Design and Analysis of the Rear Bumper of a three-wheel vehicle, Minidor Force

Chala Efrem Olana

A Thesis Submitted to the Department of Mechanical Engineering

College of Mechanical, Chemical, and Materials Engineering

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Automotive Engineering

School of Graduate Studies
Adama Science and Technology University

May, 2025
Adama, Ethiopia

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I hereby declare that this Master's Thesis entitled "Design and Analysis of the Rear Bumper of a three-wheel vehicle, Minidor Force" is my original work. That is, it has not been submitted for the award of any academic degree, diploma, or certificate in any other university. All sources of materials that were used for this thesis have been duly acknowledged through citation.

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LIST OF ACRONYMS

CAD	Computer-aided design
CFRP	Carbon fiber reinforced polymer
DGC	Department Graduate Council
FS	Factor of Safety
FRP	Fiber-reinforced polymer
FEA	Finite-element analysis
FEM	Finite Element Method
FRC	Fiber-reinforced composite
GMT	Glass mat thermoplastic
HAS	High alloy steel
MBD	multi-Body Dynamics
NHTSA	National Highway Traffic Safety Administration
OPGS	Office of Postgraduate Studies
SGC	School Graduate Committee
SMC	Sheet Molding Compound
TS	Tensile Strength
UTS	Ultimate tensile strength
ASTU	Adama Science and Technology University

LIST OF SYMBOLS, AND UNITS

a	Acceleration due to Gravity
A	Bumper Area of Cross-Section
b	Breadth of bumper
E	Modulus of Elasticity
F	Force acting on the bumper
I	Moment of inertia
M	Bending Moment
m	Mass of the Bajaj crashed on the bumper
δ	Deformation
σ	Engineering stress
ε	Engineering strain
τ	Shear modulus

ABSTRACT

The increasing number of accidents involving three-wheel vehicles like the Minidor Force, as reported by the Asela Police Station between 2012 and 2016 E.C., has raised serious concerns about vehicle safety, particularly regarding rear-end collision protection. Traditional steel bumpers, while widely used, are heavy, susceptible to corrosion, and provide limited energy absorption. This thesis addresses these challenges by optimizing the rear bumper design using E-glass/epoxy composite material to improve crashworthiness, reduce weight, and enhance overall vehicle performance. The study's primary goal is to design and analyze a rear bumper for the Minidor Force using SolidWorks for 3D modeling and ANSYS for Finite Element Analysis (FEA), with specific objectives including the modeling of four distinct bumper designs and evaluating their stress, deformation, energy absorption, and reaction force under a simulated 20 km/h impact. Compared to conventional steel bumpers, the E-glass composite bumper exhibits lower stress, superior energy absorption, and significantly reduced weight, contributing to better fuel efficiency and handling. Its resistance to permanent deformation under impact further enhances crashworthiness and reliability. Among the models analyzed, Model D is recommended for implementation due to its optimal performance and safety margins, highlighting E-glass/epoxy composites as a viable alternative to steel for rear bumper systems, offering improved occupant protection and structural efficiency.

Keywords: *Rear bumper design, Minidor Force, Structural Analysis, E-glass/epoxy composite, Finite Element Analysis*.

CHAPTER ONE

INTRODUCTION

1.1. Background of the Study

Auto accidents occur daily, resulting in thousands to millions of injuries and fatalities each year, as indicated by statistics. Enhancing vehicle safety has been shown to directly contribute to lowering accident rates (Geber Michael, 2017). Three-wheel Vehicle, Minidor Force has been increasingly popular in recent years due to their small size, maneuverability, and fuel efficiency. These vehicles are mainly used for urban transport, delivery operations, and recreational purposes. However, maintaining Three-wheel Vehicle, Minidor Force safety and crashworthiness becomes increasingly important as their number on the road rises (Supriya & Prasat, 2021).

Figure 1.1: Three-wheel Vehicle, Minidor Force

Three-wheel Vehicle, Minidor Force, depicted in Figure 1.1, is used in Ethiopia's transportation industry, particularly in the cities of regional states, and is mainly imported from India. These cars are becoming more common in Ethiopian state cities' transportation networks, providing transportation services primarily for the general populace and occasionally for freight.

Designing and analyzing vehicle components is essential to ensuring vehicle performance and safety. The rear bumper is one such essential part that serves as a crucial protection element in the case of a rear-end collision. The back-bumper design is even more crucial for protecting the car and its occupants in the case of Three-wheel Vehicle, Minidor Force, which is becoming more and more prevalent in urban areas (Motgi, 2013).

To achieve the greatest mix of rigidity, weight, and cost-effectiveness, the design process considers a number of factors, including material selection, safety standards, and vehicle specifications (Rambhad et al., 2020). Because it enables engineers to create accurate and lifelike 3D models of car components, SolidWorks software is a crucial tool in the design process. Engineers can evaluate the rear bumper's performance and behavior under varied loading conditions by using these models as the foundation for further analysis and simulations. It is common practice to assess the structural soundness of rear bumper designs using finite element analysis techniques. FEA is used by engineers to model real-world situations, such as car crashes, and analyze the energy absorption, deformation, and stress distribution of the rear bumper (Keni et al., 2021).

This study helps to discover possible areas for improvement and offers important insights into the performance of the design. Current research indicates that incidents using three-wheeled vehicles can occasionally result in more significant injuries and fatalities among pedestrians, passengers, and property damage (Bogale and Kidan, 2013).

Figure 1.2: Three-wheel Vehicle, Minidor Force in Transport

Additionally, as seen in Figure 1.3, the Three-wheel Vehicle, Minidor Force bumper is subjected to dynamic loads, which could weaken the structure's overall stiffness and strength. Throughout the vehicle's life cycle, both static and dynamic service loads will be supported by the frame structure. In addition, the vehicle structure is designed to maintain its integrity and provide adequate protection for most accidents. The crashworthiness of the vehicle is an important security measure and improves the safety performance of a vehicle (Rambhad et al., 2020; Starkey, n.d.).

Figure 1.3: The rear bumper of the Three-wheel Vehicle, Minidor Force is impacted during a collision

Since fiber-reinforced composite materials have high specific strength, modulus, and damping capacity, they are frequently utilized in vehicle structures. The application of S-glass fiber-reinforced epoxy resin composite materials in a tricycle vehicle bumper beam to optimize energy absorption is used in the work of (Engineering, 2018; Prabhakaran et al., 2012a; Singh et al., 2016). Doing the modeling and analysis work will provide useful insights into the structural performance and crashworthiness of the intended rear bumper, allowing automobile manufacturers and designers to improve the safety features of Minidor Force Bajaj vehicles while improving their overall performance and reliability as stated in the literature (Agar and Amalakkannan, 2017; Chattaraj, 2013; Dange et al., 2015; Mahatme et al., 2019; Motgi, 2013; Prabhakaran et al., 2012b; Raut, 2017).

The conventional steel bumper in passenger vehicles (Figure 1.4) is replaced with an advanced composite material to enhance energy efficiency through mass reduction, while simultaneously offering superior durability, corrosion resistance, fracture toughness, design adaptability, mechanical resilience, and high performance-to-cost efficiency(Starkey, n.d.2021).

Figure 1.4: Steel bumper material

For this thesis, the new three-wheel vehicle, Minidor Force vehicle bumper, made from E-glass fiber-reinforced epoxy resin, is designed using SolidWorks for modeling and ANSYS software for simulation. Finite Element Method (FEM) analysis is employed to evaluate stress concentration distribution and identify potential impact scenarios. Therefore, the primary goal of this thesis is to model and analyze a rear bumper, as shown in Figure 1.5, for Three-wheel vehicle, Minidor Force.

Figure 1.5: Three-wheel vehicle, Minidor Force Rear bumper

1.2. Statement of Problems

Rising Accident Rates from year 2012 to 2016 E.C, that can I gather information from Oromia asela police station reported a significant increase in accidents and injuries involving Three-wheel vehicle, Minidor Force.

Current steel bumpers add weight and corrode simply, this study focuses on optimizing the bumper design using E-glass/epoxy composite materials to improve crashworthiness, reduce weight, and enhance overall safety and performance. (Hossein Mohammadi et al., 2022).

The absence of a thorough 3D model and Finite Element Analysis (FEA) for the rear bumper design limits the ability to accurately assess its performance under various modeling conditions. (Mr. Nitin S. Adwani and Dr.B.M. Shinde,2023).

1.3. Objective of the Study

1.3.1. General Objective

The general objective of this study is to design and analyze the rear bumper of the Three-wheel vehicle, Minidor Force using Solid Works and ANSYS software.

1.3.2. Specific Objectives

Specific objectives of the study were;

- ✓ To model rear bumper three-wheel vehicle, Minidor Force using SOLID WORKS;
- ✓ To evaluate stress, deformation, energy absorption, and reaction force by using ANSYS simulation for deferent four bumper models using E-glass/epoxy composite material.

1.4. Significance of the Study

The significance of this thesis lies in its contribution to the safety, and functionality, of the Three-wheel vehicle, Minidor Force rear bumper. In order to reduce accident damage and increase overall vehicle safety, this research attempts to improve the bumper's capacity to absorb and disperse impact forces by design and material selection optimization. (Rambhad et al., 2020).

In addition to providing a complete solution for both performance and design, the findings will guarantee that the bumper satisfies high requirements of quality and aesthetic appeal while protecting Three-wheel vehicle, Minidor Force and its occupants in the event of an accident. (Smith, J., and Lee, K. 2019).

1.5. Scope of the Study

The modeling and study of the Three-wheel vehicle, Minidor Force rear bumper are the main topics of this thesis. Different bumper models were made with Solid Works, and their performance was assessed by simulations using ANSYS software. The research comprises the evaluation of two materials, E-glass Fiber-Reinforced Composite (FRC) and steel, to ascertain which one performs better for the bumper.

1.6. Organization of the Study

There are five chapters in this thesis. The study is introduced in Chapter One, which also describes the context, goals, scope, and general structure of the thesis. A review of related literature is included in Chapter 2, which also examines earlier research investigations and the resources and techniques used by other researchers. In Chapter Three, the study's methodology is covered in detail, including the modeling, analysis, and design of the rear bumper of the Three-wheel vehicle, Minidor Force as well as the steps taken to build the model and run simulations.

The analytical results are compiled in Chapter Four, which also compares the model solutions and offers discussions based on results from the ANSYS and Finite Element Method (FEM) simulations. Finally, Chapter Five wraps up the research by outlining the main conclusions of the analysis and making suggestions for additional research.

CHAPTER TWO

LITERATUREREVIEW

2.1. Bumpers

Strength, durability, usability, and conformity to safety regulations should be prioritized in the design of a Three-wheel vehicle, Minidor Force rear bumper (Motgi et al., 2012). By carefully considering these factors and carrying out comprehensive testing, an effective rear bumper can be developed to enhance the overall safety of the Three-wheel vehicle, Minidor Force and its occupants (Hambissa et al., 2022a; Osokoya, 2017).

2.2. Composite for Automotive Bumper

Mohammadi et al. (2023) investigated the production of a Jute Fiber Composite for car bumpers and contrasted it with bumpers made of aluminum B390 alloy and mild steel coated with chromium. The jute fiber composite bumper performs better than other materials, according to the results, providing a high strength-to-weight ratio and crashworthiness. The Auto Rickshaw (Bajaj) industry in Burao, Somaliland, was the subject of a research that found both advantages and disadvantages.

On the down side, problems like collisions, breaking traffic laws, and disregard for other passengers were noted. Fast service, revenue generating, and affordable prices were among the advantages. Young men of various educational backgrounds made up the majority of the drivers. According to Kunle et al. (2019), the study suggested driver training, stringent speed and load limit regulations, enhanced passenger safety, and cultivating community respect.

By contrasting its strength-to-weight ratio and deformation with that of other materials, including aluminum alloy and mild steel coated with chromium, the study by Bogole and Kidan (2013) explores the usage of jute polymer composite material in car bumpers. Because of its lightweight design and crashworthiness, the composite is appropriate for a bumper. The ultimate tensile strength (UTS) of three low-carbon steel materials used to make car bumpers was shown to increase with strain rate; the highest UTS was observed in high alloy steel (HAS) compositions.

The study also discovered that, in comparison to other materials, had material had the highest strain energy and the least displacement. The study highlights how crucial it is for the building industry to comprehend material dynamic behavior.

