mo	Al	Cu	Ti	Nb	Co	B	Zr
IF Steel	0.001	0.112	0.009	0.017	0.002	0.012	0.01	0.043	0.02	0.026	0.018	0.001	0.0002	0.006
AHSS	0.028	1.45	0.009	0.023	0.026	0.034	0.006	0.044	0.007	0.004	0.017	0.007	0.0001	0.004

CHAPTER 4

TESTING AND SIMULATION

This chapter explains the material testing details and modelling & simulation part of the project.

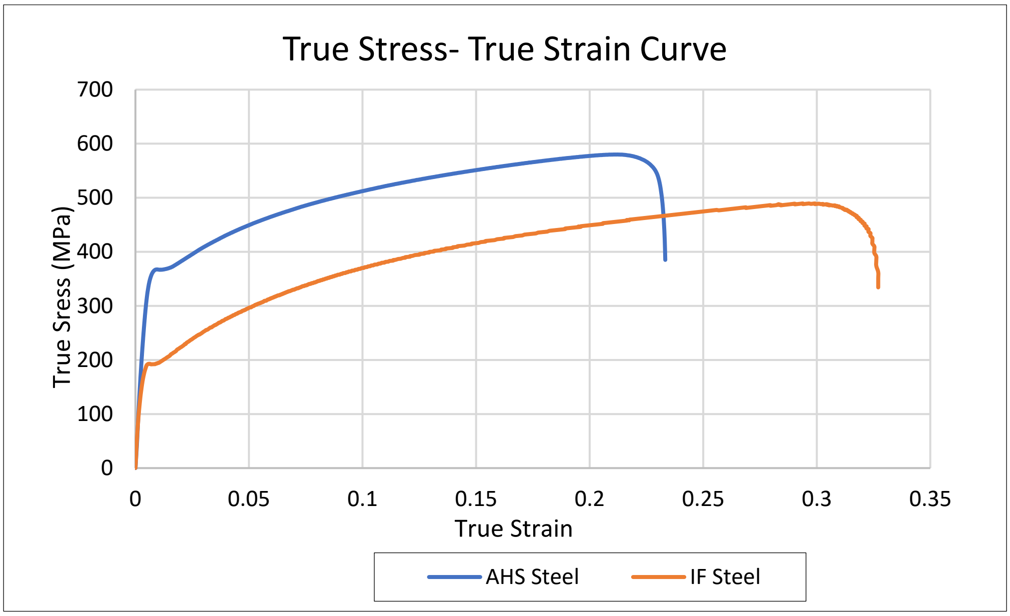
1.Tensile Testing

The reason for performing tensile test of the materials that are being used is to find out the stress-strain curve. The stress-strain curve is then used to define the load curve which is incorporated in simulation. Load curve is simply a true stress-strain curve with only the plasticity part i.e., the curve defined after the yield point. This gives the behaviour of materials under fatigue and shows the materials' energy absorption capacity. The tensile test performed was according to the standards which involves specimens cut in dog-bone shape. The specimens had an approximate thickness of 0.9 mm and gauge length of 84 mm. Both the specimens (AHSS and IF steel) were cut in the rolling direction by laser cutting.

Fig. 4.1 Image of the specimens for tensile testing

Shown below are the stress-strain graphs for both the materials as labelled. The tensile tests show the yield stress which is used further for the simulation. For AHSS, yield stress is about 380 MPa and for IF steel it comes out to nearly 180 MPa. Although from the graphs it might seem a bit different but th data is taken from the original report generated after tensile testing.

Fig. 4.2 True Stress – True Strain Graph



2. Modelling and Simulation

The simulation performed was all set on standard values. The FEM model and its constraints were already defined by the George Washington University National Crash Analysis Centre. They made & assembled this model for the use by NHTSA (National Highway Transportation and Safety Authority, USA) which incorporate crash testing by adopting the NCAP regulations according to their country's standards. The model which was available readily on the NHTSA had only full frontal crash orientation. The standard speed of the car is 56.33 KMPH or 35 MPH for crashing. This speed is defined according to the regulations of NCAP, so there have been no changes made while simulating for the study.

LS-Dyna, like most of the software packages that are used for analysis, works according to the system of consistent units. For this simulation, ton-mm-s system of unit is used in which mass is in tons, length in millimetres, time in seconds, force is in newtons, stress in MPa. The ratio for velocity in this system is 1.56E+04.

The simulation was completed in 42 steps i.e., there were total 42 stages in which the data was written of d3plot was written for the crash simulation. The simulation time i.e., 0.2 seconds was divided in 42 parts as required by user to write d3plots. Shown below are three stages, starting, intermediate and ending by which a general idea can be formed regarding the crash simulation which was completed in LS-DYNA.

Fig. 4.3 Position of car before the crash at 0.00s

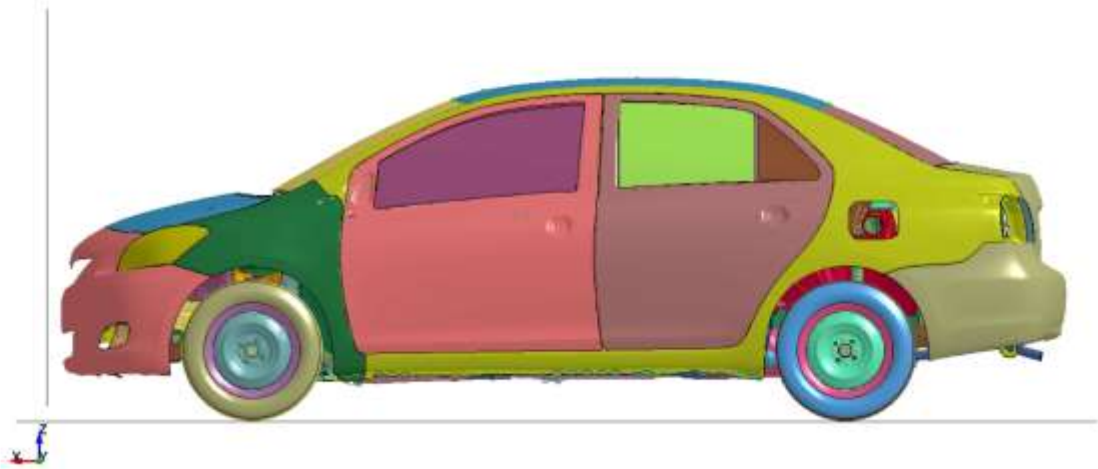
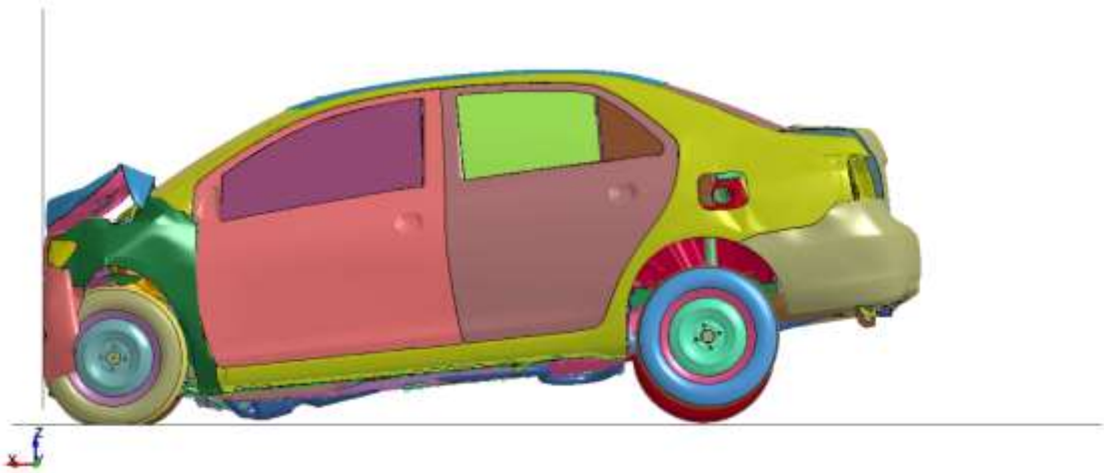
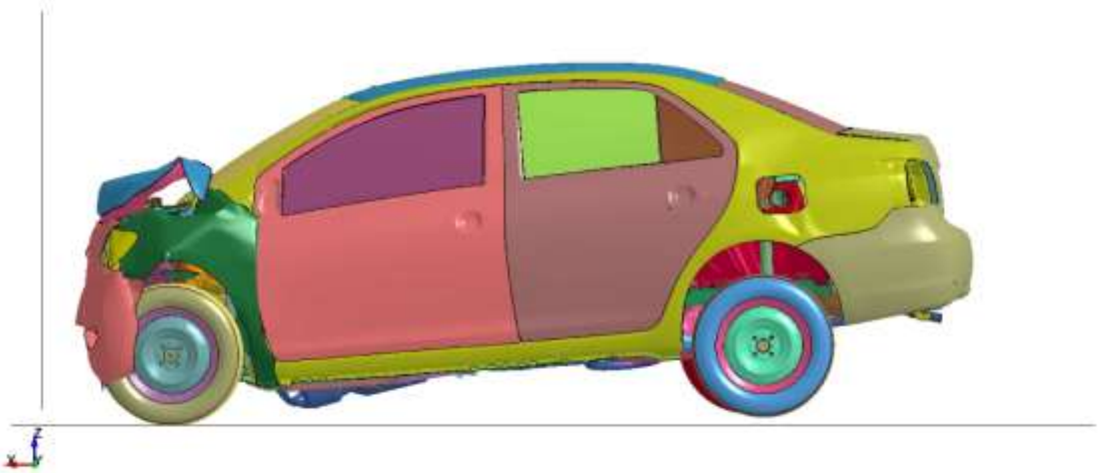


Fig. 4.4 Position of car during the crash at 0.1s



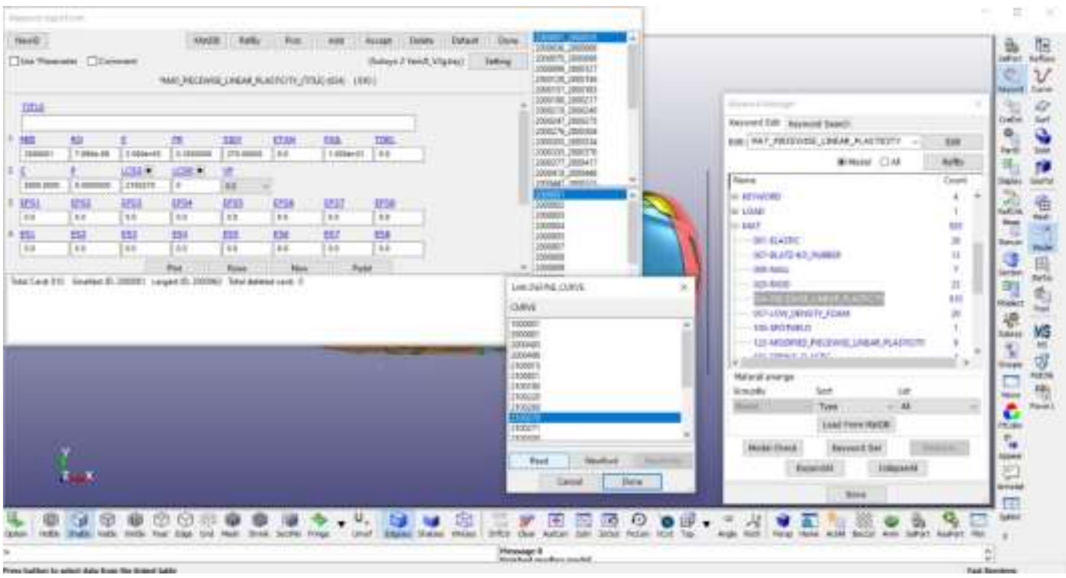
As it is clearly visible in the pictures that the front part crashes up to a certain extent. This is because of the solid engine block. It restricts the bending and the crushing of the front part. So, it leaves a limited portion of the vehicle in which the material can absorb the energy of the crash. Also, the parts can be changed up to a certain extent only respecting the consistency of the material models used in the this finite element model of the car.

