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ADDIS ABABA INSTITUTE OF TECHNOLOGY (AAIT)

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IMPROVEMENT OF A LOCOMOTIVE FRONT END TO REDUCE OVERRIDING EFFECT BASED ON IMPACT SCENARIO.

Case study: Addis Ababa – Djibouti Railway Line.

A Thesis in Railway Engineering (Rolling Stock)

By

Faraja Nyangassa (GSR/2553/11)

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Railway Engineering, Rolling Stock.

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IMPROVEMENT OF A LOCOMOTIVE FRONT END IN ORDER TO REDUCE OVERRIDING EFFECT BASED ON IMPACT SCENARIO FOR ADDIS ABABA – DJIBOUTI MAINLINE

A

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Presented to the African Railway Center of

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In Partial Fulfillment of Requirements

For the Degree of Masters of Science.

Addis Ababa Institute of Technology

Major: Railway Engineering, Rolling Stock

Under the Supervision of Dr.Daniel Tilahun and Mr. Tollosa Debrie

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APPROVED BY BOARD OF EXAMINERS

The undersigned members of the Addis Ababa Institute of Technology under the department of Railway Engineering have examined the thesis entitled **‘IMPROVEMENT OF A LOCOMOTIVE FRONT END TO REDUCE OVERRIDING EFFECT BASED ON IMPACT SCENARIO’** presented by **FARAJA NYANGASSA** of registration number **GSR/2553/11**, a candidate for the degree of **Master of Science in Railway Engineering (Rolling Stock design)** and here by certifying that it is worthy of acceptance.

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DECLARATION

I certify that the research work titled **“Improvement of a locomotive front end to Reduce Overriding Effect based on impact scenario for Addis Ababa-Djibouti Main Line Trains”** is my work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged/references.

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ABSTRACT

The locomotive crash box is an energy-absorbing device that reproduces a crash sound effect during locomotive head-on collisions. Addis Ababa- Djibouti railway is a single-track railway mostly significant head-to-head collisions. Satisfactory achievement of the energy-absorbing crash box arises in weaker destruction to a locomotive and other parts with cheaper restoration price.

Customers blame the manufacture that crash boxes are easy to damage although the collision was slow. Passengers are dead and fully damaged of locomotives because of a less energy absorption capability of an impacting crash box. The material of the crash box needs to examine to realize the replacement material that can upgrade the crashworthiness, also have stability.

The aim is to improve safety for the passengers and drivers of railway vehicles by improving the weakness of the existing locomotive crash box which is very important during the collision. The objective of this improvement is to select proper material which absorbs more impact energy in such a way that crush zones that are deformable in a defined manner convert this energy into deformation energy.

In this project, the Finite Element Method is requested to prototype the crash box structure and material of the crash box. All models are modeled by using CAD software such as SOLID WORKS. Simulation using finite element analysis Software such as ABAQUS was carried out.

Modeling the locomotive with crash box and analyzed the structure using ABAQUS/CAE on the exact Steel, Aluminum, and Composite materials (Carbon Fiber). Predicted the time history of the impact process such as load, energy, velocity, and deflection. To measure the energy absorbed by the materials. To predict the energy absorption capacity of the materials. To improve materials by proper material selection and propose suitable material for the locomotive crash box. The selection of suitable material is after compared the Finite Element Analysis results of the conventional materials which are (steel, aluminum) and composite materials (carbon fiber) for the crashworthiness.

The study is performed using ABAQUS software to design the locomotive crash box made from steel, aluminum, and carbon fiber and the von misses' stress, deformation, and energy absorption are evaluated by the use of Finite Element Analysis to determine the impact cases.

Lightweight composite materials (carbon fiber) provide opportunities for reducing locomotive weight and other advantages compared to steel and aluminum for a locomotive crash box. The result was shown to be the best when employing carbon fiber material for locomotive crash boxes. From ABAQUS optimization the energy absorption for the steel crash box is 10 KN-M, aluminum crash box 12.5 KN-M and carbon fiber crash box is 13.375 KN-M. Von misses stress for steel crash box is 1538 mpa, aluminum crash box 980.5 mpa, and carbon fiber crash box 682.6 mpa. Deformation for steel crash box is 11.5 mm, aluminum crash box 5.3 mm and carbon fiber crash box is 2 mm. Results conclude that using carbon fiber material for the crash box can reduce deformation and stresses force during a collision of locomotives also has the highest value for energy absorption. It is recommended as a better approach to replace the metallic locomotive crash box.

KEYWORDS: Energy-absorbing device, Crash box, Locomotive, Overriding, Kinetic Energy, Abaqus software, stress, deformation, aluminum, steel, carbon Fiber.

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LIST OF ACRONYMS AND ABBREVIATIONS

USA	United States of America
UK	United Kingdom
ERC	Ethiopia Railway Corporation
AALRT	Addis Ababa Light Rail Transit
LRT	Light Rail Transit
FEM	Finite Element Method
LE	Low Energy
HE	High Energy
MU	Multiple Unit
ANSYS	Analysis Software
RISSB	Rail Industry Safety and Standard Board.
TSI	Transport safety Investigation
ECDR	effective crushing distance rate
E	Energy
SE	stroke efficiency
CFE	Crush force efficiency
FRA	Federal railroad administration
NZ	New Zealand
CAD	Computer-aided drawings
w_1	Is kinetic energy per cycle
V_d	Impact velocity at the shock absorber
V	Velocity moving mass
F	Propelling force
C	Cycle per hour
S	Shock absorber stroke
W	Weight of the vehicle car-body.
I	Pitch inertia about the rear truck (I$\approx I_{CS} + ml_2{}^2$).
V	Collision velocity

L_1	The interval from the skeleton end to the rear truck
L_2	The interval from the car body center of gravity to the rear truck.
Δx	Interval of longitudinal overlap $^{b}/_{n}$ colliding skeleton during the time of overcome beginning.
Δy	The exchange in the assessment of the skeleton during the time of overcome impact.
w_2	Propelling force energy per cycle
w_3	Energy per hour
m_f	Total energy per hour
m_e	Effective weight
FEA	Finite Element Analysis
m	Mass to be decelerated

CHAPTER 1 INTRODUCTION

1.1 Background

In East Africa as well as in many other parts of the world, rail networks are distinguished into urban rail networks and mainline. In the same regard, Ethiopian networks have AALRT and Ethio-Djibouti mainline.

The railway lines construction in Ethiopia was first started in October 1897 from Ethiopia to the Djibouti port in the regime of Emperor Menelek II. The earliest commercial service started in July 1901, from Djibouti to Dire Dawa. By 1915 the line gets to Akaki, at most 23 kilometers out of the capital, and two years behind came to Addis Ababa itself (ERC, 2014).

Railway transportation system had been used as a major freight and passenger transport to the eastern part of Ethiopia starting from 1917 to 2007 E.C. The system comes into existence during the reign of Emperor Menelik II and covers a total of 781km powered by diesel engine and jointly owned by Ethiopia and Djibouti. Great improvement of the road network is prevailing in Ethiopia, but with limited connectivity, high cost of transportation, and poor quality of service. The mobility need of the country's population and the development of the transportation system are far from compatible. Therefore; the country requires modern, economic, time-saving, and long-lasting transportation which will ease the import-export system and result in fast development. To this end, the government of Ethiopia has embarked on a railway system. The major causes for the renewed interest in the railway are environmental, economical, and safety-related issues (ERC, 2014).

- **Introduction to Ethiopia-Djibouti electric railway line (Thesis Area).**

This is the mainline which links Ethiopia’s capital Addis Ababa, to the red sea port of Djibouti, a stretch of more than 750km (466 miles). The new service cuts the journey time down from three days by road to about 12 hours because the mainline was designed for 120 km/hr speed for trains. The modernization includes restoring the meter-gauge section with a 1,435mm gauge line, and charge at 25kV. The railway line was designed for 120km/h speed to accommodate trains traveling in the line, the new line was built in agreement with Chinese electrified railway standards.

Figure 1.1Trains traveling in the line designed for 120 km/hr. (ERC, 2014).

The railway transport system is greater crucial transport system in the world with mass transport, very high speed, safety, and durability. Now a day, there is a high demand for railway transportation systems in the world including in Ethiopia for short and long-distance transport of passengers and goods. The new rail network in Ethiopia and the railway track must show the necessity of efficient management of railway systems. The design must aim toward reducing costs and increasing safety, as well as reliability of the railway systems. The override prevention is the greater crucial point that must be checked to determine the capabilities of a train and consider its safety (Ambrosio, 2000).

One of the most widely used and comfortable modes of transportation system is the railway mode of transportation, but occasionally, accidents occur due to collisions and other reasons. It is very difficult to stop such head-on collisions because of the speed of moving trains, which needs a lead distance to stop. Collisions are happened due to human errors and/or faulty equipment. Addis Ababa-Djibouti railway is a single line track railway mostly which significances the head to head collision.

The railway accidents are happening due to the carelessness in manual operations or lack of workers. The other main reasons for the collisions of the train are:

- Train derailment in curves and bends

- Running train collisions with the standing train example in ERC they are using a single line track. A head-on collision is possible to occur.

To this end, the thesis work was found to be one of the efficient methods to prevent avoid overriding of railway vehicles by using energy absorbent devices known as crash boxes fitted in front of the locomotive chassis which withstanding vertical forces locomotives collision for Addis Ababa – Djibouti mainline (ERC, 2014).

In this study crash, box structure analysis of Addis Ababa-Djibouti passenger locomotive made of exact Steel material and Aluminum material are analyzed and finally comparing the result with the other crash box performance experiment using Composite material. Crash boxes, one of the inactive protection components of locomotives, have to occur attempted to manufacture composite material to raise protection and minimize mass.

Crash boxes have traditionally been made from Steel and Aluminum material, which have been the benchmark of the automotive industry for several decades now. However, crash structures made of metal do not provide the same energy absorption capability, stiffness to weight ratio, and corrosion and fatigue resistance as compared to a crash box made up of composite material.

A crash box with composite material is anticipated to buckle sufficiently to suck up more collision energy, to reduce the chances of harm for employees, passengers and to protect the nearby locomotive components (Albertsen, 2007).

- **Brief Introduction about Locomotives used in Ethio-Djibouti Mainline.**

A locomotive or engine is a rail transport vehicle that provides the motive power for a train. If a locomotive is capable of carrying a payload, it is usually rather referred to as multiple units, motor coach, railcar, or power car; the use of these self-propelled vehicles is increasingly common for passenger trains but rare for freight. In Ethiopia Railway Corporation they used the locomotives known as HDX1C manufactured from China used for carrying passengers and freight. This paper explains how to implement an energy-absorbing device (crash box) in front of locomotive number ERP 0003 which will help in increasing crashworthiness in a collision scenario. The crash box is the face shape of the HDX1C locomotive that has the aim of energy absorption throughout the low-speed collision, generally made by Steel. The design of the locomotive subsystem for lightweight and safety seems to lead the designer toward opposite directions. Quite interesting solutions can be obtained with the use of composite materials. Using composite materials instead of steel leads to an effective decrement of the locomotive weight without affecting the structural safety performances (Campbell, 2004).

Figure 1.2 Ethio-Djibouti Railway mainline (ERC, 2014).

Figure 1.2 above shows locomotives used in ERC. All locomotives were shipped from China. 41 available electric locomotives are elected to haul freight trains and to perform freight handling, while only three electric locomotives serve passenger transport services. As well, several diesel locomotives are to provide services off the mainline. The locomotives were derived from the platforms mentioned in table 1.1 below.

The platform data for the HXD1C indicate, that the employable power of 7200 kW is also obtainable for regenerative braking. Two freight locomotives can couple and can do two-locomotive train control with heavy freight trains for railway slopes >0.9 %. As well as, the electric locomotives hauling passenger trains come with a dedicated power supply transformer to provide electric power for the air-conditioning/heating units of the passenger cars under the extreme climatic conditions of Ethiopia (Molinari, 2015).

Table 1.1: List of Locomotives used in Ethio-Djibouti Railway Mainline.

TYPE	MANUFACTURER	SERIAL NO.	OPERATION MODE	MAXIMUM SPEED [KM/HR]	POWER [kW]
Electric locomotive	CRRC-HXD1C	ERP 0001 – ERP 0003 (ERP: Ethiopian Railways Passenger)	Passenger transport (mainline)	120	7200
Electric locomotive	CRRC – HXD1C	ERF 0001 – ERF 0032 (ERF: Ethiopian Railways Freight)	Freight transport (mainline)	120	7200
Diesel locomotive	CRRC – DF4DH	(DF4D 418-0xx) (not owned by Ethiopian Railways)	Freight transport (mainline)	100	2940

1.2 Problem Statement

With the rapidly increasing number of railway vehicles, cases of head-on collisions have risen in recent decades. This has been contributed by the poor performance of the locomotive crash-box materials leading to severe damage to the locomotive and death of the passengers on low-cost collisions of the locomotives due to the low energy absorption capability of the materials used to design crash boxes. Originally crash boxes were made of metallic materials like steel and aluminum which offers low energy absorption capability, high stiffness to weight ratio, high level of material corrosion, and low fatigue resistance. This has offered little or no guarantee for safety during railway transportation. For better safety and protection of the railway locomotive vehicle drivers and passengers, the existing materials need to be improved and an alternative material should be sought to mitigate the rising accidents.

This thesis timely seeks to propose and analyze suitable composite materials (Carbon Fiber) as alternative materials in manufacturing the crash boxes due to their dependable structural characteristics by simulation study on impact processes such as load, energy, velocity, and deflection using CAD software such as SOLID WORKS and Finite Element Analysis software like ABAQUS/CAE for impact simulation.

1.3 Objectives

1.3.1. Main objective

The main objective of this thesis is to analyze and select suitable locomotive crash box materials to mitigate the increasing low impact energy absorption during locomotives head-on collision accidents.

1.3.2. Specific objective

The specific objectives of this paper are:

- To predict maximum energy absorption capacity and deformation of the different materials and selecting the best suitable for crash box application.

- To study one of FEM software ABAQUS/CAE and to implement for this study to construct each part, assemble, and simulate the locomotive impact for slow speed.
- To improve materials by proper material selection and propose suitable material for the locomotive crash box.
- To propose suitable carbon fiber composite material for the locomotive crash box.

1.4 Significance and Limitation of the study.

1.4.1 Significance

The importance of this research will go to Ethiopian Railways Corporation (ERC) further research. This thesis will be the starting point for ERC for further research in the area of choosing suitable materials for locomotive front-end protection during collision scenarios. So this will help ERC to focus on developing and propose a replaced composite crash absorbent as energy-absorbing devices for the safety of passengers and employees of the Ethiopian Railway Corporation (ERC) which could satisfy the following requirements,

- Easy to manufacture by simplifying the shape. This was accomplished by improving the geometry (shape and dimensions).
- Being economical by utilizing low-cost composite materials.
- Achieving reduced weight compared to the metallic locomotive crash boxes.
- Achieving improved impact behavior compared to the current metallic structure.

Improving the locomotive front-end protection from time to time will help the ERC to be safe and profitable.

1.4.2 Limitation

Some of the limitations that might be encountered when conducting the research include, ignoring the effect of other components like locomotive coupling, others like anti–climbers, also pantograph of locomotive and wheels bogie and being theoretical only without practical testing in the workshop. The result is based on Abaqus's dynamic analysis. In general, this research may require ample time.

1.5 Structure of the thesis

A short description of chapters is presented below to get an overview of the general structure of the thesis.

Chapter 1: It outlines the background part, problem statement, objectives, significance and limitation of the study, and structure of the thesis.

Chapter 2: Deals with the literature review discussions that constitute the review of the part works which are related to this thesis work.

Chapter 3: In this part deal with methodology, the well-known commercial software ABAQUS/CAE for modeling and simulation has been introduced, the procedure of creating finite element models in ABAQUS/CAE is presented in this chapter. The algorithms with ABAQUS that are used in this thesis are briefly presented and dynamic analysis approaches were explained. In short Finite element impact simulation and procedures using ABAQUS software were briefly discussed and presented.

Chapter 4: The results from the impact simulation using ABAQUS software are presented and discussed briefly and finally validated.

Chapter 5: Finally the conclusion and recommendations are presented.

CHAPTER 2

2.1 Literature Review

This chapter presents a detailed literature review of the crashworthiness in trains and how to design and modeling crash boxes that act as energy absorbent devices, used to improve crashworthiness during collisions of locomotives. Reassess of the keep going literature give superior perception for generating a superior shape and lowering of suffering in locomotive through out face to face impact disaster in ERC. Unlike analysis were agreed on dissimilar locomotive crash box examines in dissimilar material procedures and investigation to the world in words of value-helpful and suitable for uses.

The purpose of this literature review is to give background information on the issues to be considered in this study and to emphasize the relevance of the present study. This section includes reviews of available research reports about previous work related to improving crashworthiness, impact analysis of aluminum, steel, and composite materials components, and impact analysis on the automotive structures. At the end of the writing survey, the knowledge gap in the earlier studies is presented.

In the last 20 years, many projects started to improve locomotive front-end protection in Europe, the USA, Japan, and India. Many head-on crash scenarios have been introduced in the standards to assess the crashworthiness of wagons and that of train consists. Standards have long taken account of the seriousness of frontal collisions and emphasize the need for protection against head-on crashes (Centre for Railway Engineering, 2000)**.**

Starting in 2000, Federal Railways Administration (FRA) in the United States conducted 6 full-scale crash tests on passenger cars with and without crash zone systems in 3 different test scenarios: single wagon impact into a rigid wall, two wagons impact into a rigid wall, and train to train impact (Diriba, 2014)**.**

The FRA and Volpe (Administration, 2019) were conducted several train-to-train impact experiments to other to assess the quality of the locomotive crashworthy elements that were expanded in the 2009 plan. These experiments were organized at the Transportation Technology

Centre (TTC) in Pueblo, CO. It was expected that the locomotive that will be adjusted for utilization in such experiments is the F40 locomotive constructed by EMD. The earlier advanced crashworthy elements were purposely reconstructed into a motive power MP40 locomotive. Proper dissimilarities in the producer of these two locomotives, the device for the crashworthy elements, wanted to be adjusted so that it is acceptable for an overhaul into an F40 locomotive, more especially, an F40 locomotive that presently is funded at the TTC and is obtainable for use in approaching experiments.

Also (Rezvani, 2014) succeed to raise the crashworthiness parameters of a passenger train to utilize the dynamical simulation tool LS-DYNA. Tampons of a sample passenger train (Iran DH4-1 PARADISE) in the Iran railway were modeled and the crashworthiness characteristic of it was raised by utilize the crashworthy element behind the set and also differing its shell material type.

Recent subjects have appeared that accurately manufactured composite impact boxes give good outcomes in energy absorption than metal impact boxes. As a result, it has been observed that reinforcing cylindrical profiles with glass fiber increases energy absorption. In addition, as an outcome of the drop tests performed by placing epoxy foam in the inner part of the cylindrical form, it was seen that the placement of the epoxy foam in the inner part of the profile increased the energy absorption (Xing, 2014).

Many factors can affect the crashworthiness attribute of the crash box in the impact computer simulation method, involving energy-absorbing machine structure, wall width, and materials, and so on, in which material behaviors have great results on structure characteristics. There are many types of materials in the locomotive producing industry, insignificant material has always been a disaster area (Zang, 2014). An aluminum alloy material is one of the classic insignificant materials.

According to Prabhakaran, Chinnarasu, and Senthil Kumar (Kumar, 2012), the shape, making, and experimenting of steel and composite bumper. They moreover differentiated the outcomes of the two bumpers to mass, fuel wealth, and price and collision opposition. As an outcome for the equal prototype of the bumper offer a steel bumper comes to 5.15kg and the mass of the composite bumper is 2.38kg. This appears that the percentage ratio of 53.8% is minor than steel bumper as the outcome fuel wealth of the car is upgraded. The price of a composite bumper is 80% smaller than a steel bumper so composite materials are price productive than steel material.

M. Anil Kumar and N. Phani Raja Rao (Rao, 2015) examine a bumper designed at dissimilar velocities for dissimilar materials steel, ABS plastic, and carbon fiber reinforced has smaller than that of steel that signifies the tension values are smaller and differentiating the outcomes, the tension values are smaller for composite. At lastly they proposed that composite materials are greatest for vehicle bumpers than steel.

Pandey, Patil, and Nikumbh (Pankaj, 2016) show in their study honeycomb structure also have a cell geometry that is efficient of flexible bending, which offers the honeycomb design to reclaim its shape and effects after an impact. Aluminum honey comb designs if buckled in an impact then have to be replaced or restored. The majority of the bumpers have to be replaced or restored if probable after their initial impact. CFRP is the expensive one because of its prolonged and difficult making procedure. The honeycomb design has the toughness and sucks up more energy which makes sure passengers protection. Foam bumper assembled by age solidity of the aluminum indicate the development of foam with great invalid sizes but not with little sizes. Mainly steel bumpers are applied in heavy cars and the remainder of the bumpers are applied in nearly all types of cars.

Kirkpatrick et al. (Kirkpatrick, 2001) Conducted research and said that current multibody dynamics and FEA Procedures can be applied in the analysis of train impacts, crashworthiness, and the absorption of energy in the design. Investigations might vary from the clarified one-dimensional model used to estimate interlinkage between locomotive underframes and learn the results of varying parameters such as the impact toughness to detailed three-dimensional finite element crash computer simulation that can be applied as a component of the car structure procedure.

Paulius and Antanas (Ziliukas, 2003)**,** investigate the energy-absorbing productiveness of longerons below axial pressing filling and also evaluate the collision of longerons structural characteristics and material failure on the rail vehicles protection investigational and performed numerical calculations. They said that to assess the crashworthiness of longerons the main purpose was to learn the character of thin-walled machine components below axial filling environments using the FE model. Conditions. They generated digital FE models by using the computer code LS DYNA. They experimented with two prototypes of longerons with dissimilar part appearances and for each of them, materials were applied with the four dissimilar mechanical properties. Authentication of generated FE model was carried out following the experimental analysis and the outcomes were achieved authenticated FE models of car impact investigation (Report, 2001) . The outcomes of the investigation indicate that the benefit of absorbed energy by the longerons of up-to-date cars overstep the benefit of the aged vehicles. The deterioration of systems in the aged vehicles has an outstanding effect on the sucked-up energy. The impact layout briefed by these experiments in-cab car led passenger rail vehicle impact with an ordinary locomotive led passenger rail vehicle.

Zangani et al. (Zangani, 2009)conducted an experimental test and performed a finite element analysis to predict the performance of aluminum welds in rail vehicles under highly dynamic loading conditions and provided design guidelines to reduce the likelihood of the occurrence of weld unzipping. He said that the use of aluminum alloys in rail vehicle manufacture has introduced many advantages, namely good corrosion resistance, lightweight, and superior surface finish. He discussed furthermore that the use of double-skinned aluminum extrusions that can be welded together to form the vehicle body has enhanced the efficiency of the manufacturing and assembly methods and closed-cell extruded sections have an inherently excellent resistance to impact loading that contributes to the crashworthiness of modern rail vehicles. It has been found that a double-skinned train carriage made of aluminum longitudinal hollow extrusions behaves like a rigid body during a collision. For this reason, impact energy-absorbing zones (crumple zones) are introduced at either end of the carriage to absorb the impact energy that would otherwise be transferred to the passengers, crew, and equipment.

The intention was to determine what modifications to the components could improve the crashworthiness of the locomotive beyond the baseline Crash Energy Management design without introducing new hazards to the passengers. O’Neill and Carruthers (Carruthers, 2011) described the conceptual design and analysis of a lightweight energy absorber for rail vehicles that meets the level crossing impact requirements outlined in European crashworthiness standards.

Carruthers and Robinson (Robinson, 1998) describe the design, validation, and prototyping of a lightweight crash-worthy rail vehicle driver's cab using advanced composite sandwich materials. By exploiting the light-weighting, energy absorption, and design integration benefits of composites, an innovative modular cab structure was developed that provides significant savings in mass, cost, and part count compared to conventional cab designs.

Also when he designed the frontal nose section which is the area most likely to suffer incidental in-service damage, has been designed to be easily removable for repair or replacement. Removing the nose also provides easy access to the primary energy-absorbing devices for inspection or replacement purposes.

Milho et al. (Milho, 2003) introduced authenticated multibody prototype for the structure of rail vehicle crashworthy parts. A structured procedure for crash-worthy designs was introduced (Milho, 2003)**.** He conducted the methodology by proposed two models of train cars and racks and their simulation was performed for a crash event for which experimental test results were also available. It has been shown that for the first model, which only includes design specification data in the form of ideal force-displacement curves for the energy-absorbing sub-structures and mechanisms, it is possible to obtain simulation results that correlate well with the outcome of the experimental testing. Also, he said that an improved train model, for which the buffers, couplers, structural devices, and suspension element's force-displacement data match the actual deformation response of these elements measured in the experimental test, has been simulated. At last, he concludes by showing that the results obtained with the improved model are similar to those measured in the experimental test.

Cerit et al. (Cerit, 2007) performed the frontal crash analysis of the structure of a bus front body according to the ECE-R29 European regulatory requirements and the strength of the bus structure was checked to whether the safety requirements are satisfied. First, he started to explain that the failure mechanism under frontal collision of a passenger bus manufactured in Thailand is analyzed employing explicit dynamic finite element analysis. It was shown that the current design does not pass ECE-R29 regulation with a large intrusion of the steering system into the driver manikin of 125 mm. According to this reason, Frontal impact shares the major cause among all bus accidents leading to great injury risk and fatalities of the driver, crew, and occupants. It seems most passive protection qualities mandatory for buses are more linked to the protection of the passengers and smaller to the protection of the driver. Rules and/or guidelines particularly organized for the frontal collision of the bus design are not obtainable. He said his study aims to analyze the bus structural strength and assess the deformation characteristics of the bus body under frontal crash based on ECE R29 regulations enforced to the truck cabin. **Cerit et al.** (Cerit, 2007) Designed three improved models based on two structural zones, these are a front crumple structure to absorb impact energy and a rigid compartment structure to protect the driver from any contact with the vehicle. As he said before A finite element model of bus front structure is developed in Hyper mesh and the analysis is performed by using nonlinear explicit dynamic code ABAQUS. Finally, he concludes by improving the bus structural crashworthiness and his recommendation based on two different deformation zones in the front. He proposed a Thin-walled tubular structure in the crumple zone to primarily dissipate the collision energy. For the self-protection zone, a rigid non-deforming driver compartment is achieved by strengthening the A-pillars with the use of high-strength steel and increase in the stiffness of the pillar profiles.

Kim et al. (Kim, 2007) Tried to explain and said the history of crashworthiness research of rail vehicles is not extensive. While some studies are dealing with crashworthy designs of new rail vehicles as well as the crashworthiness assessment of existing conventional rail vehicles, little literature focuses on analyzing and improving the crashworthiness characteristics and weaknesses of existing conventional vehicles. This is especially true for lateral impact studies. Most of the relevant projects were launched and completed around the globe during the last few decades. It is now understood that the idea that ‘stronger is always better’ conflicts with the need to provide better occupant protection.