In a different study, Uddandapu (2013) used Pro/Engineer and SOLID WORKS software to examine the materials and structure of automobile bumpers for crashworthiness. The findings indicate that ABS plastic lowers weight and stress levels while providing superior impact resistance. The study highlights how crucial statutory bumper regulations are for minimizing minor crash damage.

The mechanical behavior of three carbon steel materials for bumper beam applications is examined in the study by Alemayehu et al. (2017), which finds that high alloy steel (HAS) has better qualities. The study highlights the significance of comprehending material dynamics for energy absorption and impact resistance. When paired with numerical simulations and experimental testing, the analysis helps make well-informed decisions about vehicle safety components (Alemayehu et al., 2017). In addition, the article by Keni et al. (2021) highlights the use of various materials and technologies in rear bumper construction.

The benefits of using energy-absorbing materials, like thermoplastic elastomers and composites, that can effectively distribute collision energy are examined by the author. When creating a product, the writers emphasized the need of considering factors including cost, weight, and ease of manufacturing (Keni et al., 2021).

An extensive examination of the impact rear bumpers has on safety for Bajaj Tricycles is given by Lut, 2023; Osokoya, (2017). It highlights the significance of having this function in order to lower hazards and enhance passenger and pedestrian safety. Different literature suggests intriguing avenues for further research and development in this area, which are indicated by the use of energy-absorbing materials and the proposed conceptual design.

To understand the performance requirements for passenger cars in low-speed front and rear collisions, the National Highway Traffic Safety Administration (NHTSA) produces some bumper standards for light passenger vehicles, which are followed in this paper. It applies to passenger cars' front and rear bumpers to guard against harm to the vehicle's body and any safety-related components. The following bumper requirements should be met by every bumper (Olorunnishola & Adubi, 2018).

- ✓ The front and rear bumpers on passenger cars should prevent damage to the car body.
- ✓ The bumper withstands at a speed of 2 mph across the full width and 1 mph on the corners.
- ✓ The bumper should also withstand a 5-mph crash into a parked vehicle.
- ✓ Placement of the bumper is 16 to 20 inches above the road surface.

The theory of bending and Newton’s second law of motion were applied in different literature to determine the force acting on the bumper (Moghaddam & Ahmadian, 2011; Motgi, 2013; Prabhakaran et al., 2012).

Three primary design factors for this structure, shape, material, and impact conditions, are examined in this impact modeling study of a commercial front bumper beam composed of glass mat thermoplastic (GMT), which is conducted using LS-DYNA/ANSYS. The findings are compared with those of conventional metals, such as steel and aluminum. Finally, the recommendation to swap out the current GMT for a high-strength SMC bumper reflects the previously indicated characteristics (Laad & Sharma, 2021).

2.3. Steel for Automotive Bumper

The potential consequences of rear-end collisions, such as whiplash injuries or structural damage to the vehicle, were covered by Laad & Sharma (2021). In order to lessen the degree of injuries suffered by the driver and passenger, the authors emphasized the significance of having a rear bumper that can absorb and disperse impact forces. The evaluation also covered the use of advanced engineering techniques, such as SOLIDWORK and finite element analysis (FEA), to maximize the bumper's structural integrity and crashworthiness, as well as the numerous rules and standards established by transportation authorities that specify the minimal requirements for rear bumper design and performance.

Several pieces of literature have addressed the significance of taking into account elements like material choice, form, and size to guarantee that the bumper can efficiently absorb impact energy. For instance, Alemayehu (2013) and Laad & Sharma (2021) found that a successful design is achieved by assessing the bumper's performance under various crash situations using both numerical models and physical testing. All things considered; the literature analysis gave a thorough rundown of the techniques used to create a rear bumper that puts safety first for Bajaj. The many aspects of bumper design, including impact resistance, material strength, and structural integrity, were discussed by (Sakib et al. 2024).

The author evaluates the rear bumper's ability to improve safety and avert collisions through tests and simulations. In the end, the analysis by (Ali and Mohshin,.2017) highlights how crucial a well-designed rear bumper is to guaranteeing the security of the car and its occupants.

A Bajaj's rear bumper safety was examined by a number of authors (Harrison et al., 2020; Mishra et al., 2022). The authors' goal was to evaluate how well the rear bumper reduced the chance of collisions and injuries. They performed a number of experiments to assess the bumper's performance in various situations in addition to analyzing the bumper's structure and design.

The findings indicated that the rear bumper indeed played a vital role in ensuring safety by providing additional protection to the vehicle and its occupants. It effectively absorbed impacts during collisions and minimized the severity of injuries. The authors concluded that the implementation of a properly designed and tested rear bumper can significantly enhance the safety of Three-wheel vehicle, Minidor Force and reduce the overall risk of accidents.

(Geber Michaiel,.2017) stated that the general vehicle structure to provide a safe structural environment for occupants of vehicles involved in high-speed (> 15 km/h) collisions has drawn considerable resources, as the safety of humans is at stake. Low-speed effects, since these do not cause severe injuries to the occupants, do not generate much concern. However, structural design for this situation has generated a lot of damage caused by these types of collisions. Various designs of crash-box that can be fitted within the packaging space have been assessed for low-speed impact. Geometric parameters like length, wall thickness, and cross-section shapes (rectangle, hexagon, and octagon). Using thinner walls, it was possible to limit major deformation to the crash box. The major use of the crash box is to reduce permanent deformation and to decrease the replacement of rails after the impact.

The bumper design enables the geometric design of the longitudinal members, and is first clear what kind of loads can occur in real frontal collisions. These loads are determined by the parameters describing the frontal crash and their predominant values. Besides the collision speed, the obstacle type, the impact location and direction, also the vehicle mass also have a large influence on the crash behavior (Moona et al., 2015; Motgi et al., 2012; Noorbhasha, 2010; Singh et al., 2016).

Their focus is on the safety of the rear bumper for a Three-wheel vehicle, Minidor Force. The authors discuss various methods used to assess the safety of the bumper. They highlight the importance of conducting thorough crash tests to evaluate the bumper's performance in different scenarios. Additionally, computer simulations are used to analyze the structural integrity and behavior of the bumper under different load conditions.

The essay highlights the necessity of a sturdy and dependable rear bumper design to guarantee the Bajaj Tricycle users' safety. The absence of scientific studies or study on the safety consequences of rear bumpers made especially for Three-wheel vehicle, Minidor Force is, in general, the research gap in this article. By putting out a technique that combines a literature analysis, experiments, and field tests to assess the safety features of rear bumpers for tricycles, the authors hope to close this gap (Hambissa et al., 2022; Moghaddam & Ahmadian, 2011; Prabhakaran et al., 2012).

Prior research has focused on the safety of bumper designs, particularly in relation to material selection (Manuka et al., 2019; Singh et al., 2016; Sorade and Kulkarni, 2021). The writers stress that the bumper's construction material is crucial to defending the riders and cushioning the effects of possible collisions. They go over the benefits and drawbacks of several materials, including fiber-reinforced polymer (FRP), steel, and aluminum. Aluminum is lightweight but could not be as sturdy as steel, which is thought to be strong but hefty.

FRP, on the other hand, provides a balance between strength and weight but is more expensive. The researchers emphasize the need for thorough testing to determine the optimum material for the rear bumper of the try-cycle to ensure maximum safety for the riders. They design fabrication and testing of steel and composite bumper. They also compared the results of the two bumpers about weight, fuel economy, cost, and impact resistance. As a result, for the same model of the bumper, a steel bumper weighs 5.15kg and the weight of the composite bumper is 2.38kg. This shows that the percentage ratio of 53.8% is lesser than steel bumper as a result fuel economy of the vehicle is improved. The cost of a composite bumper is 80% less than a steel bumper so composite materials are cost cost-effective than steel materials.

Noorbhasha, 2010 and Prabhakaran et al., 2012a, conducted a study to evaluate the safety of a rear bumper for a Three-wheel vehicle, Minidor Force. The researchers focused on conducting experiments to assess the effectiveness of the rear bumper in preventing potential accidents and minimizing injuries. Based on their experiments, they found that the rear bumper significantly enhanced the overall safety of the try-cycle by reducing the impacts on the rear end in case of collisions. This study provides valuable insights into the implementation of rear bumpers as a safety measure for try-cycles and emphasizes the importance of conducting such experiments to ensure optimal safety.

The work of different researchers explained that the design, fabrication and testing of steel and composite bumper through the experimental results deduces that the Impact strength of composite bumper is 7.35 J/mm^2 whereas steel bumper is 3.25 J/mm^2. And also, by using ANSYS software they analyzed steel and composite bumper model to determine the maximum stress induced in the composite bumper and got a numerical value for composite is 159.36 N/mm^2 but in steel is 292.669 $N/mm^2$and the factor of safety for the composite bumper increased by 64%. They concluded that fiber-reinforced plastic material is the best material for a bumper (Olorunnishola & Adubi, 2018).

Balamurugan, (2017) and Reddy, (2018) conducts an impact test to measure a material's ability to resist impact, determining factors in the service life of the material were used. The authors determine the amount of energy absorbed by a material during fracture because the absorbed energy gives the material toughness. The authors take a specimen with dimensions of are v-shaped notch, 2mm deep, with a 450 angle and a 0.25mm radius along the base. The authors used ANSYS software for static-nonlinear analysis to determine the deformation and stress distribution over the structure. Using ANSYS software, they analyzed the steel and composite bumper model and determined the maximum stress induced in the composite bumper and steel.

2.4. Research Gap

Despite the significant role of rear bumpers in enhancing vehicle safety and structural integrity, there are several critical gaps in existing research, particularly concerning the rear bumper of the Minidor Force Bajaj.

These gaps include:

- ✓ The existing research on low-speed collision studies and energy absorption optimization of Three-wheel vehicle, Minidor Force rear bumpers has left several key areas unexplored. (Mahmood, S. M., et al. 2020).
- ✓ The dynamic load response of the bumper under varying model is not well investigated, leaving uncertainty about the structural performance and energy absorption capacity of different designs. (Song, J., and Yu, J. 2018)
- ✓ There is a lack of detailed finite element analysis (FEA) specifically tailored to evaluate the stress, deformation, and crashworthiness of the Three-wheel vehicle, Minidor Force rear bumper under real-world conditions. (Patil, S. B., and Kulkarni, A. J. 2016).

CHAPTER THREE

MATERIALS AND METHODS

3.1. Materials

The materials used in the design and analysis of a bumper for the Three-wheel vehicle, Minidor Force were selected based on their mechanical properties and performance during impacts. E-glass/epoxy composite and steel were the two main materials used in this investigation.

3.1.1. Steel

Steel's strong strength, ductility, and capacity to absorb energy make it a popular material for automotive applications. A structural grade of steel has been chosen for this investigation. The steel's unique characteristics include: The mechanical characteristics of steel guarantee that it can. It is the perfect material for important structural elements like bumpers since it can sustain large loads and deformations. Additionally, it has outstanding machinability and weldability, making manufacturing simple. Steel was chosen for the Three-wheel vehicle, Minidor Force rear bumper because of its exceptional energy absorption qualities, high strength, and durability, which make it perfect for withstanding crash forces and guaranteeing passenger safety.Large-scale production is feasible because to its affordability, ease of manufacture, and recyclability; lifespan and adherence to vehicle safety regulations are guaranteed by its resistance to wear and predictable deformation behavior. Steel is a sensible and dependable material for bumpers because of these qualities as well as its demonstrated ability to withstand impacts.

Table 3. 1 Materials Used in Minidor Force Bajaj (Source: woldsteel.org)

Material	Characteristics	Reason for Use
Mild Steel	Cost-effective- Easy to weld and form	Ideal for mass production and provides structural reliability
High-Strength Low-Alloy (HSLA) Steel	High strength- Lighter compared to mild steel-Durable	Ensures robustness, durability, and enhances vehicle performance

Justification:

- Mild steel is utilized because it ensures structural integrity while striking a balance between cost and manufacturing feasibility.
- A better strength-to-weight ratio provided by HSLA Steel enhances the longevity and performance of the vehicle.