Fig. 4.5 Position of car after the crash at 0.2s



Now talking about the material model involved, as discussed earlier, MAT_024 that is Piecewise linear plasticity model which works according to the Cowper-Symonds material model. The model which primarily works on the principle on which the elasto-plastic materials behave.

Fig. 4.6 User interface and dialog box for making changes in material



In the above picture, from the keyword manager MAT 024-PIECEWISE_LINEAR_PLASTICITY model was selected. In the keyword input form, the values for the parameters are entered. As the study is comparative, the values were already filled and only two of the above parameters were changed, SIGY and LCSS. LCSS is the load curve and from DEFINE_CURVE, the new curve according to the AHSS and IF steel was created and entered. In the Keyword input form dialog box, on the right most side, there are series of numbers available which are part numbers. For each part, same or different values for the parameters and curves can be defined under the same material model i.e., MAT_024.

In the table below, there is distinctive mention about the changed parameters. Since the only material model under consideration was piecewise liner plasticity, hence, it was assumed in the table that the changes made for AHSS and IF fall in the same model. So, there was no need of mentioning the same.

Table 4.1 Changed parameters for simulation.

Part ID	Part Name	Yield stress (MPa)	LOAD CURVE ID	Material
2000190	Hood	180	21001002	IF Steel
2000100	Hood_Inner	180	21001002	IF Steel
2000191	Fender left	180	21001002	IF Steel
2000352	Fender right	180	21001002	IF Steel
2000138	Framefront right	380	21001003	AHS Steel
2000142	Framefront left	380	21001003	AHS Steel
2000163	Railout left	380	21001003	AHS Steel
2000168	Railout right	380	21001003	AHS Steel
2000164	RailLiner left	380	21001003	AHS Steel
2000166	RailLiner right	380	21001003	AHS Steel

From the tables, it is obvious that only load curve has been changed for some parts, while the value of SIGY (yield stress) is changed. But for the material IF steel, the value of SIGY is decreased in certain amount and load curve is also changed.

Fig. 4.7 Parts depicted in white for which the material has been replaced by AHSS

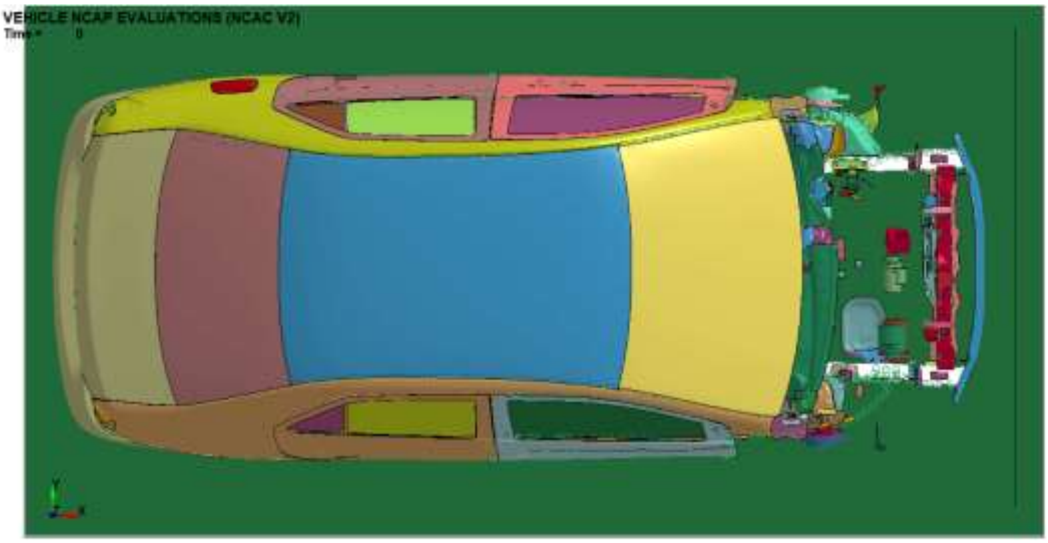
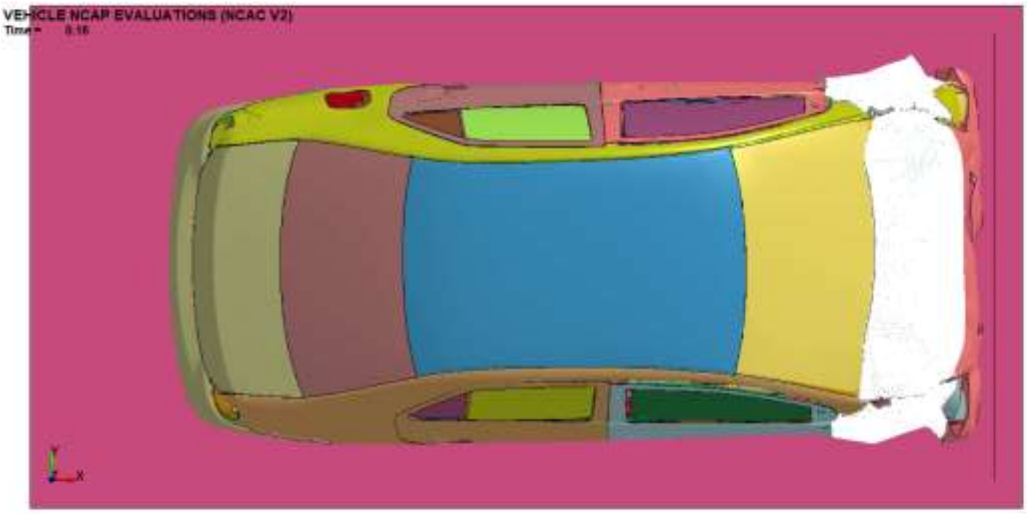


Fig. 4.8 Parts depicted in white for which the material has been replaced by IF steel



In the above pictures (Fig. 4.7 and Fig. 4.8), some of the portion is depicted in white colour. This represents the parts which have been replaced by the new material. in the Fig. 4.7 the frame front, rail liners, which are an integral part of the chassis, have been replaced with the new material in the simulation. Similarly in Fig. 4.8 hoods and fenders have got their materials replaced while simulation. So, it is evident by just looking that a significant amount of material was replaced with IF steel and AHSS, which after simulation has given some positive results which can be seen in the coming chapter of the thesis.

CHAPTER 5

RESULTS & DISCUSSION

In the tables above, the changed values have affected the energy absorption of the material. The study's focus was to examine the materials' behaviour and crashworthiness in a crash test. So accordingly, the parts have their individual results which have been represented through energy absorption graphs and crash pulse. In the later part of the results, the overall effect on the crash by the change in these parts is shown and a comparison is drawn based on the increase or decrease of the energy absorption and crash pulse.

The graphs shown below are represented by their part numbers which show their individual effects.

5.1 Energy absorption curves

Some of the results might show the decrease in the absorption but the interest solely lies on the overall effect on the car.

The Energy absorption is shown in the units of Newton-millimetres which is not a IS unit of energy, which is Joules, but in the software, there is a system of units which has to be followed in order to get the consistency in results. These units can also be converted by simple multiplication/division. The system of units which is employed is highlighted in the appendix which can be referred.

The details above the graph describes the part for which the graph has been drawn.

In the graph, as mentioned, the continuous blue line represents the curve for originally used material while the orange continuous line represents the new or changed material.

Fig. 5.1 Energy Absorption Curve for Frame-front (right)

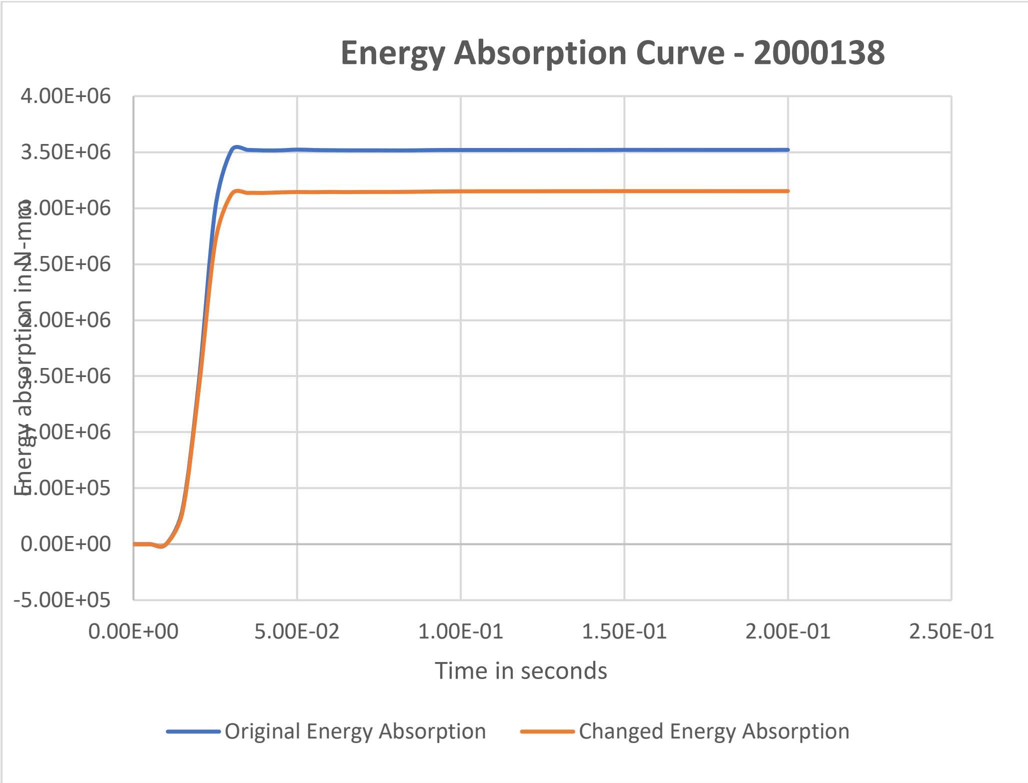


Fig. 5.2 Energy Absorption Curve for Frame-front (left)