Mayville et al. (Mayville, 2002) Developed the coach car crush zone. The following explanation below tried to teach us how he develops the coach car crush zone, this dissertation outline the structure of a current face car design that governs the correspondence collision filling of balance impact as a vertical weight to the next unburden lengthwise section. Only by applying both lengthwise sections and along a continuing overlapping marking, sufficient energy can be sucked up in face design to stop distortion of the passenger partition. To stop an incomplete curving crumble, the current lengthwise sections contain two usable parts: an inner square compressing pillar for a standard solid crucial strength level and a rigid exterior slipping helping design that offers the required extra folding opposition. Joined cable networks transfer the force to another lengthwise section. With this fabrication device theory, a car has equal energy absorption in the face design for the whole area of impact environments (full, offset, oblique).

Employing numerical crash simulations, this concept has been optimized and evaluated. Results show that for an entire range of frontal collision situations similar deceleration curves can be gotten. Although, to extra decrease the harmful level of the populations, improved crash braking for several crash speeds are important. To this purpose, a procedure is outlined for numerical FEM fake computer simulations to get improved crash pulses for different velocities. The novel concept is very suitable to adapt the structural stiffness to these new deceleration pulses. To obtain the adaptive braking throughout the crash for each speed, classifications have been proposed based on governable energy absorption by increased clashing or formulated on governable hydraulic flow opposition. With this complete construction, an improved car braking curve is likely for each speed over the whole face impact range, yielding the lowest levels of the occupant injury criteria.

Other researchers are mentioned below and explained in short what they have done about crashworthiness Chirwa et al. (Chirwa, 1994) Classified crashworthiness concepts in rail vehicles in which considered new design parameters. Smith et al. (Smith, 1996) Studied the crashworthiness of trains based on background principles. Leutenegger et al. (Leutenegger, 2001) developed a lightweight structure to meet tougher crashworthiness standards. Lewis et al. (Rogers, 2001) Investigated a collision between an IC255 train and a car in detail. Walter et al. (Walter, 2002) Studied a new European standard of crashworthiness of rail vehicles and the effects on safe trains.

Jacobsen et al. (Jacobsen, 2004) Conducted a full-scale test on a passenger rail train and established the degree of enhanced performance of alternative design strategies for the passenger rail car crashworthiness. Spirka et al. (Spirka, 2012) talked about the structure of a deformable barrier to be used in manufactured rail and road collisions as directed by scenario 3 identified by standard EN 15227. Carolan et al. (Carolan, 2007) studied the capability of one specific crash energy management (CEM) system structure for passenger trains.

Tyrell et al. (Tyrell, 2006) conducted six tests to evaluate the crashworthiness effecting of the remaining equipment and to measure the effecting of instruments incorporating CEM features. Xue and Schmid (Schmid, 2005) presented a crashworthiness assessment of a conventionally designed railway passenger vehicle and suggest modifications for its improvement. Witowski et al. (Witowski, 2009) presented the topology optimization of devices under higher non-linear dynamic loading, for example, crash. Chuang and Yang (Chuang, 2009) reviewed discussed three commercially available methods of topology optimization for crashworthiness design.

2.2 Design Requirements and Material selection of Locomotive Crash box.

2.2.1 Design Requirements of Locomotive Crash box

A crash box is a device for absorbing energy fitted to reduce replacement price in low-velocity train impacts. A crash box is a device installed to or integrated with the locomotive's front and rear ends, to suck up impact in a minor collision, ideally minimizing repair costs. Crash boxes offer protection to other locomotive components by dissipating the kinetic energy generated by an impact. This energy is responsible for locomotive mass and velocity squared.

The main structure of an energy absorber device consists of thin-wall structures such as a crash box. Attaching this component to the locomotive frame can provide safety during a collision. The crash boxes are changeable and after a collision, one can replace and attach a new crash box to the locomotive front end. In the part of a crash, the energy absorber takes the load initially and deform to dissipate the impact energy although transferring the load to the structure can cause bending and deformation of other parts. Different classes of energy absorber systems will be discussed later, however, classically thin-walled tubular structures have been used in the transportation industry for many years. Generally speaking, a crashworthiness analysis includes various aspects about the effectiveness of a locomotive to provide safety, the performance during and after a collision, and the collapse properties of the structure (Nagel, 2005).

After realizing the importance of kinetic energy dissipation during a collision, various types of crushing energy absorbers have been suggested over time. The basic idea among all those devices is the same which is to consume the impact energy in an irreversible way such as plastic behavior or fracture. There are effective parameters that can distinguish the energy-absorbing systems such as cost, weight, ease of assembly, and replacement. In this section different types of energy-absorbing systems are discussed as follows:

- Metallic thin-walled structures
- Foam structures

- Reinforced structures

Metallic thin-walled structures- Thin-walled tubes are the most popular type of energy-absorbing system. These structures are in use in many structural applications. The idea behind their design is to provide a controllable crushing mechanism and progressively convert the kinetic energy to dissipated plastic energy. Needless to say that the material properties and the structural geometry are the two influential parameters in the energy absorption capacity of the device. In terms of structural geometry, many different thin-walled cross-sections such as circular, square, rectangular, and honeycombs were drawn the attention of researchers in this field. In the following sub-section, we will review some of the most common cross-sections for designing energy absorbers (Zhang, 2009).

Rectangular crushing tubes - Another cross-section of the thin-walled absorber is rectangular cross-sections with perpendicular walls. The response and performance of these tubes have been investigated since 1984 which then followed by more in-depth works on the behavior of these structures under static and dynamic loading conditions. Although there are similarities between the crushing load-displacement diagrams of rectangular tubes with circular ones, their deformation modes are different. Jensen et al. (Jensen, 2004) reported that rectangular tubes have a high variation of crushing load during the collision.

Moreover, the geometry of these structures must be meticulously controlled such as initial length, cross-section dimensions, and thickness, as these tubes tend to deform under global bending conditions which are counted as an unstable crushing mode. Global bending of a tubular structure significantly decreases its capability in energy absorption. One way to prevent global bending and buckling of the tube was to provide a triggering mechanism (chamfer/tapered) at the end of square tubes to guide and control the beginning of wrinkling (El-Hage, 2005).

A more key influence of foam-filled crash box is hence the upgraded collision energy absorption in over center impacts. In application, the advantage out coming from particular cross-section devices is verified to not be price effective. The analysis indicated that both fully and partly foam-filled boxes were powerfully more effective than vacant boxes more than analytical foam filler comparative density. In complete foam filling although reduced the analytical foam filler density at adding box wall width.

Geometric Requirements of the crash box is as follows

Thickness: should expand sideways, at minimum, estimated to 1/3 points across the width of the end of the locomotive; should too expand sideways to the main lengthwise pillar of the locomotive.

Depth: Center should expand to the inside 4 inches of the attract frontal of the coupler with the draft gear completely compacted and should expand no less than 10 inches from the locomotive face plate for its needed thickness. Cannot restrict to other instruments, except it is admitted that such instrument can be smoothly diverted. The crash box elements shall be created so that they can be combined into locomotives (Railroads, 2004)**.**

The specific locomotive platform chosen for development is a motive power HDX1C locomotive number ERP 0003 used for carrying passengers in the Ethio-Djibouti mainline, which will help in increasing crashworthiness in a collision scenario. Figure 2.1 below is the example of locomotives used in Ethiopia Railway Corporation.

Figure 2.1 shows Ethiopians Railway Locomotives with crash boxes (ERC, 2014)**.**

The construction for the distorted crash box utilizes four ongoing bending tubes (crush tubes) cemented onto the fore part plate of the locomotive. Two tubes are indicated at the foot of the short bonnet, and two tubes are indicated underneath them. The crash box is designed to resist the upward motion of the coupler of a colliding vehicle to help prevent an override. The design requirements are comprised of performance requirements, geometric requirements, operational requirements, and making conditions. The energy absorption conditions and several other crashworthiness descriptions are obtained from occurrence achieved in more crashworthiness strategies. The majority of the hardiness conditions and several of the crashworthiness descriptions are obtained from the APTA (Association, 2006) and AAR (Railroads, 2004) standards.

A crash box, with which a locomotive is fitted out at the nose of the face side frame, is one of the majority of significant automotive members for crash energy absorption. For an example of a head-on crash accident, for example, the crash box is expected to collapsing with sucking up crash energy before other body members so that the demolition of the major cabin mounting is decreased and passengers/drivers are rescued their survivals. Hence, particular awareness has to be disposed to this structure to have a superior consideration concerning its machine of buckling and sucking up kinetic energy from the collision, moreover on wherefore to obtain superior crashworthy behaviors from this device. Crashworthiness, which is the study of plastic deformation of structures, has been performed in several crucial structures found on vehicles, subfloors of helicopters, and highway dividers. The crash box installed in a locomotive refers to a thin wall structure made of metal or composite material that is fixed or mounted at the frontal area of the locomotive. The structure serves as an energy-absorbing member to the locomotive due to collision in the event of a crash (Hussain, 2017)**.**

As a passive safety system in a locomotive, this crash box structure is expected to be capable of absorbing kinetic energy in a frontal crash, in maintaining the locomotive deceleration at a safe limit, and for minimizing the chance of injury on the locomotive’s passenger during the collision. Different thin wall structures, such as cylindrical, square/polygon, conical/tapered, and hat sectional beam, have been studied and compared to understand their plastic deformation behavior and how well they can adapt as an energy-absorbing component (Wang, 2018)**.**

2.2.2 Material selection of a locomotive crash box.

Crash Zones are frequently incorporated in locomotives to improve their deformation behavior in collisions. These improvement aims to suck up the impact energy in this manner that crush zones that are deformable in a defined manner convert this energy into deformation energy and in the procedures the loads to which the persons in the locomotive are exposed are minimized, moreover to ensure that the survival spaces in the locomotive are not too severely deformed to reduce the likelihood of injury to the locomotives occupants. To evaluate the structural achievement and the energy-absorbing capability for the crash box different materials were considered. These are steel, aluminum, and composite materials, the detailed mechanical characteristics of the three materials are documented and explained. One possible application area that allows a material replacement to achieve Locomotive light-weighting is the crash box subsystem. Optimization of the locomotive crash box subsystem can improve not only weight reduction but also structural energy absorption. The Crash box takes part in the main responsibility in the energy absorption during a collision. The materials selected for the locomotive crash box have been recently a concern. The main governing criteria for material selection are stiffness and strength properties that will determine the overall performance of locomotive crash boxes during dynamic loading conditions. Material replacement is regarded as the most effective approach to meet the requirement of lightweight. Considerable efforts have been dedicated to replacing heavy metallic materials with lightweight materials such as aluminum alloy, magnesium alloy, and fiber-reinforced plastic composite materials. Especially, fiber-reinforced plastic composite materials have drawn much attention, thanks to their advantages in high specific strength, high specific stiffness, and tailorable properties, for improving structural safety (Badie, 2011).

Carbon fiber composites are mandated 21at centenary locomotive materials. It has many advantages such as small density, great toughness, great pitch, high-temperature opposition, erosion opposition, character polishing, better electrical conductive/ heat capability, and low heat expansion coefficient. So that several excellent behaviors, carbon fiber composites have become very important raw materials in preparing various structural and functional composites. But, compared to the materials such as steel or aluminum, the value of carbon fiber composites is expensive to be commonly applied in locomotive construction. most because several investigation coordination is aware no attempts to reduce the construction price of carbon fiber composites, the degeneration of carbon fiber composites locomotives upcoming genuine shortly. Hence, carbon fiber composites are applied in the locomotive crash box alternatively of steel and aluminum in this investigation (Boria, 2012).

Composite materials are established by uniting two or more materials that have different characteristics. The dissimilar materials collaborate to offer the composite individual characteristics, however inside the composite, you can simply tell the dissimilar materials apart – they do not diffuse or blend into each other. Composite materials are composed of a matrix and a reinforcement assembly which offer useful effects sooner than the separate section. Fiber-reinforced polymer matrix composites are the most applied composites. Glass fiber, carbon fiber, and boron fiber are classic kinds of fiber applied in composites in words of power and price factor. Composite materials have many benefits above further standard materials so that of their upper class-specific behaviors; such as durability and rigidness to weight ratio, upgrade erosion, and surrounding opposition as well as, design plasticity, upgrade tiredness survival, and possible decreasing of practicing, fabrication and life cycle price (Mallick, 1993)**.**

2.3 Energy Absorption.

In an end-on collision, the train’s kinetic energy must be absorbed as the trains come to rest. Some part of this energy, termed the collision energy, is sucked up by the vehicle structures and components such as buffers and draw gear. One of the main purposes of structural crashworthiness is to suck up this energy in a controlled and predictable manner.

The collision energy is given by the expression:

$$E_C = {}^{m_1 m_2}/_{2(m_1+m_2)} V^2 \tag{1.1}$$

Where $m_1 m_2$ are the masses of the trains involved and V is the approach velocity. It must be well known that where the trains rebound, some of this energy may reappear as kinetic energy. The main assumption in this expression for E_C is that the two trains each act substantially as a single mass, that is, all parts of each train have, during the collision, substantially the same velocity. Where this is not true, for example, where a train is loosely coupled or parts, then the energy absorption may be less. Nevertheless, in any crashworthy design, E_C is a good measure of the energy which must be absorbed as strain or mechanical energy in the couplers, buffers, body structure, etc. of the vehicles. There is, of course, a practical limit on the quantity of energy that might be absorbed reliably and economically in these components and this will govern the severity of collision which can be used as a design case.

Norman Jones and Tomaz Wierzbicki (Jones & Wierzbicki, 1998) tell that energy in crashes is absorbed in two ways, hydraulic energy absorber, and controlled structural collapse. This system has the approach of structural collapse to manage the crash energy. When energy is sucked up in a collapse there needs to be some way to describe this, therefore a load curve diagram often is used. An example in the diagram below is the first peak of the load curve is the initial peak load that responds to the load where the system collapses and it is called Pmax. The subsequent peaks are results of the following collapse mode. The stiffer cross-section that is used the higher peak- and sub-peak-forces you get and at the same time the crushing distance is narrowed down. The initial peak load is therefore a very important design variable. The peak force for the crash-box has to be lower than the initial peak force (Pmax) in the side member or else the side member will collapse first.

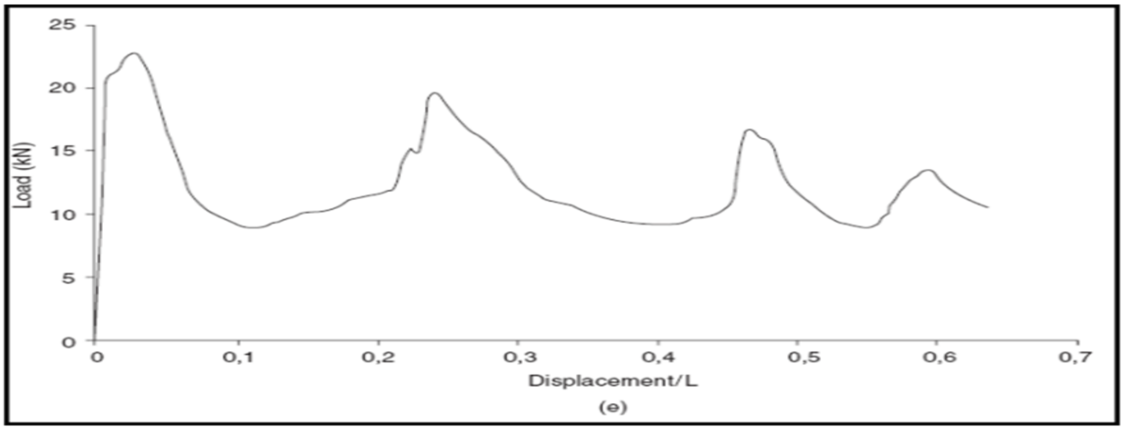


Figure 2.2 shows a typical load curve (Jones & Wierzbicki, 1998)**.**

In (Jones & Wierzbicki, 1998) Norman Jones shows that it is desirable that for the system to work as efficiently as possible, a high constant load curve is wanted. To get this result the collapse has to be promoted and with the support of a suitable design have a collapse mode that reaches the desired energy absorption. The energy absorbed when a structure collapse is dependent on three basic factors:

- Material properties
- Collapse mode
- Structure geometry

These parameters will be discussed further as follows

- **Collapse Mode**

The main part of the locomotive is built from steel/metal structures. The energy is sucked up through the collapse of these. In the crash moment, the goal is to keep the deceleration down for the driver and passengers. Norman Jones and Tomaz Wierzbicki (Jones & Wierzbicki, 1998) show that this is done by having structures that can absorb energy over a longer time. At the same time, the structure should absorb as much energy as possible and do so in a controlled manner. In a crash, there are two ways for a crash-box to collapse. First, there is bending, which is the natural but unwanted collapse mode. The second way is axially collapsed. This is what the crash box must be designed to handle. An axial collapse absorbs other energy compared to the bending collapse and the axial collapse is easier to control. To have a managed collapse mode is very important. The desired behavior is that the box will collapse this way in every type of impact so that the energy is sucked up in the right manner. To be able to absorb the energy wanted the crash box has to be designed to deform in an axial folding way. The phenomena of beams that collapse can be described in three ways.

- **Global bending**

This is the normal way for the crash box to collapse, this mode of collapse is the most energy-efficient way for the beam to collapse and therefore a collapse way that easily occurs.

- **Axial folding**

The axial folding mode of collapse is another way where the axial folding absorbs other energy compared to the global bending mode.

- **Axial folding with global bending**

This is a combination of the two previously global bending and axial folding. Often the collapse can start with axial collapse but then turn into a global bending. This is typical behavior in collapses of structures.

When the initial peak force is the force that is needed for the structure to start its deformation the subsequent peak forces are the result of the following deformation when the folding pattern occurs. When the collapsed device has begun the bending stiffness is decreased and that minimization can lead to bending failure. The maximum load opposition of the crash box during collapsing is relying on the corner crush strength. To keep a strong folding the global buckling stress must be larger than the maximum load opposition of the corner. The crushing of crash box structures is influenced by the geometry of the structural elements, boundary conditions, and material properties (Jones & Wierzbicki, 1998).

There are three main specifications for constructing crash boxes. The beginning is the crush force efficiency (CFE) which is described as the proportion between the maximum first folding force and the mean dynamic force. The conceptual bumper can display a CFE of 100% with a rectangular-shaped force crush distance curve. It means that the first folding force and means force is the same but in the application, the condition of CFE specification equal to 1 is not obtainable. The mean dynamic force is purposely of collision speed while the mass of hard hitter hasn’t observable effect on it (Ghasemnejad, 2008). The next main specification is the stroke efficiency which is the proportion of the crushed distance at the collapse to the first length of the bumper. One of the important crashworthy parameters is the deformation length of the energy absorber during the impact. Therefore, the required crushing energy to be dissipated per unit of length can be determined. This parameter is defined by dividing the maximum allowable crush distance by the initial length of the energy absorber. Due to the nature of crushing and densification of the deformed absorber this parameter is less than unity.

The tertiary specification is specific absorbed energy which is the area below the force crush distance curve subdivide by the mass of the sample model. Supposing that the donation due to the stretchy bending is minor, the occupied energy can roughly be estimated as the energy corrupted by flexible bending (Ghasemnejad, 2008).

In designing the crash box (calculation of cash worthiness) during collision is explained as follows, the crashworthiness of the crash box indicates the value of absorbed energy per mass. One of the indexes to measure crashworthiness is (Griškevičius, 2003)

$$\eta_c = E_{d}/M_s \tag{1.2}$$

Where E_d is the absorbing energy of the crash box; M_s is the mass of the crash box.

Also For the crash box with thin-walled sections having the same section shape, the crashworthiness index can be calculated by the following equation:

$$\eta_c = F_m/A_s l \tag{1.3}$$

Where F_m is the mean crash force; A_s is the area of section; l is the length of the thin-walled sections. The mean crash force is the mean value of the crash force curve vs. collapse displacement, which indicates the whole energy of the thin-walled sections absorbed.

During the frontal crash between two bodies with an impact speed v and the vehicles mass m the required deformation energy of structures is approximately equivalent to the kinetic vehicle's energy before impact:

$$E_K = MV^2/2 \tag{1.4}$$

Also, the Calculation of Specific energy absorption (SEA) for steel (for locomotive collision) is explained below, for balancing, the energy absorption dimensions of specimens is a standard that describes the mean collapse load and specific energy absorption (SEA). Specific energy absorption (SEA) is estimated by dividing the area under the load-displacement curve by the column mass (Ali, 2012).

$$\mathrm{SEA} = \frac{\text{Total Energy absorption E}}{\text{Column Mass M}} = \frac{\int \mathrm{P d\delta}}{\mathrm{M}} \qquad (1.5)$$

Where P is the load, δ is the displacement and M is the column mass.

2.4 Mechanics of Override.

The most demanding requirements for the locomotive front-end protection systems get up out of the requirement to stop override in impacts. Therefore, the conditions must be commanded by knowledge of this impact way. A foundations condition for an override to happen is the presence or formation of a dissimilar in the joining cars under frame heights. This dissimilar possibly give out as a dissimilar in the original height of the underframe even so most regularly it happens as an outcome of the dynamic forces, movement, and bending throughout an impact. On one occasion, a bank is established by local bending at the very end of the car. On another occasion, the formation of a plastic hinge inboard of the vehicle results in a catapulting and override phenomenon (Duschinsky, 1996).

Both mechanisms require substantial forces. Such forces arise because of the need for the entire system to absorb the collision energy. Stiff structures, as currently typified by North American construction, will necessarily attain high forces to achieve this energy absorption.

High collision forces have another deleterious effect. A high force is needed to lift one vehicle underframe over another under the dynamic conditions of a collision. In contrast to quasi-static conditions, for which a force of approximately one-half the vehicle weight is needed for lifting one end, the forces needed under dynamic conditions increase rapidly as a function of collision speed to overcome the vehicle’s pitch inertia. This force is given approximately by (Kim, 2007).

$$F = \frac{WL_2}{L_1} + \frac{I(\Delta Y)V^2}{{L_1}^2(\Delta X)^2} \qquad (1.6)$$

Where W= the weight of the vehicle car-body.

I = the pitch inertia about the rear truck (I≈ $I_{CS} + m{l_2}^2$).

V= the collision speed.

L_1 = the distance from the underframe end to the rear track.

L_2 = the distance from the vehicle body center of gravity to the rear track.

Δx= the distance of longitudinal overlap $^{b}/_{n}$ colliding underframe during the time Override initiation.

Δy=the change in the evaluation of the underframe during the time of override Collision.

The overriding issue of train collisions is studied through the collision scenarios of locomotive impacting with rigid walls and front-end collisions between two identical trains. We study the effect of the number of vehicles and the impact speed on the overriding in train collisions. The critical speed of overriding is obtained in terms of the wheel rise at different speeds.

2.5 Overriding studies

In the case of a head-on collision between two locomotives, a considerable amount of energy must be dissipated. One of the potential results of such a collision is the override of one of the locomotives onto the other. Because of their prolonged strength and stiffness, locomotives are particularly allowing to override when they strike with another vehicle. The consequences of an override are often catastrophic.

A review of accident data globally has highlighted that end-on collisions (head to head or rear on collisions) are responsible for most of the serious and fatal injuries to passengers and crew in train accidents. Within these reviews, locomotives overriding has been identified as one of the foremost factors in determining the number and severity of injuries, it has been demonstrated that the casualty rate, especially the fatality rate increases if overriding occurs. It is evident therefore that override prevention will significantly improve passenger and crew safety on the Ethiopian rail network. Before this can be achieved, however, a deeper understanding of the causes of Overriding is necessary (Ambrosio, 2000).

Collisions between rail vehicles take place essentially in the direction of the vehicle longitudinal axis, while a variation in level, due for example to dissimilar loading states of the vehicle involved in the collision, may under certain conditions get what is entitle “ override “.

To stop this effect, protection in the form of an anti-override structure is as long as in most cases, with crash boxes as long as with a tooth structure typically being mounted onto each vehicle. In the case of a collision said plates interlock and stop the override. The study of European accidents produced the following general conclusions.

- If overriding occurs, the fatality rate is 3-4 times higher than for similar collisions without overriding. Most fatalities are in the overridden vehicle.
- Fatalities occur in 70% of all overriding collisions.
- With buffered stock, overriding can occur at closing speeds as low as 15km/h.
- Overriding may occur at collision energies as low as 2.5 MJ but becomes likely at collision energies greater than 10MJ.
- Collisions involving vehicles with buffers are approximately three times more likely to result in override than collisions without buffers.
- There is unconfirmed to propose vehicle pitch contributes to overriding in passenger vehicles.

Overriding in end-on collisions is the single most serious event that can happen as far as the safety of passengers is concerned. Surfaces, which can easily deform or slide over one another, e.g. buffers, are Instrumental in allowing vertical forces to develop which initiate override. Accident investigations and other forms of reports have shown that crashworthy systems built into the front ends of conventional locomotives are generally ineffective in preventing override. The impact between colliding couplers can induce dynamic vertical forces that cause one of the colliding locomotives to pitch significantly.

If the safety of passengers and crew is to be increased by the prevention of overriding, serious consideration needs to be given to specifying a common design of crash boxes fitted to all locomotives in the same way that buffer position has been specified in the past (Manuel, 2001).

The tendency for increasing the trains' speed of travel is followed by the great attention of researchers. Derailment, over-turn, direct and incline train collision are the most catastrophic events in railway transportation which are classified in crashworthy analyses. Hence, the safety of rail vehicles confronted with these accidents is vital and urgent in design plans.

Nowadays, heavier traffic and the higher speed of rail vehicles obliged engineers to be more cautious about safety concepts. Lewis et al. carried out crash tests and developed a finite element model to predict crashworthy behavior of the rail vehicle (Rasaiah, 1996).

Cab car- and multiple units (MU) locomotive-led trains present a challenging situation in collisions. The existence of passengers in the front car of lighter weight and lower strength, in similarity with conventional locomotives, give out a potential danger in the case of a collision. Cab cars, MU locomotives, and conventional coach cars must support an 800,000-pound longitudinal static load applied at the buff stops without permanent deformation (U.S. Department of Transportation, 1999).

Rail safety issues for passenger train vehicles around the world demand a high-energy (HE) crush or crumple zone on the training front and low-energy (LE) crush zones between vehicles to suck up the crash energy of a collision. A Crush zone is an area where the structure or equipment in a locomotive is permitted to collapse and suck up the kinetic energy of an impact in the course of the collision and decrease the kinetic energy moved to the train driver in the cab and the passengers in each vehicle. There is a general trend though, to improve the passenger and driver safety of railway vehicles by vehicle end protection (Centre for Railway Engineering, 2000).

The locomotive front-end protection like energy shock absorbers, Anti-climber, buffers, and other parts are going to address in this research paper to reduce the accident and how to minimize if the accident happened and this will make the research more important and feasible. Here this thesis presents the solution for the huge loss in material and safety of passengers as the result of the crash. This is done by studying the locomotive front end protection system for the von-misses stress and deformation and design for the absorbers, Anti-climber, buffers, and other parts has been done with the mind of reducing the property and human loss while the collision occurs. In recent years, studies are concentrated on break up the impact of kinetic energy in a stable, ordered, and manageable way, and decreasing the damage to occupants. Hence energy absorption structure is the key part of the crashworthiness structure. For the great range of deformation modes, efficient energy absorption capacity, and agreement price, the thin-walled structure has been widely used in the crashworthiness design of traffic vehicles.