Table 3. 2 Material Properties of steel (Source: Matweb.com)

Material Property	Value
Density ρ	≈ 7850 kg/m^3
Unit weight γ	≈ 78.5 kN/m^3
Modulus of elasticity E	210000 MPa
Shear modulus G	$G = E / [2 \cdot (1 + v)] \approx 81000$ MPa
Yield strength f_y	460 MPa
Ultimate strength f_u	540 MPa
Poisson's ratio in the elastic range, v	0.30
Coefficient of linear thermal expansion α	12×10^{-6} °K^{-1}

3.1.2. E-Glass/Epoxy Composite

Since e-glass/epoxy composite is lightweight, corrosion resistant, and has a high specific strength, it was selected as a substitute material. E-glass fibers incorporated in an epoxy resin matrix made up the composite. High tensile strength and stiffness were supplied by the E-glass fibers, and superior adhesion, chemical resistance, and durability were provided by the epoxy resin. The composite's lightweight design makes it especially well-suited for lowering pollutants, increasing fuel economy, and decreasing the vehicle's overall weight.

Table 3. 3 Summary of Main Fiberglass Types and Their Uses (source: Su et al. 2024)

Type	Properties	Common Applications
E-glass	General-purpose, high-strength-to-weight ratio, electrical insulation	Automotive, construction, and electrical insulation
S-glass	High strength and stiffness, excellent tensile strength	Aerospace, military, and high-performance sports equipment
C-glass	Excellent chemical resistance, moderate strength	Chemical processing, corrosion-resistant tanks
A-glass	Good strength, less weather-resistant	Glass containers, insulation materials
R-glass	High resistance to temperature and chemicals	Aerospace, military, industrial applications
T-glass	High impact resistance, tough	Protective coatings, armor, and high-durability applications
B-glass	High thermal stability, good resistance to thermal shock	Heat-resistant components, laboratory equipment

The particular application and performance criteria determine which type of fiberglass is best. Because of its many qualities, including strength, resistance to corrosion, and affordability, e-glass is the most widely used material for electrical insulation, construction, and automotive applications. Other fiberglass varieties, such S-glass and C-glass, might be chosen for specific applications in high-performance, chemical-resistant, or hot-temperature settings.

Table 3. 4 Material Properties of E-Glass (source: Chopade, Narkar, and Satav 2007)

E- glass/Epoxy composite Properties		
Properties		Value (MPa)
Modulus of Elasticity(E)	x-direction (Ex)	34000
	y-direction (Ey)	65300
	z-direction (Ez)	65300
Tensile strength(σ)	longitudinal	490
	Transverse	900
Compressive strength(σ)	longitudinal	300
	Transverse	450
Shear modulus(τ)	xy-direction (τxy)	2433
	yz-direction (τyz)	1698
	zx-direction (τzx)	2433
Flexural modulus (E_{bend})	-	40000
Flexural strength ($\sigma_{Failure}$)	-	1200
Poisson ratio	xy-direction	0.217
	yz-direction	0.366
	zx-direction	0.217
Density	-	2540kg/m^3

3.1.3. Material Selection Criteria

The following crucial factors were taken into consideration when choosing steel and E-glass/epoxy composite for the rear bumper design:

i. Impact Resistance, Steel renowned for its exceptional strength and durability, steel has the capacity to absorb large impact pressures, offering superior protection in collisions. Under dynamic loading circumstances, E-Glass/Epoxy Composite provides strong energy absorption capacities while preserving structural integrity.

ii. Weight Considerations, Steel Despite its strength, steel has a higher density, which adds to the weight of the vehicle and may affect handling and fuel economy. E-Glass/Epoxy Composite: It is a perfect substitute for bumpers because of its lightweight design and high specific strength, which enhances vehicle performance.

iii. Cost-Effectiveness, Steel is a cost-effective choice for mass production since it is widely accessible and reasonably priced. E-Glass/Epoxy Composite: A little more costly initially, but it saves money over time because it is lighter, uses less fuel, and requires less upkeep.

iv. Durability, Steel Needs frequent maintenance because it is prone to corrosion and environmental wear if left untreated. E-Glass/Epoxy Composite: Long-term durability with little maintenance is guaranteed by its inherent resistance to corrosion.

v. Manufacturability, Steel Suitable for conventional production techniques, steel is easier to form and weld. E-Glass/Epoxy Composite: Provides precision and design flexibility but necessitates sophisticated fabrication procedures. When these factors are taken into consideration, steel offers a strong and affordable option, while E-glass/epoxy composite shows up as a creative substitute that strikes a balance between high performance and lightweight design for rear bumper(Jain, Mittal, and Chaudhary 2020).

3.2. Methods

The general framework of the thesis is shown in Figure 3.1, which is applied to achieve the main goal of the Three-wheel vehicle, Minidor Force bumper design and analysis under impact force.

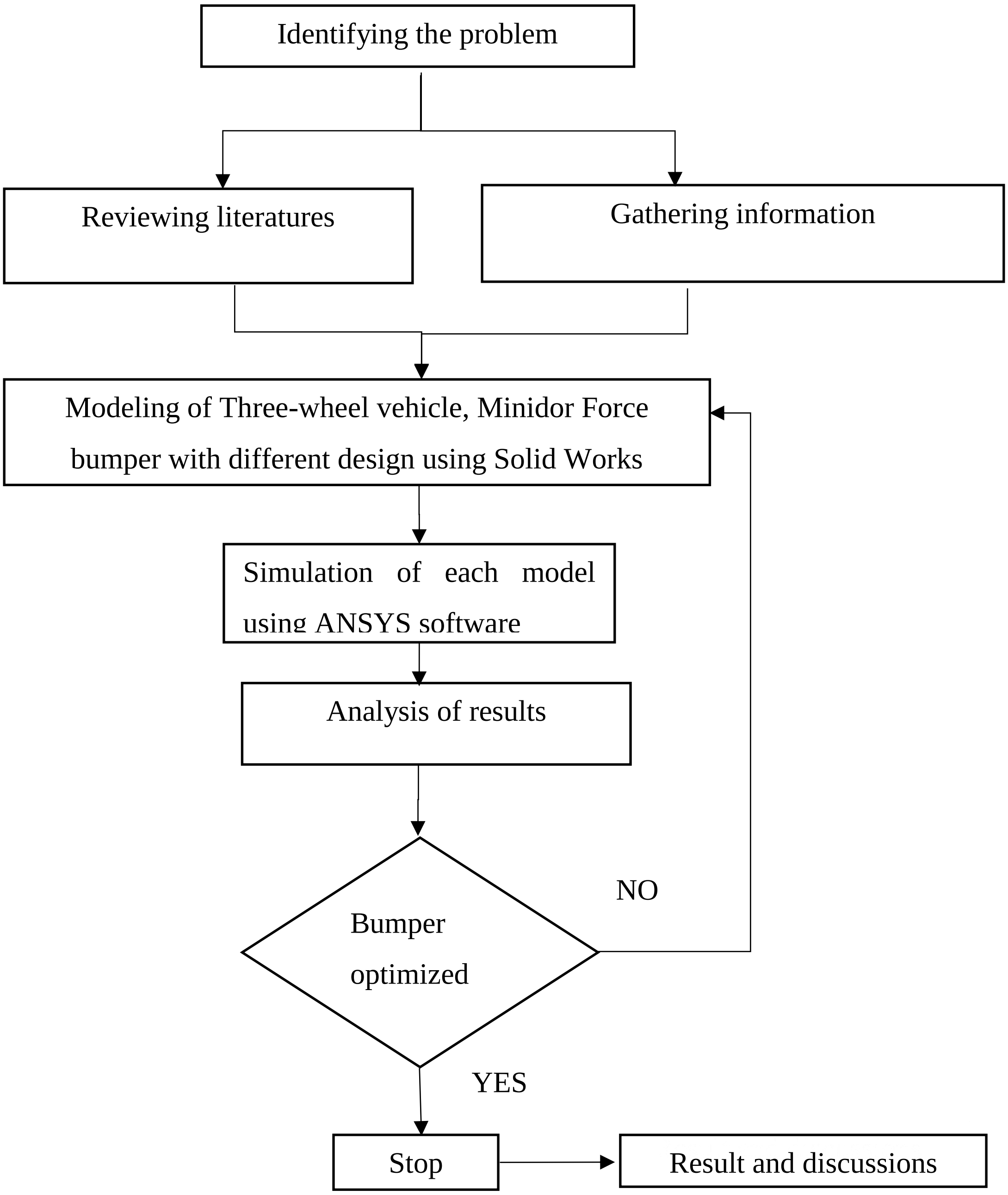

Figure 3.1: General Framework of the Thesis

3.2.1. Data Collection

Data were collected from Asela police station about accident and death of occupants at the Minidor Force Bajaj through collecting relevant historical records and documents and also the demographic information, of the Bajaj were identified through survey.

3.2.2. Material Selection

The materials for the bumper were selected based on their mechanical properties, as described in Table 3.3 and 3.4 Steel and E-glass/epoxy composite. E-glass/epoxy composite were chosen due to their excellent strength, impact resistance, and manufacturability. The material properties were input into the analysis software to simulate realistic behavior under loading conditions.

3.2.3. Conceptual Design and Modeling of the Bajaj Rear Bumper

A conceptual design of the bumper was developed considering the dimensions and structure of the Minidor Force Bajaj, crashworthiness, and aesthetic and functional considerations. Then, using SolidWorks software, a 3D model of the rear bumper was created to simulate and minimize damage to the vehicle and occupants during a collision.

3.2.4. Simulation of the Bumper using ANSYS

Finite Element Analysis was conducted to evaluate the structural performance of the bumper under impact loading. After the 3D model of the rear bumper was done using SOLIDWORKS, the model was imported to ANSYS to analyze the bumpers performance under impact load. A fine mesh was generated to capture the details of stress distribution accurately. Tetrahedral elements were used based on the complexity of the geometry. The bumper was fixed at appropriate points to simulate its attachment to the vehicle. Impact forces were applied to replicate collision scenarios. The mechanical properties of steel and E-glass/epoxy composite were assigned to different regions of the bumper model. The simulation was run to analyze the stress and deformation of the bumper under E-glass/epoxy composite material and impact loading conditions or Pressure.

3.2.5. Stress Analysis Using ANSYS Software

After conducting the simulation, the stress distribution and deformation of the rear bumper were identified form ANSYS. The performance of the bumper was assessed using the FEA data. The maximum stress, the bumper's capacity to disperse collision energy, and the degree of deformation are important performance metrics. The design was iteratively improved to improve performance in light of the findings. Adjustments included modifications to material distribution, thickness, and geometric features.

3.2.6. Selection of best Bumper Materials

Designing bumpers for various types of vehicles involves determining the equivalent design parameters and stress under impact loading or pressure scenarios. The materials used in the bumper construction need to be chosen based on their ability to withstand the anticipated loading conditions. To find the equivalent design parameters, analyzing maximum stress, impact velocity, and collision angles are essential. By accurately determining the equivalent design parameters and stress, it can ensure that bumper materials can effectively absorb and dissipate energy during impacts. Therefore, after analysis, appropriate materials were selected for rear bumper.

3.2.7. Validation of bumper design

The final design was validated through a comparative study with existing bumper designs and theoretical calculations. Additional simulations were performed under impact loading to ensure robustness and reliability.

3.2.8. Design of Bumper and Load Determination

The moment for steel and composite bumper is assumed the same. Therefore, the moment for steel is

$$\frac{M}{I} = \frac{\sigma}{y} \tag{1}$$

Where;

- ✓ M is bending Moment (Nm),
- ✓ I is moment of inertia(m^4), σ is tensile strength (N/m^2) ,
- ✓ y is d/2, d is the thickness of bumper (m) and
- ✓ b is the Breadth of bumper (m).

For rectangular cross-section moment of inertia becomes

$$I = \frac{1}{12}bh^3 \tag{2}$$

There are three sections of the bumper, so it has three moments of inertia, i.e. I_1, I_2, and I_3 as figure below.