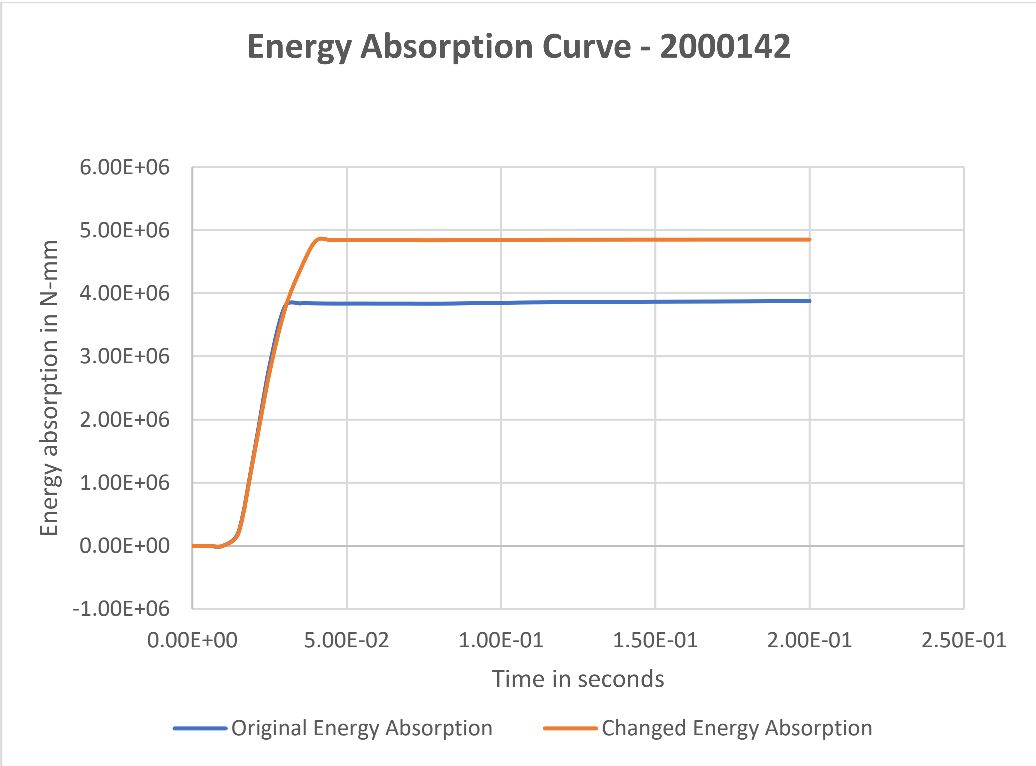


Fig. 5.3 Energy Absorption Curve for Rail-out (right)

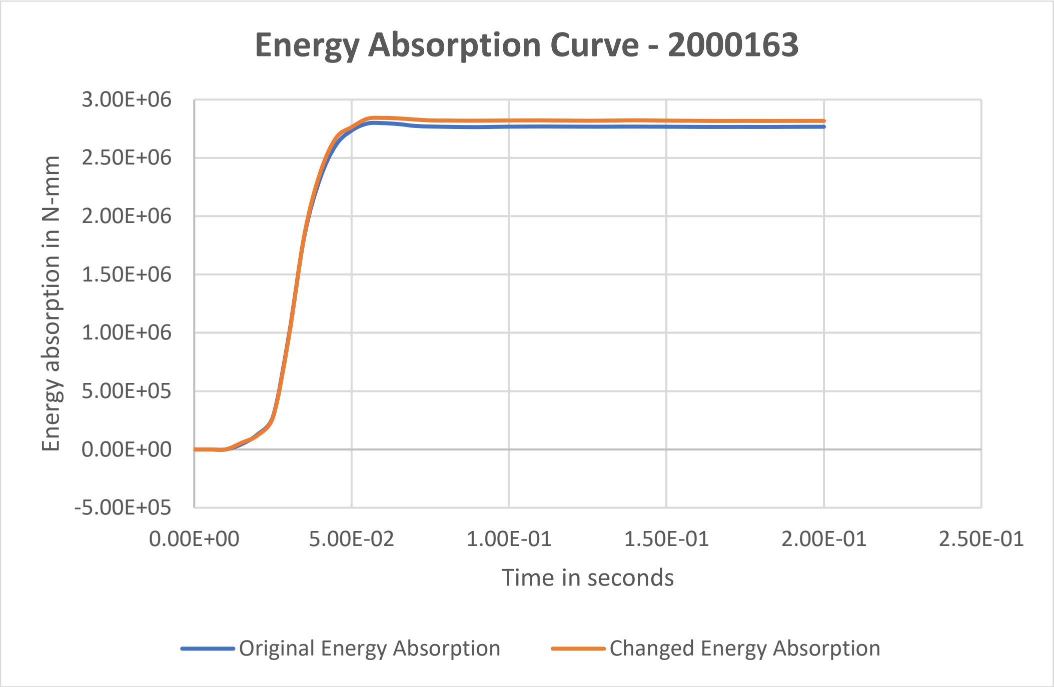


Fig. 5.4 Energy Absorption Curve for Rail-out (left)

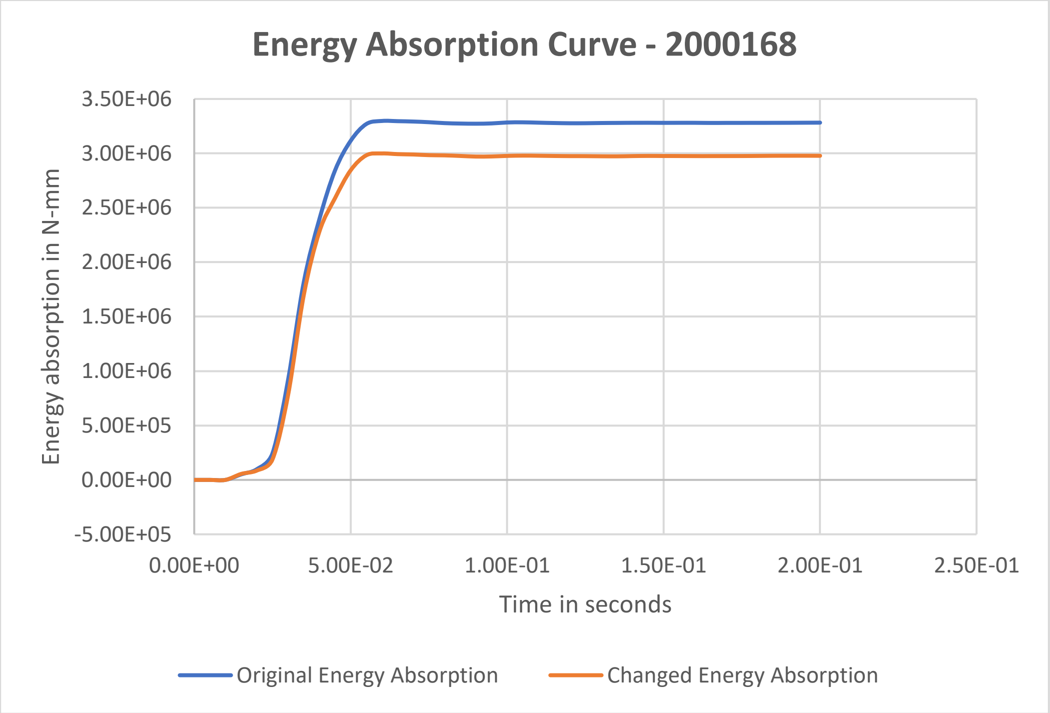


Fig. 5.5 Energy Absorption Curve for Rail-liner(right)

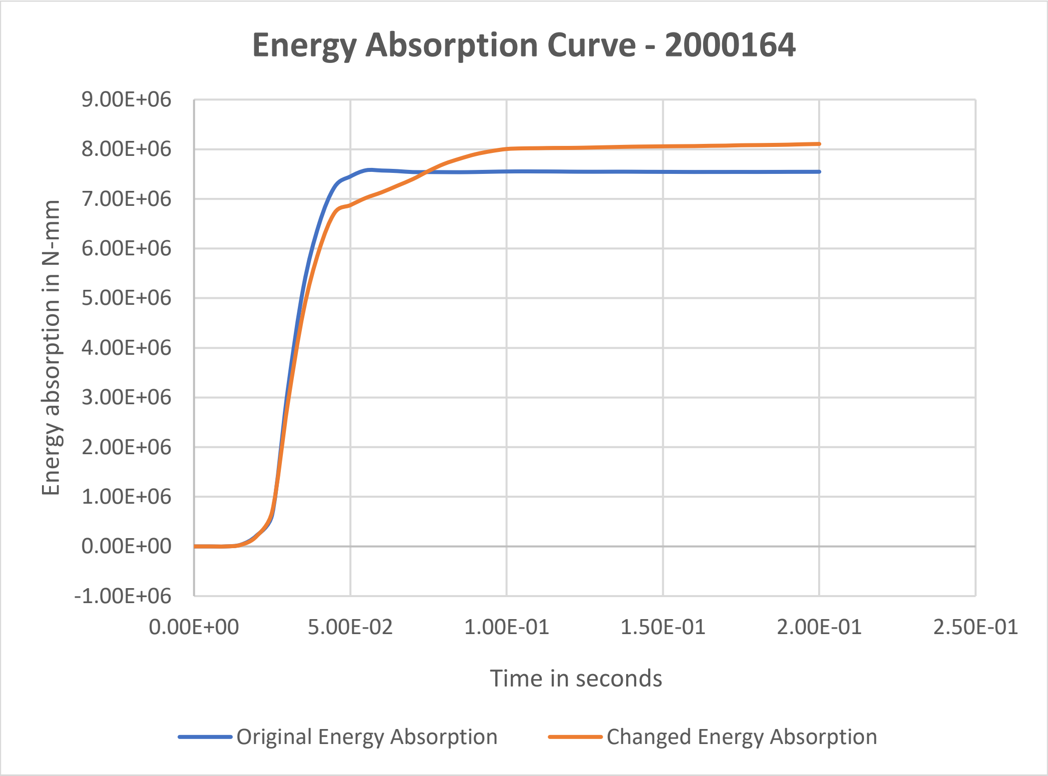


Fig. 5.6 Energy Absorption Curve for Rail-liner(left)