The practical crush process of rail vehicles has a complicated natures make rail vehicle end protection design and development for improving its crashworthiness should be done by simulating the structure dynamic behavior under collision scenario and this very complex task to accomplish for its linearity. In recent rail vehicle end protection design nonlinear FEM has mainly used this method is very useful at early design stapes to minimize the number of prototypes to be tested practically and this will help reduce the cost of the production and time spent to manufacture the rail vehicle. Moreover, prototypes are required to be tested experimentally, since the large scale and highly non-linear nature of vehicle end protection dynamic simulation make it impractical to conduct direct optimization on the full non-linear model of the structure (Robinson, 1998).

2.6 Energy dissipation mechanisms

A crash energy disappearing device for a locomotive must be designed to satisfy crashworthiness requirements. They must perform following a set of authorized crash scenarios, mostly assumed from frontal collisions. The energy dissipation mechanisms can incorporate various structural design features and special equipment to absorb the energy without either interfering with the survival spaces of the occupants or compromising the deceleration levels (Ochelski, In Press, Corrected Proof).

Through appropriate designs, localized large deformations of the crush zones at selected locations can be minimized whilst maintaining maximum energy absorption levels. Most of the crash energy absorption occurs at the front end of the train during a frontal collision.

Hence, the crush zone at the front end is usually referred to as the high-energy (HE) crush zone. Absorption of the remaining energy and the subsequent impact energy between the locomotives happen at the coupler locations.

Because of the comparatively lower energy absorption requirements between cars, these areas are known as low energy (LE) crush zones. Both the HE and the LE crush zones can take the form of a sequential crushable assembly such as a push-back coupler followed by crushing tubes made of tubes or honeycombs followed by adequate corner posts (Tyrell., 2002).

Normally, these crashworthiness standards are based on multi-stage energy-absorption methods using passive safety-protection technology, in which a distorted anti-climber is climbed in a fixed position on the front part of the locomotive to suck up the kinetic energy of the impact. Forecast the railway vehicle's coupling, anti-climbing, and energy absorption properties, the longitudinal size of the deformable anti-climber go beyond the longitudinal size of the coupler system. Large plastic deformations of the structure occur only at the vehicle cab front end to absorb the kinetic energy of the impact (Xu, 2016). Figure 2.3 illustrates energy absorption systems.

In general, the crash-worthiness design concept of the locomotive is assumed from the assumption that only an energy-absorbing design can disappear the impact kinetic energy while quitting the residue of the locomotive structure intact. On my side therefore I focus primarily on the subject of particular energy-absorbing structures. These special energy-absorbing designs are usually attached with the anti-climber, which sucks up the impact kinetic energy and stops the vehicle from climbing. Special energy-absorbing design can be categorized into axial collapse, cutting, splitting, expansion, and bending, and inversion structures. To enlarge the energy absorption, carrying capacity, and efficiency of the energy-absorbing structure, a thin-walled structure with different types of honeycomb aluminum can be used (Sun, 2016).

In recent years, better the distortion strokes and energy-absorption capability of energy-absorbing design in limited vehicle space, the greater part of researchers planned a variety of energy-absorbing designs with large distortion strokes, such as the shrink circular tube and the cylindrical splitting tube, the distortion strokes of which have approached 100%. A novel energy absorber effective of generating a huge distortion stroke than its free length has also been planned (Yu, 2018); the effective crushing distance rate (ECDR) of this structure can exceed 1.

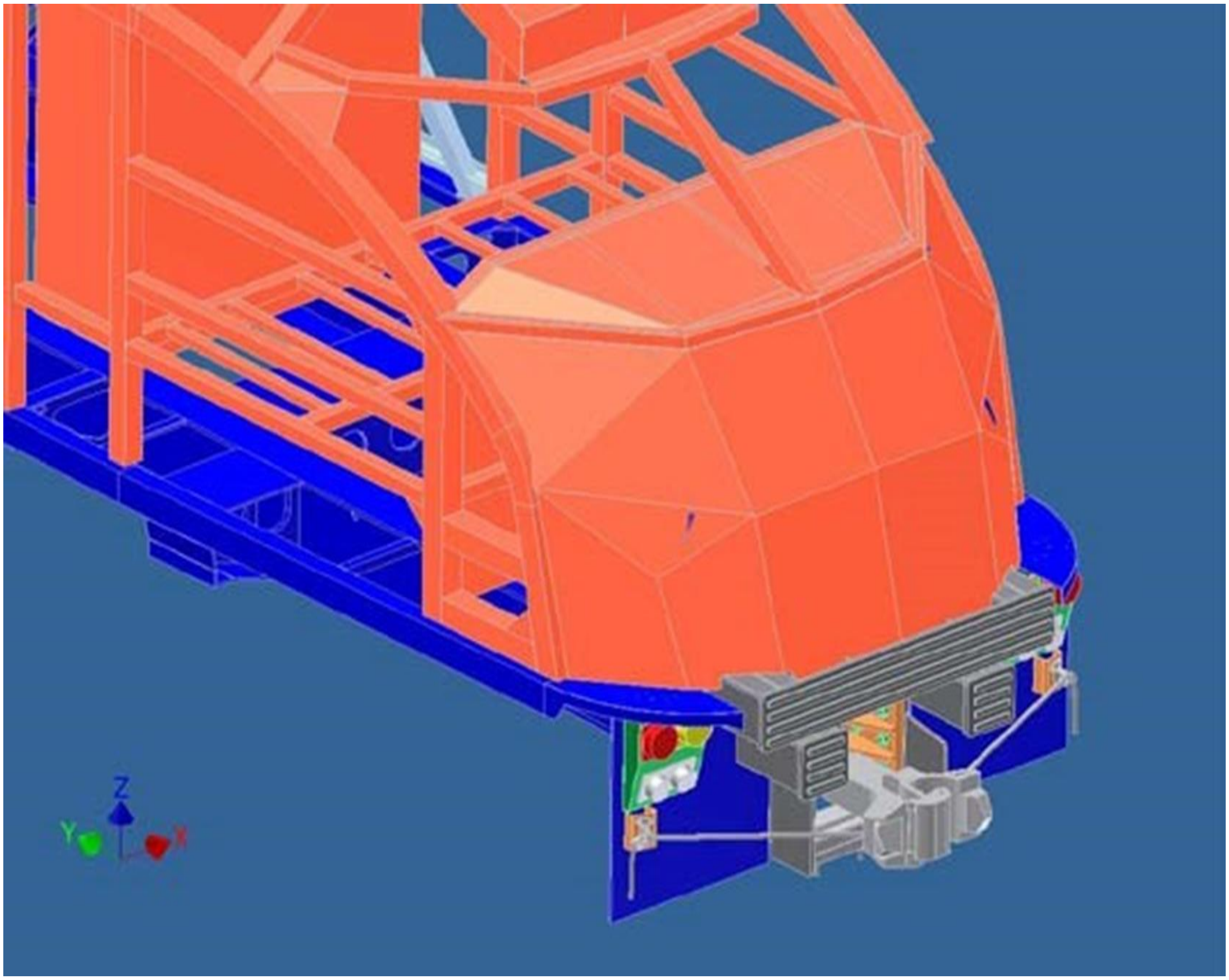


Figure 2.3 illustrates multi-stage energy absorption systems using passive safety protection technology (Railroads, 2004)**.**

CHAPTER 3 METHODOLOGY

This chapter outlines the approaches and techniques that were used to meet the objectives of my research work. For improving the locomotive front-end protection, the following methods will be used. The overall study flow chart is shown in figure 3.1 below.

Figure 3.1 show a flow chart of the paper methodology

3.1 Numerical CAD modeling of the locomotive with crash box model.

Modeling is a pre-processor tool, the modeling was performed by using CAD software such as SOLID WORKS, and SolidWorks is used by students, designers, engineers, and other professionals to produce single and complex parts, assemblies, and drawings. All models were generated by using 2D shell elements and 3D solid elements to ensure obtaining a reliable numerical result. 3D solid modeling has developed into a testing position of any resulting development, acting as the base for design, simulation, and makeup of any member and assembly affecting a wide area of industries, products, and applications.

The locomotive with crash box models was modeled and imported with file format such as Para solid to finite element analysis software, ABAQUS. The crash box model and the model of locomotive each were assembled into one final model. The final models were used to carry out the simulation.

For the locomotive with the crash box model, the locomotive is fitted with a structure known as a crash box at the nose of it which is assembled to form one final model. The crash box is a crash-worthy structure.

Consider the objective of this report is to absorb more impact energy in just like that crush zones that are deformable in a defined manner convert this energy into deformation energy. Improvement of the keep going crash box is also considered because the Crash box as an energy absorber is proposed to raise the energy absorption range of the locomotive nose during the collision/impact.

The following figures show models of locomotive and crash box already modeling by using ABAQUS/CAE and the main dimensions of locomotive collected as data from ERC, also dimensions or main parameters of the crash box taken from standards shown in the reference (Railroads, 2004).

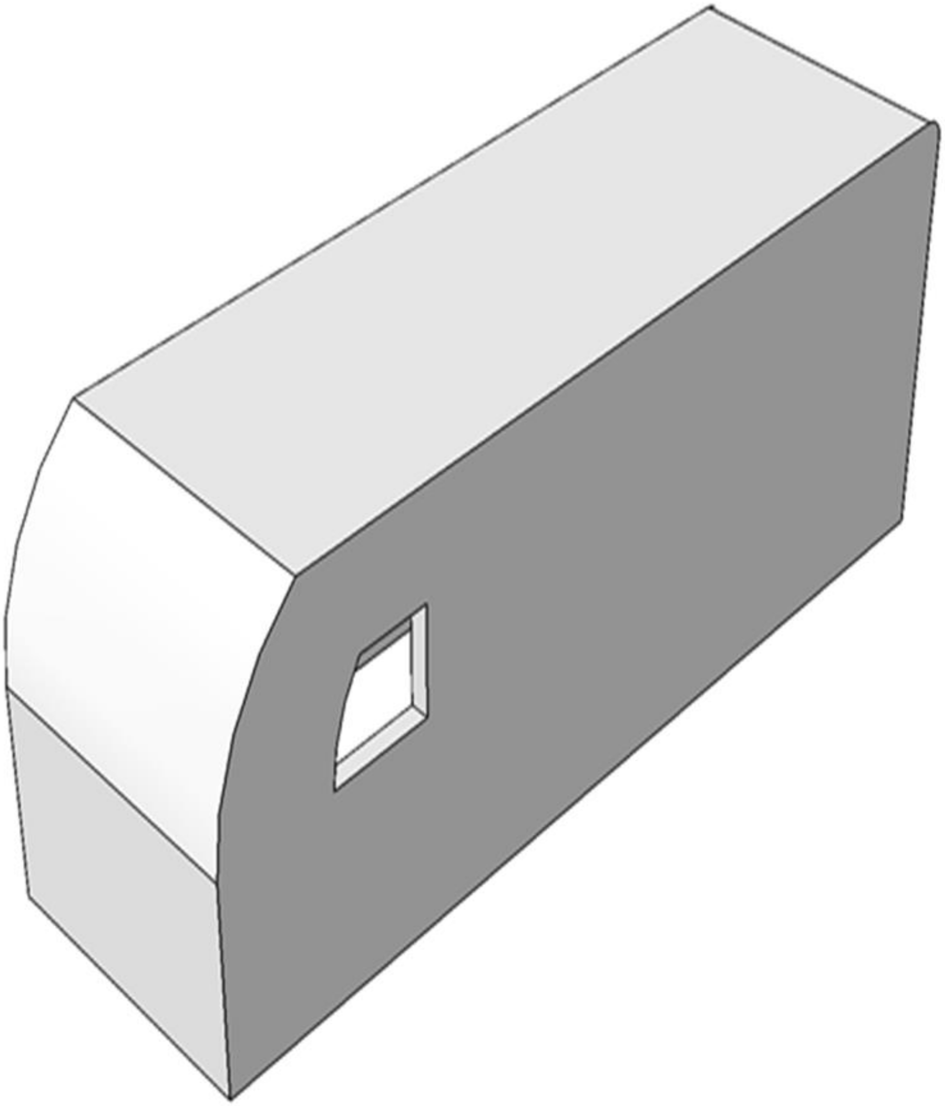


Figure 3.2 shows the locomotive model.

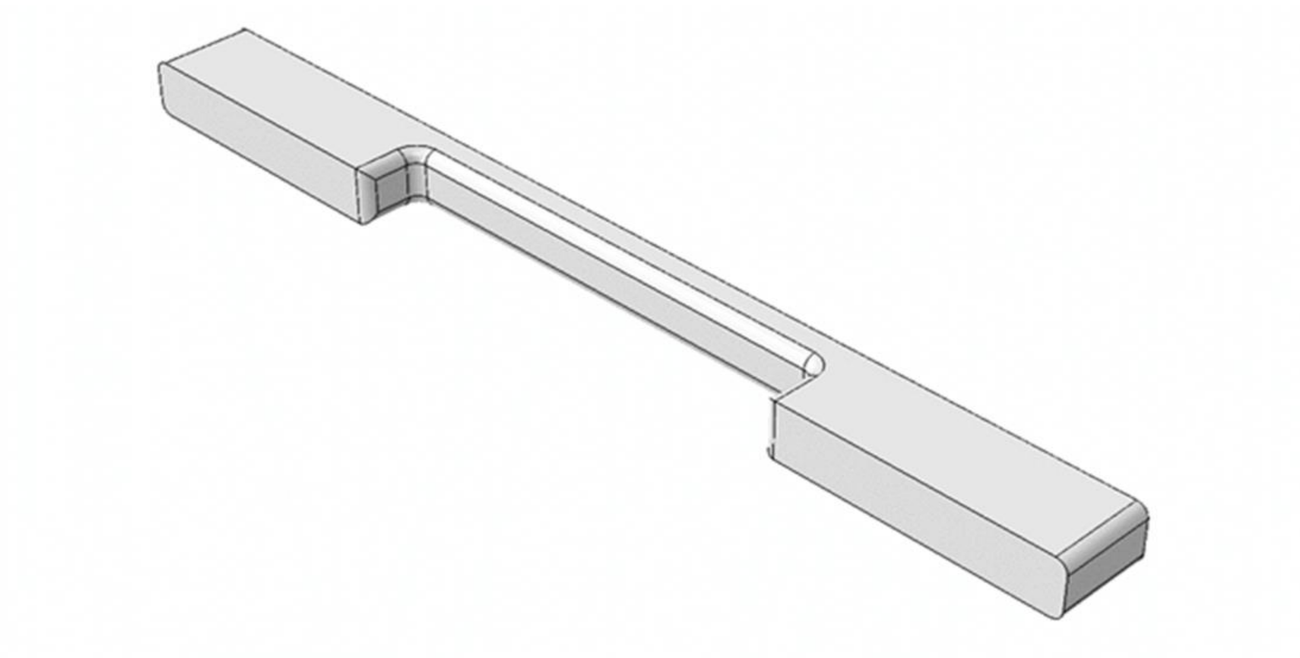


Figure 3.3 shows the designed crash box model.

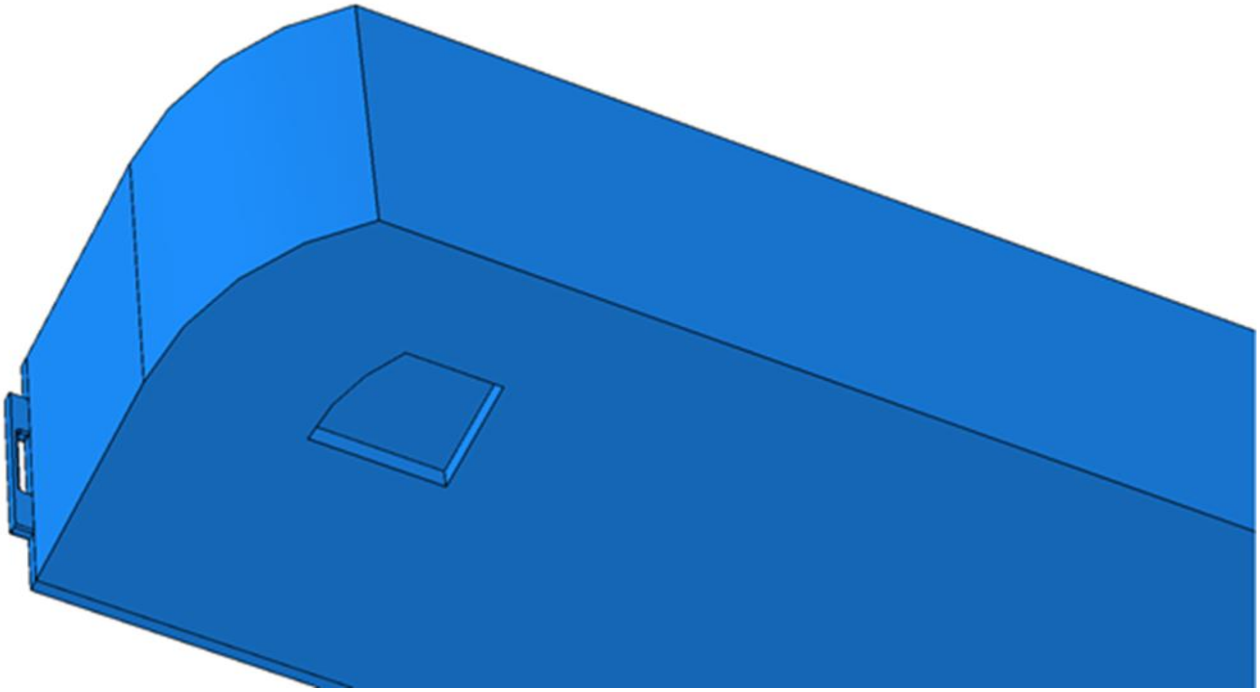


Figure 3.4 shows a locomotive with a crash box model.

3.2 Material selection for the locomotive and crash box.

Determining the right material during the selection process is very important. The material selected should meet the expectation of the engineering. The material should prove mechanically feasible and should be economical. Apart from this, the selected material must convincingly prove better than the currently used material. The proposed material properties may help the material engineers to perform the right material selection during the selection stage. The choice of material for the crash box depends on the following factors:

Energy Absorption (EA) - One of the key factors in the choice of material for a crash box is the capacity of the material to suck up the kinetic energy of a collision. This capacity of the material to suck up energy is called impact toughness. Impact toughness is explained as a measure of the capacity of the material to suck up energy during impact.

Weight - One of the primary reasons for engineers to check for a new kind of material is the weight-lightening factor. The lightening of weight does an important part in fuel consumption. By lightening in weight, we aim that the lightening in the dead weight of the locomotive. Reduction of the load on the engine guard that less power is needed for the constant load, therefore, lowers the fuel consumption. Therefore the decreasing in weight of any component of a locomotive reduces the net dead weight.

Accessibility of the material also is another factor and can be classified into two; namely the accessibility of the raw materials and the details regarding the raw materials. The details concerning the materials are the requirement for the producer during the design process.

The manufacturing process necessary is also needed to be considered while selecting the greatest material for the product development process. The manufacturing procedure contains the choice of the greatest procedure either forming or shaping to reach the necessary design.

Performance is defined as the capacity of the material to stay rigid during an impact. This also is another factor for the choice of the material of a crash box.

Main Influencing Factor to Crashworthiness-There is many conditions that can impact crashworthiness features of crash-box in the collision simulation procedure, as well as energy-absorbing structure shape, wall thickness, materials, and such like, in which material properties have great results on mechanisms properties.

The comparison will be done for three different materials. The best suitable material (Minimum weight and cost-effective) is suggested for manufacturing (Krishnan, 2013).

There are numberless materials in the locomotive industries, thin material has every time been a hot spot. Aluminum material is one of the classic thin materials.

In this work, the crash box was manufactured using aluminum, Steel, and Carbon fiber materials. Table 3.1-3.7 provides the main material characteristics parameters.

For the side of the crash box, the Material used to design the crash box is **aluminum** as I said before. These materials have interesting combinations of properties such as high stiffness, strength combined with high energy absorption capacity, and formability. The purpose of the crash box/ locomotive front end system is:

- To suck up energy at the beginning of a crash and to pilot another crash forces into the other part of the body assembly.
- At low and medium speed: to decrease the destruction of the locomotive to minimize maintenance cost.
- At higher speed: to pilot the crash forces into the body assembly thus that the probability for a decomposition of the body assembly is low and the life of the occupants is secure.

The above purposes of the crash box make me choose aluminum material, also the first aspect is ensuring that the locomotive front sections crush or collapse upon impact, because their main function is to provide maximum absorption of the kinetic energy in the crash. The following is that the passenger chamber maintains it is constructional stronger. Accordingly is important to know the capacity of unlike materials to suck up energy in a locomotive crash. **Aluminum** provides very good energy absorption.

The material selected to design and modeling the locomotive and crash box is Steel. Steel is the primary material used to make cars, mostly in the typical ‘body in white, which is a car’s basic skeleton, as well as in the chassis. Steel is very stiff, strong, and durable, which make sure safety and upgrade the way a chassis pick up, manufacturing it a useful material for car bodies and chassis. Steel permits for a superior brand and dissimilar welding techniques, which were adjustable to mass production, authorizing locomotives to be made in greater volumes and at a lower cost.

The relatively low cost of steel compared to other materials makes it an attractive choice although the cost of High Strength steel is greater than the mild steel grades commonly used in many applications. Steel is limitless reusable and can be recycled into a new product except lowering in quality. And with its magnetic property, you may simply pull during the recycling process. Steel is less energy-intensive to manufacture and gives off fewer greenhouse gases through fabrication. However, it has higher use-phase energy consumption and carbon dioxide emission. To meet fuel economy goals, some automakers are using high-strength steel which allows reduction of thickness while achieving even higher-strength performance. Material selection can also provide advantages by reducing member deflection, increasing chassis and cab cabin strength, and can control the quantity of reinforcement required. Steel is selected as an engineering material mainly because of its excellent rust protection in many environments. The corrosion resistance of steel is due to its high chromium contents. The reasons why I choose steel to design locomotive are:

- Heavy but strong, with a potential infinite fatigue life
- Easy to weld and needing no special heat treatments
- Though prone to rust, steel is easily painted, and with the correct coating choice, is easily and successfully repaired.

In the construction of energy dissipating structures, the concept of a space frame composed of **composite materials** has been recognized as a well-organized impact energy absorbing system. In this type of construction, energy absorption will usually occur by a combination of progressive folding and bending collapse of the prismatic column.

For lightweight designs, low-density composite material, such as **carbon fiber**, has the possibility of rising the energy absorption of a crash box. The increase of energy will be absorbed by the large compressive deformation of the structure. Recent developments of cost-effective processes for the production of low-density cellular materials, such as carbon fiber, have cleared the way for using it in energy absorption devices to reinforce a space frame structure. There is a huge area to upgrade the energy absorption ability of the crash box using various techniques. As discussed above there is a greater part of factors that influence the energy absorption ability of the crash box. Use of the carbon fiber is the current change and one of the choices to enlarge the energy-absorbing ability of the crash box. Instead of this material, we can use other materials such as various low-density polyethylene materials. Another parameter that influences energy absorption is shaping. We further proceed to simulate using different materials like steel, aluminum, and carbon fiber of cross-sectioned crash boxes in order at the end to compare the result which crash box material show high-performance experiment (Wei, 2014).

The crash boxes transform the kinetic energy into else appearance of energy at the instant of the crash. Therefore, the impact absorbers are manufactured from materials with high absorption specifications and geometries. It is considered that using carbon fiber materials that show high performance under sudden impacts and dynamic weights in the crash boxes in the locomotive industry can be an alternative to the conventional crash box materials. By comparison, the crash-box of aluminum, steel, and Carbon fiber material will tell us which material is better than the other matter to absorb energy in completely overlap low-speed collision.

3.3 Energy absorber design and calculation.

The kinetic energy absorber can estimate depend on crush scenarios. For the crush against another vehicle kinetic energy will be equal to

$$w_1 = \frac{m_1 * m_2}{m_1 + m_2} * (v_1 + v_2) * \frac{1}{2}$$

Vehicle weight (empty, average) m_1 = 41000Kg $a = 19.44\, m/s^2$

Vehicle weight (full, average) m_2 = 63000Kg V_2 = 5.55m/s

$w_2 = F.s$ V_1 = 6.944m/s S = 0.127m

$w_3 = w_1 + w_2$ c = 20 cycles/hour $w_4 = w_3 * c$

$V_d = V_1 + V_2$ $m_e = \frac{2.W_3}{V_d{}^2}$

Where w_1 = is kinetic energy per cycle

w_2 = is propelling force energy per cycle

w_3 = is energy per hour

m_f = is total energy per hour

m_e = is effective weight

m = mass to be decelerated

V_d = impact velocity at shock absorber

V = velocity moving mass

F = propelling force

C = cycle per hour

S = shock absorber stroke

$$F = m_1 a = 19.44\, m/s^2 * 41000 K_g = 797.04 K_N$$

$$W_1 = \frac{1}{2} \times \left[\left(\frac{m_1 \times m_2}{m_1 + m_2}\right)(V_1 + V_2)^2\right] = \qquad (1.7)$$

$$\frac{1}{2} \times \left[\frac{41000*63000}{41000+63000}\right](6.944 + 5.55)^2 = 1938.61 K_J \qquad (1.8)$$

$$W_2 = F \times S$$

$$W_2 = 797.04 kN \times 0.127 m = 101.22 K_J \qquad (1.9)$$

$$W_3 = W_1 + W_2$$

$$W_3 = 1938.61 K_J + 101.22 K_J = 2039.83 K_J \qquad (2.0)$$

$$W_4 = W_3 \times C$$

$$W_4 = 2039.83 K_J \times 20\ C/h = \ 40796.6\ K_J/hr \qquad (2.1)$$

$$V_D = V_1 + V_2 = 6.944\, m/s + 5.55\, m/s = 12.495\, m/s \qquad (2.2)$$

$$m_e = \frac{2.W_3}{{V_D}^2} = \frac{2 \times 2039.83 N_m}{(12.495)^2} = 26.13 K_g \qquad (2.3)$$

$$Q = \frac{1.5 \times W_3}{S} = \frac{1.5 \times 2039.83 K_N/m}{0.127 m} = 24092.48 K_{N/m^2} \qquad (2.4)$$

For the crush against the wall

$$w_1 = \frac{m_2.{V_2}^2}{2} \qquad W_1 = \frac{63000 \times (5.55m)^2}{2} = 970278.75 K_J \qquad (2.5)$$

$$\mathrm{W}_2 = F.s \qquad W_2 = F \times S = 797.04K_N \times 0.127m = 101.22K_J \tag{2.6}$$

$$\mathrm{W}_3 = w_1 + w_2 \qquad w_3 = w_1 + w_2 = 970278.75k_J + 101.22k_J = 970379.97K_j \tag{2.7}$$

$$\mathrm{W}_4 = w_3 * c \qquad w_4 = w_3 \times c = 970379.97K_j \times 20\,c/h = 19407599.4\,K_j/h_r \tag{2.8}$$

$$\mathrm{V}_d = V_2 \qquad V_D = V_2 = 5.55\,m/s \tag{2.9}$$

$$m_e = \frac{2.W_3}{V_d{}^2} \qquad m_e = \frac{2\times w_3}{V_D{}^2} = \frac{2\times 970379.97K_g}{(5.55)^2} = 63006.57K_g \tag{3.0}$$

$$Q = \frac{1.5\,W_3}{S} = \; Q = \frac{1.5\times W_3}{s} = \frac{1.5\times 970379.97K_N/m}{0.127m} = 11461180.75K_{N/m^2} \tag{3.1}$$

3.4 Proposed System Specifications

In this section, we shall see the standard specifications of a locomotive with a crash box constructed by Steel material. Data collected from Ethiopia Railway Corporation. Also, the standard specifications of a crash box are made up of Aluminum and composite material (Carbon fiber). Others are defining material property of steel according to EN 10025:2004 and material properties of aluminum and carbon fiber. In designing 3D CAD model generation input data dimensions of steel locomotive is collected from Ethiopia Railway Corporation and that for crash box is according to (Railroads, 2004).