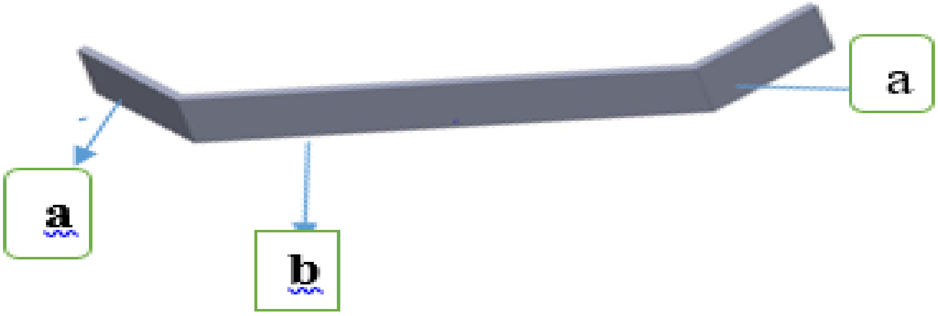

Figure 3.2: Bumper section

$$I_1 = \tfrac{1}{12} b h^3, \quad I_2 = I_3 = \frac{1}{12} a\, h^3$$

$$I_T = I_1 + I_2 + I_3 \quad , but I_2 = I_3 \tag{3}$$

$$\tfrac{M}{I} = \tfrac{\sigma}{y} \text{ But, } M = \tfrac{\sigma I}{y}$$

$$\frac{M}{1/12bd^3} = \frac{\sigma_y}{d/2} \tag{4}$$

Where; σ_y is yield strength and d is the thickness of the bumper

The thickness of the composite bumper can be determined by the above formula,

$$d_i = \sqrt{\frac{6M}{\sigma_y * b}} \tag{5}$$

The thickness of individual sections of bumper d_1, d_2, and d_3 calculated by this above formula

Forecasting on bumper (F)

$$F = m * a \tag{6}$$

Where m = mass of the Bajaj crashed on the bumper (990kg)

a = acceleration due to gravity (m /sec^2)

$$a = \frac{u - v}{t} \tag{7}$$

Where;

- ✓ v = Final velocity after collapsing (m/sec)
- ✓ u = Initial velocity before collapsing (m/sec) u = 20km/hr. =5.556 m/sec (taken from NHTSA),
- ✓ t = time taken for collapsing (sec)

Area of bumper

$$A = l * b \tag{8}$$

Where, l = length of front face bumper in mm and

b = breadth of bumper in mm

The Design Factor of Safety, FS was taken as 1.3

This relatively high value is taken to account for the uncertainty like forces.

$$F_N = F * FS \tag{9}$$

The load delivered to the bumper is uniformly distributed (pressure load).

So, the calculating pressure load is provided below;

$$P = \frac{F}{A} \tag{10}$$

Where A = bumper area of cross-section and

F = force acting on the bumper.

3.2.9. Engineering Stress with Strain

These quantities are defined relative to the original area and length of the specimen. The engineering stress (σe) at any point is defined as the ratio of the instantaneous load or force (F) and the original area (Ao). The engineering strain (ε) is defined as the ratio of the change in length $(L - L_O)$or deformation (δ) and the original length (Lo)

$$\sigma_e = \frac{F}{A} \tag{11}$$

$$\varepsilon = \frac{\delta}{L_O} \tag{12}$$

$$\delta = L - L_O \tag{13}$$

3.2.10. Modeling and Analysis of the Minidor Force Bajaj Bumper

The process of producing a digital model or simulation of the Bajaj Bumper, a particular model of three-wheeled vehicle produced by the Indian automaker Bajaj Auto, is referred to as modeling of the three-wheeled Bajaj Bumper. Typically, this modeling entails creating intricate 3D models that precisely represent the Bajaj Bumper's dimensions, form, parts, and structural features using Solid Work software.

Glass is the most often utilized fibber in polymer matrix composites. The most popular glass fibbers are E-glass, S-glass, R-glass, C-glass, and D-glass. The E in E-glass stands for electrical, indicating that it was created for electrical applications. This material is commonly used for boat hulls, floors, and vehicle bodies. The most common type of glass utilized is E-glass, as shown in Table 3.3.

However, it is currently employed for a variety of reasons, including decorating and structural applications. An existing ambassador steel bumper serves as a mould for the composite bumper design. Dimensions are considered to be the same as those of a steel bumper for manufacture (G/Michaiel, 2017; Prabhakaran et al., 2012).

The bumper dimensions and properties of the existing steel bumper are in Table 3.5 Modelling makes it possible to do several simulations and analysis on the car. This comprises, among other things, thermal analysis for heat management, aerodynamic analysis for efficiency, and structural analysis to guarantee strength and safety. To guarantee that the vehicle satisfies performance, safety, and aesthetic standards before being produced and released into the market, modelling the Minidor Force Bajaj Bumper is crucial for effective technical research, design, prototyping, and marketing.

Table 3. 5 Three-wheel vehicle, Minidor Force Rear Bumper Dimension (Mohammad, et al., 2024)

Three-wheel vehicle, Minidor Force Rear Bumper Dimension		
Overall Dimension	Length	1000 mm
	Thickness of cell wall	5 mm
	Height	80 mm
	Width	300 mm

The bumper beam is demonstrated and investigated; the displaying is done in solid modeling software it is investigated in FEA programming. The parameters which impact the execution of the bumper is thickness, speed, materials and shape of the object. The thickness of the bumper is 5mm.

The three-wheel vehicle, Minidor Force Rear bumper beam is modeled and drawing specification of the bumper is shown in Figure 3.3.

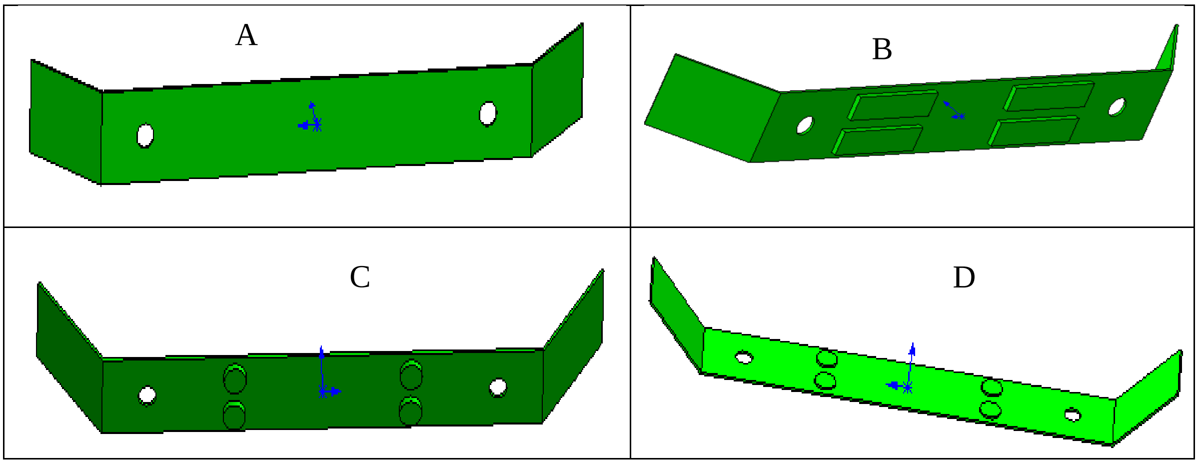

Figure 3.3: Three-wheel vehicle, Minidor Force Rear Bumpers models

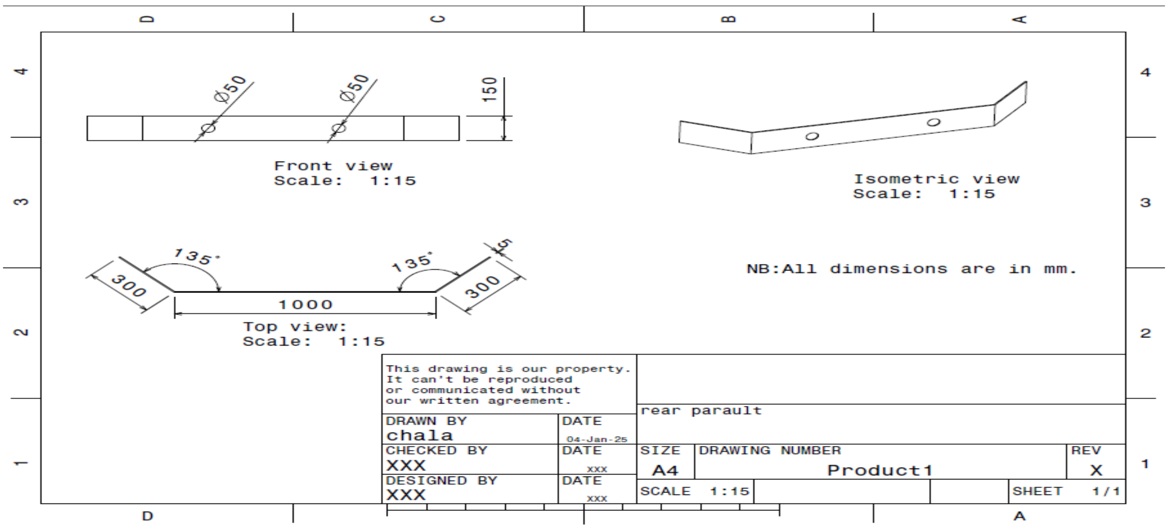

Figure 3.4: Baseline Bumper beam Model

3.2.11. Analysis of the Minidor Force Bajaj Bumper

- Mass of the car with bumper =990 kg
- Speed of the Minidor Force Bajaj = 20 kmph= 5.556mpsec
- Assume this car is hitting at another identical one and it will stop in 0.1seconds
- Force acted during collision = m*a=990*55.56 = 55KN
- m= mass of car in kg,
- a = acceleration of car in m/s^2

In FEA software we can directly apply this load on the beam as a point load. We are applying the load as point because, when the bumper beam is impacted with impact or the area of concentration is very less. So, the load is treated as point load. But for full impact we have to convert this load in to pressure. For the easiness of calculation this force is converted into a pressure which is acted on the front surface of the modeled bumper.

By considering the total load is acting on the frontal area of the beam the boundary conditions will change: -

- Area of the front face of bumper = 128,000 mm^2
- Pressure acted on the bumper = F / A = 0.43 N/mm^2
- F= Force acted during collision in Newton's,
- A = Area of the front face of bumper in mm^2.
- Pressure of 0.043Pa is applied on the bumper beam

3.2.12. Simulation of the Bumper

The primary objectives of the bumper simulation involve by assessing its design under particular conditions to testing its resilience to impacts. Determine which characteristics of the bumper's operation such as its strength, deformation, and energy absorption need to be reproduced. Using solid work software, make a 3D model of the bumper. This model needs to faithfully depict the bumper's dimensions, form, and composition. Give specifics about the elasticity, density, and strength of the material. These characteristics will affect how the bumper performs under pressure. Finite Element Analysis (FEA): This method is often used to simulate how a machine might behave in different scenarios.

The bumper is disassembled into smaller components to examine deformation, tension, and strain. Multi-Body Dynamics (MBD): MBD can be used to model how the bumper moves overall and interacts with the car's other components or outside objects. Crash Simulation: To analyse bumper performance in real-world circumstances, specific simulations are made to simulate collisions and impacts.

The simulation of each bumper model was simulated in ANSYS software and the optimum bumper was selected from the alternatives of bumper models. The following are the procedures used in the current simulation work of bumper in Explicitly Dynamic Analysis.

A. Engineering data

In this case, the properties of E-Glass material for the bumper were selected and shown in Figure 3.5.

Properties of Outline Row 6: E-Glass

	A	B	C
1	Property	Value	Unit
2	Density	2600	kg m^-3
3	Isotropic Elasticity		
4	Derive from	Young's Modulus an...	
5	Young's Modulus	7.3E+10	Pa
6	Poisson's Ratio	0.22	
7	Bulk Modulus	4.3452E+10	Pa
8	Shear Modulus	2.9918E+10	Pa

Figure 3.5: Properties of E-Glass material

B. Geometry

In this section, the geometry for each Bumper model was uploaded and the external impact models were done in the geometry section as shown in Figure 3.6. Circular hollow rigid shell impactor was selected since the Three-wheel vehicle, Minidor Force can be collided with another vehicle with collision bars. Most vehicles have circular cross-section collision bars at their front and rear ends. In addition, using circular hollow rigid shell impactor is simpler in a way that it is simpler to see the deformation of bumper.