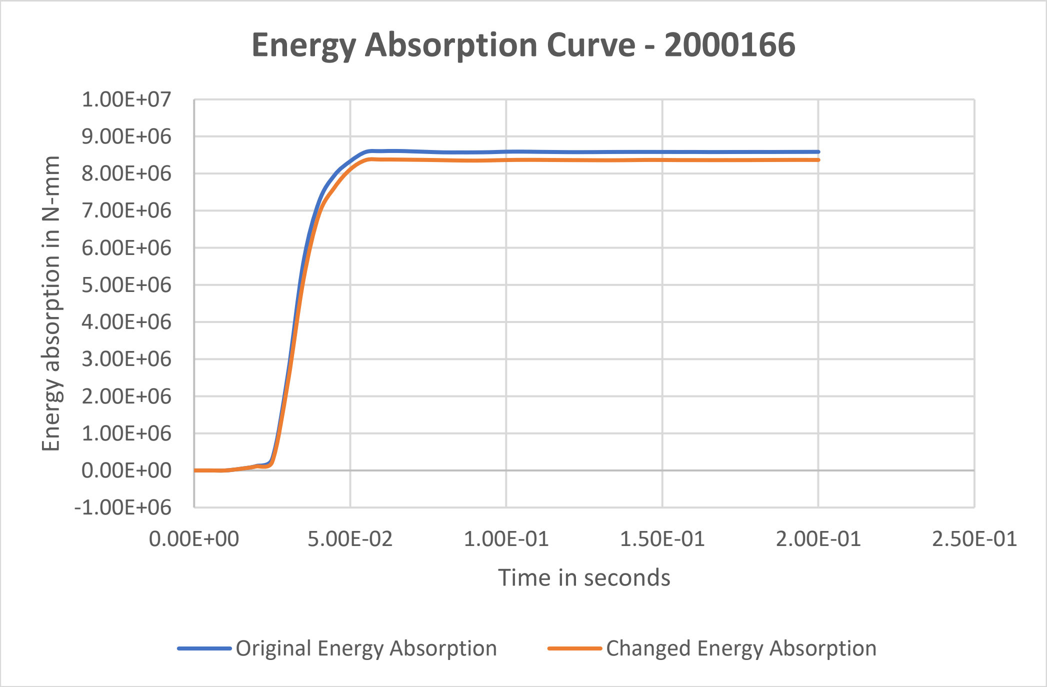


Fig. 5.7 Energy Absorption Curve for Hood

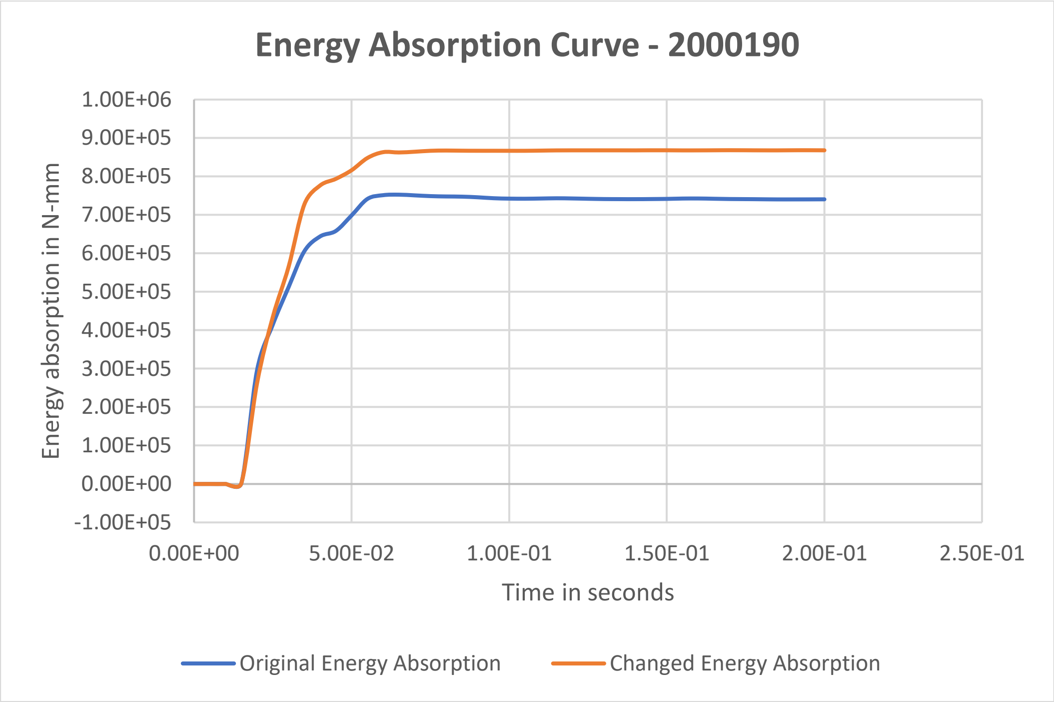


Fig. 5.8 Energy Absorption Curve for Hood-inner

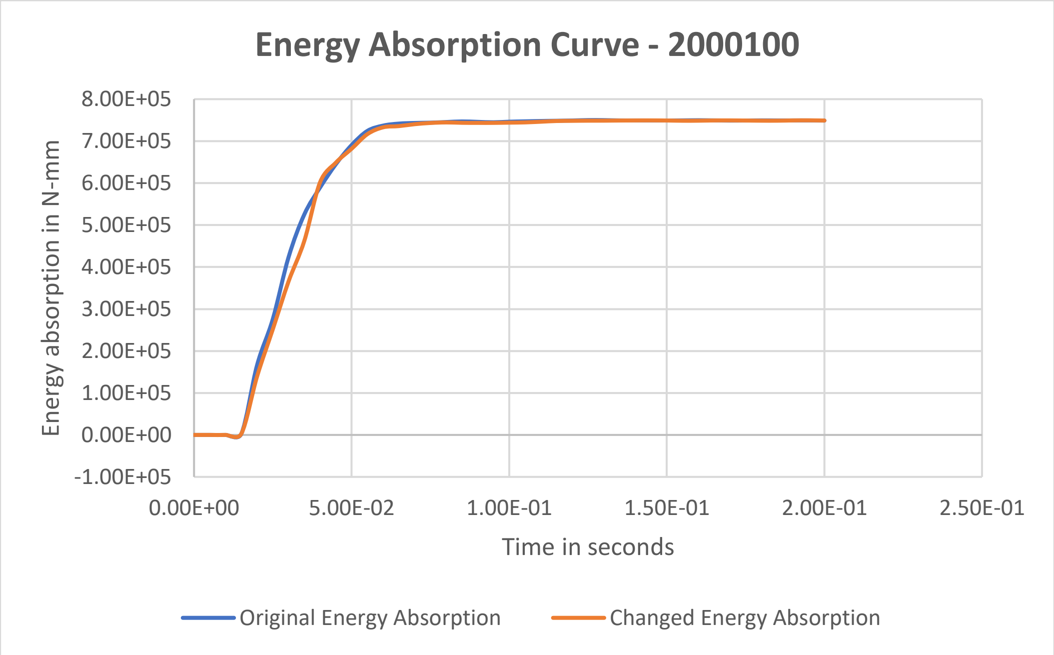


Fig. 5.9 Energy Absorption Curve for Fender (left)

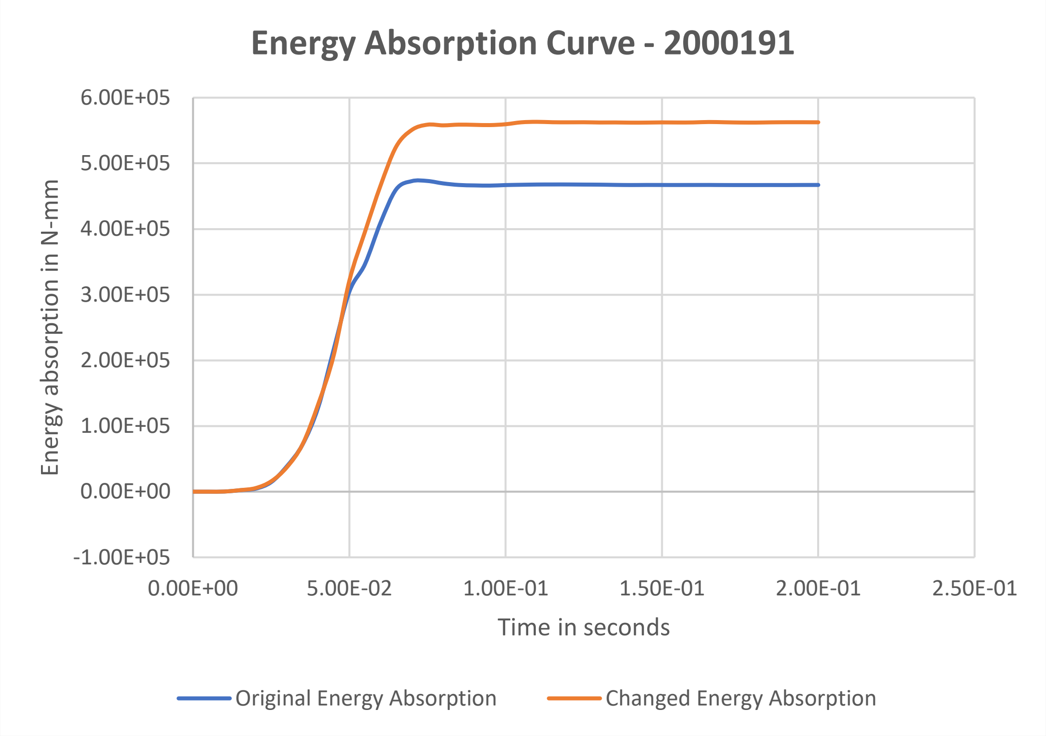
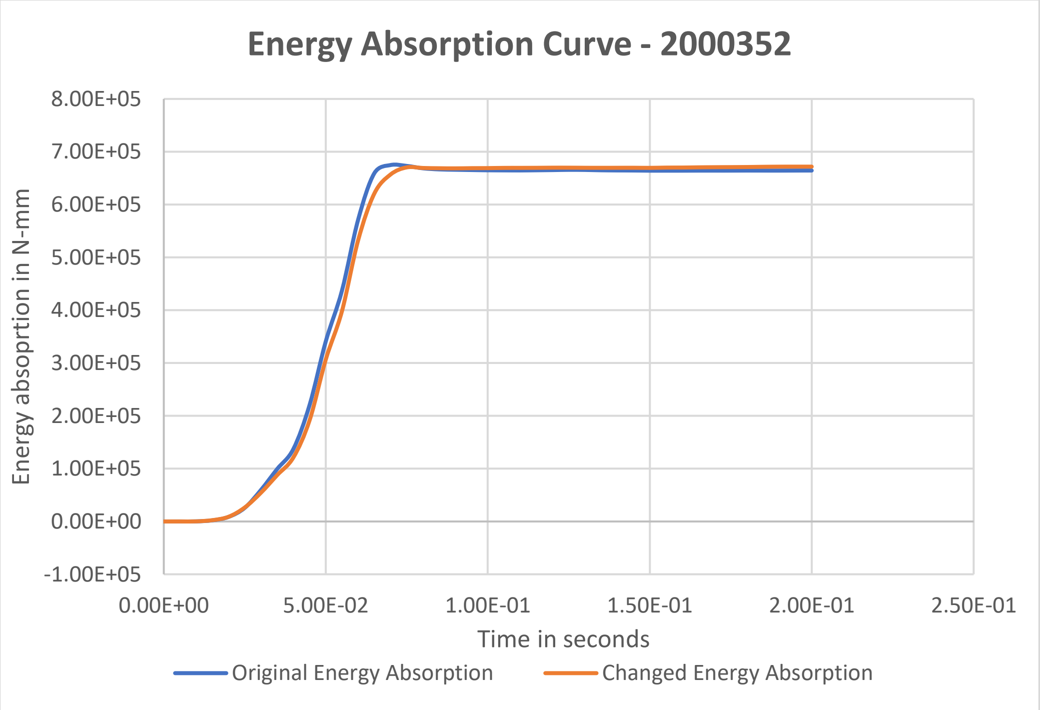


Fig. 5.10 Energy Absorption Curve for Fender (right)



5.2 Crash Pulse

Some of the graphs might show the negative results but the interest solely lies on the overall effect on the car which will be stipulated further in this study.