Main Technical Parameters for locomotive Shown in the following table 3.1. (ERC, 2014).

S/NO.	DESCRIPTION	UNIT	VALUE
1.	Length of Locomotive	mm	22,670
2.	Width of Locomotive	mm	3100
3.	Locomotive height upon pantograph dropping	mm	4760
4.	The wheelbase of locomotive	mm	16260
5.	Locomotive service weight	Tone	138
6.	Locomotive weight with additional	Tone	150

The following table 3.2 shows the mechanical properties of steel material used to construct locomotive with crash box.

Material	Young Modulus(mpa)	Poisson's Ratio	Density (kg/m3)
Steel	210000	0.3	7850

Table 3.3 below show Plasticity Value of steel material for locomotive with crash box.

Yield Stress	Plastic Strain
380E6	0
420E6	0.04
470E6	0.12
500E6	0.19
530E6	0.25

Table 3.4 below shows Crash box specifications (Geometrical parameters of the crash box) (Railroads, 2004).

S/NO	DESCRIPTION	UNIT	VALUE
1.	Width of the crash box	mm	1033
2.	Depth of crash box extends from the locomotive front plate	mm	250
3.	The depth center of the crash box extends from the pulling face of the coupler	mm	100

The following table 3.5 shows the mechanical properties of aluminum material used to make up the Crash box as an absorbent device.

Material	Young Modulus(mpa)	Poisson's Ratio	Density (kg/m3)
Aluminum	70000	0.3	2.5e-09

Table 3.6 shows the Plasticity Value of Aluminum material for the Crash box.

Yield Stress	Plastic Strain
250	0
300	0.1

Table 3.7 shows the mechanical properties of Carbon fiber materials for crash box.

Material	Young Modulus (mpa)	Poisson's Ratio	Density (kg/m3)
Carbon Fiber	350000	0.3	1800

3.5 Finite Element Impact Simulation Using Abaqus Software.

3.5.1 Introduction

Abaqus is a collection of strong engineering simulation programs, developed on the finite element method (FEM), which resolve problems that differ from approximately simple linear analysis to the most testing nonlinear simulations. Abaqus software carries a considerable library of elements that can model effectively any geometry. It has various registers of material models that can simulate the habits of most representative engineering materials including composites, metals, polymers, and reinforced concrete.

Abaqus provides an extended of capabilities for the simulation of linear and nonlinear applications. Complications with many components are modeled by connecting the geometry defining each component with the allocated material models and identifying component interactions. In a nonlinear analysis, Abaqus mechanically allocate load increments and convergence tolerations and changeable them during the analysis to guarantee that the correct solution is obtained effectively. A complete Abaqus FEA usually comprises three distinct stages: preprocessing, simulation, and post-processing (Hibbit, 1992) (Smith, 2009).

Generally, the majority of authors surveyed previously have used this software at some points in their works especially for low-velocity impact problems, and it is a preferred choice for this study due to the comprehensive and intuitive modeling environment featured in the software, and the ability to readily perform dynamic explicit analysis.

In this work, the Abaqus/Explicit dynamic analysis method is used because this analysis step can handle large deformations, non-linear material models, and complex contacts, and also the time spent for running the analysis has been considerably reduced.

Crash analysis requires a dynamic analysis formulation (body movements) and a non-linear transient dynamic explicit type of finite element analysis. A non-linear dependency describes the relation between the applied conditions and effects (e.g. surfaces in contact change in time or large deformations of metal parts). Therefore, a non-linear investigation is required in crash analysis, since a large quantity of plastic deformation happens in most collision scenarios.

Transient (with time integration) analysis is a type where the development and body deformations are time-dependent. In crash circumstances, the time frame is short and the analysis is highly dynamic. The explicit formulation of FEA is a specific mathematical approach that is mostly utilized for high velocity, short time frame circumstances. The explicit FEM has been found an outstanding tool to solve complex tasks that include large deformations of structures, great inertia effects, and analysis of contact is developed in several algorithms which make it much easier to perform and control the response than in implicit solvers.

3.5.2 Finite Element Analysis of locomotive with crash box.

Before performing any type of analysis solid modeling of locomotives and the crash box is mandatory. As I stated earlier, to build the models of the crash box and locomotive drawn in a computer-aided design (CAD) environment used SOLIDWORKS and import the model with a file format such as Para solid to finite element analysis, ABAQUS.

The FEA is a computing method that is applied to get an approximate conclusion to boundary value problems. It employs a numerical method called the FEM. FEA involves the computer models of a design that is loaded and assessed for specific results, such as stress, deformation, deflection, natural frequencies, mode shapes, temperature distributions, and so on.

In this report, analysis is performed in the following procedures.

- To Model and Simulate locomotive crash box for the impact at the Centre of the crash box. Here two locomotives with crash boxes collided head-to-head collision.
- To use different materials such as Steel, Aluminum in simulation to generate design parameters for better impact attenuation crash box.
- To Model and simulate locomotive crash box impact phenomenon for composite materials to study crash dynamics.
- To Compare the FEA results of the conventional materials which are (steel, aluminum) and composite materials for the crashworthiness.

The collision speed for each scenario or step will be 36 km/hr. which is minimum impact speed according to EN 15227:2008.

The main purpose of the Crash box is to suck up a shock in case of an impact. Several materials seemed used to succeed these shock-absorbing capabilities, such as steel, aluminum, carbon fiber, grass mat thermoplastics, and sheet molding compound. The purpose of this thesis is the construction of a crash box which is to upgrade the crashworthiness of the locomotive crash box.

Crashworthiness is the capability of the crash box to prevent occupant injuries in the event of an accident and this is achieved by minimizing the impact force during the collision.

Simulation using FEM contains three major phases:

- **Pre-processing**, in which the analyst evolve a finite element mesh to split up the subject geometry into subdomains for mathematical analysis, and claims material characters and boundary conditions,
- **The solution,** through which the program determines the governing matrix equations from the model and answer for the primary quantities, and
- **Post-processing**, in which the analyst examines the effectiveness of the results, examines the number of primary quantities (such as displacements and stresses), and determines and examines additional quantities (such as specialized stresses and error indicators).

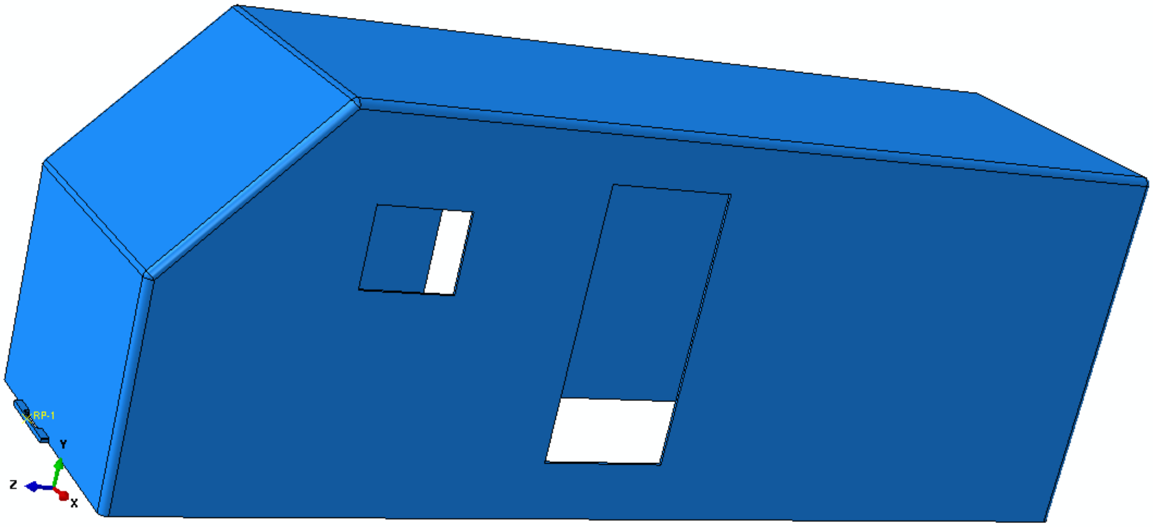


Figure 3.5 shows an assembly of the locomotive and crash box.

Assembly of the parts in locomotive and crash box.

The main rule of the assembly module was to create and modify the assembly. In this module the parts that were created, the locomotive and crash box was assembled in one model. In assembling the crash box tied with the locomotive at the front end. Figure 3.5 above shows the assembly model of the parts.

The meshing of the conventional and modified locomotive:

Meshing is discretizing the solid object to the finest parts to perform the analysis to get the precise value at each element of the meshed object. For every modeling software before running the models must be meshed. The following figures show meshed models for locomotive and crash box.

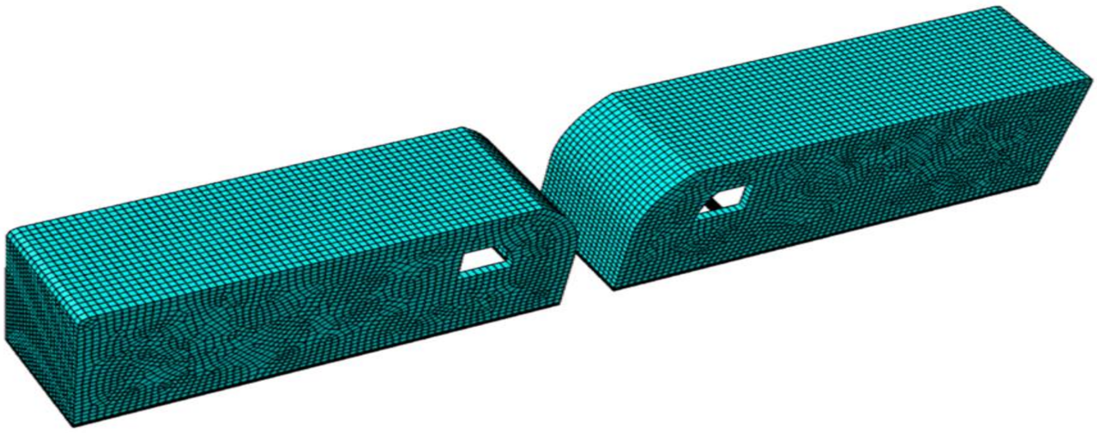
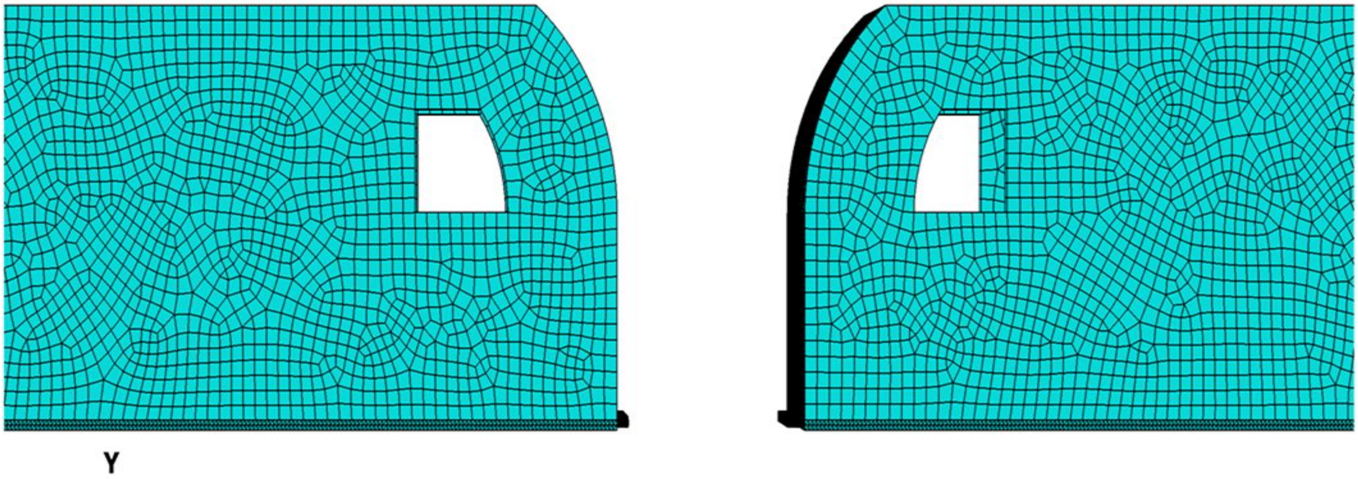


Figure 3.6 shows meshed locomotive models.

For every modeling software before running a model it must have meshed. The smaller the mesh sizes the more accurate results and takes too much time to compute. Every instance has meshed dependently because we mesh on parts and assembled to the model. Mesh element size is 20 mm and mesh element type is C3D81.



Figures 3.7 show side views of a meshed locomotive with a crash box model.

The **interaction module** is high priority part of FEA when two or more objects are in contact. Interactions are a step- dependent objects, which means that when you define them, you must indicate in which steps of the analysis they are active. In this research, the interaction properties were produce using the general contact algorithm. A contact interaction property in both locomotive and crash box models is defined using frictional tangential behavior with a friction coefficient of 0.3 and hard contact normal behavior. The space between the two instances models is about 1000 mm.

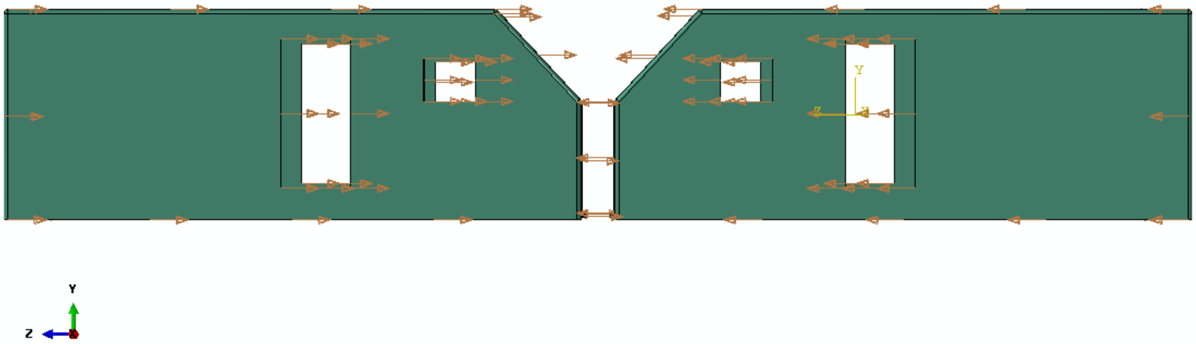


Figure 3.8 shows the distance between two models and predefined fields

In every engineering problem, there are **boundary conditions** because in software it is impossible to put everything as it is. So the features that are not present can be replaced by the boundary conditions. After completion of the finite element model and mesh, it is required to apply constraints and loads to the model. For both locomotives in each step fixed ENCASTRE boundary condition was applied to the bottom of two locomotives, the aim is neither translation nor rotations were present for both locomotives at each step. These boundary conditions are as follows,

- The locomotives are only moving longitudinally and are not moving laterally, this reduces the computational time. Here we selected the displacement/rotational step.
- Also, two locomotives move forward at a certain distance of about 500mm each but in a different direction. We selected a predefined field and put two different speeds/velocities in opposite directions. The step time which used is about 0.01 second.

The job module is the final step of the pre-processing. After I have defined my model, I am ready to analyze it. Analyzing a model involves some steps. Once I have completed all of the assignments required in determining a model (such as defining the geometry of the model, assigning section properties, and defining contact), I may be used the Job module to study my model. The Job module allows to create a job, submit it to ABAQUS/Explicit for analysis, and to monitor its progress.

Visualization module - In the post-processing, the Visualization module provides a graphical display of finite element models and their results. The visualization module shows the results in form of color codes and according to the color on the model and the same color on the color code tree, the output can be known.

CHAPTER 4 RESULT AND DISCUSSION

In this chapter, the results of interest are presented. As we know in the previous chapter the numerical impact simulation procedure of locomotives with the crash box using Abaqus/CAE was discussed. In this chapter, its result was presented and discussed briefly. Also, the full simulations results were presented in different figures.

Before, the locomotive with a crash box designed was evaluated against the design requirements using explicit dynamic Finite Element Analysis to assess their performance in the collision scenarios. The ABAQUS/Explicit Finite element analysis was used to conduct the analyses. As stated in the design requirements, the consequences of three collision scenarios were evaluated. These three collision scenarios are

1. Two locomotives with a crash box made up of steel material collided

2. Two locomotives with a crash box made up of aluminum material collided.

3. Locomotive with Carbon fiber material crash box collided with another locomotive with a crash box of the same material.

The standard references for crashworthiness requirements (standardization, 2008) of EN 15227 is explained that full train on train head-on collision is required to be assessed, which can involve impact speeds up to 36 km/hr. depending on the class of rolling stock. However, for light rail vehicles, the impact speeds for crashworthiness assessment are only 15 km/hr.

For each collision scenario, several results are described and shown below. Start with a brief presentation of the FEA result for locomotive with steel crash box followed by finite element analysis result for locomotive with a crash box made up of other materials like aluminum and carbon fiber material.

Finally, in this chapter comparison between finite element analysis result simulations for the locomotives with different materials of the crash, a box is performed. Then, in addition, the stresses-time and deformation-time history results for the three collisions conditions for each case are compared. These results validated which parameter (material) is absorbing more energy and resist the stress with the same velocity, mass, and time.

4.1 Finite Element Analysis Result for Locomotive with Steel Crash box.

- **Von-misses stress Analysis result**

The outcomes of the simulation of a 36 kilometer per hour collision of the locomotive with a steel crash box and another same locomotive are summarized in the Figures below. Both trains are moving in a different direction and the impact speed of 36 km/h was chosen to provide von misses stress and enough kinetic energy to the system to bring it to the point where both the push-back coupler and anti-climber strokes were exhausted. Key values and more details regarding the results from the simulated crash are presented here and others are in appendix A. Sequential photographs from the simulation are shown in Figure 4.1 to Figure 4.8.

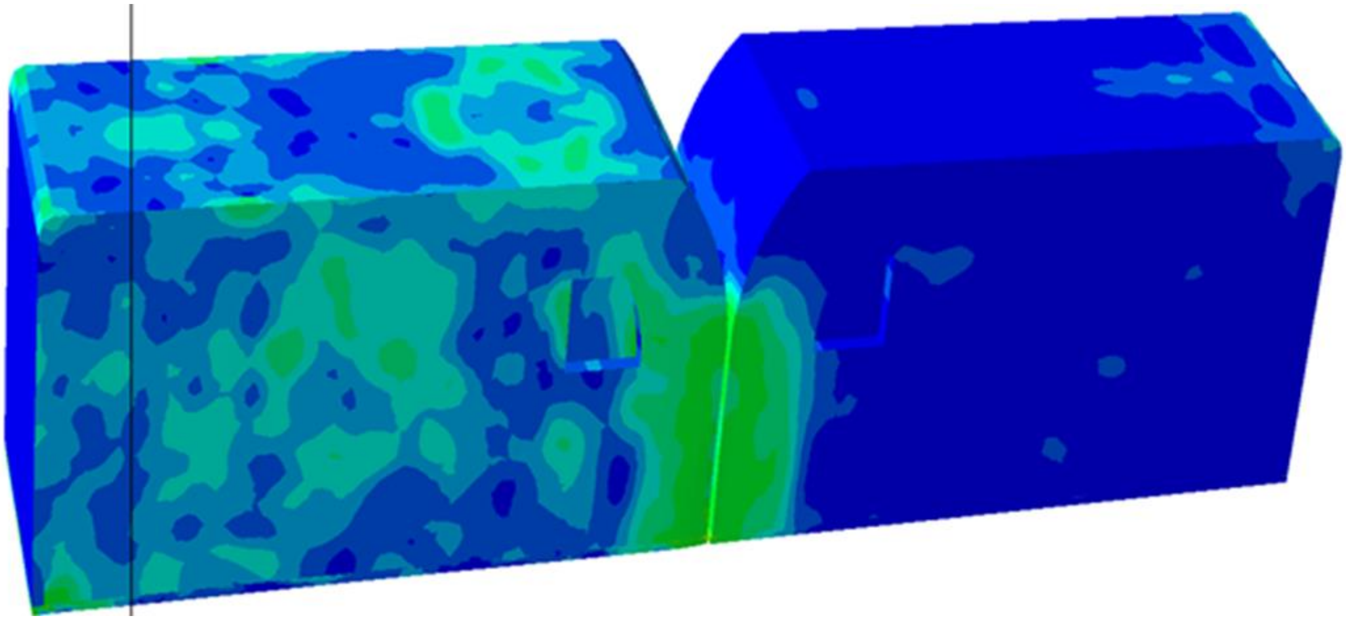


Figure 4.1 Collision of two locomotives with steel crash box: Showing crush of locomotives after 0.0056 seconds of crush.

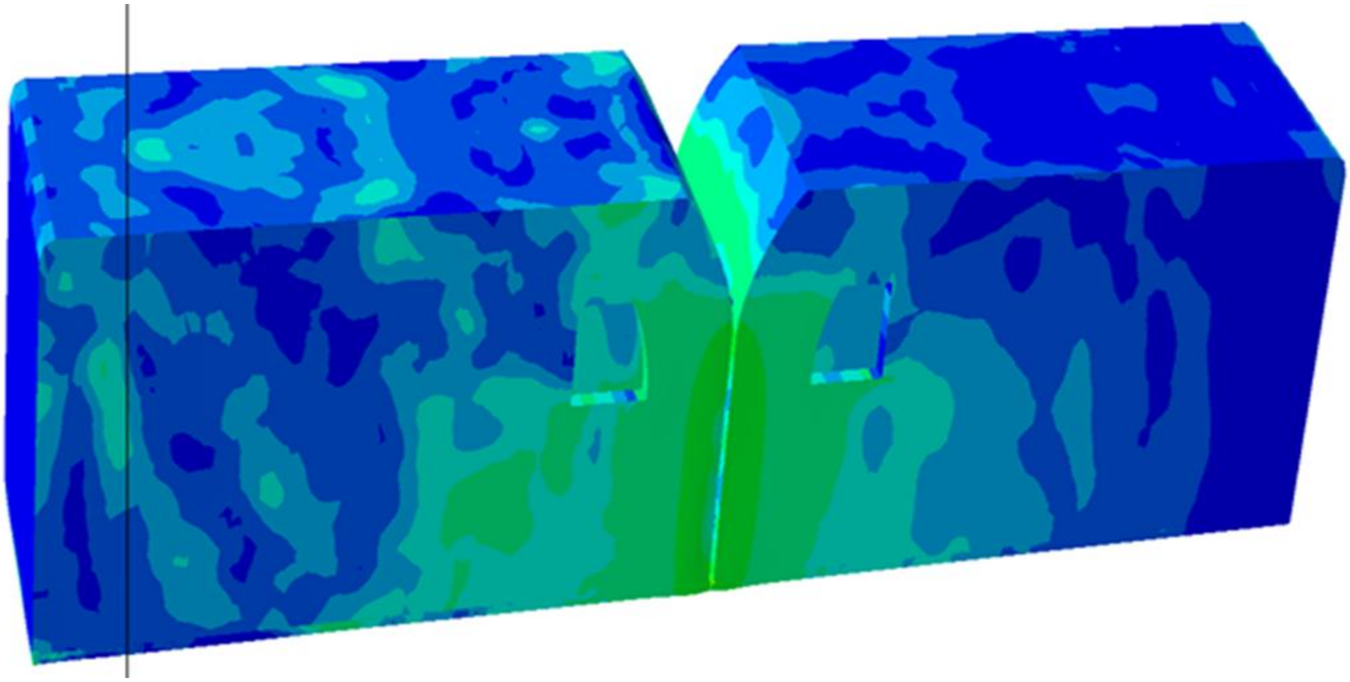


Figure 4.2 Collision of two locomotives with steel crash box: Showing crush of locomotives after 0.0065 seconds of crush.

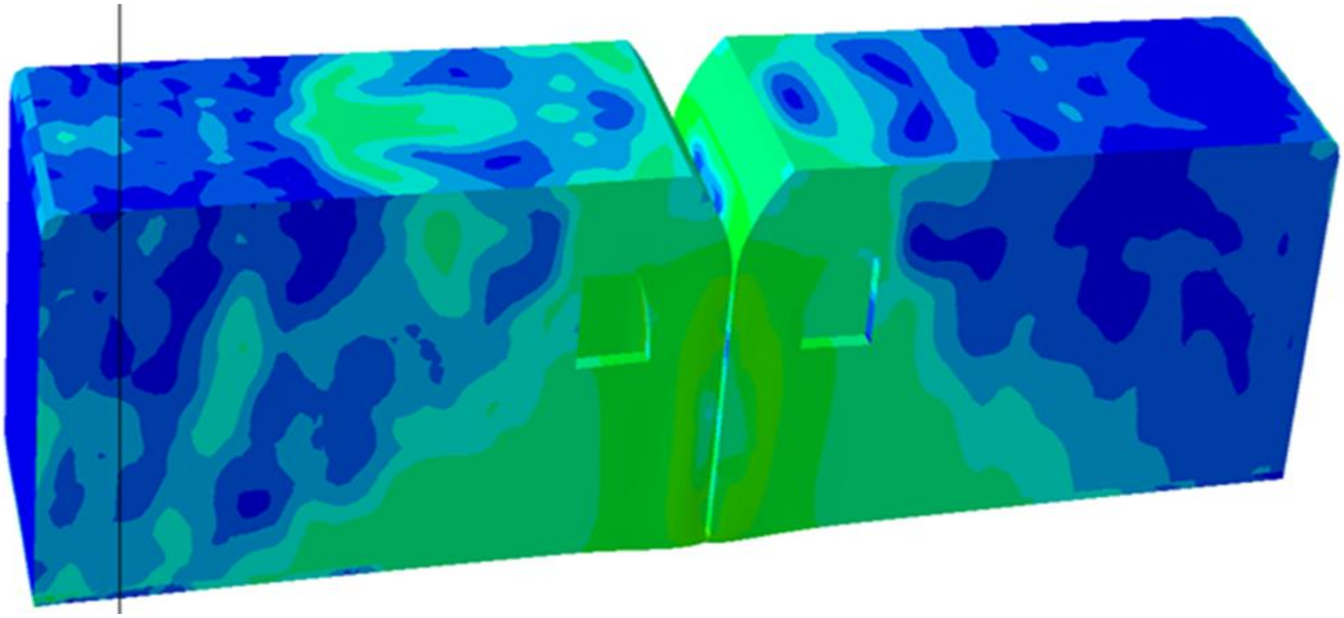


Figure 4.3 Collision of two locomotives with steel crash box: Showing crush of locomotives after 0.008 seconds of crush.