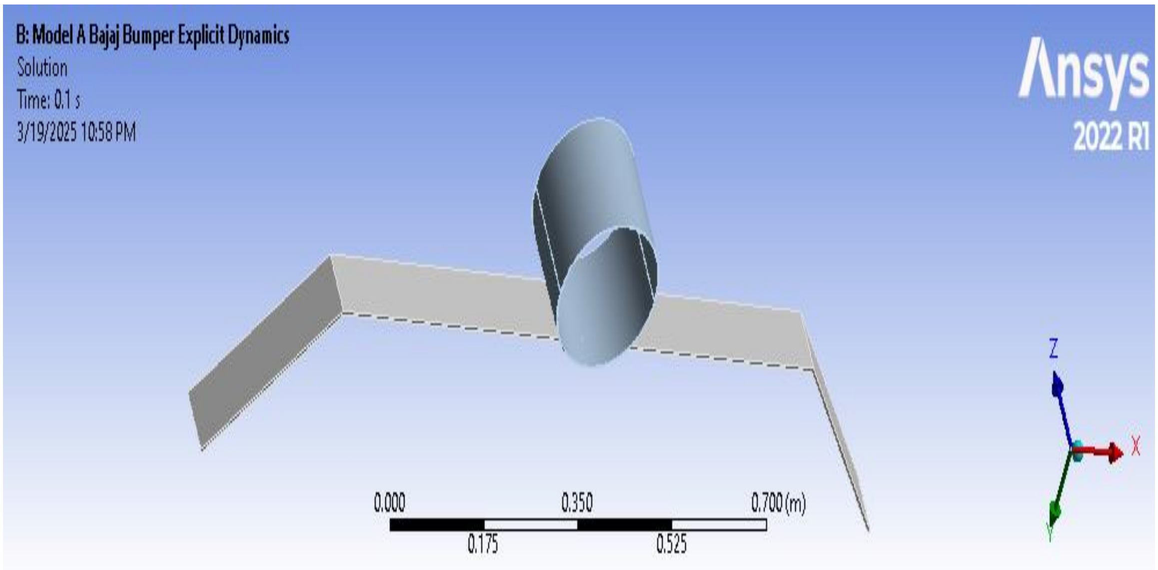

Figure 3.6: Geometry of Bumper and external impact model

C. Model and Meshing

In ANSYS workbench explicit dynamic analysis, different mesh size for the rigid impactor and flexible bumper was setup. Linear order impactor element size was set to be 0.038232. However, since the concern is about the characteristics of bumper material, finer mesh size with body sizing setting, about 0.005, was adjusted.

With these mesh setting, a total of 5,384 elements and a total of 11,354 nodes were generated, as shown in Figure 3.7. A finer mesh than this would incur high computational cost which makes it impossible with available laptop capacity at hand.

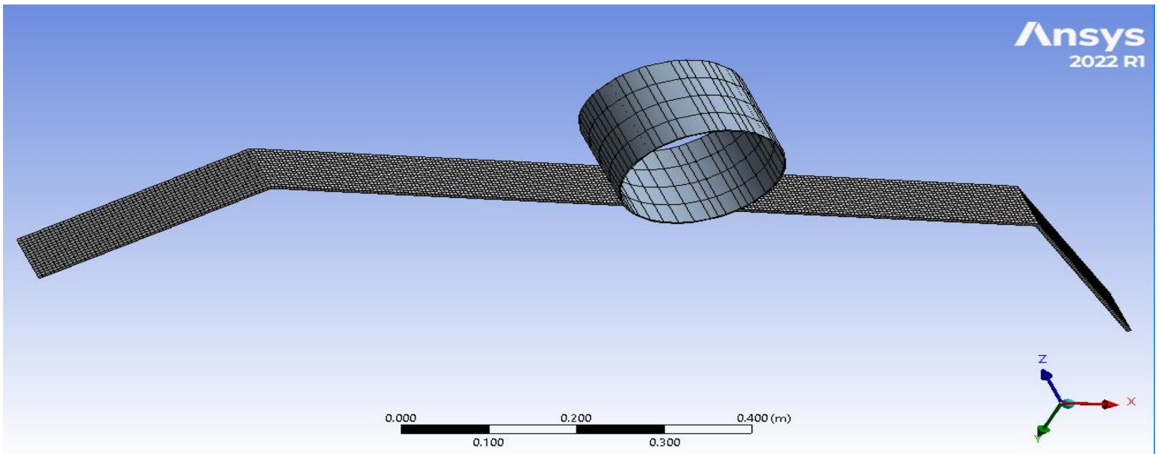

Figure 3.7: Meshed Model of Bumper

However, for models B to model D, finer mesh around stress concentration areas were created, during the finite element analysis, the primary input is the velocity of the bumper, which is applied during its operation. Various analysis steps involve different inputs affecting both the bumper model and the fixed rigid wall. However, the key input revolves around the bumper's velocity due to its movement. In the analysis, the displacement in the vertical direction at the bumper's edge is constrained. In most cities, there is a speed restriction for vehicle drives.

Although most drives did not follow it, the maximum speed inside city roads is set to be not more than 15 km/hr. For the case of this study, 5.556m/s which is about 20 km/hr. was set in Ansys workbench explicit dynamics analysis. The impactor was also constrained to a maximum of 120 mm displacement into the body of the bumper.

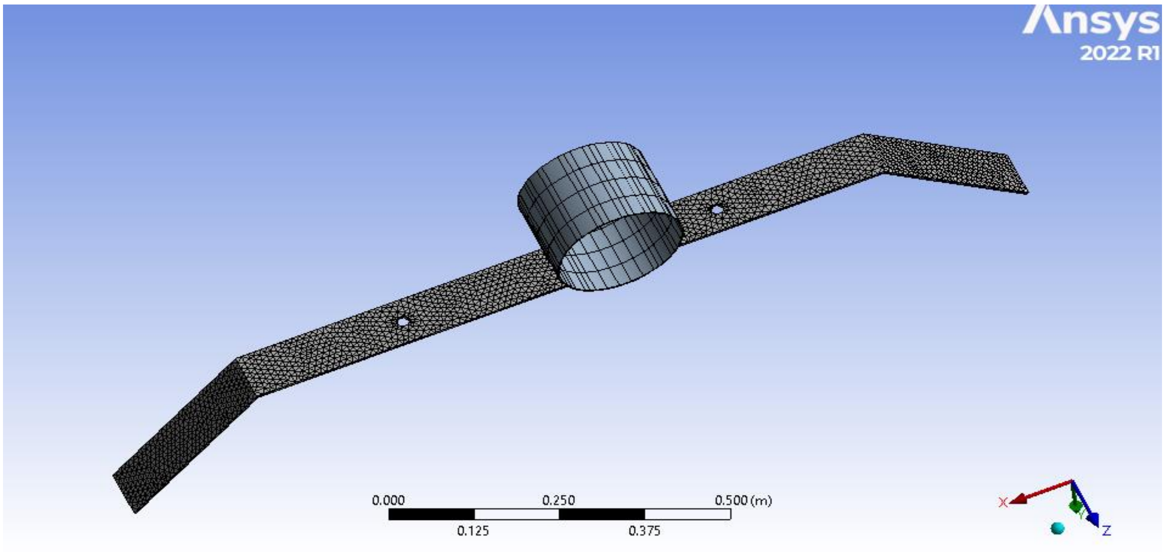

Figure 3.8: Mesh of model B

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1. Stress, Deformation, Energy and Reaction Force Analysis of E-glass/Epoxy Composite Bumper

The analysis of stress, deformation, Energy and Reaction Forcein materials is crucial for designing components that meet both safety and performance standards, particularly in automotive sector where reliability and durability are paramount. Among various materials in automotive engineering, E-glass fiber-reinforced composites have gained prominence due to their high strength-to-weight ratio and excellent impact resistance(Harrison et al., 2020; Prabhakaran et al., 2012b; Safety et al., 1970).

4.1.1. Equivalent Stress for Model 'A' (Base Line)

The stress analysis results for the Bajaj Bumper model "A" E-glass epoxy bumper shown in Figure 4.1, are based on testing at a velocity of 20 m/s. This examination assesses how the components and structure of the bumper react to the dynamic loads produced at this speed. When exposed to an input velocity of 5.56 m/s, Model "A" displayed a minimum total stress of 1.1363 MPa and a maximum stress of 715.85 MPa. This range of stress levels highlights how velocity affects the bumper's structural soundness. Red is used to represent the bumper's fascia and beam parts, which are under the most stress, while blue is used to represent the canter section, which is under the least stress.

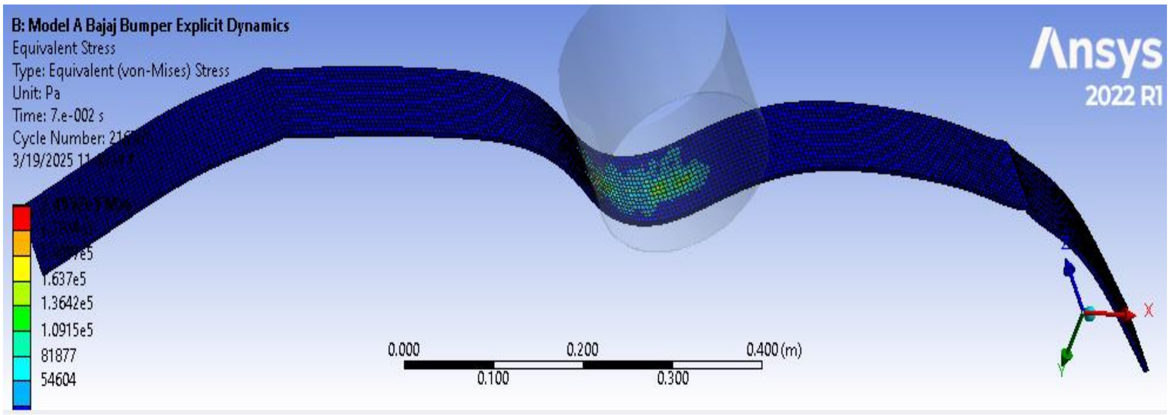

Figure 4.1: The stress analysis results of the bumper for model "A" at a velocity of 20 km/hr.

The maximum principal stress developed in model “A” to resist a 20km/hr. steel rigid impacted was 104.40MPa, Figure 4.2, are based on testing at a velocity of 20 km/hr. This analysis evaluates how the bumper’s structure and components respond to the dynamic loads generated at this speed.

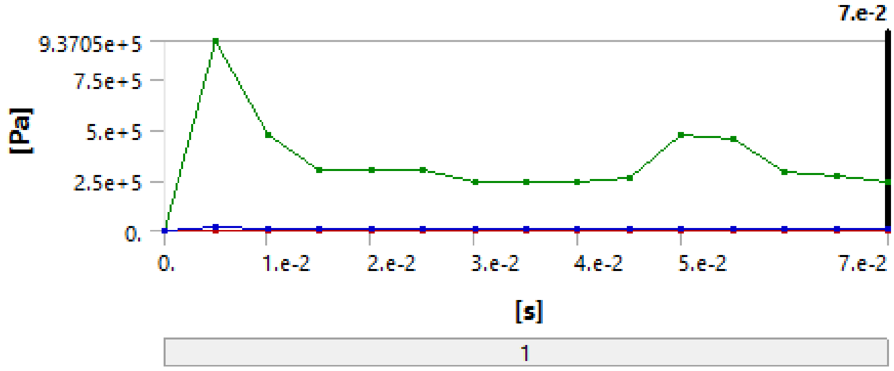

Figure 4.2: Average, maximum and minimum equivalent stress of Model “A” at 20km/hr. impacted

4.1.2. Equivalent Stress for Model “B”

Model “B” of the rectangular point-out shape bumper at an input velocity of 20 km/hr., indicating the impact’s influence on its structural integrity, experiences the greatest total stress of 719.73 MPaand a minimum of 1.6222 MPa when subjected to an input velocity of 20km/hr Figure 4.3 below shows the Minidor Force Bajaj Bumper Model “B” overall stress. At input velocity of 20 km/hr., the dynamics of how the rectangular point-out shape bumper interacts with the impacting object are critical. The bumper's shape influences how forces are distributed upon impact. The rectangular point-out design can result in a concentrated area of impact, potentially leading to higher localized stress.