Fig. 5.11 Crash Pulse for frame-front (right)

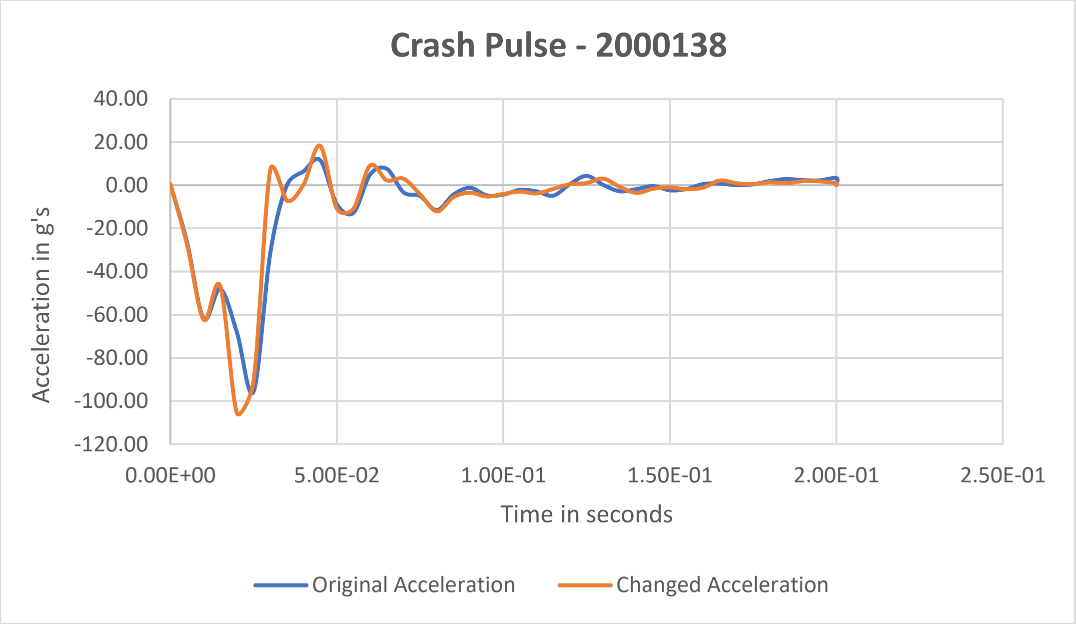


Fig. 5.12 Crash Pulse for frame-front (left)

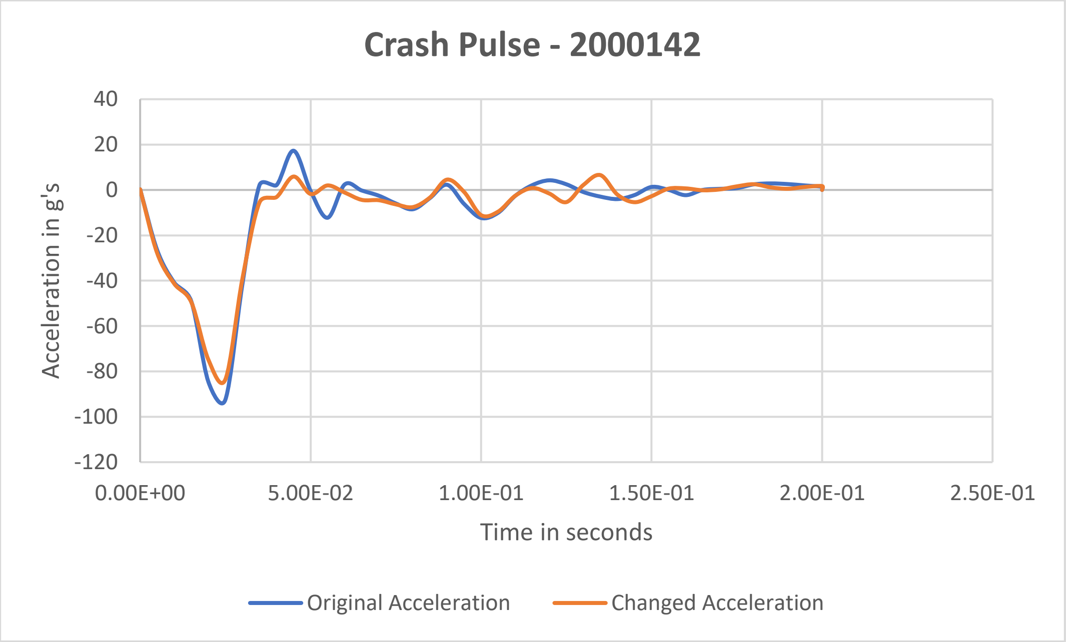


Fig. 5.13 Crash Pulse for Rail-out (right)

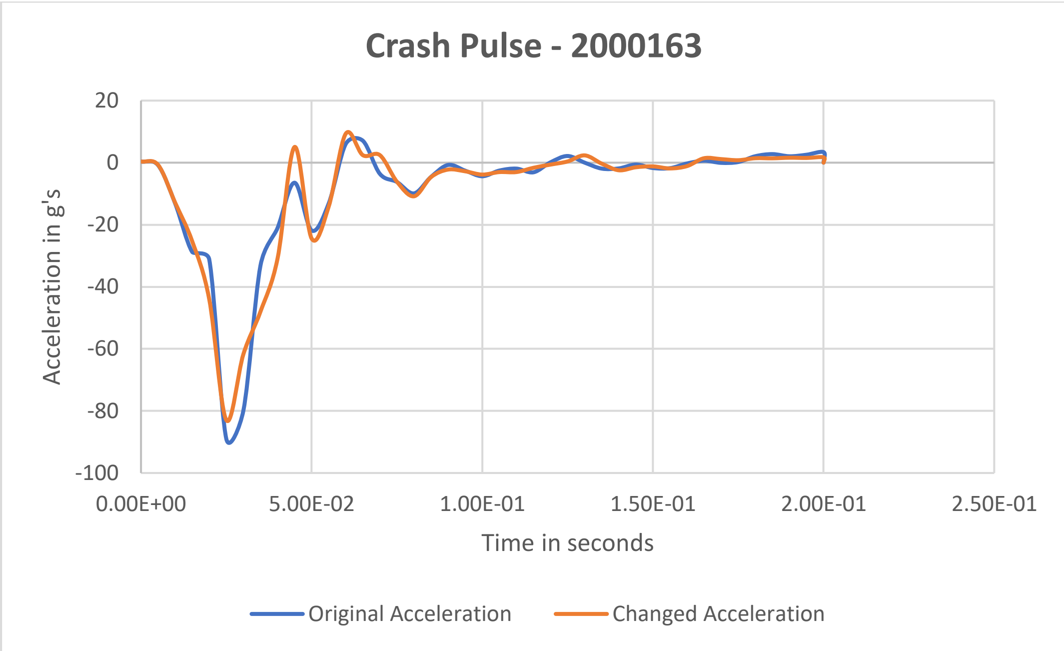


Fig. 5.14 Crash Pulse for Rail-out (left)

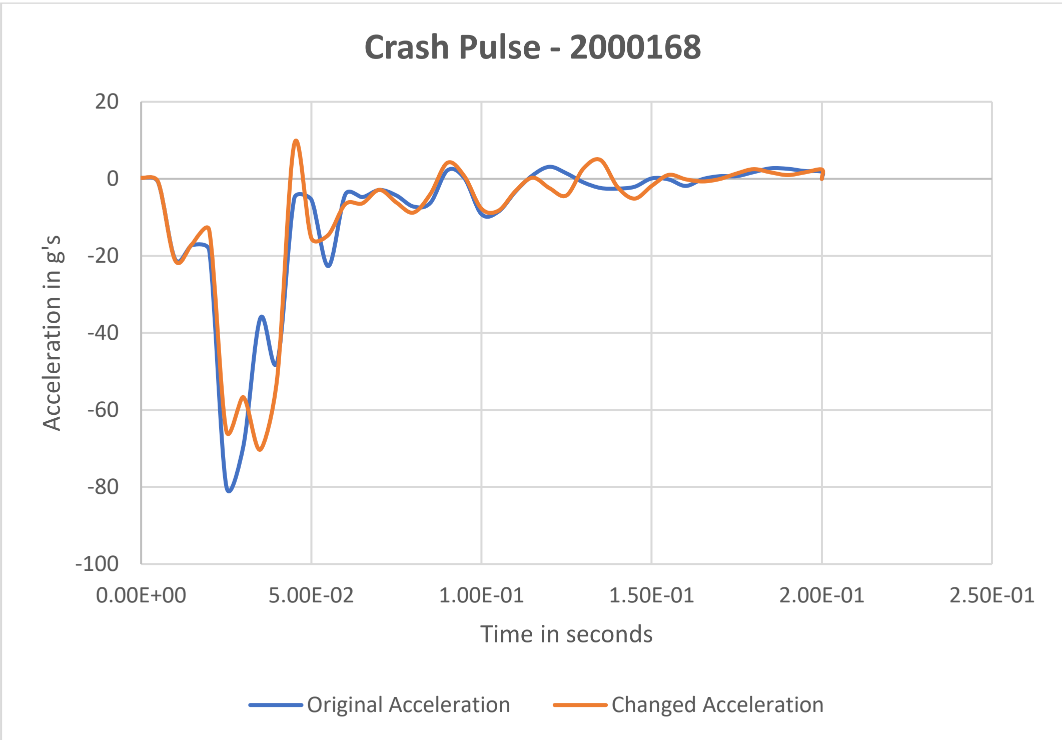


Fig. 5.15 Crash Pulse for Rail-liner (right)

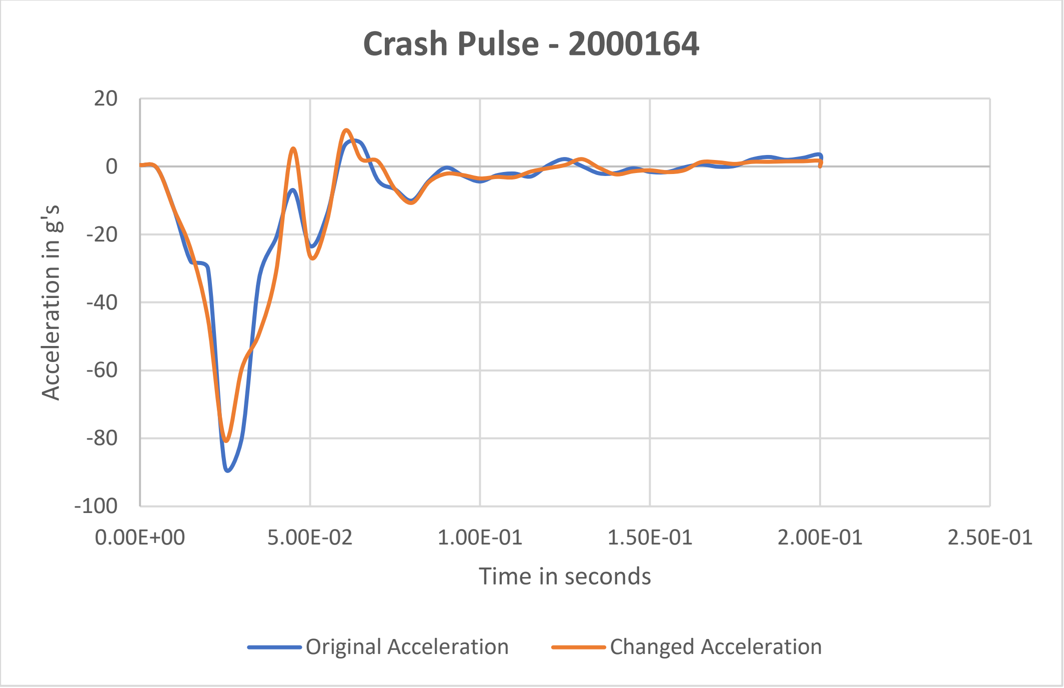


Fig. 5.16 Crash Pulse for Rail-liner (left)