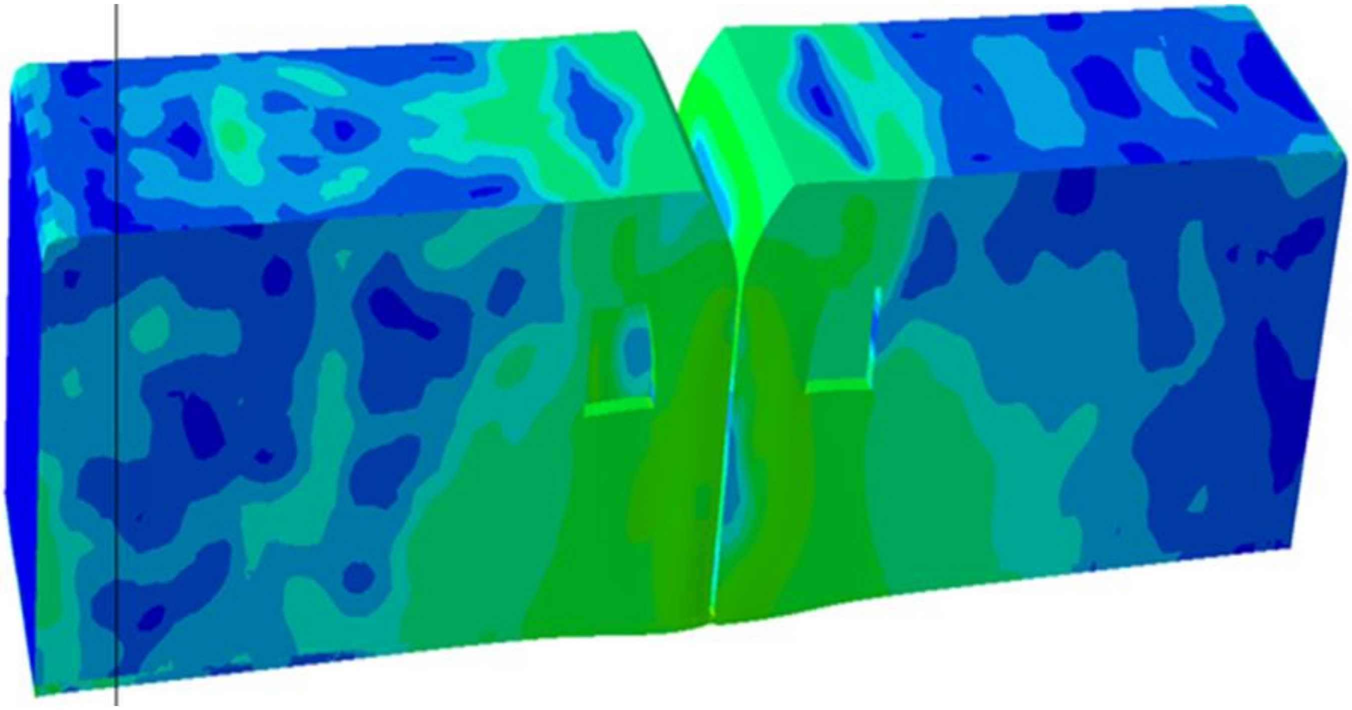


Figure 4.4 Collision of two locomotives with steel crash box: Showing crush of locomotives after 0.009 seconds of crush.

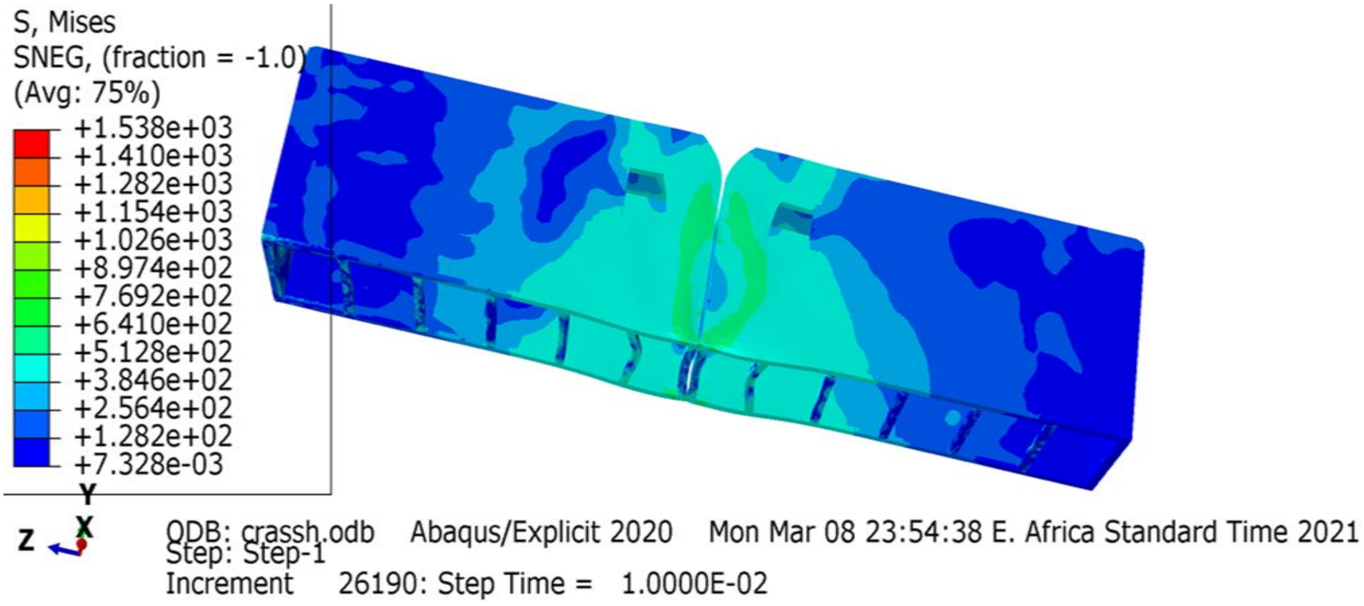


Figure 4.5 illustrates the deflection of two locomotives with steel crash boxes that experienced the largest deformation after crush.

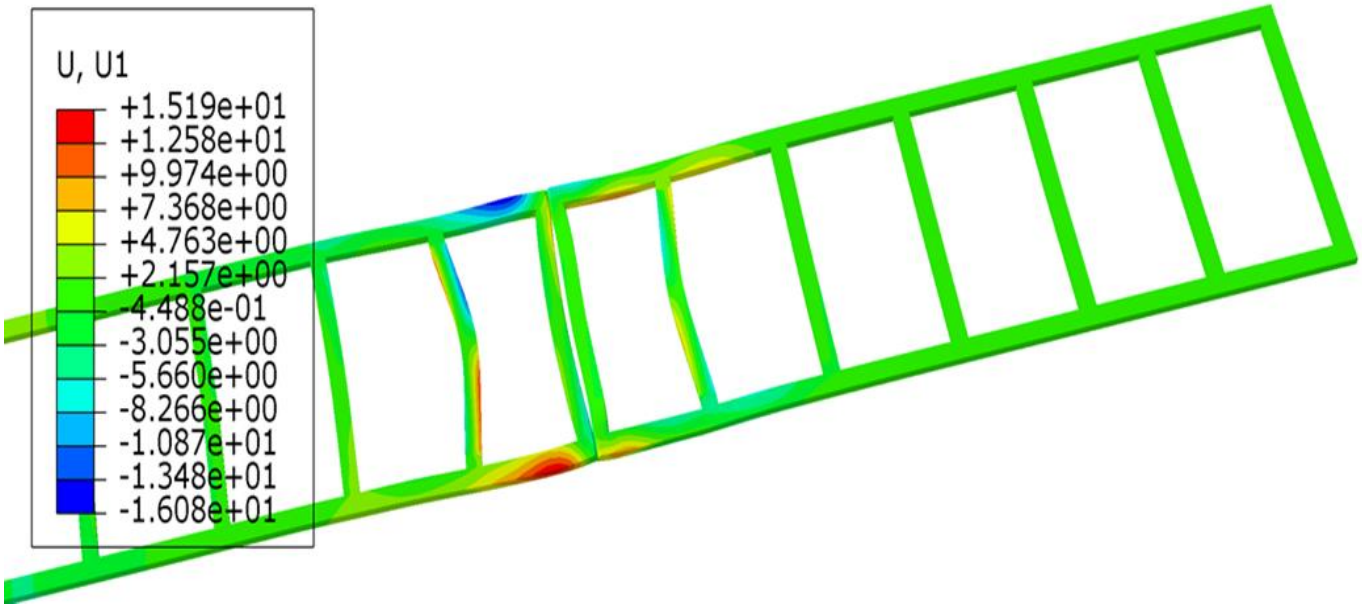


Figure 4.6 shows the damage of the chassis model after locomotives with steel crash box crushed.

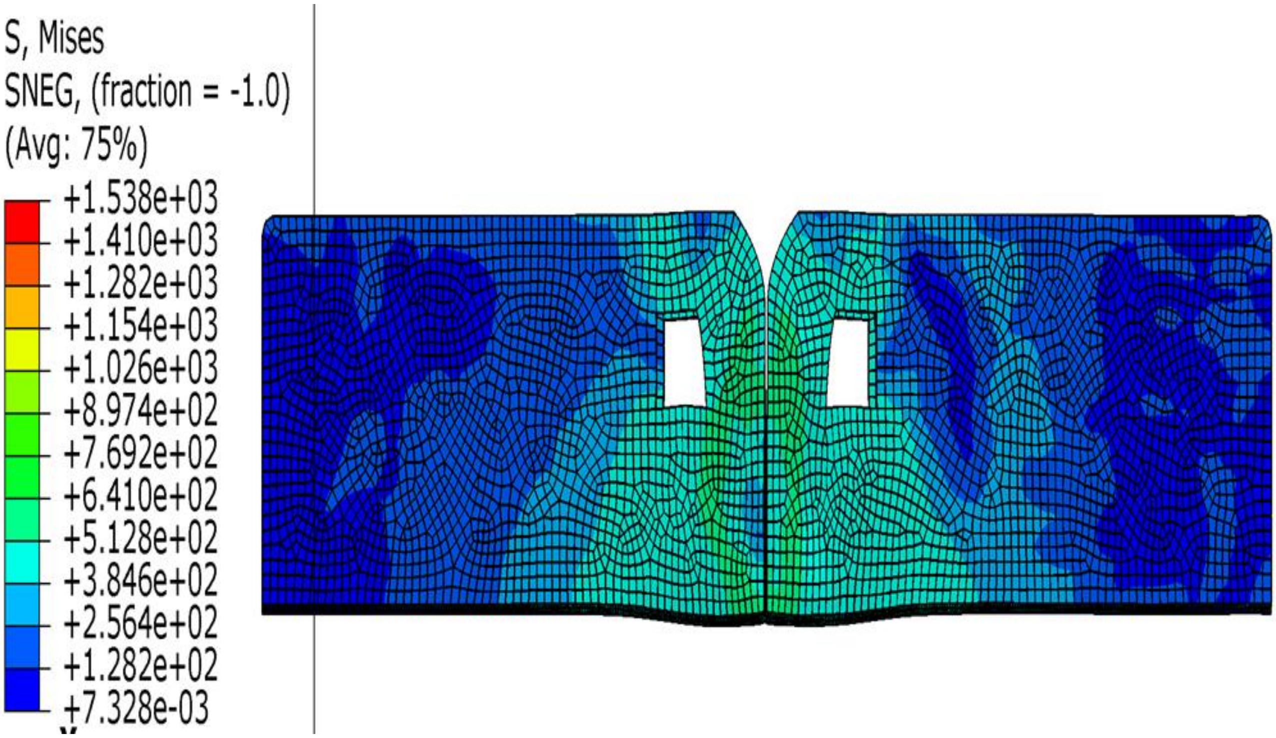


Figure 4.7 Side view showing damage of locomotives with steel crash box at 0.01 second after crushed.

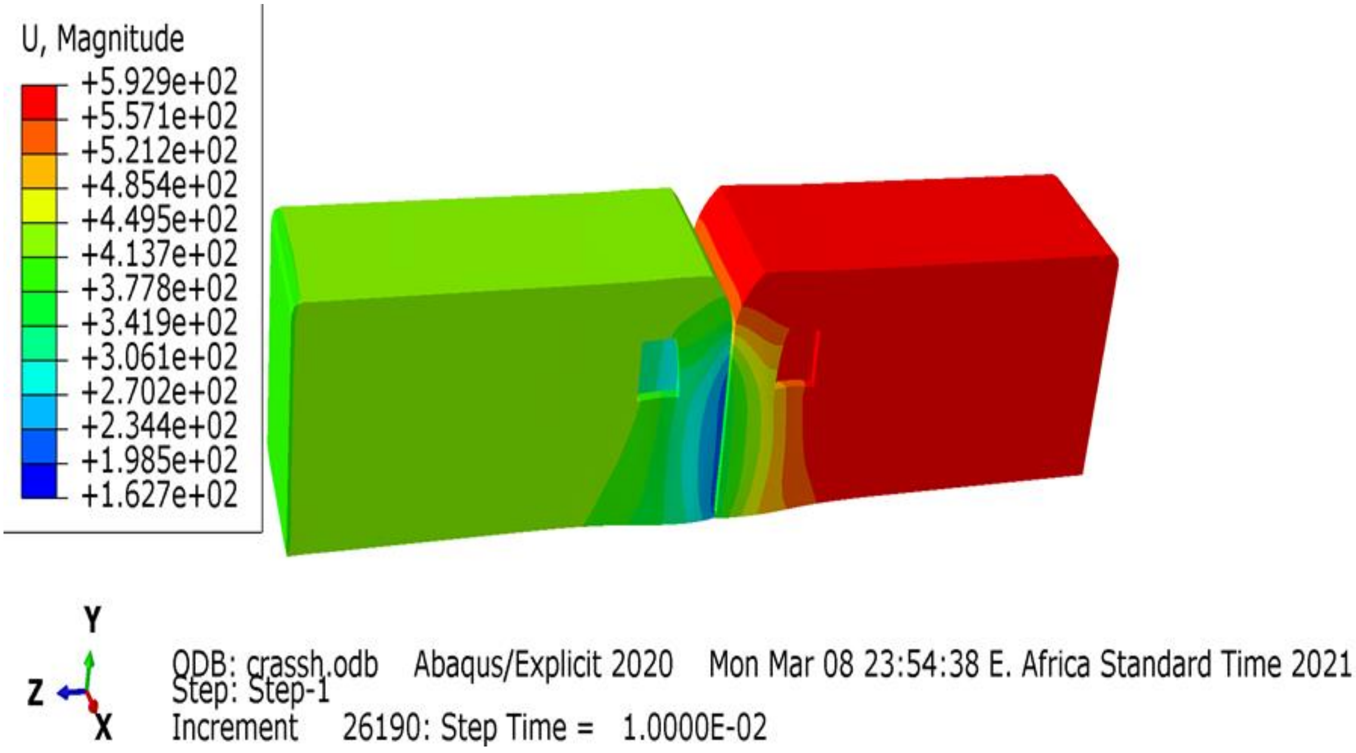


Figure 4.8 illustrates the total displacement of two locomotives with steel crash boxes after the impact ended at 0.01 seconds. Maximum displacement value of 592.9 mm.

4.1.1 Discussion for the Finite element analysis result of the locomotive with steel crash box.

The stress analysis results of the simulation of a 36 km/h collision of the locomotive with a steel crash box into another locomotive with a steel crash box are summarized in Figure 4.1 through Figure 4.8. Figure 4.1 to Figure 4.8 illustrate the deformation that arises as to the locomotives with steel crash box crushed. The results can be visualized according to the color code. Approximately 0.0056 seconds after the impact of locomotives with steel crash box Figure 4.1 shows deformation is occurring in both locomotive front end structures. Stress in the locomotive with a steel crash box can be observed in Figure 4.1 and the maximum stress obtained is 901.3 mpa.

After 0.0065 seconds of crush Figure, 4.2 shows the maximum value of stress rises and reached 1072 mpa and the underframe of locomotives with steel crash box has begun to buckle. Figures in Appendix A show the key values for stresses. From Figure 4.3 to Figure 4.4 after 0.008 seconds and 0.009 seconds of locomotives crush, the front end of locomotives with steel crash box begun to show significant plastic deformation. Photographs show that there are the stress variations of the steel crash box revealed at 0.008 seconds to 0.009 seconds and the analysis is near to the end. The maximum value of stresses drops off and reached 984 mpa in Figure 4.3 and 957.7 mpa in Figure 4.4. See Appendix A for values of stresses.

After 0.01 seconds of a crush as it is seen in Figure 4.5 shows the maximum stress obtained is 1538 mpa. This is the maximum stress obtained after the ending of the analysis of locomotives with steel crash box. 0.01 seconds is the total time taken to complete the analysis of the collision scenario. Figure 4.7 showing side view collision of locomotives with steel crash box after 0.01 second of crush, both locomotives damaged. The blue color in this photograph is used to show the lowest stress area. This means that the back end of locomotives stresses is not too high compared to the front end of both locomotives.

4.2 Finite Element Analysis Result for Locomotive with Aluminum Crash box.

- **Von Misses stress analysis result**

The below Figures illustrate the second step collision scenario results after analyzing locomotives fitted with aluminum crash boxes. The finite element analysis results of the simulation of a 36 kilometer per hour collision of the locomotive with an aluminum crash box and another locomotive with an aluminum crash box are summarized in the Figures below. Key values and more details regarding the von misses stress analysis results from the simulated aluminum crash box are presented here and others are in **appendix B**. Sequential photographs from the simulation are shown in Figure 4.9 to Figure 4.15.

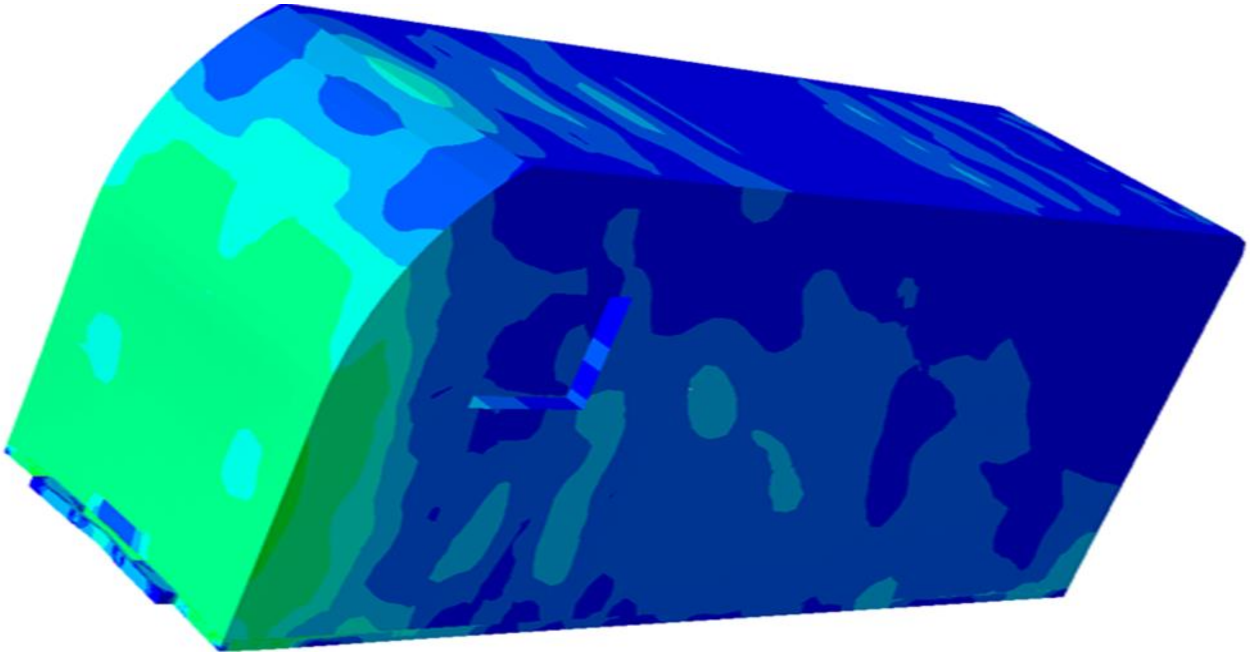


Figure 4.9 Isometric views showing the front end of the locomotive with aluminum crash box after 0.001 seconds of crush.

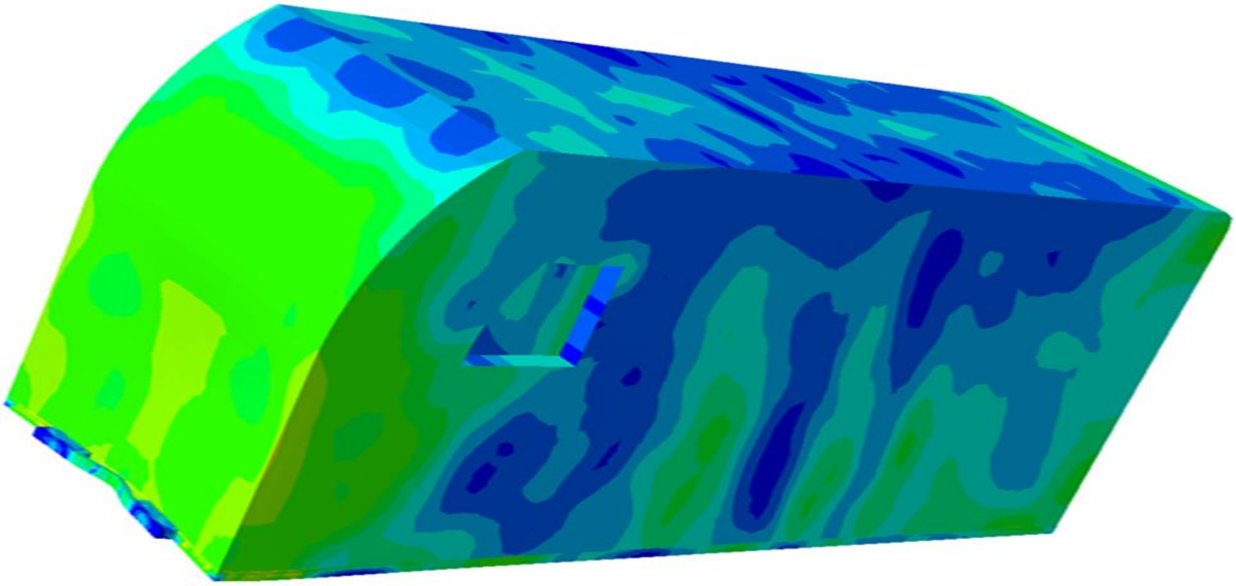


Figure 4.10 Isometric views showing the front end of the locomotive with aluminum crash box after 0.002 seconds of crush.

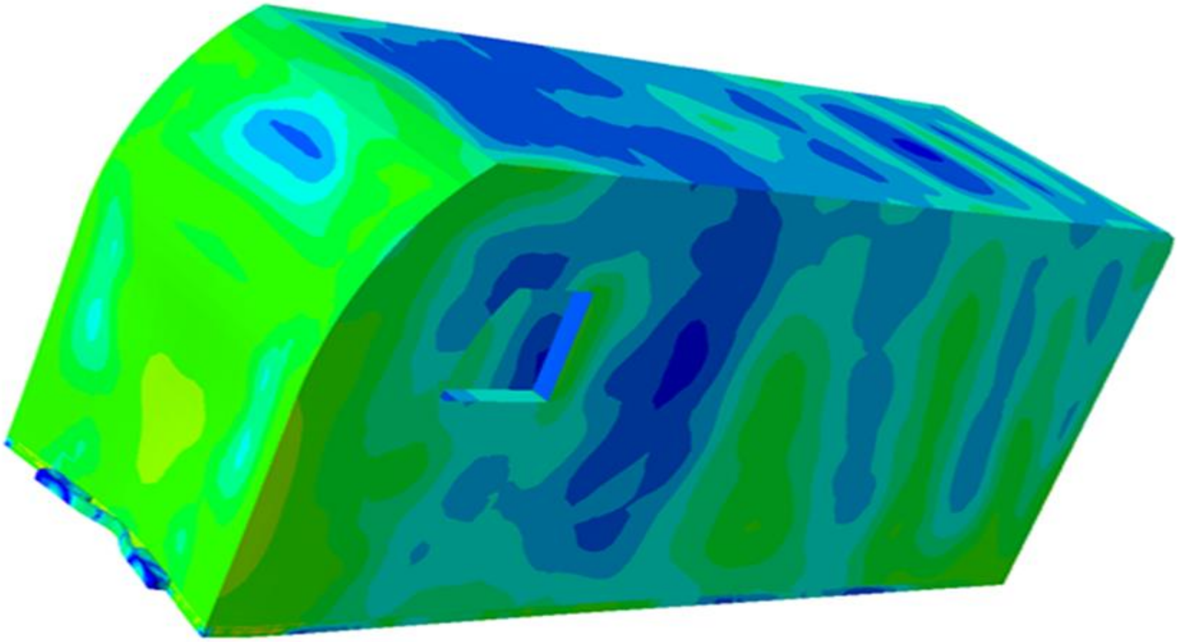


Figure 4.11 Isometric views showing the front end of the locomotive with aluminum crash box after 0.003 seconds of crush.

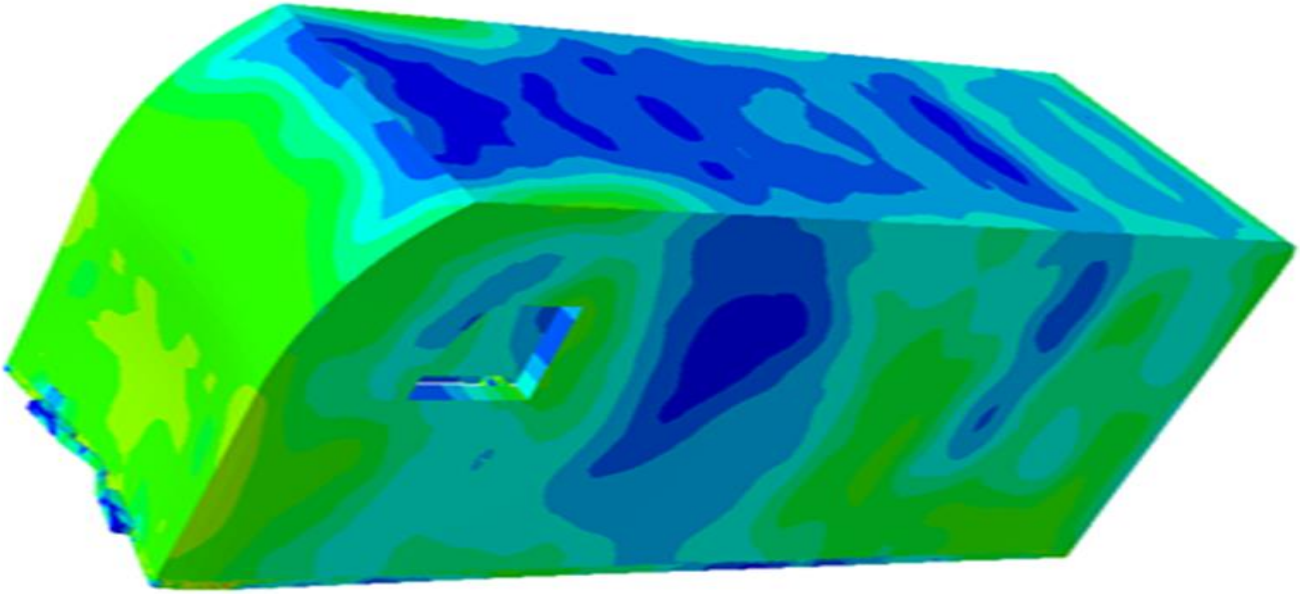


Figure 4.12 Isometric views showing the front end of the locomotive with aluminum crash box after 0.004 seconds of crush.