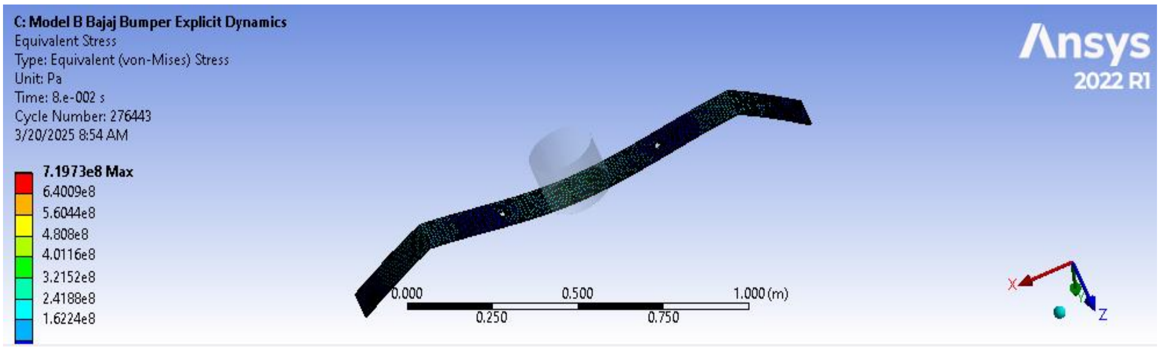

Figure 4.3: Stress analysis results of the bumper for model “B” Rectangular Point out shape

The maximum average equivalent stress of model “B” was 120.35MPa, Figure 4.4.

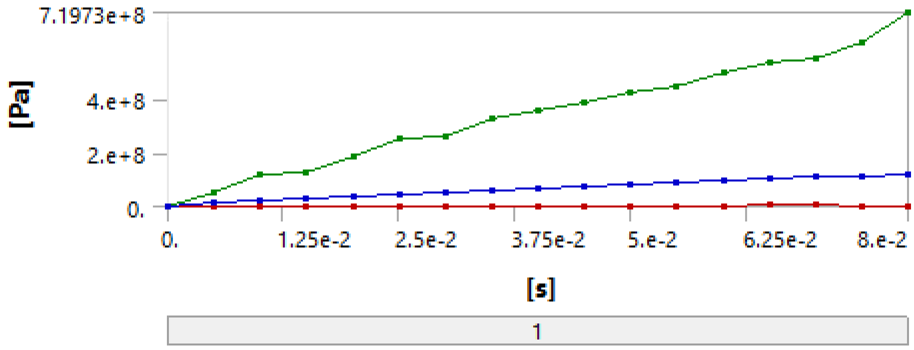

Figure 4.4: Average, maximum and minimum equivalent stress of Model “B” at 20km/hr. impacted

4.1.3. Equivalent Stress for Model C

As shown in Figure 4.5, the stress analysis findings for the Bajaj Bumper Model “C”, which features a circular point-out design, are evaluated at a velocity of 20 km/hr. This analysis examines how the bumper's structure and individual components respond to the dynamic stresses generated at this speed. The Figure above illustrates the von Mises stress for Model “C”, the circular point-out cross-section bumper, at a speed of 20 km/hr. At this velocity, the maximum stress experienced by the bumper beam was 665.45 MPa, while the minimum stress recorded was 1.4813 MPa.

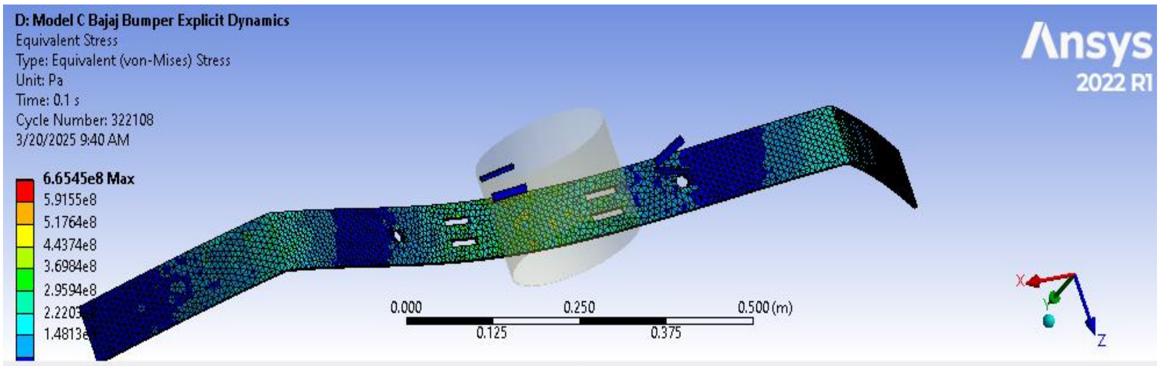

Figure 4.5: Stress analysis results of the bumper for model “C” Circular Point-out Shape

The average maximum equivalent stress of model “C” when subjected to 20km/hr impactor was 126.05MPa, Figure 4.6.

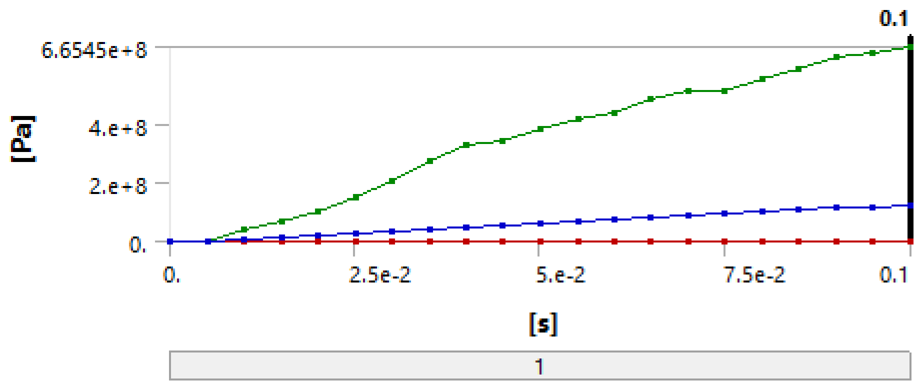

Figure 4.6: Equivalent stress of model “C” at 20km/hr. impacted

4.1.4. Maximum Principal Stress for Model “D”

As shown in Figure 4.7 below, the stress analysis findings for three wheel, Minidore Force Bumper Type “D”, with a circular point-in modeling, are based on a velocity of 20 km/hr. This analysis typically involves examining how the bumper's structure and its components respond to the dynamic stresses generated at this speed. The maximum principal stress for Model “D”, which has circular point-in geometry and an input velocity of 20 km/hr, is depicted. These numbers are used to determine the maximum principal stress levels, although the outcomes alter as the impact time varies. The maximum principal stress for Model “D” has a maximum of 647.69 MPa and a minimum of 0.1926 MPa. The maximum stress occurs at the canter of the bumper beam and barrier. Since this stress is below the yield strength of the material, the bumper beam is considered safe. The maximum stress model “D” is particularly important and acceptable because it is significantly lower than the material’s yield strength.

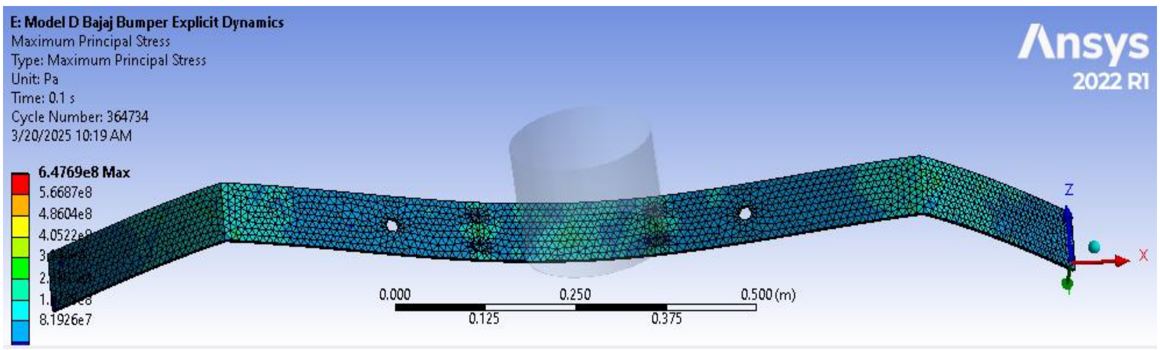

Figure 4.7: Stress analysis results of the bumper for model “D” circular point-in cross-sectional shape

The average maximum principal stress of model “D” when subjected to 20m/s impacted was 126.05MPa, Figure 4.8.

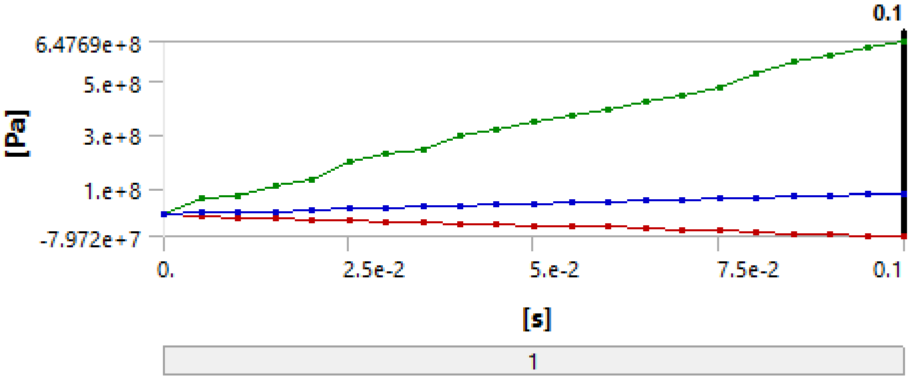

Figure 4.8: Maximum principal stress of model “D” at 20km/hr. impacted

4.1.5. Total Deformation for Model “A”

The Figure 4.9 illustrates the total deformation of the bumper at a speed of 20 km/hr. The maximum total deformation recorded was 84.356 mm, while the minimum deformation was 18.74 mm. The maximum directional deformation was 16.694 mm, with a minimum of -16.626 mm. The minimum deformation occurred at the midsection of the bumper, while the maximum deformation was observed at the end portion of the bumper.

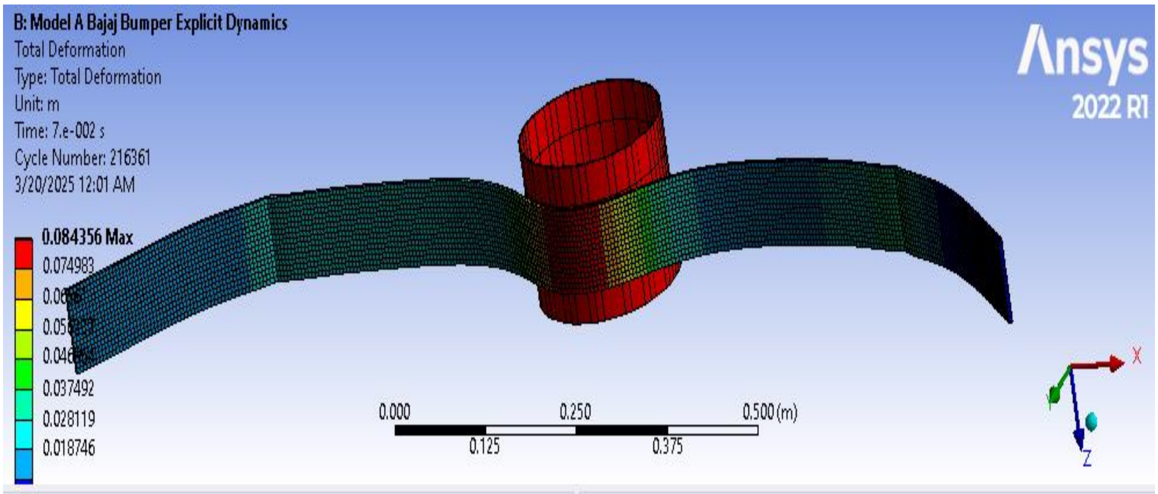

Figure 4.9: Total Deformations analysis results of the bumper model “A” at 20 km/hr.

The average deformation of model “A” when subjected to 20km/hr. impacted was 25.00 mm, Figure 4.10.