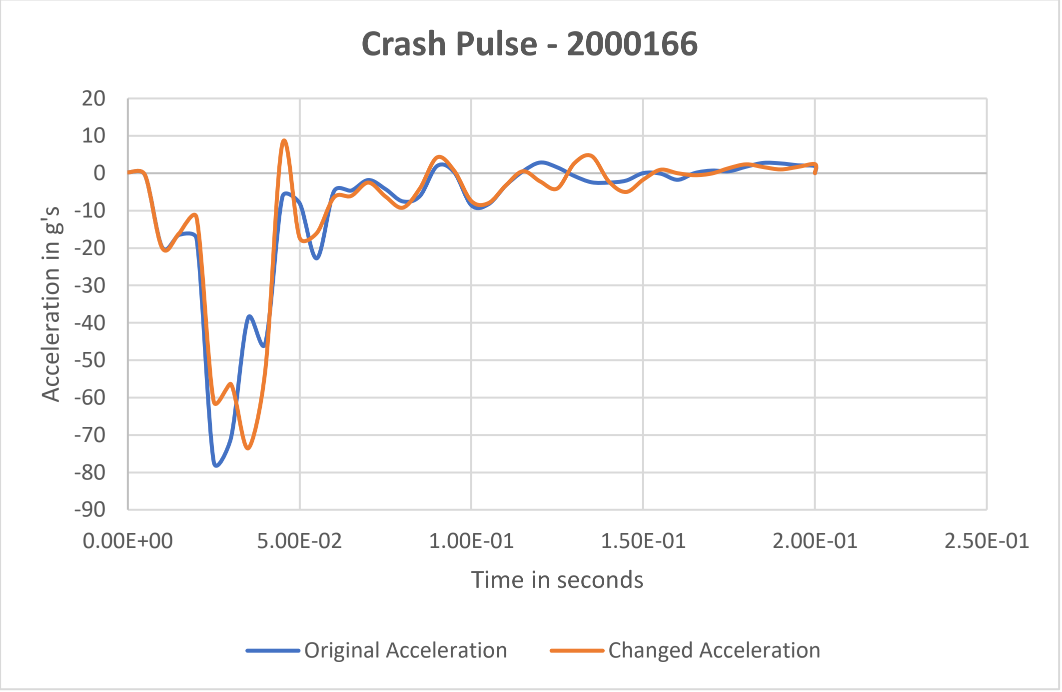


Fig. 5.17 Crash Pulse for Hood

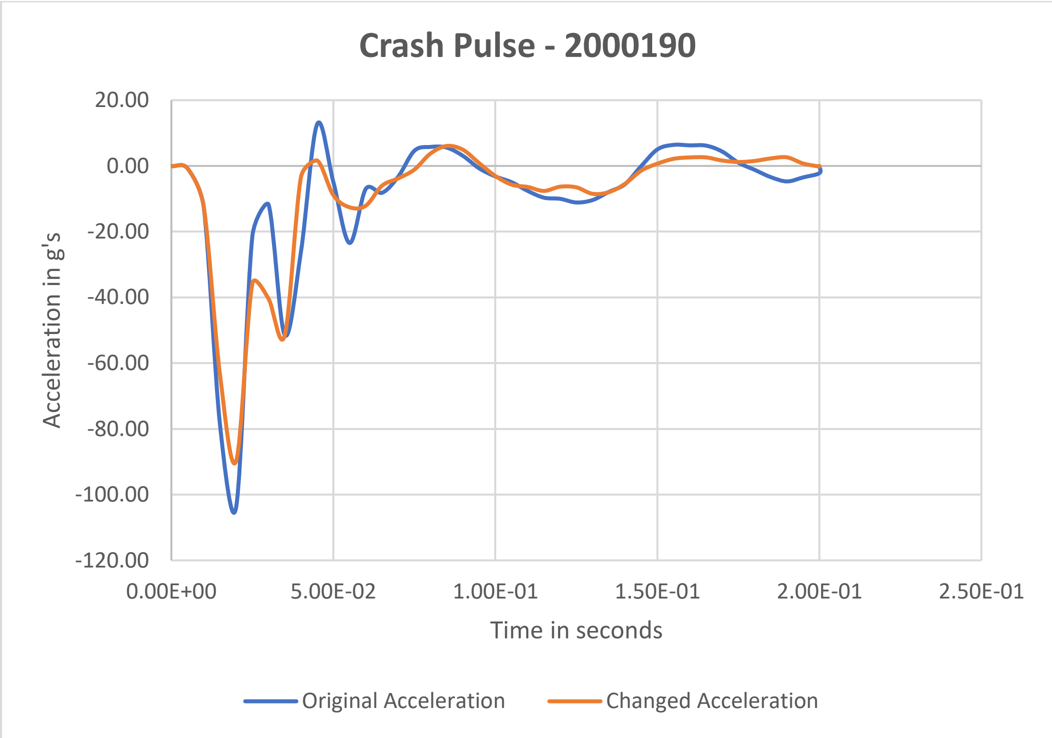


Fig. 5.18 Crash Pulse for Hood-inner

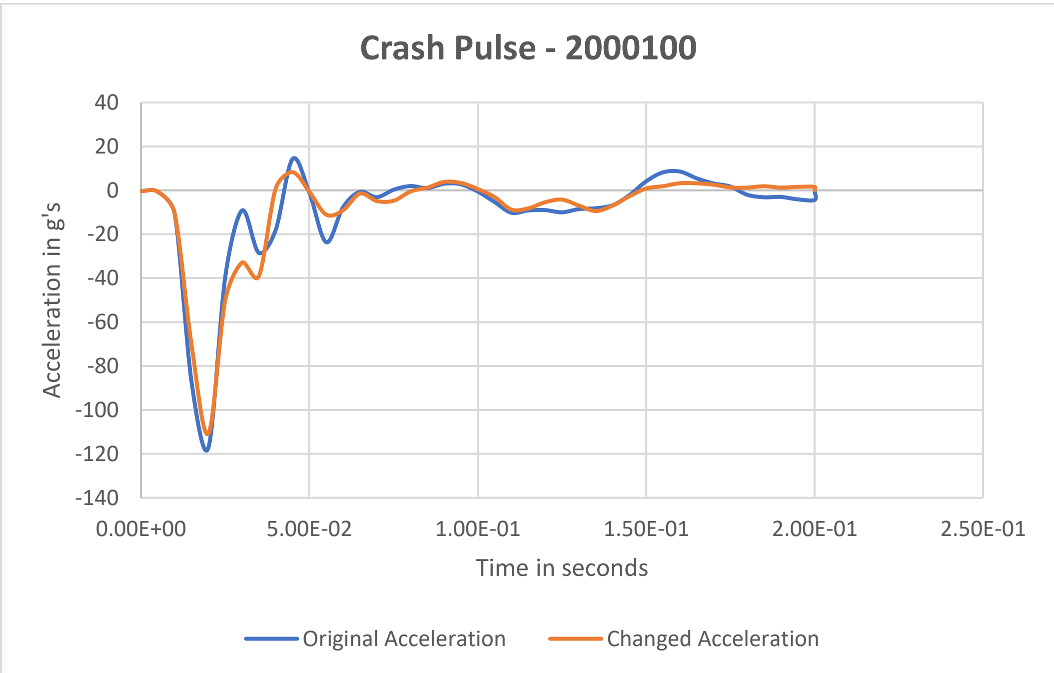


Fig. 5.19 Crash Pulse for Fender (left)

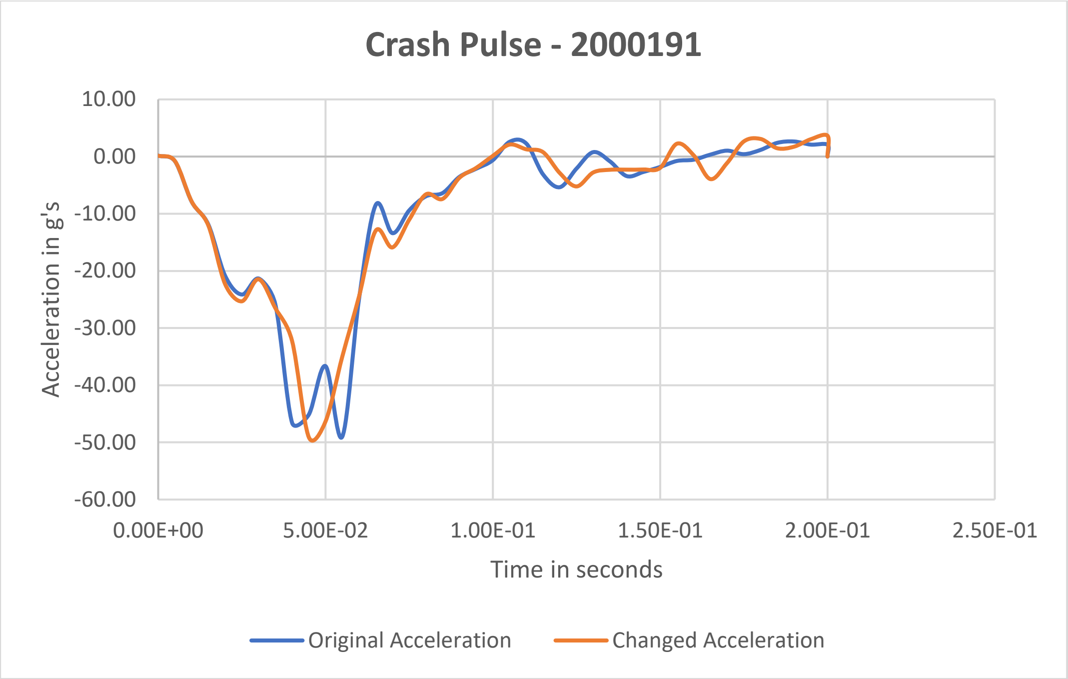
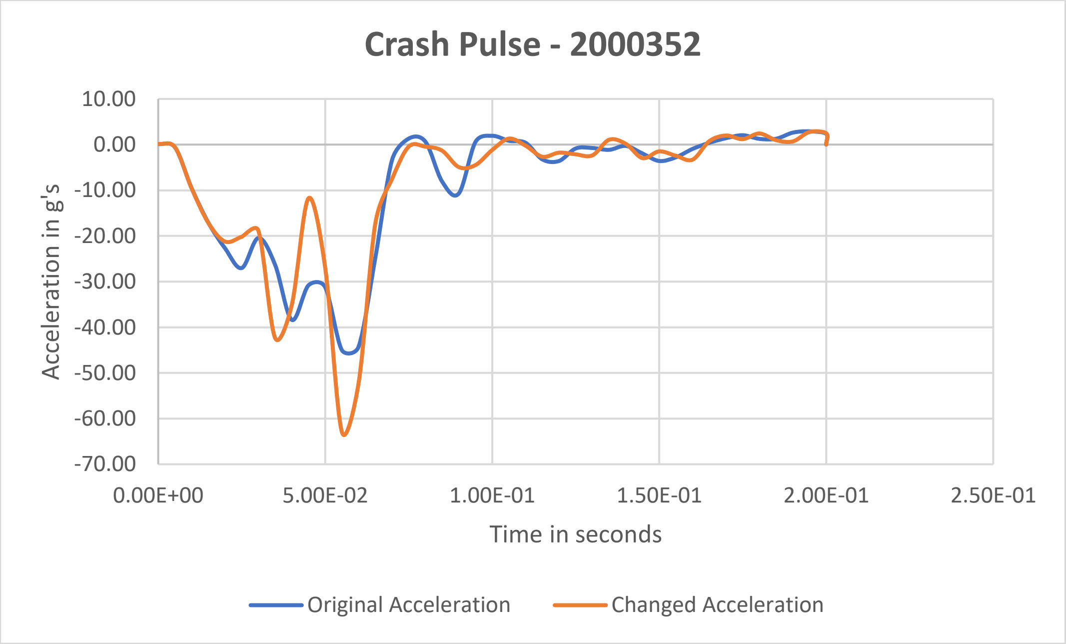