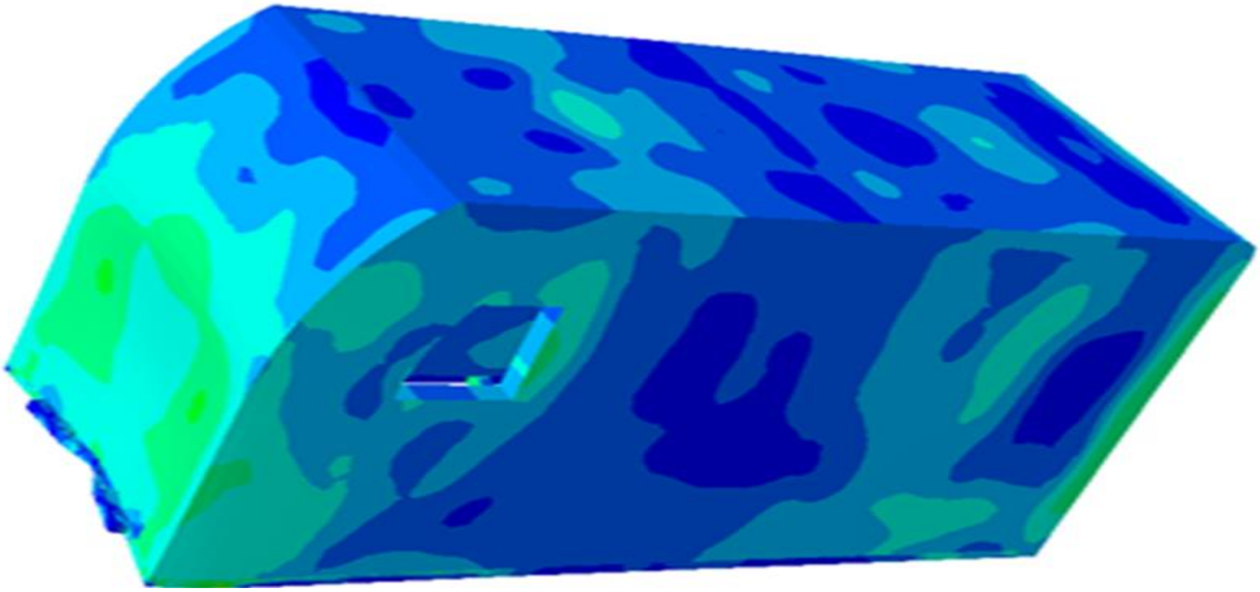


Figure 4.13 Isometric views showing the front end of the locomotive with aluminum crash box after 0.0052 seconds of crush.

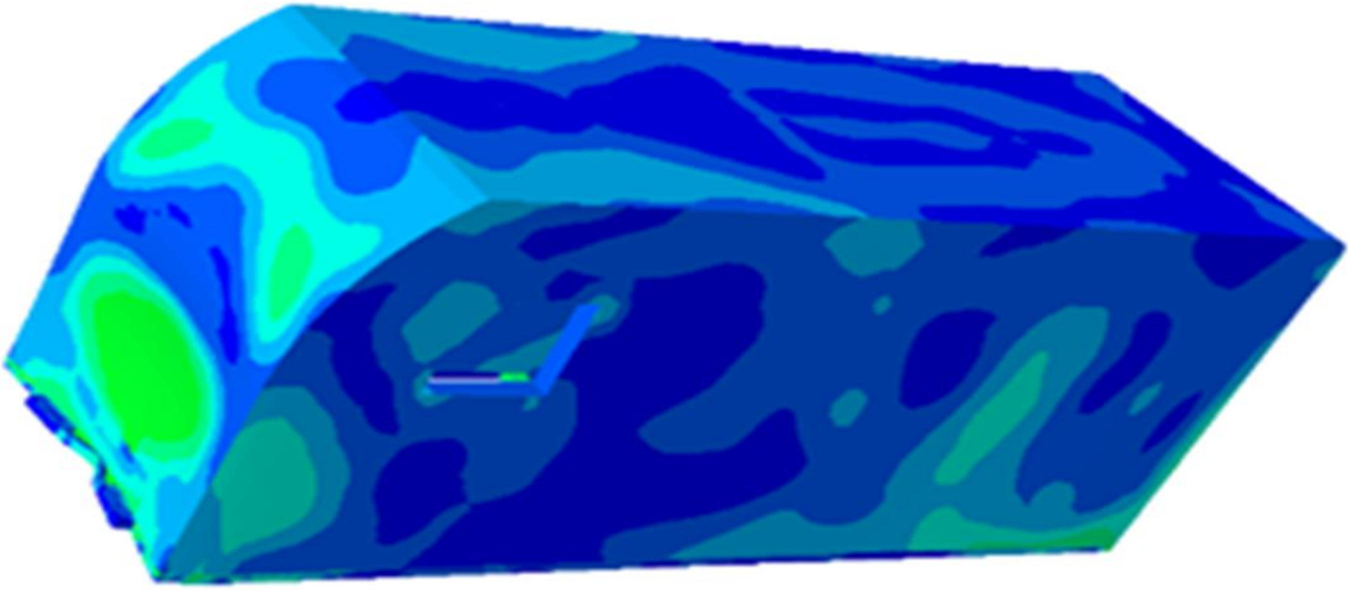


Figure 4.14 Isometric views showing the front end of the locomotive with aluminum crash box after 0.0065 seconds of crush.

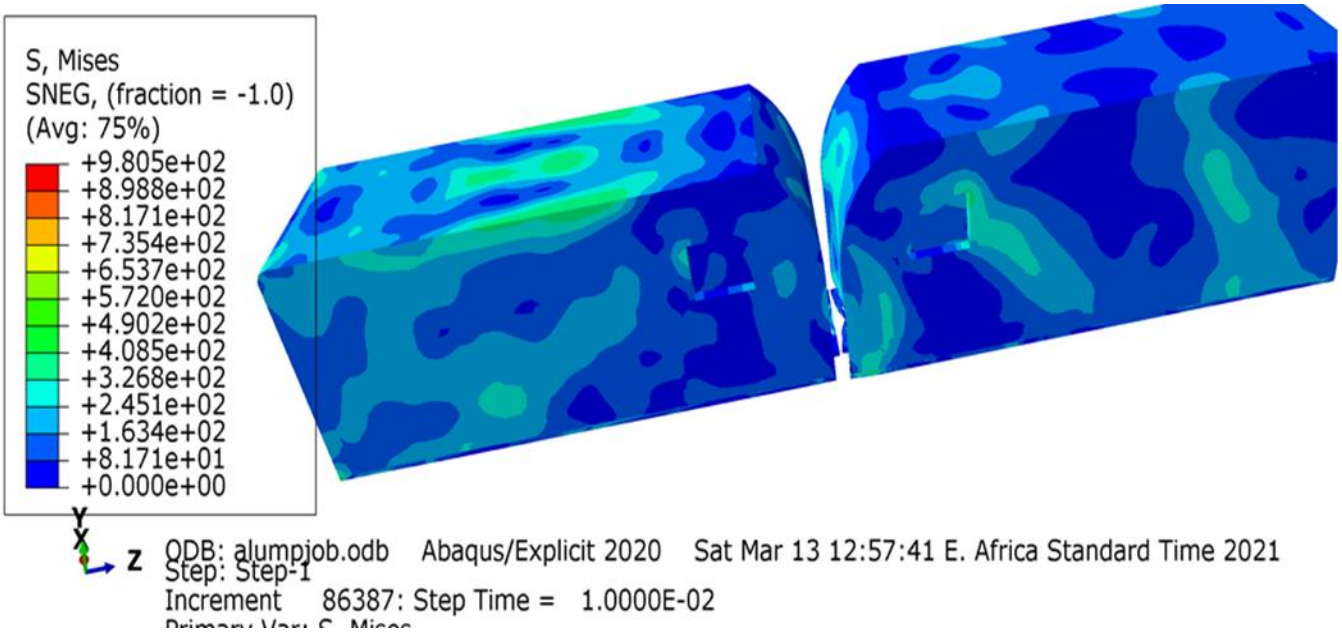


Figure 4.15 Collision of two locomotives with an aluminum crash box showing crush of locomotives after 0.01 second of crush.

4.2.1 Discussion for the Finite Element analysis result of the locomotive with aluminum Crash box.

Locomotive with an aluminum crash box collided with another locomotive with an aluminum crash box. The Finite element analysis result started when two locomotives impact after 0.001 seconds of the crush the maximum stress obtained is 1053 Mpa. Figure 4.9 shows Isometric views of the front end of the locomotive with aluminum crash box started to deform before the locomotive cabin/car body.

After 0.002 seconds of the crush, the value of maximum stress was reduced to 695.4 mpa. Figure 4.10 shows locomotive with aluminum crash box damaged effect reduced because the maximum stress obtained also reduced. Figure 4.11 shows the aluminum crash box and the body of the locomotive damaged after 0.003 seconds of crush. Figure 4.13 shows the aluminum crash box already buckled as shown in the figure after 0.0052 seconds of the crash.

In figure 4.15 after 0.01 second, the analysis of locomotive with aluminum crash box collision reach at the end. The analysis stop and the maximum stress is approximate 980.5 mpa.

4.3 Finite Element Analysis Result for Locomotive with Carbon Fiber material Crash box.

- **Von misses stress analysis result**

Locomotive with carbon fiber material crash box collided with another locomotive with carbon fiber crash box. Figure 4.16 represents von misses stress analysis result for the carbon fiber crash box. The result is taken out from the explicit dynamic analysis. After 0.01 seconds the analysis of the carbon fiber crash box is done and obtained the von misses stress of about 682.6 mpa. Figure 4.16 is the representation of the Isometric view showing the front end of locomotives with carbon fiber material crash box damage after a crash at 0.01 seconds.

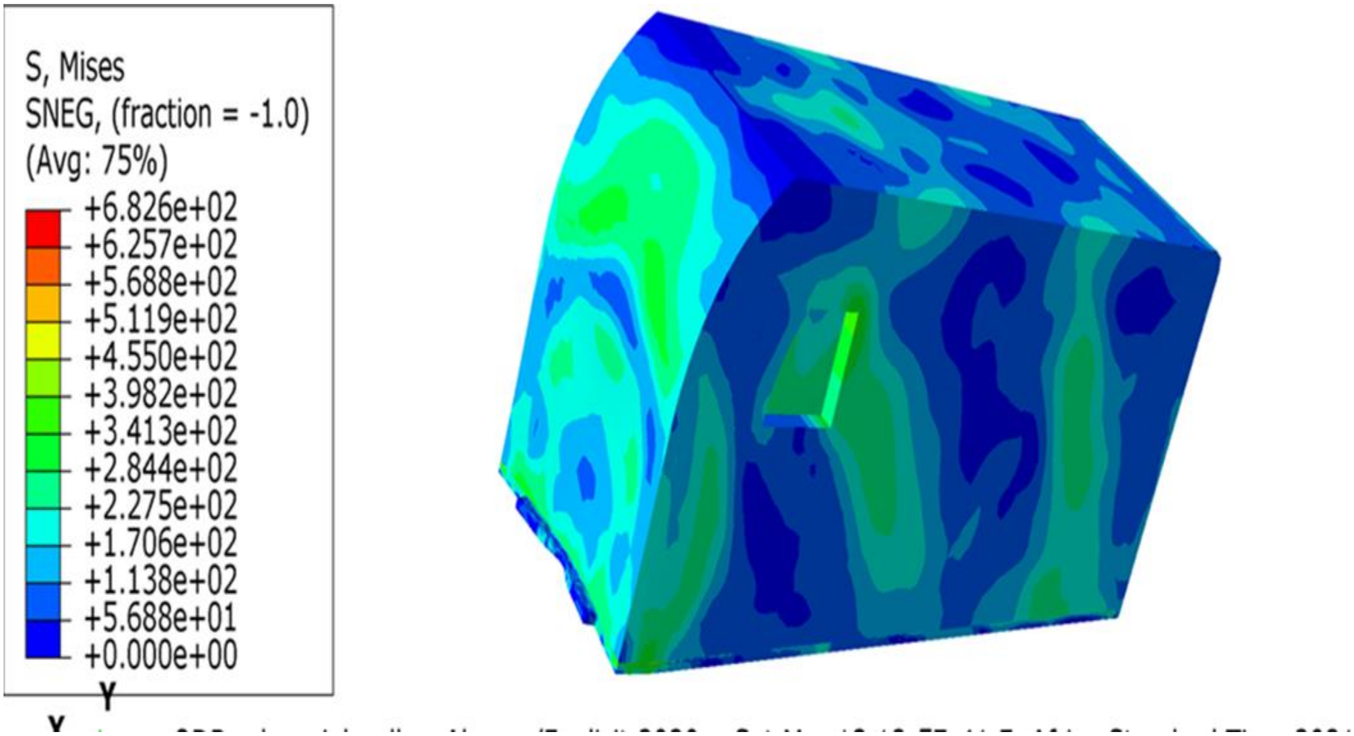


Figure 4.16 Isometric view showing the front end of locomotives with carbon fiber crash box damage after a crash at 0.01 second.

4.3.1 Discussion for the Finite Element analysis result of the locomotive with carbon fiber Material crash box, Steel and Aluminum crash box using graphs.

An annotated stress versus time curve is shown in figure 4.17. Graphical representation of von misses' stresses analysis results for steel, aluminum, and carbon fiber materials crash boxes are shown. Crash analysis of the locomotives crash box is done and we observe a change of stresses. The stresses in an object depend mainly on the material and the number of forces applied.

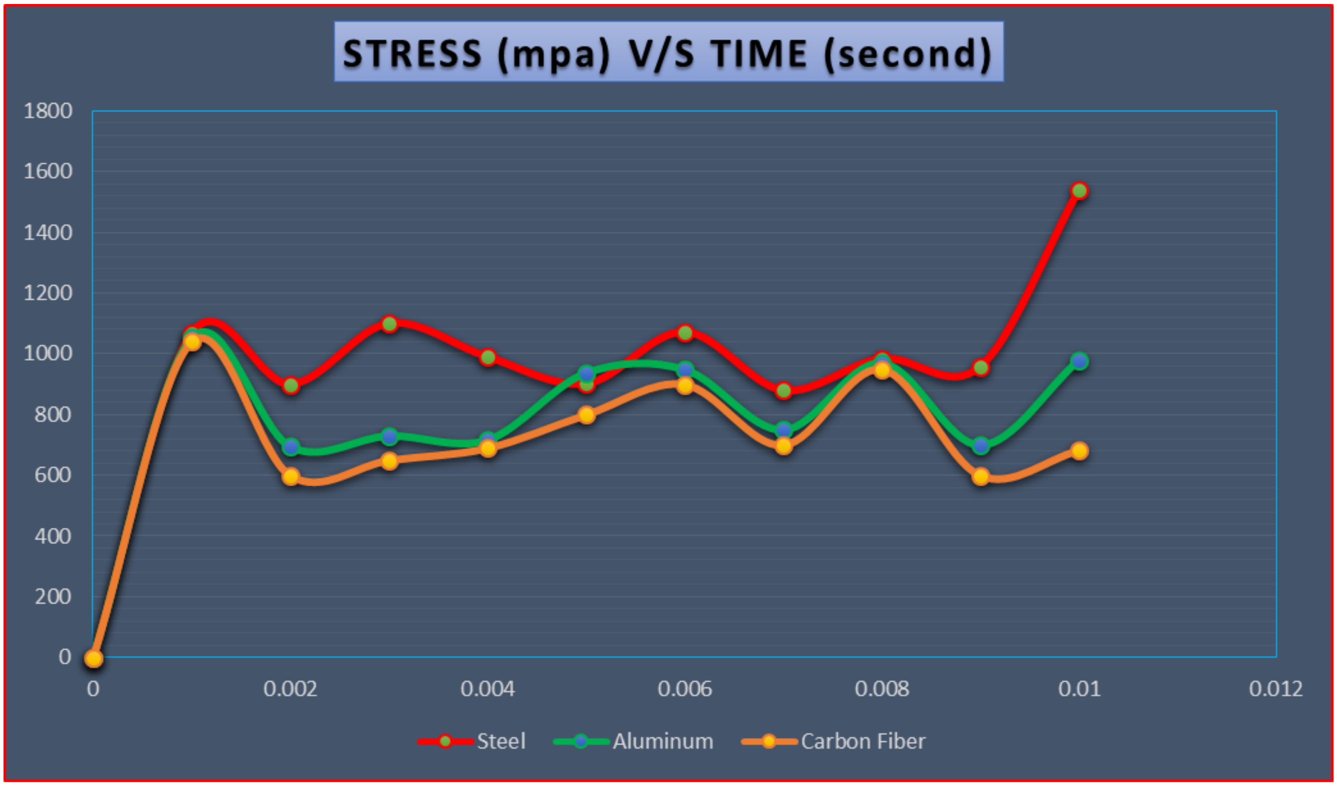


Figure 4.17 Graphical representation of the von misses stress analysis result for the steel, aluminum, and carbon fiber crash box models after impact with the velocity of 36 km/hr. According to the Figure, the von misses stress value distributions of the Carbon fiber crash box are less than that of the steel and aluminum crash box, which means that the carbon fiber crash box model is better than the steel and aluminum crash box model. The first peak in the stress graph shows initial contact between the locomotive's front ends.

In the Figure above according to the comparison between the different materials of the crash box in analysis, it is indicated that the carbon fiber material crash box possessed less von misses stress about 682.6 mpa compare with aluminum 980.5 mpa and steel 1538 mpa, we aim to compare different materials to know which material is suitable for designing the crash box. It seems when you design a crash box by using carbon fiber material is better for impact because it reduced force or stresses during impact/collision of locomotives. When stress is small means energy absorption after impact is too high.

Carbon fiber material can be used as a suitable crash box for minimization of damage on locomotive and injuries in humans during head-on collision accidents.

In the present research, the size of the front damage from a collision phenomenon was measured and used to verify the numerical configuration. Parameters in the external dynamics of a locomotive collision such as the location of the contact point and velocity of the striking locomotive were taken into consideration.

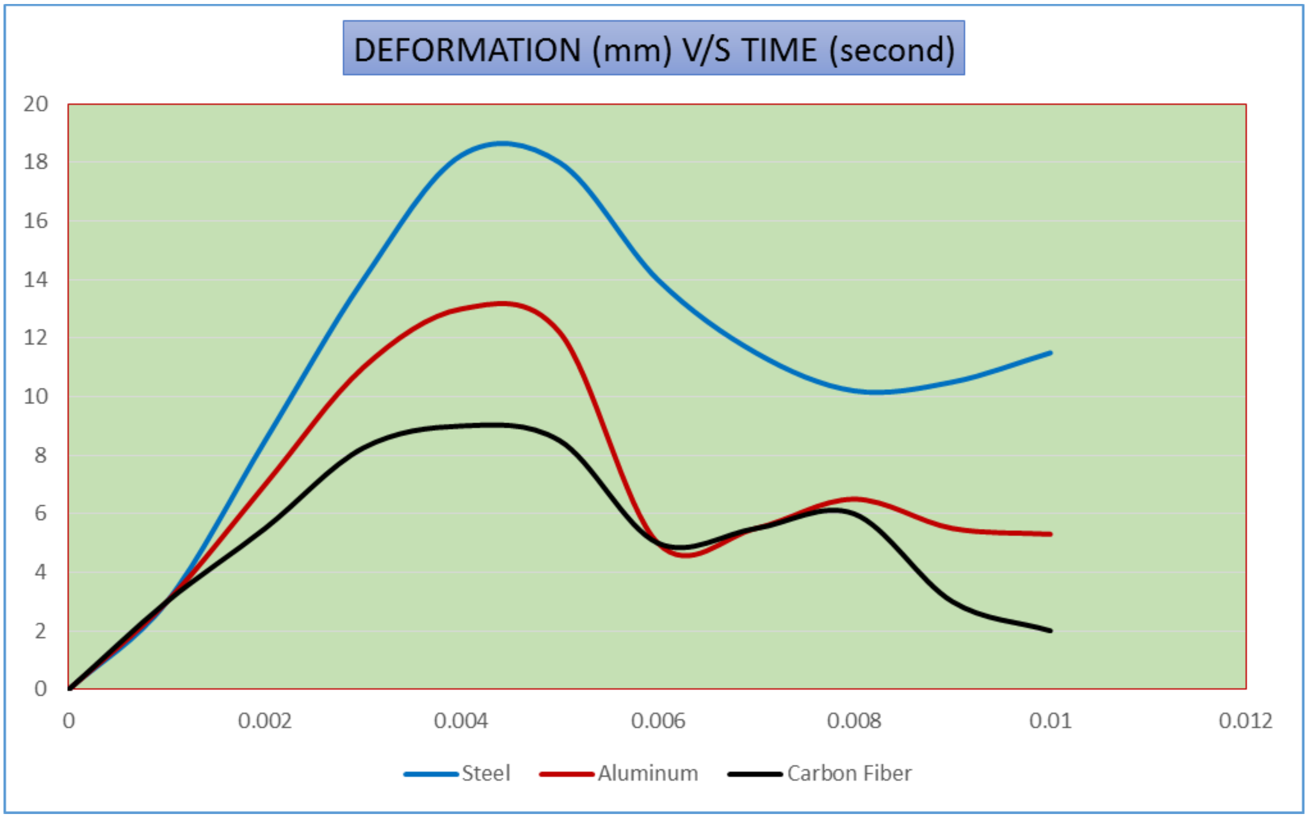


Figure 4.18 is the representation of the deformation time curve for different materials locomotive crash boxes.

In the impact of two locomotives train where the crash boxes contact in the front end of locomotive having stresses and deformations. In this work, one point in front of the locomotive is chosen and after the impact, the maximum values of stress and deformation are found at the point of contact. This is called reference point which is taken at node 3 at the front end or front Centre of the locomotive crash box. This is the part of the model where stresses and deformations are taken from. After the impact of locomotives the stresses and deformation time graphs are plotted.

Figure 4.18 shows that stress will cause deformations. Deform may imply a change of shape through stress, injury, or accident of growth. Local deformation destruction includes damage produced by mechanical external effects and damage caused along with buckling as an outcome of decline of strength. Material with the least deformation as compared to another material is suitable for crash impact because meets requirements of high strength and higher stiffness.

Figure 4.18 shows deformation analysis result at different materials and maximum deformation for each material are as follows. Steel 11.5 mm, aluminum 5.3 mm, and carbon fiber material 2 mm. Through the analysis of thin materials, carbon fiber is chosen as the material of the locomotive crash box instead of steel and aluminum to reach the lightweight design.

Explicit Dynamic Analysis			
Material	**Steel**	**Aluminum**	**Carbon Fiber**
Deformation (mm)	11.5	5.3	2
Stress (mpa)	**1538**	**980.5**	**682.6**
Energy Absorption (KJ)	10	12.5	13.375

Table 4.1 representation of analysis result of three kinds of material specifications is shown. It can be seen that deformation and stresses of carbon fiber material are improved which ensures the effective delivery of impact force. Hence the lower deformation and stresses crash box material is selected as an optimum material. The carbon fiber material is proposed for improved safety of locomotives.

4.3.2 Comparison of crushing force (Load) and Displacement for steel, aluminum, and carbon Fiber locomotive crash box models.

Finite element analysis results show the comparison of different collision scenarios for locomotives with crash boxes made up of different materials by using a Load-displacement curve. Consider the figure 4.19 below help to explain an impacted or crushing behavior between two bodies, the load-displacement curve can be subdivided into three distinct regions as indicated in Figure below.

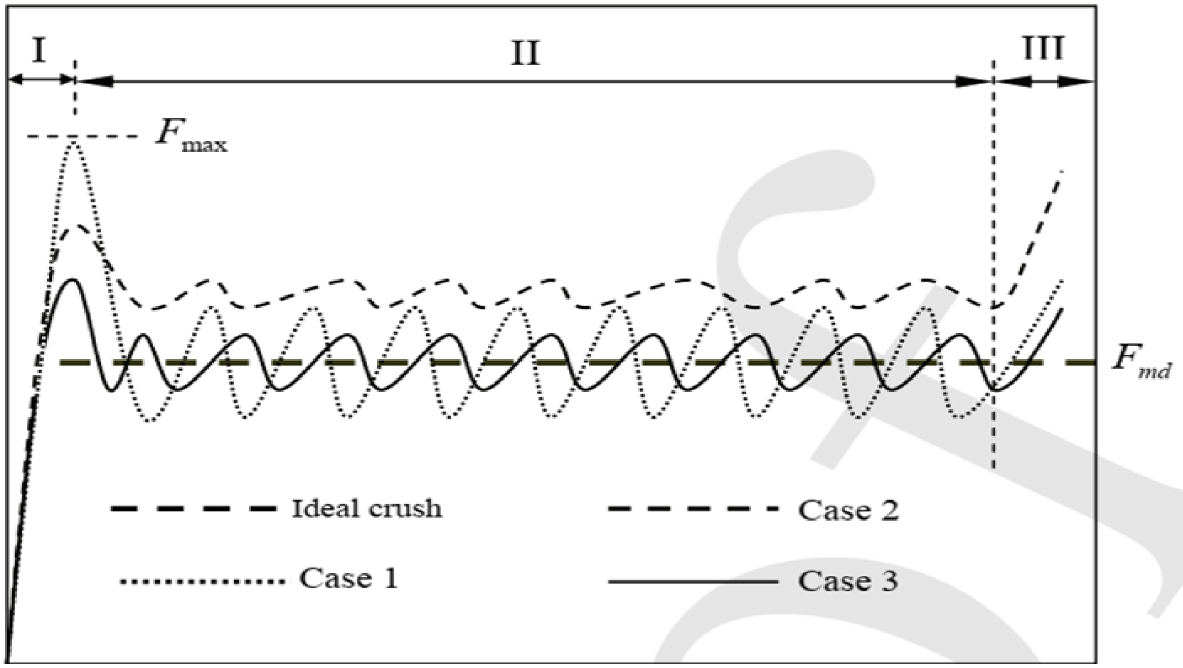


Figure 4.19: Comparison of the different scenarios of the load-displacement curve during impact. (Ghasemnejad, 2009)**.**

In region I, the load/force increases rapidly and reaches a maximum (F_{max}) before dropping. If you have different designs, case 1 design has the highest initial maximum collapse force or load among the others, and hence it is dropped; though its F_{md} is about the ideal solution.

In region II, the force or load fluctuates around a mean dynamic force (F_{md}) while a series of folds form successively so that a folded zone grows progressively in a form of mushrooming failure. Case 2 will suck up higher energy in the identical crush distance but its mean dynamic force is excessive than the ideal crush solution.

In region III, all lobes touch each other, and the box stiffness to the impacted object increases, and this will cause a rapid increase in the force or load. In Case 3, the initial collapse force is relatively low and the mean crush force is equal to the ideal crash box which fluctuates with low amplitude around the ideal mean dynamic force (Ghasemnejad, 2009).