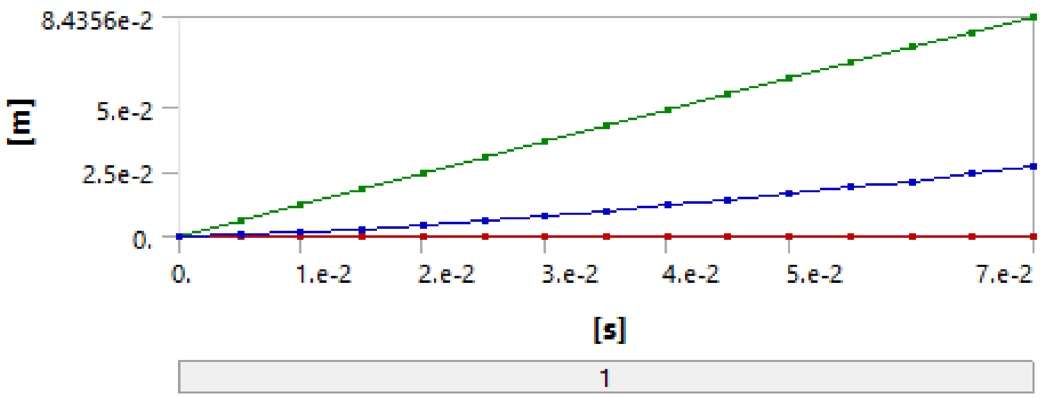

Figure 4.10: total displacement of model “A” bumper with 1 second time collision

4.1.6. Total Deformation for Model “B”

The Figure 4.11 shows that the maximum deformation region is indicated in red, while the minimum deformation is marked in blue. At a speed of 20km/hr, the maximum total deformation recorded was 137.55 mm, and the minimum deformation was 30.56 mm. The maximum directional deformation was 22.249 mm, with a minimum of -22.33mm. The maximum deformation occurred at the midsection of the bumper, while the minimum deformation was observed at the end portion of the bumper.

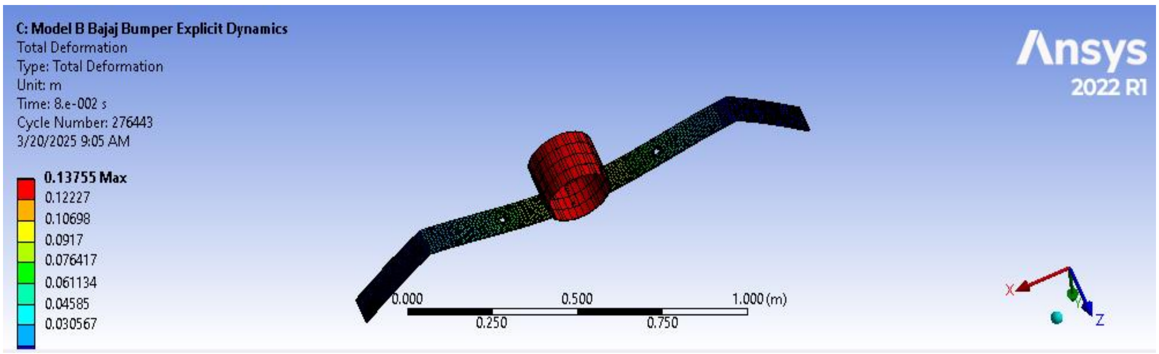

Figure 4.11: Total Deformations analysis Model “B” Rectangular Point-out Model

The average deformation of model “B” when subjected to 20m/s impactor was 49.516 mm, Figure 4.12.

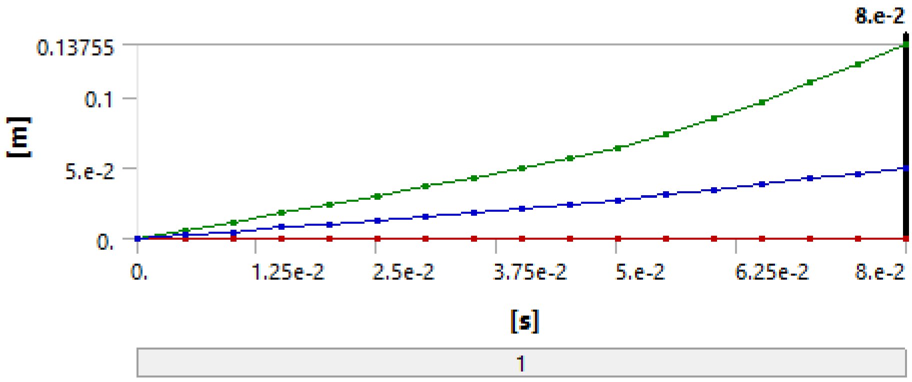

Figure 4.12: Total deformation of model “B” at 20km/hr.

4.1.7. Total Deformation for Model “C”

As shown in Figure 4.13, regions of maximum deformation are indicated in red color, while regions of minimum deformation are shown in blue color. At a speed of 20 km/hr, the maximum total deformation recorded was 123.8 mm, and the minimum deformation was 27.57 mm. The maximum directional deformation was 20.055 mm, with a minimum of -20.264 mm. The figure reveals that the maximum deformation occurs at the outer ends of the bumper, while the minimum deformation is observed at the midsection of the bumper.

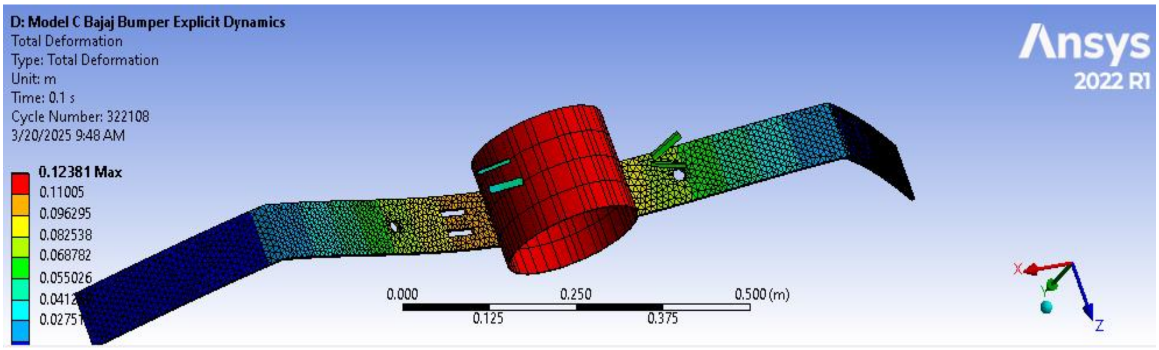

Figure 4.13: Total Deformations analysis Model “C” Circular Point-out Model

The maximum average deformation of model “C” was 25.28mm, Figure 4.14.

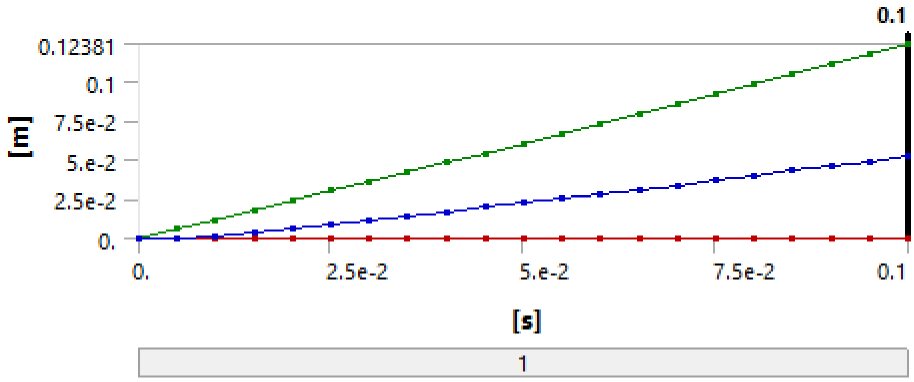

Figure 4.14: Total deformation of model “C” at 20km/hr.

4.1.8. Total Deformation for Model “D”

Total deformation refers to the change in the bumper model from its initial or starting configuration to its current configuration under the applied velocity. This means the configuration represents the set of positions of the bumper model now of impact with the wall(Chinnasamy & Periasamy, 2021; Roopesh & Rao, 2015). Maximum deformation is indicated in red color, while regions of minimum deformation are shown in blue color. The maximum total deformation recorded was 135.93 mm, and the minimum deformation was 30.20 mm, Figure 4.15. The maximum directional deformation was 14.89 mm, with a minimum of -14.88 mm.

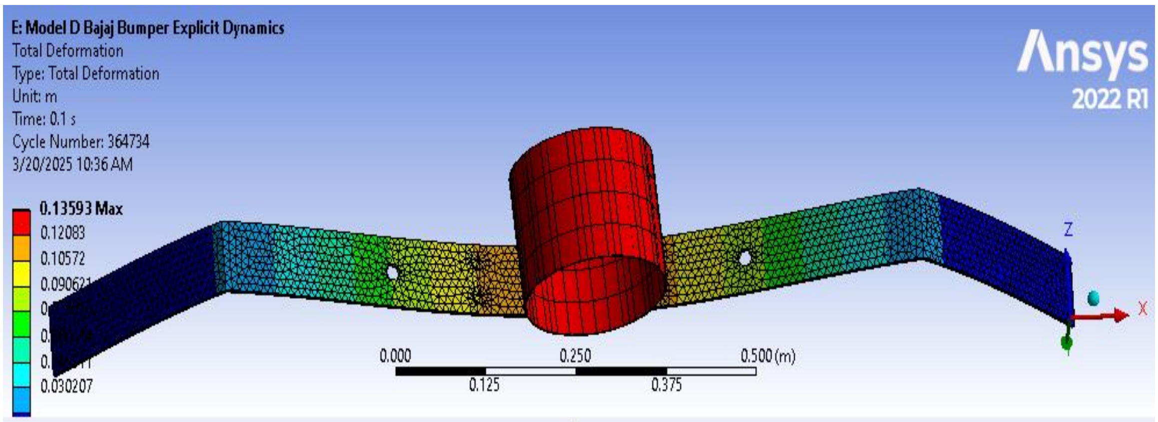

Figure 4.15: Total Deformations analysis Model “D” Circular Point-out Model

The maximum average deformation of model “D” was 52.28mm, Figure 4.16.

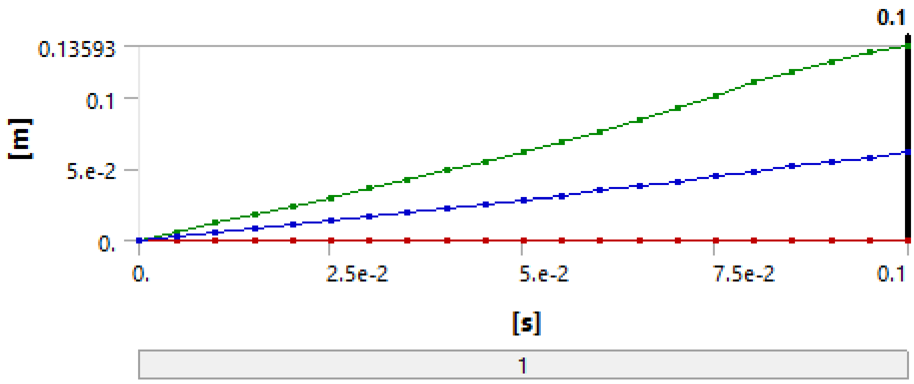

Figure 4.16: Total deformation of model "D" at 20km/hr.

4.1.9. Total Energy and Reaction Force for Model "A"

The maximum total energy of model "A" bumper was 137.22 J when subjected to 20m/s impacted, Figure 4.18. The maximum internal energy of model "A" was 118.00J.

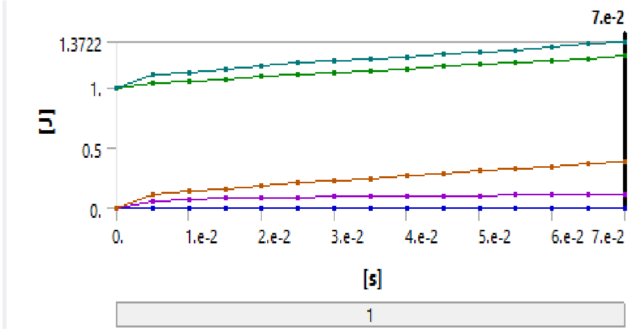

Figure 4.17: The maximum total energy of model "A" at 20 km/hr. impactor

The maximum of 3.15KN total reaction force was generated at the fixed support of Model "A" bumper to resist a 20km/hr. impacted, Figure 4.19.