Fig. 5.20 Crash Pulse for Fender (right)



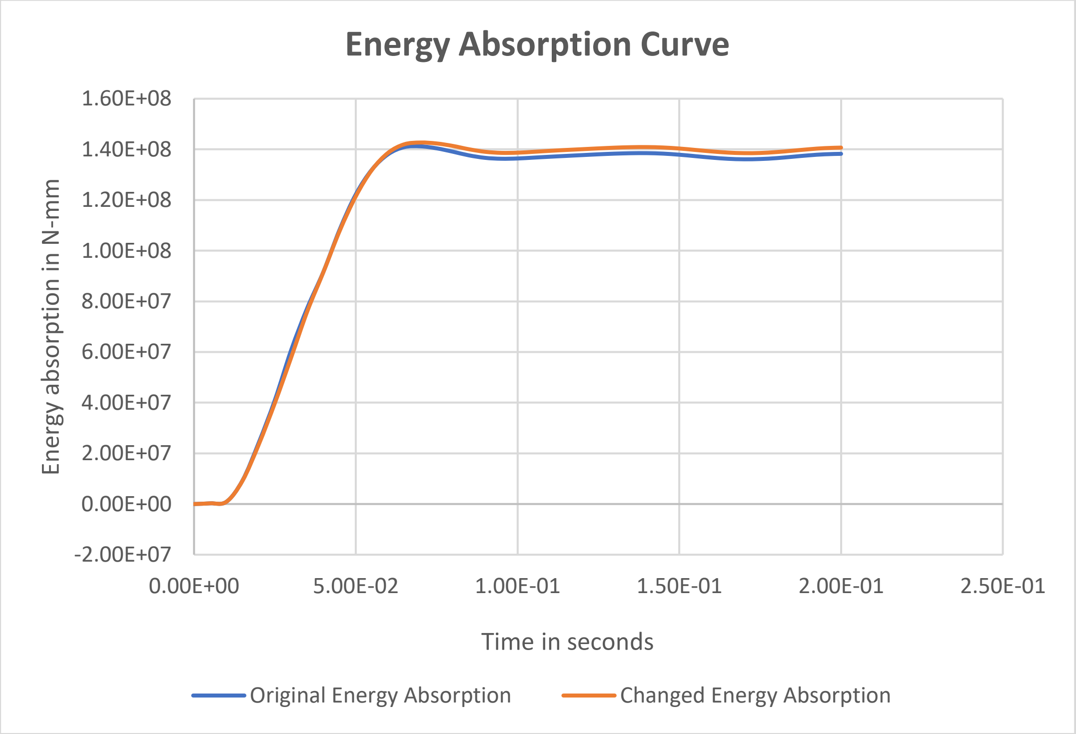
5.3 Overall effects

The above results for parts in which changes were made have affected the overall results in the crash. Energy absorption curve is depicted as internal energy graph in LS-Dyna.

5.3.1 Energy Absorption : The graph shown below depicts a slight increase in the internal energy of the car which in other words mean that the energy of the crash is absorbed by car through its parts has been increased slightly.

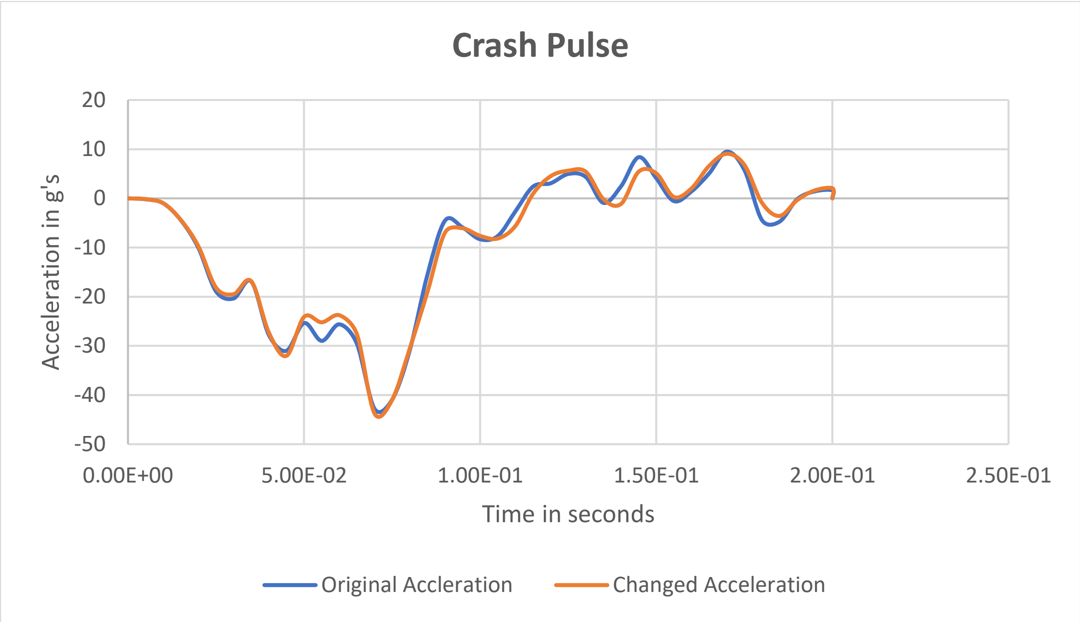
On comparing the maximum energy absorbed by previous and the changed material, the increase is very sigificant. As the trend is almost similar till their highest points, so it is better to consider the maximum absorption for calculation. Though the changes are not much bigger in their aspect as they have been made in very small number of parts. According to the graph shown above, there is an increase of **1.8%** in energy/ shock absorption which is generated by crash.

Fig. 5.21 Energy absorption curve for the whole car body i.e., internal energy graph



5.3.2 Crash Pulse : The graph shown below is the decelaration of the driver's seat. The lower the negative peak of the crash pulse, lesser is the impact of the crash or in other words lower is the transmission of shock to the driver and his seat.

Fig. 5.22 Crash Pulse for the seat of the driver or deceleration curve for the seat of the driver.

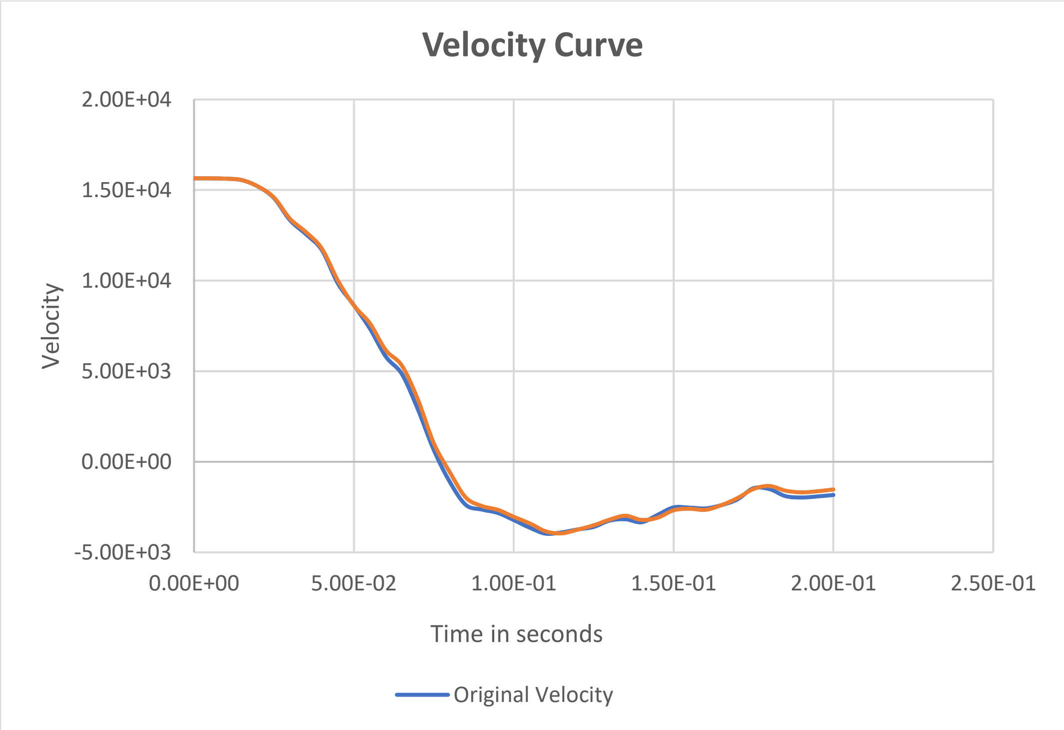


In the Fig. 5.22, graph, it is visible that both the curves are almost overlapping with an exception of the peak points where the changed material has slightly more negative decelaration. But on finding the the percentage increase point-wise and taking an average of the total, the result was positive, that means in the favour of changing the material. the curve generated on changing the material is smoother than the previous one. So, the net decrease in negative acceleration or deceleration is approximately **1.42 %.** In an ideal condition this curve is smooth and has a constant decrease with the least negative slope possible so that the driver and passengers don't get fatally injured.

5.3.3 Velocity Curve : As the crash pulse for the driver's seat was observed, similarly the velocity curve for the seat is oberved. The idea here is to decrease the speed of the driver and passengers falling or crashing on the dashboard is gradual. since, in the crash the forces exceeed the values in tens of g's.

The graph below show the decrease of the velocity of the drivers's seat. So, the thing to observe here is how gradual the speed is decreased.

Fig. 5.23 Velocity-time curve for the seat of the driver



The graphs seems almost identical and both the curve overlap each other to a great extent. But a slight change is visible and it can be observed that negative velocity has decreased at peak points. The percentage decrease in negative velocity or the velocity at which the seat of the driver is pushed forward can be calculated in a similar fashion as calculated for the deceleration of the seat. The average decrease in the velocity is **1.92%.** This means at several points the negative velocity has been slightly less than the velocity of seat at original material.

With the amount of material replaced in the car, it is evident that the results are quite significant and can be considered as a good solution. By looking at the figures 5.5 and 5.6, the crashing parts whose material were replaced are depicted in white. So, only these parts with a small change in their materials have given some positive results which are worthy of consideration for further research.

NOTE : There is an important point to be noted here. As the velocity and acceleration are both vector quantities, the negative sign implicates the change in the direction that is different from the velocity and acceleration of car while travelling i.e., after the crash, the car was travelling backwards and the seats were travelling forward due to inertia and this difference in their respective direction is denoted by a negative sign which shows the motion of seat relative to the motion of car. Therefore, while calculation, absolute value or only magnitude is to be considered so that there is no mistake in determining whether the value under observation is increasing or decreasing.