Figure 4.20 illustrated absorption levels during a collision and crash energy management designs are ideally located at the extremities of the locomotives. Crashworthy energy-absorbing zones occupy minor volumes of a train and can sustain large plastic deformations.

The load-displacement results obtained from finite element analysis simulations for all locomotives made up of different materials for crash box collisions are shown in figure 4.20 together with various stages of deformation of both locomotives and crash box during the deformation.

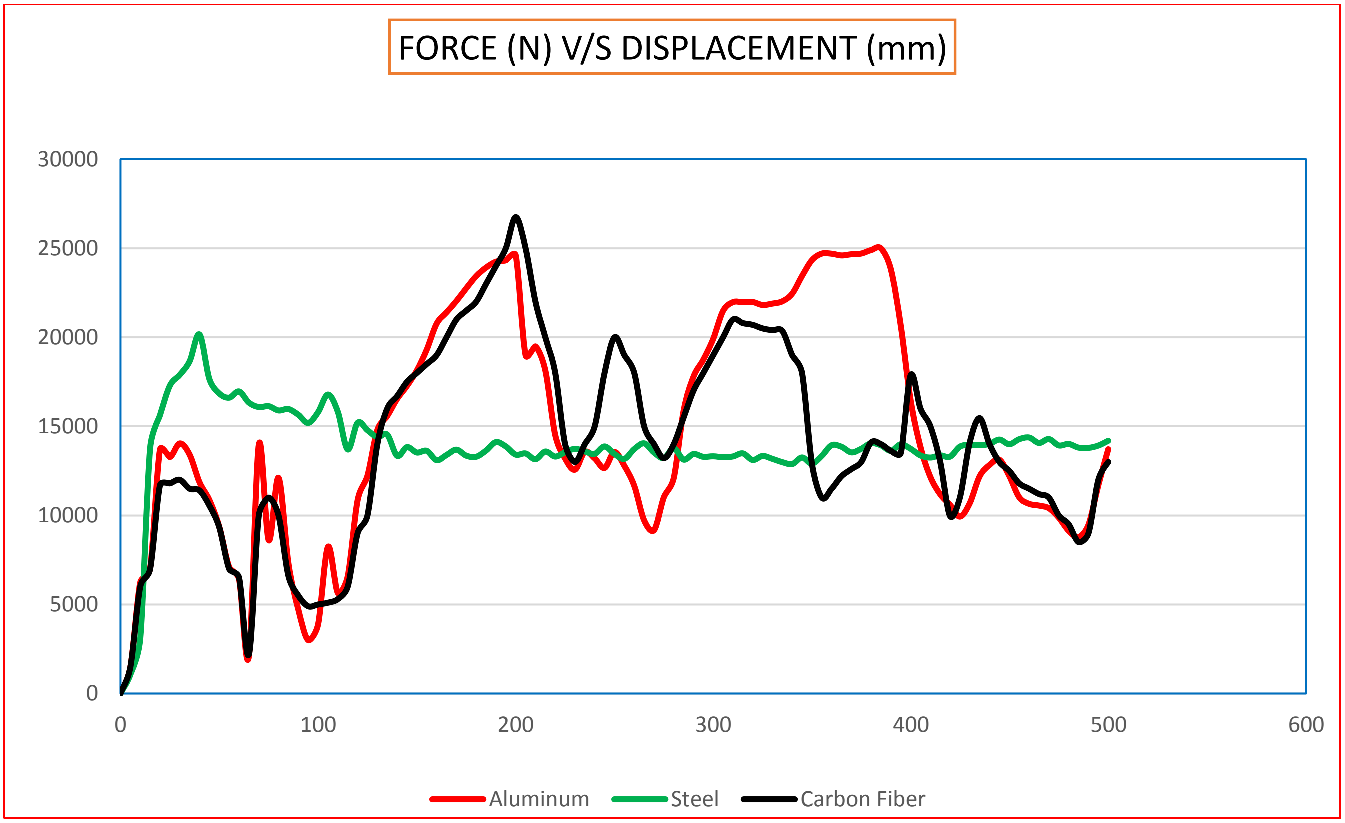


Figure 4.20 shows the Comparison of crushing force (load) versus displacement curves for steel, aluminum, and carbon fiber locomotive crash box models collision.

As written before, in a force-displacement graph are easily definable some important points like the mean and the maximum crushing forces and the conditions that a locomotive with a crash box must be respected are related to those values. The maximum initial crush load of the locomotive with light material crash box models like carbon fiber should be lower than the maximum initial crush load of the locomotive with other materials crash box models like aluminum and steel. Also lower than the mean crush load of the locomotive with aluminum and steel crash box as shown in figure 4.20; for the locomotive with carbon fiber crash box finite element model the maximum initial crushing force/load is approximately 12,000 N and for that of locomotive steel crash box model is 20,000 N. Maximum initial crush load for the locomotive with an aluminum crash box is 14,000 N.

Figure 4.20 represents a curve that shows locomotive with steel crash box model obtain higher initial crushing load/force experienced after models collide. This means that high force/load will be transferred to the components and occupants of the locomotive during the collision. Due to this reason, we modified the locomotive by fitting or replace the crash box with other materials like aluminum and carbon fiber. After using other materials far from steel the maximum initial crushing force is reduced or is lower compared to that of steel locomotive models. This is the indication of the internal energy absorbed by the crash box makes it initially deformed. Initial Crushing force needs to be small because it is related to the deceleration of the locomotive with aluminum and carbon fiber crash box models during impact (Jones & Wierzbicki, 1998). This is why the initial crush force for aluminum and carbon fiber materials models is smaller than that of steel models. This will help to reduce damage to the locomotives and safety for passengers. From the load-displacement curve, carbon fiber material qualifies to design crash box because will give the result of small initial crush force during the collision as shown in Figure 4.20.

As we discussed before the first peak in the graph or at the start the initial sharp rise in load curve is evident in each graph as the locomotives initially are in contact at the front end of both locomotives for all collision scenarios. Once the elastic limit of the collision is reached the load rapidly drops to enter a range where it levels out and fluctuates about a mean value. The load drop is related to the appearance of the plasticized zone and then the structure starts to fold. For the locomotive with steel crash box model in figure 4.20 after high maximum initial crushing load (peak force) reduced means that there is no need for such a large force to start the deformation process thus we saw the amplitude of the little peaks which signify progressive folding collapse are higher initially and gradually decrease. Since biomedical loading caused by the impact will be experienced by the locomotive with steel crash box occupants, a lower mean dynamic crush force is desirable as long as the energy absorption criterion is satisfied.

Figure 4.20 shows the impact force-indentation relationship (Force-displacement) during the dynamic impact for various examined steel, aluminum, and carbon fiber crash boxes. The force-displacement curves can be divided into two categories. Each force-displacement curve has an ascending section of loading, reaching the maximum load value, and a descending section of unloading.

The ascending section of the Force-displacement curve is called bending stiffness due to the resistance of the crash box material to impact loading, at the point when the maximum load value reaches the highest maximum load. After reaching the maximum load value, a descent in force occurs as a result of the impact bouncing off the examined material surface or damage of the material. A sudden force decrease causes buckling of the crash box structure by the impact force. (Patryk, 2014).

It was discovered that for the examined materials, the maximum load/force values are lower for crash boxes with steel than for those containing aluminum and carbon fiber. Crash box with steel maximum force is 20,000 N, a crash box with aluminum maximum force is 25,000 N, and crash box with carbon fiber maximum force is 26750 N.

One of the parameters used in the process of crash box structure damage assessment resulting from dynamic impact is impact energy and absorbed energy. Energy is explained as the amount of energy involved by the crash box assembly during the dynamic collision. The absorbed energy can be concluded from the force-displacement curves registered during dynamic impact. (Sohn, 2000).

The point of getting to maximum force controls the areas of damage establish energy until the maximum force point is attained, as well as the area of damage spread energy after attaining the maximum force point.

Generally, a crash box with carbon fibers material absorbs more impact energy and is characterized by higher maximum load/force values in comparison to a crash box containing aluminum and steel.

Crash boxes with carbon fibers material, show relatively small damage deformation, which makes them comparatively brittle and influences their susceptibility to damage due to dynamic impact. Crash boxes with carbon fiber material are characterized by higher impact resistance in comparison to crash boxes with aluminum and steel material structures. It is proved by higher maximum load /force levels in Figure 4.20.

4.4 Validation of work.

Wang et al. (wang, 2015) through their paper, studied the effect of the type of material on the impact behavior, the specifications of steel and carbon fiber composite were assigned to the bumper beam in separate impact simulations. They show the energy curves of the two impact models whose bumper beam is made of steel and carbon fiber composite, respectively. Through analyzing the energy curves, the validity of the finite element model can be determined.

The ECE R42 standard does not provide a reference point to measure the deformation. They used a node whose deformation is the biggest in the bumper beam taken as a reference point to observe the deformation of the bumper beam. The deformation versus time diagram is shown and the maximum deformation is 19.1 and 16.3 mm for steel and carbon fiber composite respectively. The maximum deformation point is 0.084 seconds for steel and 0.080 seconds for carbon fiber.

In my project, it is seen that in figure 4.18 the deformation time curve shows the maximum deformation is 19 mm steel, 13 mm aluminum, and 9 mm carbon fiber. The maximum deformation point is 0.004 seconds.

If you compare the reason for this situation is that the stiffness of carbon fiber composite is higher than the stiffness of steel and aluminum. According to experience, when the deformation changes to the lowest value with a slight fluctuation, the collision ends. The end time of the collision is 0.01 seconds. The maximum deformation of the carbon fiber crash ox is lower than that of steel and aluminum crash boxes. Through using the carbon fiber material, the impact performance of the crash box is improved.

Ali, Dadrasi et. al (2012) through his research (Ali, 2012) explain that total energy absorption is calculated by the area under the load-displacement curve or the energy absorbed during crush was calculated by integrating under the crushing load versus crush distance curve.

Locomotive structure or partly constructed from composite materials must meet or exceed crashworthiness standards such as Federal motor vehicle safety standard (FMVSS) 208. Therefore for a composite structure designed to support the integrity of the automotive structure and provide impact protection, it is imperative to understand the energy absorption characteristics of the candidate composite structures.

Muhammad et al. (Muhammad, 2015), detailed finite element analysis is presented to evaluate the energy-absorbing characteristics of a carbon fiber reinforced polymer composite lower rail, a critical impact mitigation component in automotive chassis. For comparison, the analysis is repeated with equivalent aluminum and steel lower rails. The study was conducted using the ABAQUS Zone module, finite element analysis software. The simulation results show that the composite rail crushes continuously under impact load which generates a force-displacement curve. The energy curves obtained from reactive force-displacement graphs show that the composite rail absorbs 240% and 231% more energy per unit mass as compared to aluminum and steel rails. This shows a significant performance enhancement over equivalent traditional metal (aluminum and steel) structures and suggests that composite materials improve the crashworthiness of automobiles while offering opportunities for substantial weight reductions. In my project, it is seen that after simulation in Figure 4.20 energy absorption by steel, aluminum, and carbon fiber are 10 KN-m, 12.5 KN-m, and 13.375 KN-m respectively.

When you compare energy absorption you will see the locomotive with carbon fiber crash box model satisfies the energy absorption requirements which improved more than that one of the locomotive crash boxes made up of aluminum and the one made up of steel. In short, using a crash-worthy structure made up of carbon fiber in the front end of the locomotive improved energy absorption during collision scenarios, help to reduce the force transmitted to the driver, passengers and other components of the locomotive hence reduce damage. Crash box with carbon fiber materials meets all its performance requirements

To increase the energy absorption and efficiency of the energy-absorbing structure, a crash box with carbon fiber materials can be used (Sun, 2016) (Guohua, 2018).

This project can be validated by the experiment in the literature of (Muhammad, 2015).

Norman Jones and Tomaz Wierzibiki with a journal article titled structural crashworthiness said that the initial peak load is a very important design variable. The peak load for the crash box has to be lower than the initial peak load/force (Pmax) in the side member, or else the side member will collapse first during the collision. Figure 4.20 shows that a crash box with carbon fiber has a lower initial maximum force (Jones & Wierzbicki, 1998). Locomotive with carbon fiber crash box collapse more when you compared with a locomotive crash box made up of steel and aluminum. Figure 4.20 confirmed through the initial peak load for locomotive with carbon fiber crash box model which is small if you compared with the initial peak load for the locomotive with a crash box made up of steel and aluminum. It means that after the collision of locomotives with carbon fiber crash box models the initial peak load/force (Pmax) is lowered. The crushing force needs to be small because high force/load will be transferred to the locomotive components and passengers and cause injuries and damage to the locomotive.

The simulation using finite element software, ABAQUS was also used for validation of the models. Rail track structural requirements for railway group standard (1994) was set a minimum energy absorption of 1Mega Joule over a distance not exceeding 1metre with a mean dynamic force of 3000kN. Under this design requirements, the ideal energy absorber is a rectangle with a mean dynamic force (Fmd) less than 3000kN over a maximum allowable crush distance which absorbs the specified impact energy Ghasemnejad et. al (2009) shows this in (Ghasemnejad, 2009). So for Figure 4.20 force versus displacement confirmed this and satisfy the design requirements that mean dynamic force of crash box made up of carbon fiber is less than 3000kN over a distance not exceeding 1 meter.

Lastly, the standard references for crashworthiness requirements (standardization, 2008) of EN 15227 is explained that full train on train head-on collision is required to be assessed, which can involve impact speeds of up to 36 km/hr. determined by the type of rolling stock. However, for light rail vehicles, the impact speeds for crashworthiness assessment are only 15 km/hr.

The steel and aluminum can be replaced by the carbon fiber composite since the carbon fiber composite has great advantages over steel and aluminum in terms of lightweight.

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS.

5.1 Conclusion.

With the rapidly increasing number of Railway vehicles, the possibility of head-on collision accidents between two locomotives is becoming higher and higher. Addis Ababa –Djibouti railway is a single-track railway mostly which significance the head-head collision.

The caused casualties and property losses are huge, so the crashworthiness research of trains and other means of transport draws more and more attention. The main objective for this project was to use finite element analysis to improve a locomotive front end to reduce overriding effect also to increase energy absorption by select suitable materials for energy absorbing systems in front of locomotive such as crash box, improve the structure against crashes, to protect passengers and driving the crew from accidents in collision scenarios.

Crash boxes provide locomotive front-end protection in case of collision scenarios. In recent years studies are focused on dissipating the impact kinetic energy in a stable, ordered, and controllable way, and reducing the damage to occupants. Hence crash box is the core part of the crashworthiness structure.

In research, the impact analysis was done in three steps presented by using Abaqus/Explicit software. The three different materials of the locomotive crash box which are Aluminum, Steel, and Carbon Fiber composite material were examined by using an impact test speed of 36 km/hr. The mechanical performance of the front-end energy absorption mechanism of conventional materials steel and aluminum locomotive crash box is investigated. Moreover, the simulation result by using different materials in terms of maximum stress, maximum deformation, and energy absorption was successfully compared. The following outcomes are achieved,

- Under the condition of low-velocity impact, most of the heat is absorbed by the crash box. After impact simulations following the ECE R042 standard foreseeing the specifications which influence the impact performance, Carbon Fibre composite material has a higher value of maximum energy absorption compare to Steel and Aluminum. From this result can predict that Carbon fiber has high flexibility in material properties. Table 4.1 shows the simulation result.

- When designing the crash box, the deformation of the crash box must be less than a value to protect the other components from damage. And the maximum stress cannot exceed the yield stress. Safer structures due to higher specific energy absorption, the following outcome are indicated.
- Investigation of lightweight materials, the carbon fiber composite picked out as the material of the crash box instead of steel and aluminum to accomplish the lightweight device. Similar to the steel crash box and aluminum crash box, less crash box deformation, less von misses stress and higher kinetic and internal energy increased by the carbon fiber composite crash box.
- According to Figure, 4.17 stresses increase when the time of analysis increases also for locomotive with steel crash box impact, example after 0.006 seconds the stresses is high approximately 1600 mpa. This is categorized as the number of stresses that can cause serious damages to the locomotive. Therefore, some modifications to the design are essential. Therefore, an absorbing system was developed that needed some modifications on the headstock materials. We select other materials like aluminum and carbon fiber crash boxes.
- From the above discussion, it can be concluded that the crash box is an important member of the locomotive from the safety point of view. Thus analysis of crash box material will help to increase the safety considered to replace the existing materials like steel, and aluminum.
- The project details are used for the best crash box designs of the modern locomotive from the material point of view. Impact loading parameters can be evaluated for varying speeds.
- The design will be helpful to have an optimum material choice for frontal heavy locomotive crash box design based on comparative results of the materials.

By inserting a design of carbon fiber crash box assembly front end of the locomotive the FEA result for locomotive impact satisfied the following,

- The amount of the frontal deformation by using the crash box with carbon fiber reducing finally of analysis Figure 4.18 shown. This means that energy absorption also increased during the collision of locomotives with carbon fiber crash boxes. The crash box assembly is designed in similar that during the collision, as the time elapses, the front side of the structure collapses more.

- The low value of frontal deformation and increasing energy absorption during collision help to reduce the risk of injuries for drivers or passengers and reduced damage to the locomotive. Deformation behavior would increase confidence for achievement of the crash box in accident conditions.
- Meanwhile, from the simulation results, it observed that after using carbon fiber crash box in the locomotive impact, the initial peak of the crash force/load decreases to the value of 12,000 N. See Figure 4.20, with using the carbon fiber crash box structure, however, the measurements of the force increases when the collision time elapses in comparison with the other case when the crash box assembly using another material aluminum and steel.
- For the curve represent the steel crash box for the locomotive model in Figure 4.20 we can see the result of higher initial crushing load/force experienced after models collide. This increased measurement of the forces endured by using the crash box may cause excessive acceleration and damages to the train passengers during the crash. The value approximated to 20,000 N. The existing collision energy absorption mechanism of the locomotive is susceptible to serious damages under certain circumstances. It recognized that the structure is not crash-worthy because of the poor selection of materials. This means high force/load will be transferred to the components and occupants of the locomotive after they collide.

In this thesis, the railway passenger vehicles front end protection components have been designed, assembled, and analyzed by the use of Abaqus software and the results show an improvement of locomotive front end protection when using carbon fiber materials compared to the lasting crash box materials like aluminum and steel for the locomotive. The locomotive front end is a key system for energy absorption performance during an impact situation. For comparing crash boxes materials show different crash behavior. The crash box fitted front end of the conventional locomotive is a mechanical part whose deformation influences notably the load pattern transmitted through the whole structure specially designed for low-speed impact situations. It is concluded that the carbon fiber crash element performance with the inclusion of the crash box assembly is acceptable.

For the extensive range of deformation modes, efficient energy absorption ability, and bargain price, crash box structure with carbon fiber material has been accepted for crashworthiness design of locomotive for passengers train. This type of behavior in the crash box assembly saves the other components of the locomotive from the spread of the damages.

Worthwhile results were obtained which proved the efficiency of the suggested energy absorption device. The carbon fiber crash absorbing devices can be accomplished in the locomotive front end to reduce injuries caused by collision or derailment and the outcomes show that the amounts of the maximum stress for the locomotive design were reduced. And also the amounts of absorption of Energy were increased after being modified by using a locomotive with a carbon fiber crash box.

In this study crashworthiness of a locomotive front, end energy absorbed device was conducted to propose an energy absorbing system with carbon fiber material to make improvement of the design against crashes and to reduce the effect of overriding of locomotives during collision European EN15227 standard, was the basis of the performed analyses. In this research, the scenario of the locomotive to locomotive crash was implemented.

5.2 Recommendation.

The main purpose of the study is the crashworthiness of Ethiopia Railway Corporation locomotives used for passengers HDX1C No. ERP 0003 following EN 15227 standard. In the first step, the locomotives with steel crash box impact were modeled and analyzed. The results revealed the weakness of the existing locomotive steel crash box against collision. Therefore, a key solution is to improve the existed locomotive crash box structure from a crashworthiness point of view.

The locomotive crash box shall be designed as stiff as possible to resist the incoming compressive, vertical, quasi-static, vibration stress and at the same time, it provides safety/protection to the passengers and drivers in the cabin. The appropriate material must be selected for a locomotive crash box to reduce the weight and become stronger for the rail vehicle locomotive front end. However, this passenger rail vehicle locomotive crash box structure is made out of steel of different profiles that are believed to be available in the market at a low cost. Even though, it increases the dead load, operational cost, and efficiency of the passenger rail vehicle. It is recommended to use more strong and lightweight crash box structures that are esthetically, structurally, and operationally viable. As presented in the preceding analysis, the design of the lightweight crash box for the locomotive of carbon fiber is enhanced by strength, stiffness, and lightweight system from the existing steel. The Analyses illustrated that the suggested system can interestingly improve the crashworthy parameters of the locomotive front end. So Ethiopian Railway Corporation should use the carbon fiber material for the national railway system by undertaking further study. Is very important for locomotives under Ethiopia Railway Corporation to modify the existing locomotives steel crash box to reduce the effect of overriding and increase safety for crew and passengers.

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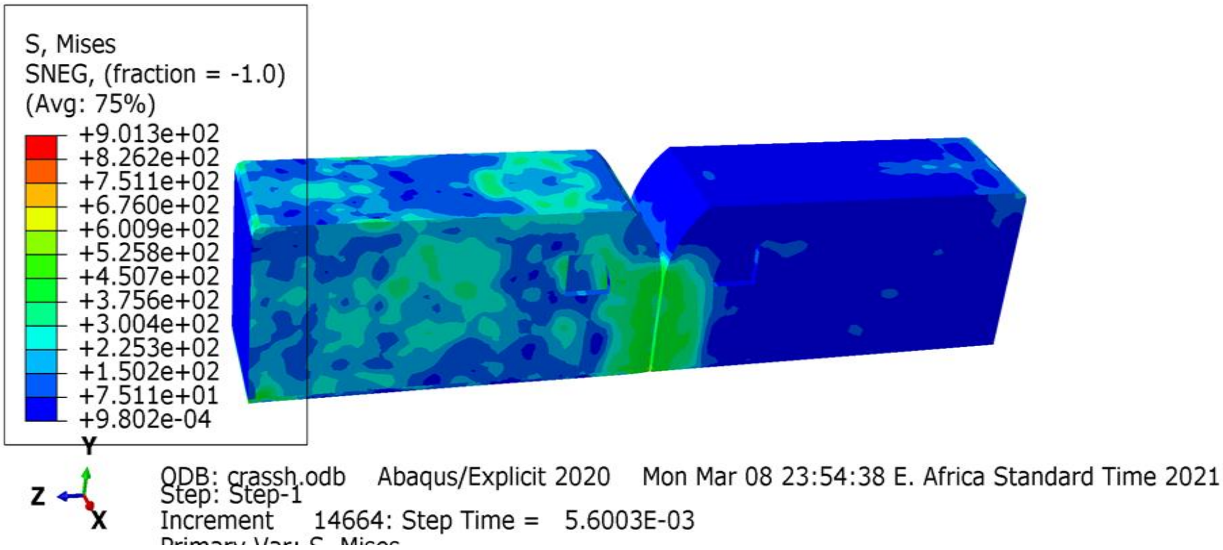
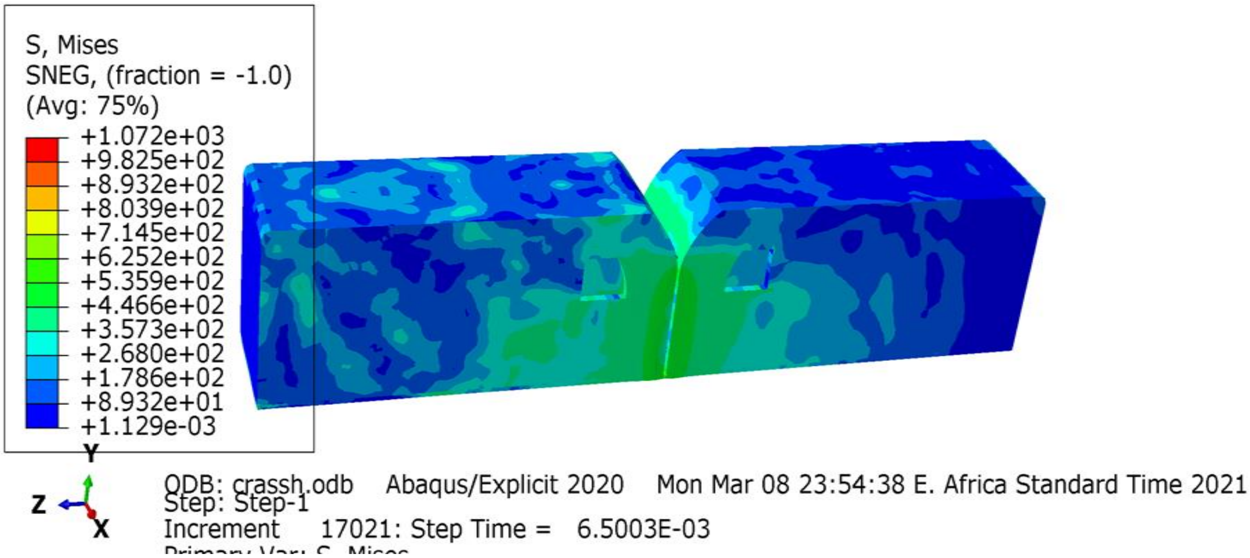
APPENDIX A

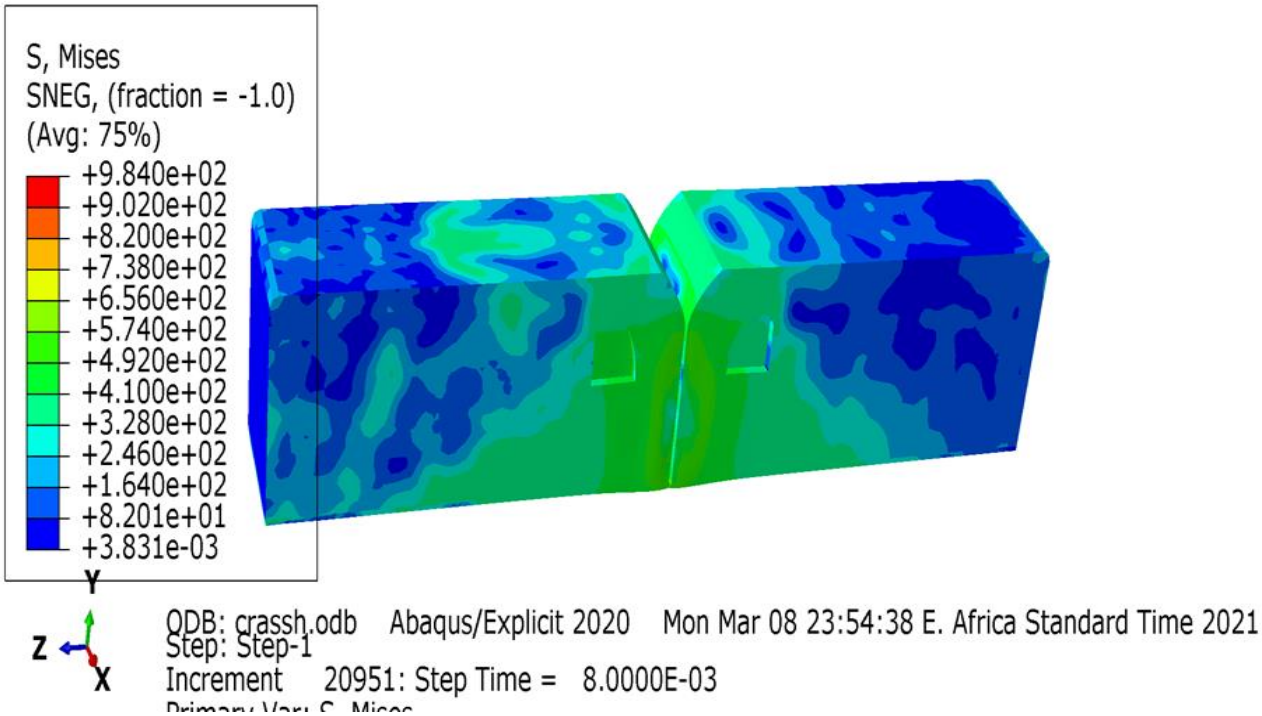
Collision of two locomotives with steel crash box: showing crush of locomotives after 0.0056 seconds of crush.



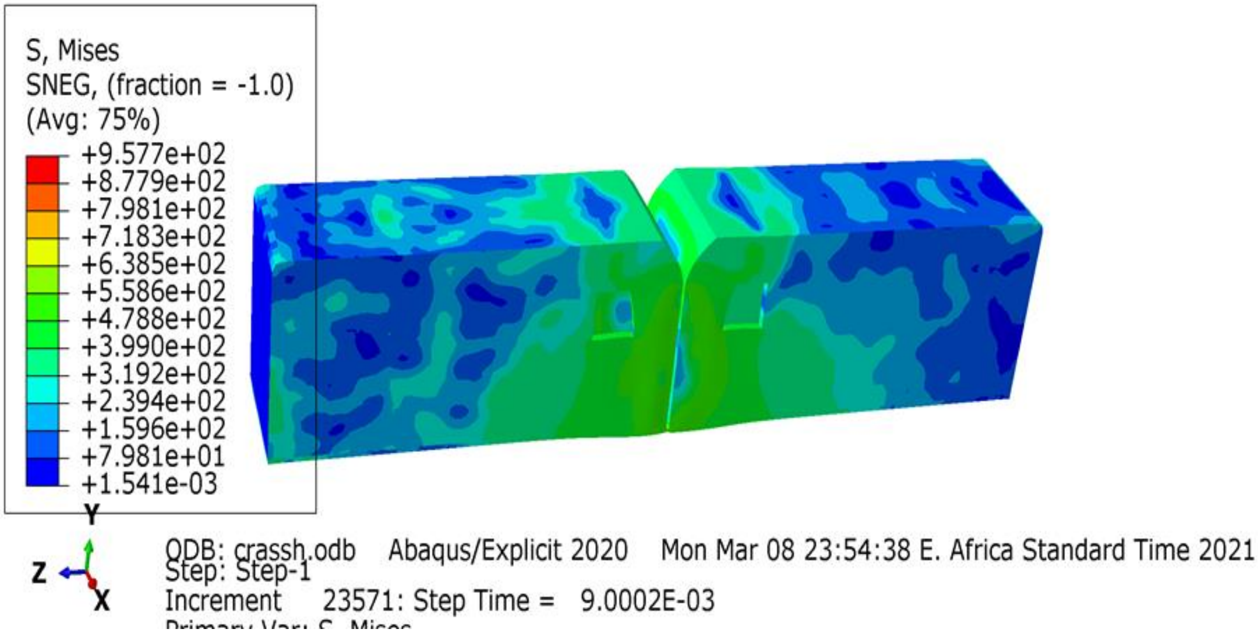
Collision of two locomotives with steel crash box: showing crush of locomotives after 0.0065 seconds of crush.



Collision of two locomotives with steel crash box: showing crush of locomotives after 0.008 seconds of crush.

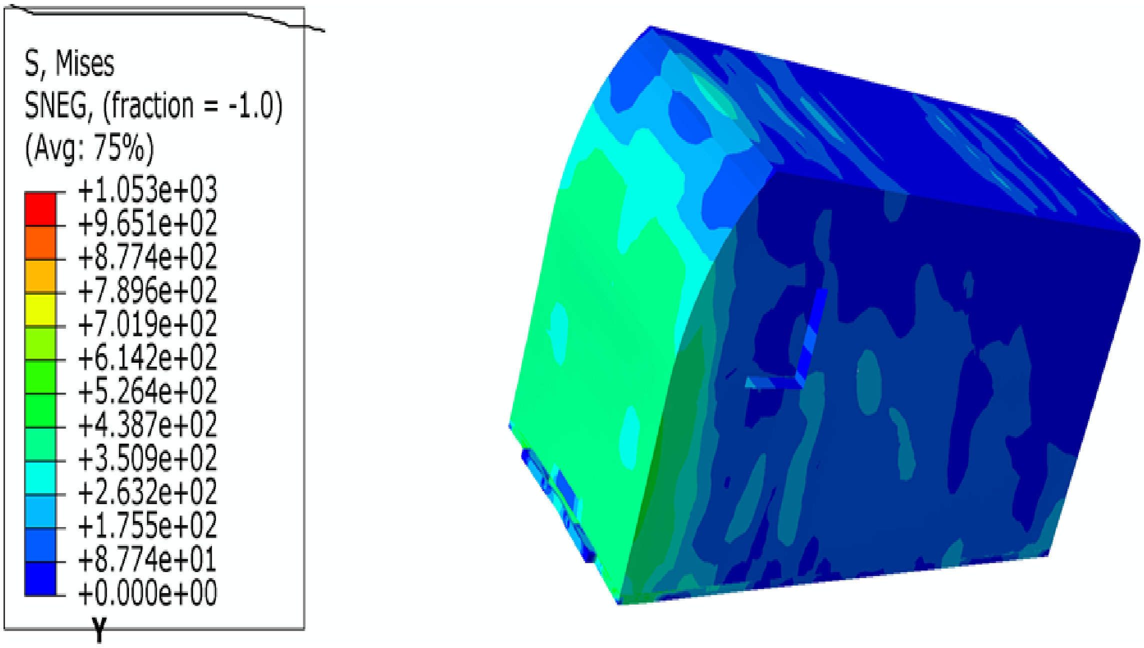


Collision of two locomotives with steel crash box: showing crush of locomotives after 0.009 seconds of crush.

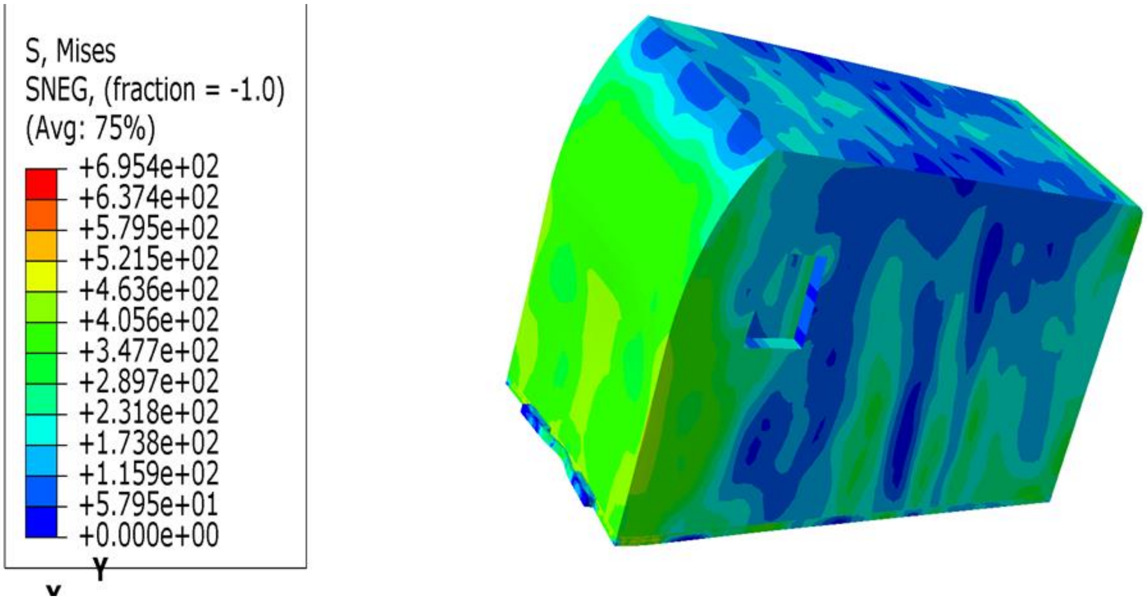


APPENDIX B

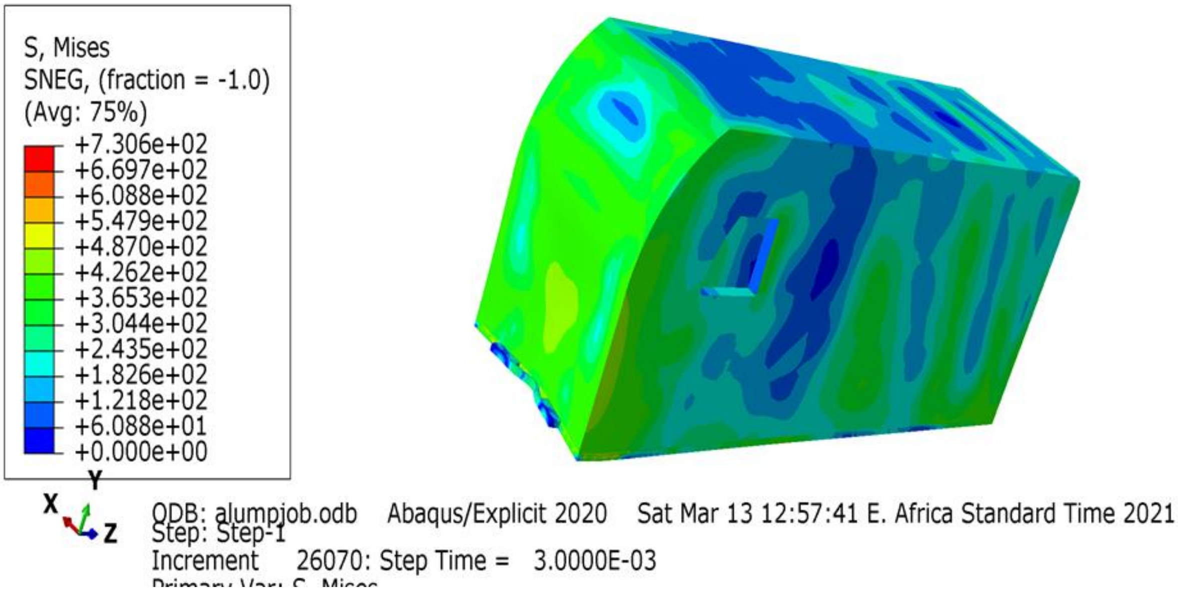
Isometric views showing the front end of the locomotive with aluminum crash box after 0.001 seconds of crush.



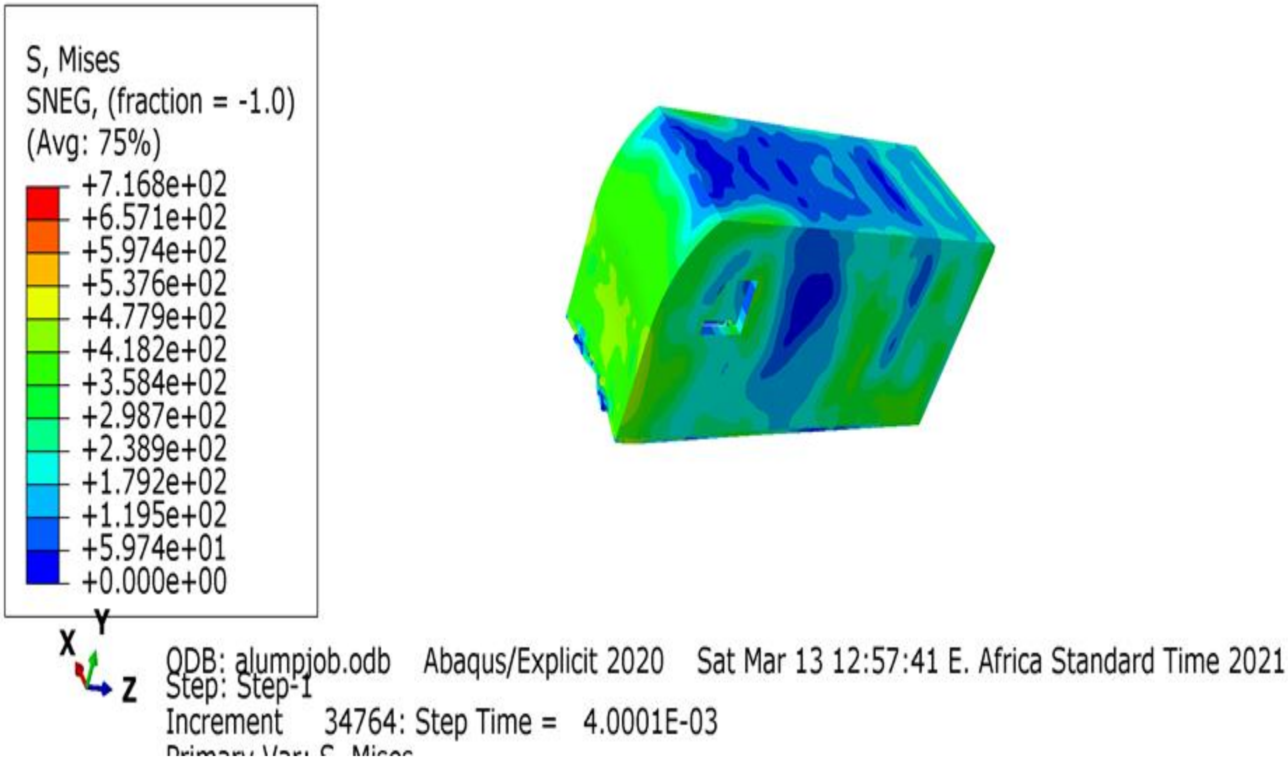
Isometric views showing the front end of the locomotive with aluminum crash box after 0.002 seconds of crush.



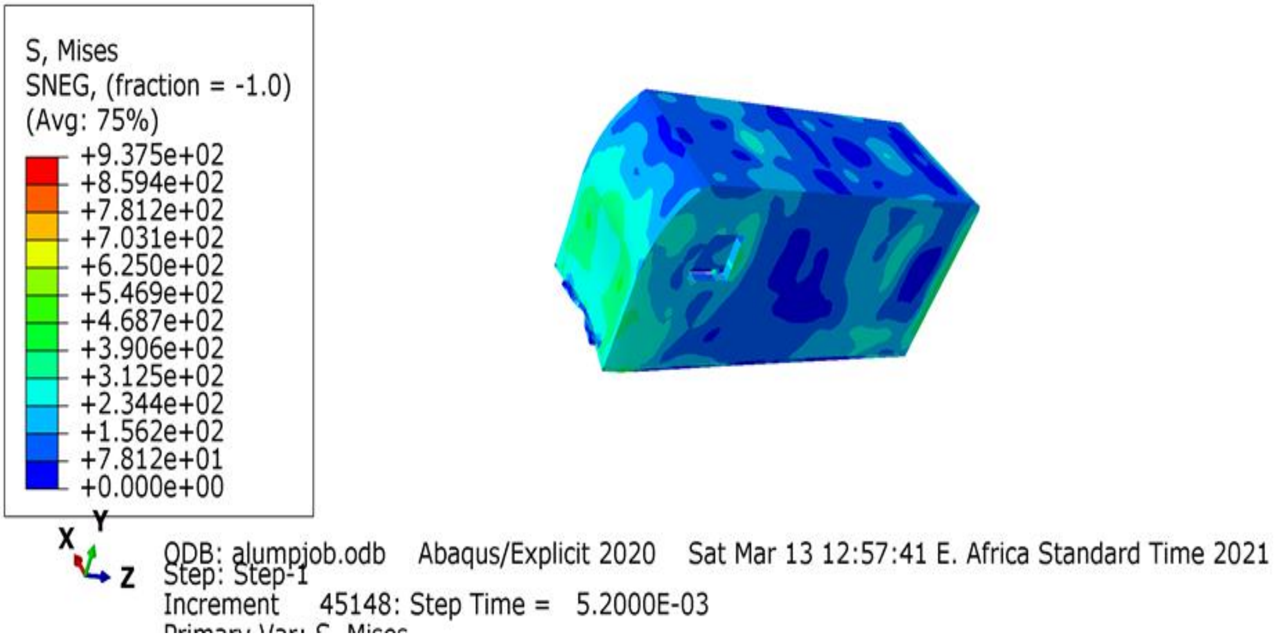
Isometric views showing the front end of the locomotive with aluminum crash box after 0.003 seconds of crush.



Isometric views showing the front end of the locomotive with aluminum crash box after 0.004 seconds of crush.



Isometric views showing the front end of the locomotive with aluminum crash box after 0.0052 seconds of crush.



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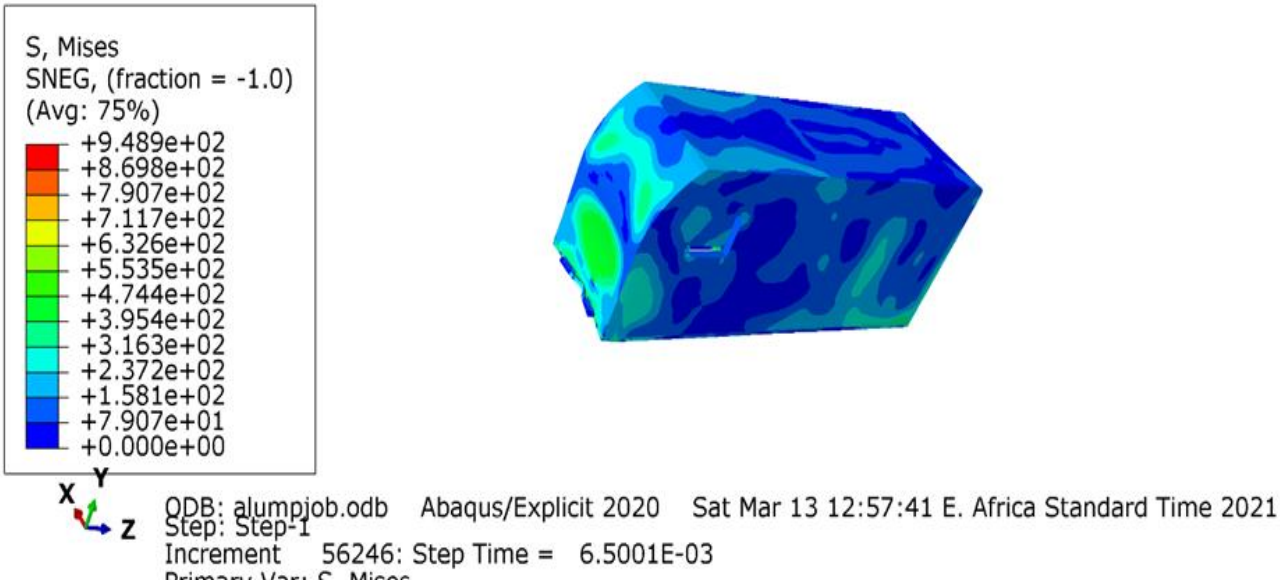
Primary Var: S, Mises

Isometric views showing the front end of the locomotive with aluminum crash box after 0.0065 seconds of crush.



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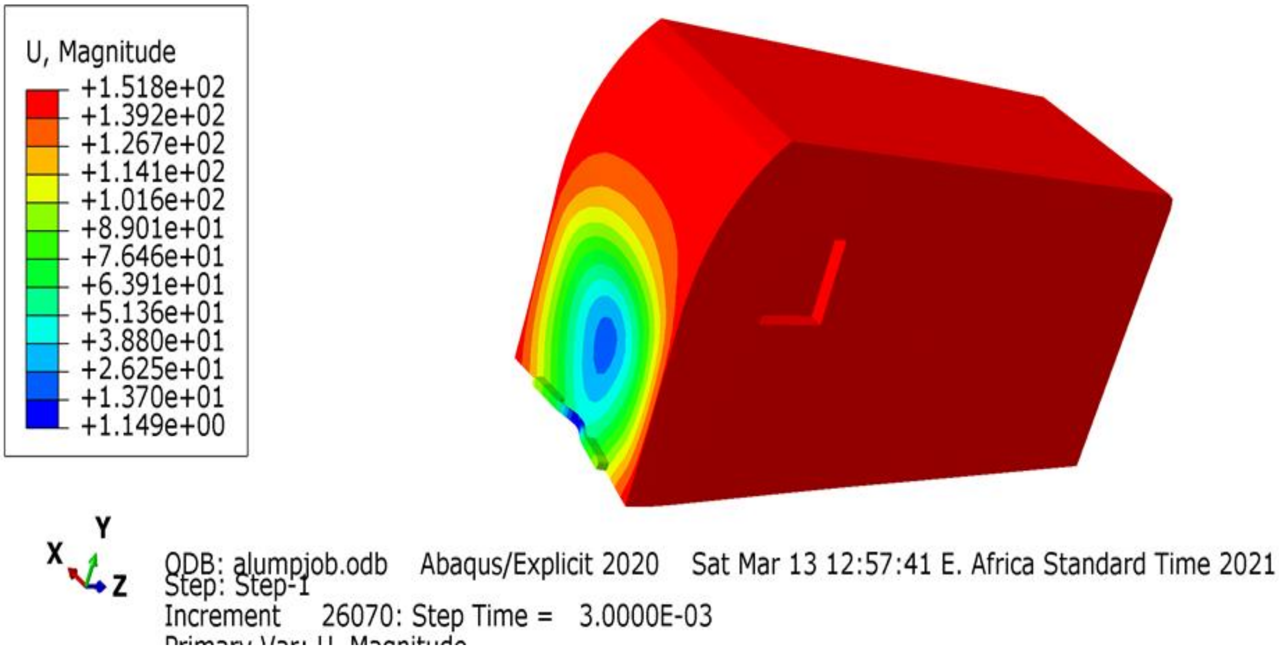
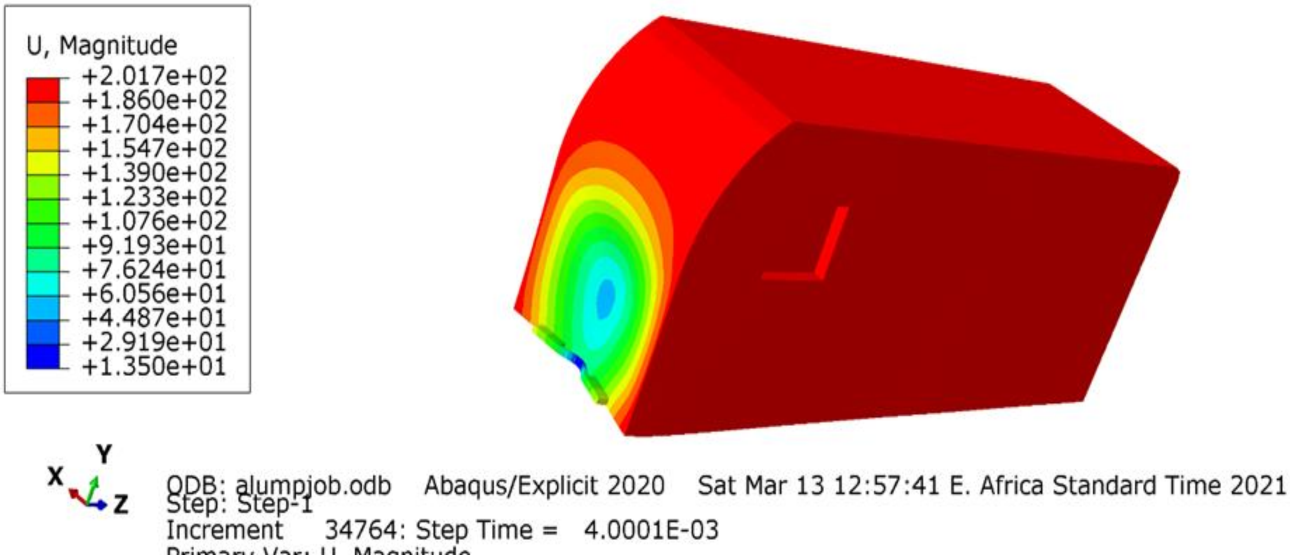
Primary Var: S, Mises

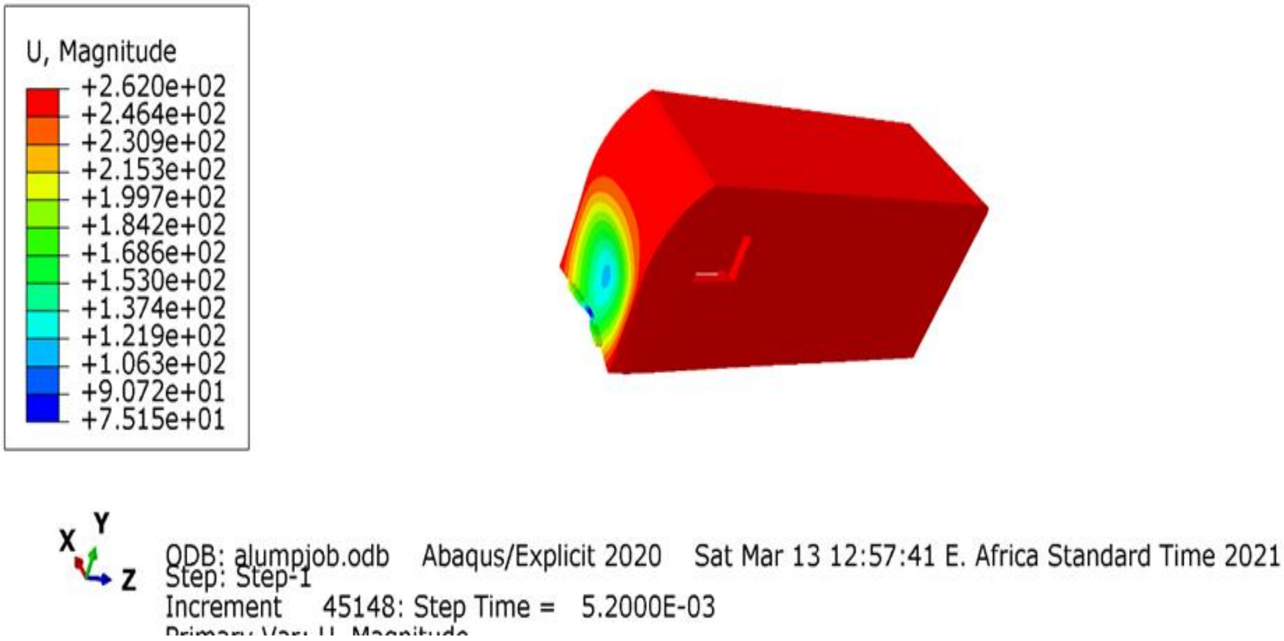
Isometric view showing the displacement at the front end of the modified locomotive after 0.003 seconds of crush. Maximum displacement value of 151.8 mm.



Isometric view showing the displacement at the front end of the locomotive with crash box after 0.004 seconds of crush. Maximum displacement value of 201.7 mm.



Isometric view showing the displacement at the front end of the locomotive with crash box after 0.0052 seconds of crush. Maximum displacement value of 2262.0 mm.



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