CHAPTER 6

CONCLUSION

The main focus of this study was to find the crashworthiness of the materials (AHSS and IF steel). With the advancement in the technology, the world is racing towards a safer and efficient material. This study heads in the same direction with a limited number of changes. With some basic changes in the properties, the crashworthiness can be increased albeit slightly.

In the earlier chapters of this thesis, it was observed that in the case of AHSS the value of SIGY (yield stress) was kept same or was increased still there is an increase in the energy absorption. The load curve or the stress-strain curve determines a lot of properties and the ability of the material to work under fatigue becomes advantageous in the case of protection from car crash. The individual contribution of the parts was contrasting to the sought result as for some parts the absorption increased and for some it decreased. Same trend was observed for crash pulses for different parts, though it was not consistent with the same parts for which energy absorption was also negative. But the overall effect on the absorption and crash pulse was positive. It was also observed that the seat of the driver was retarding a bit slowly than before which reduces the peak deceleration and velocity, ultimately leading to the increased safety of the passenger than before.

Although, the study of car crash involves forces to be studied using dummy and the inflation and deflation of air bags is also studied. Important criterion like HIC (Head Injury Criterion) is also calculated for the same. But this research was limited to explore the materials’ behaviour in crash situation keeping density, modulus, poisson’s ratio and other parameters constant. This limitation opens the scope for future studies.

For further continuing this research, the parameters C and P can be changed by finding them through the Cowper-Symonds model for the material. Also, a change in materials' density can be considered so that the weight of the car can be reduced.

The reason for increase of energy absorption in some cases and decrease in some with the same parameters can be investigated to give a clear picture of the car crash dynamics.

The same materials' simulation in the condition of side crash can also be studied and then a clear conclusion can be drawn on the fitness of this material to be used in the automobiles. Materials' crashworthiness in both full frontal and side crash should have significant increase than the previous material, then only it can be considered for replacement and further research.

The model used was an engine model in which the engine acts as a rigid block and does not help much in reducing the shock as its material is very strong. For the electric cars, the crash shock absorption and crash ratings are comparatively much better. This FE model can be altered a bit to simulate the type of crash testing as done in the case of electric cars. Although, it can only be tested in the case of full frontal crash orientation or oblique but not side crash or rolling tests. Side crash and rolling tests will involve a major dependence and affect in the case of centre of gravity of the car which is not very easy to handle while changing FE model. As most of the electric cars employ the floor batteries which provide additional balance in the traction of cars and reduce the chances of rolling, so testing the altered model in side crash and rolling tests might not give the desired results and their validation will not be possible for this changed car model. So, there is still a lot can be done by creating small changes in model and the material which can prove to be fruitful for the research and development in the field of crash testing of vehicles.

APPENDICES

APPENDIX 1

LS-DYNA CONSISTENT UNITS

A consistent system of units which is required for LS-DYNA is defined below as :

- 1 force unit = 1 mass unit * 1 acceleration unit
- 1 acceleration unit = 1 length unit / (1 time unit)^2
- 1 density unit = 1 mass unit / (1 length unit)^3

The table below gives an idea about the a consistent system of units with a few examples. Mass density and young's modulus of the steel are provided as a base for referencing while considering a unit system to be followed in LS-DYNA. The "Gravity" here denotes the 'gravitational acceleration'.

Table A.1.1 System of consistent units used in LS-DYNA [10]

MASS	LENGTH	TIME	FORCE	STRESS	ENERGY	DENSITY	YOUNG's MODULUS	35MPH / 56.33 KMPH	GRAVITY
kg	cm	s	1.0e-02 N			7.83E-03	2.07E+09	1.56E+03	9.81E+02
kg	cm	ms	1.0e+04 N			7.83E-03	2.07E+03	1.56	9.81E-04
kg	cm	us	1.0e+10 N			7.83E-03	2.07E-03	1.56E-03	9.81E-10
kg	mm	ms	kN	GPa	kN-mm	7.83E-06	2.07E+02	15.65	9.81E-03
g	cm	s	dyne	dyne/cm²	erg	7.83E+00	2.07E+12	1.56E+03	9.81E+02
g	cm	us	1.0e+07 N	Mbar	1.0e+07 Ncm	7.83E+00	2.07E+00	1.56E-03	9.81E-10
g	mm	s	1.0e-06 N	Pa		7.83E-03	2.07E+11	1.56E+04	9.81E+03
g	mm	ms	N	MPa	N-mm	7.83E-03	2.07E+05	15.65	9.81E-03
ton	mm	s	N	MPa	N-mm	7.83E-09	2.07E+05	1.56E+04	9.81E+03
lbf-s²/in	in	s	lbf	psi	lbf-in	7.33E-04	3.00E+07	6.16E+02	386
slug	ft	s	lbf	psf	lbf-ft	1.52E+01	4.32E+09	51.33	32.17
kgf-s²/mm	mm	s	kgf	kgf/mm²	kgf-mm	7.98E-10	2.11E+04	1.56E+04	9.81E+03
kg	mm	s	mN	1.0e+03 Pa		7.83E-06	2.07E+08		9.81E+03
g	cm	ms	1.0e+1 N	1.0e+05 Pa		7.83E+00	2.07E+06		9.81E-04

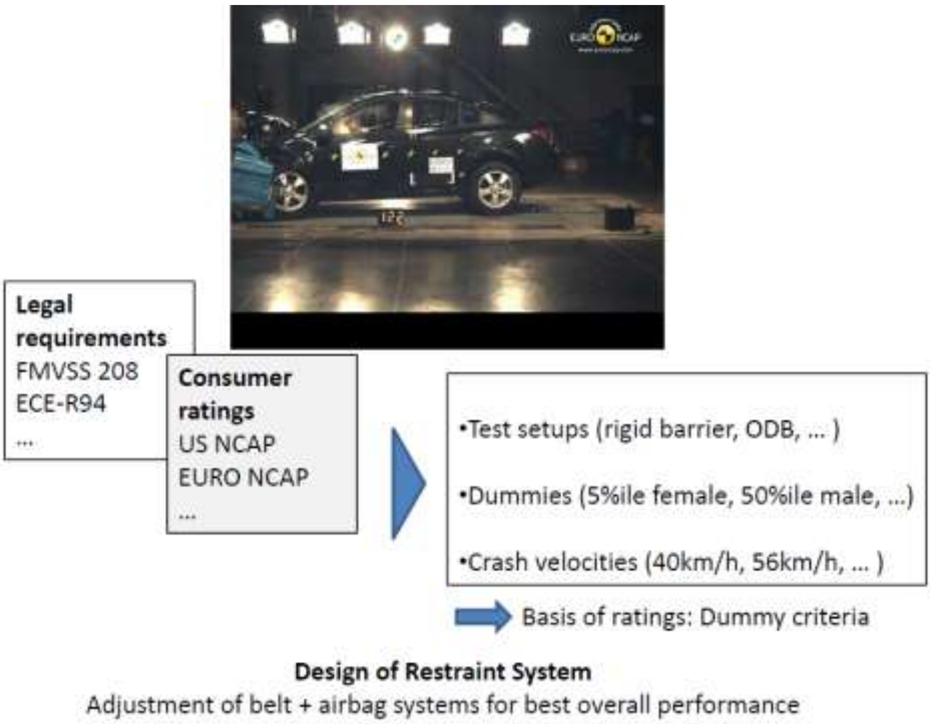
APPENDIX 2

NCAP (New Car Assessment Program)

NCAP was first created in the year 1979 by the NHTSA i.e., National Highway Traffic Safety Administration in USA. The program was established to manufacture vehicles which are safer for the consumers. Over the time, organisation improved its working and programs by addition of the programs which provide rating, results of the test being made accessible, and information format being revised consistently so that it is easier for the customers to comprehend and act accordingly. NHTSA claims that the program has inspired the makers to manufacture vehicles that regularly exceptional ratings.

Gradually, different countries adopted this system according to the regulations followed by their respective citizens and customers, for example, European New Car Assessment Programme, Global New Car Assessment Programme, Japan New Car Assessment Programme etc.

Fig. A.2.1 Crash legal and requirements and consumer ratings [10]



APPENDIX 3

FE Model Validation

Table A.3.1 Full scale crash tests involved in validation of FE model. [10]

Toyota Yaris (2006-2010)

Test Type	Test Number
Frontal Full Wall	NHTSA 5677 (56.3 km/hr), 6221 (56.2 km/hr), 6059 (39.8 km/hr), 6060 (39.8 km/hr), 6069 (39.8 km/hr)
Frontal Offset	IIHS CEF0610 (64.7 km/hr)
Side Impact NHTSA	NHTSA 5679 (62.1 km/hr), 6220 (62.3 km/hr), 6558 (61.9 km/h), 6585 (61.8 km/hr)
Side Impact IIHS	IIHS CES50638 (50.2 km/hr), CES0639 (50.0 km/hr)
Rigid Pole Test	NHTSA 7145 (7 deg, 56 km/hr)
Vehicle to Vehicle	NHTSA 7371 (15 deg, 112.7 km/hr, 50 % overlap), 7293 (7 deg, 112.7 km/hr, No frame overlap),
Roof Strength	IIHS SWR0920
Speed Bump	FOIL10002 (8 tests: varied speed bump configurations)
Sloped Terrain	FOIL 10003 (6 tests: 6H:1V slopes, 25 deg - 8, 16, and 24 km/hr)

REFERENCES

[1] Erika Fechová, Jozef Kmec, Alena Vagaská, Dražan Kozak, "Material Properties and Safety of Cars at Crash Tests", *International Conference on Manufacturing Engineering and Materials*, ICMEM 2016.

[2] K. T. Gursel, S. N. Nane , "Non-linear finite element analyses of automobiles and their elements in crashes", *International Journal of Crashworthiness*, 15:6, 667-692, DOI: 10.1080/13588261003737286, 2010.

[3] Gauri B. Mahajan, Dinesh. N. Kamble, "Crash and Impact Strength Analysis of Structural component of the vehicle for Occupant Safety", *International Journal of Science, Engineering and Technology Research (IJSETR)*, Volume 4, Issue 12, December 2015.

[4] "Structural Countermeasure/ Research Program : Mass and Cost Increase Due to Oblique Offset Moving Deformable Barrier Impact Test", *NHTSA*, DOT HS 812 523, April 2018.

[5] "Vehicle interior and restraints modelling Development of full vehicle Finite Element Model including vehicle interior and occupant restraints systems for occupant safety analysis using THOR dummies", *NHTSA*, DOT HS 812 545, May 2018.

[6] Timothy Keon, **"**Alternative Approaches to Occupant Response Evaluation in Frontal Impact Crash Testing", *NHTSA*, 24th ESV conference, Paper No. 15-0108, 2015.

[7] Volker Sandner, James Ellway, Michiel van Ratingen,"EURO NCAP FRONTAL IMPACT WORKING GROUP REPORT", Paper Number 17-0205, *Euro NCAP*.

[8] Andrew Hickey, Shaoping Xiao, "Finite Element Modeling and Simulation of Car Crash", *International Journal of Modern Studies in Mechanical Engineering (IJMSME)*, Volume 3, Issue 1, 2017.

[9] 2010 Toyota Yaris Finite Element Model Validation Detail Mesh, George Mason University, Centre for collision safety and analysis.

[10] Web valid sources : World Autosteel, NHTSA, GlobalNCAP, IIHS, Ls-Dyna manuals, Dyna support.