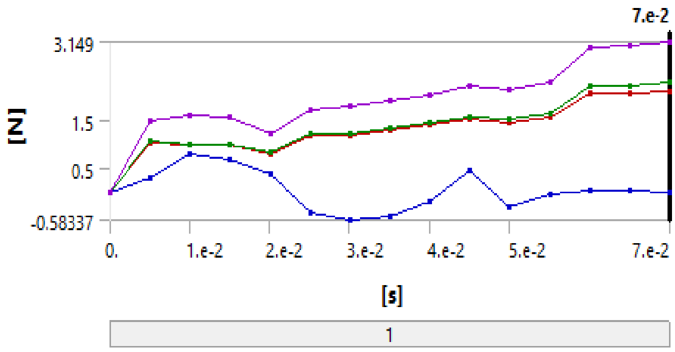

Figure 4.18: Reaction force of model "A" bumper at 20km/hr.

4.1.10. Total Energy and Reaction Force for Model "B"

The contact energy of model “B” when collided by a 20km/hr. impactor was 288.73J while the internal energy was 282.25J, Figure 4.19.

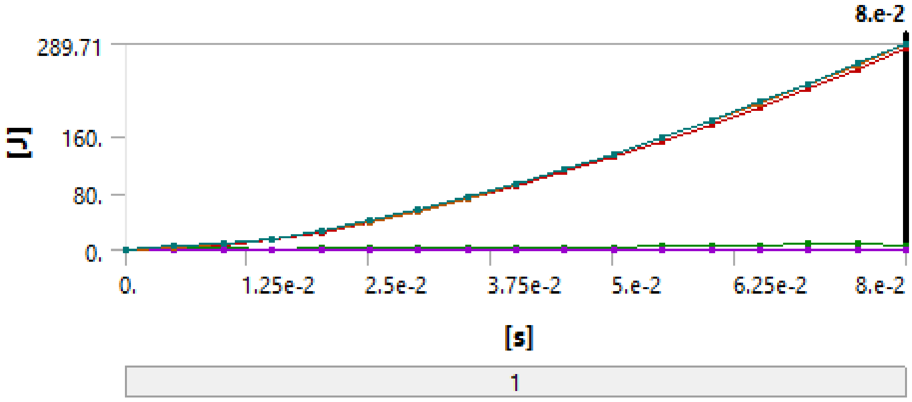

Figure 4.19: Energy of Model “B” when impacted by 20km/hr. rigid shell

The maximum reaction force generated when a 20km/hr. impactor hits the bumper was 5.72KN (compression), Figure 4.20.

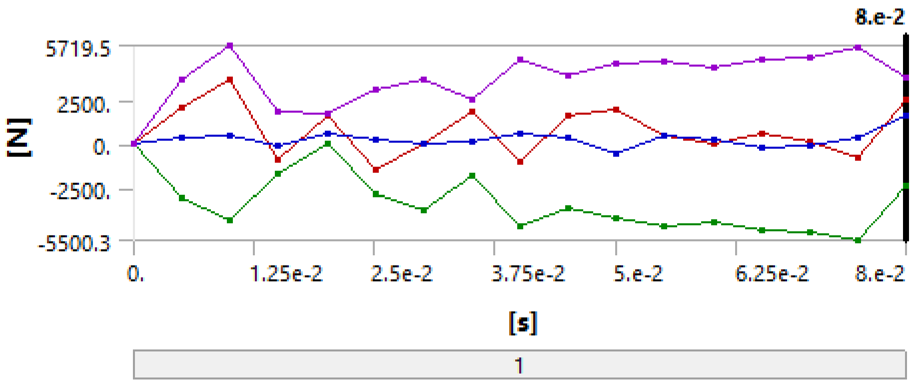

Figure 4.20: Reaction force of Model “B” when impacted by 20km/hr. rigid shell

4.1.11. Total Energy and Reaction Force for Model "C"

The contact energy of model "C" when collided by a 20m/s impactor was 293.63J while the internal energy was 292.18J, Figure 4.21.

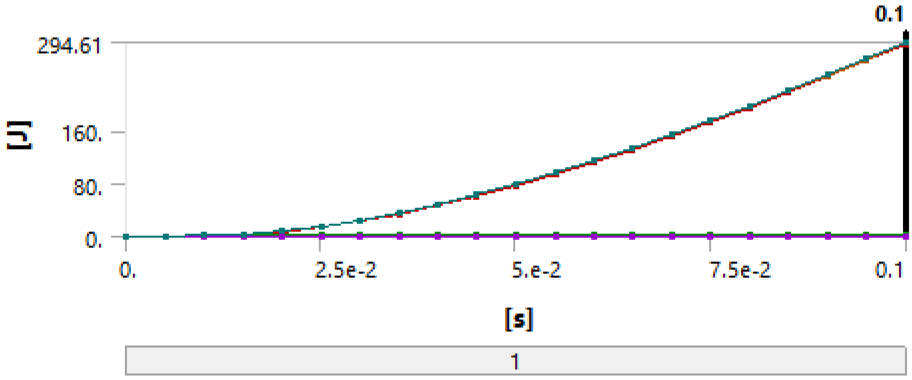

Figure 4.21: Energy of Model "C" when impacted by 20km/hr. rigid shell

The maximum reaction force generated when a 20km/hr impactor hits the bumper was 6.97KN (compression), Figure 4.22.

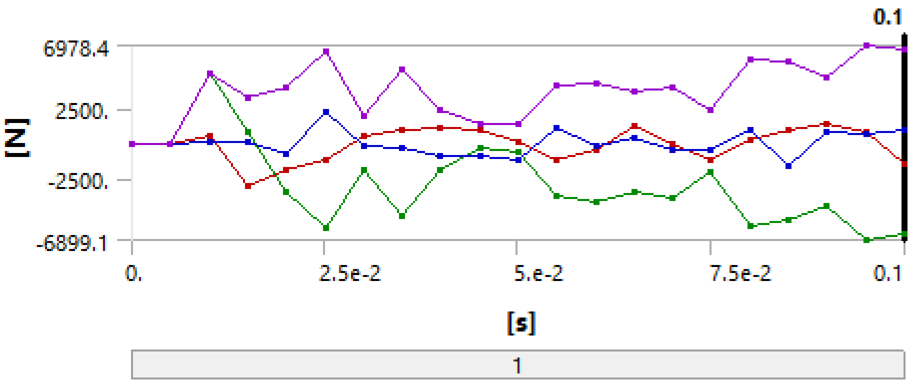

Figure 4.22: Reaction force of Model "C" when impacted by 20km/hr. rigid shell

4.1.12. Total Energy and Reaction Force for Model "D"

The contact energy of model "D" when collided by a 20km/hr. impactor was 397.43J while the internal energy was 394.9J, Figure 4.23.

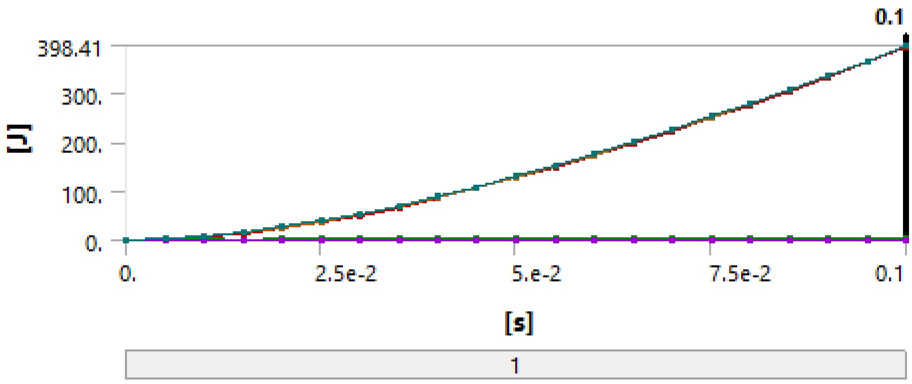

Figure 4.23: Energy of Model "D" when impacted by 20km/hr. rigid shell

The maximum reaction force generated when a 20m/s impactor hits the bumper was 7.032KN (tension), Figure 4.24. A maximum reaction force of 7.032 KN at a 20 km/hr. impact speed gives valuable insight into the bumper's ability to absorb energy and withstand force during a collision. A bumper's ability to absorb energy and withstand force during a collision is fundamental to its role in vehicle safety and structural integrity. When an impactor hits the bumper, the kinetic energy from the collision is transferred to the bumper system. A well-designed bumper absorbs this energy by deforming in a controlled manner. The deformation minimizes the energy transmitted to other parts of the vehicle, reducing potential damage to critical components and protecting passengers. In addition to absorbing energy, the bumper redistributes the impact force over a larger surface area. This helps to lower the intensity of the force at any single point, which reduces the likelihood of catastrophic failure. Design elements like crumple zones and reinforcement structures play a key role here.

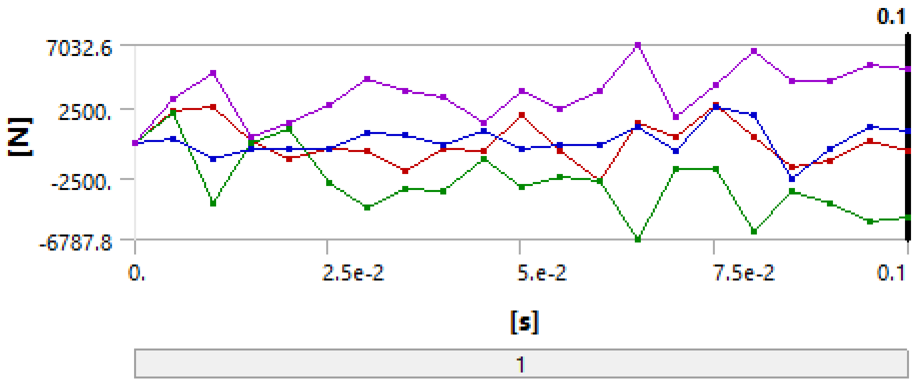

Figure 4.24: Reaction force of Model “D” when impacted by 20km/hr. rigid shell

4.2. Performance Comparison E-Glass fiber for Different Model of Rear Bumper

To effectively compare the performance of various bumper models and their respective designs (both baseline and improved), a systematic assessment across a range of relevant criteria is necessary. This involves evaluating each combination’s performance to determine which provides the best overall effectiveness or meets specific requirements. Based on the graphs and analysis results for all the models, it was found that the bumper with an E-Glass fiber Model “D” (circular point-in cross-section) exhibits superior mechanical properties and demonstrates less deformation at the given speed. The E-Glass fiber used in these models has a yielding strength of 660 MPa. The maximum stress values for Models A, B, and C, exceed this yielding strength, whereas Model D maintains a maximum stress below the yielding strength. In passenger Minidor Bajaj, bumper beams play a crucial role in absorbing impact forces during collisions.

Table 4. 1 Stress and Strain Comparison of Different E-Glass Bumper models

S/n	Bumper model	Stress (MPa)		Total Deformation (mm)		Directional Deformation(mm)		Contact Energy (J)	Internal Energy (J)	Maximum Reaction Force (KN)
		Maximum	Minimum	Maximum	Minimum	Maximum	Minimum			
1	Model “A”	715.85	1.1363	84.35	18.74	16.69	-16.62	137.22	118.00	3.15
2	Model “B”	719.75	1.6222	137.55	30.56	22.24	-22.33	288.73	282.25	5.72
3	Model “C”	665.45	1.4813	123.80	27.57	20.05	-20.26	293.63	292.18	6.97
4	Model “D”	647.69	01926	135.93	30.20	14.89	-14.88	397.43	394.90	7.03

These properties are characterized through FEM modeling under low-speed impact standards(Roopesh & Rao, 2015). The behavior of steel bumper beams under low-speed impacts is influenced by various parameters. Materials with low Young's modulus result in lower rigidity, while high-strength materials show better impact performance because their yield stress exceeds the maximum stress encountered in the bumper. Therefore, Model D is the optimal choice among the models (Eromo et al., n.d.; Roopesh & Rao, 2015; Supriya & Prasat, 2021).

In this study, the maximum principal stress is 605.2 MPa, indicating the peak tensile stress within the material. If this value exceeds the tensile strength of the material, it suggests potential failure due to tensile forces. In the context of a bumper, this high stress could be associated with impact loading or other high-stress scenarios. Although compressive stresses are generally less critical for failure compared to tensile stresses, they still influence material behavior, especially in composites.
The maximum von-Mises stress is 979.4 MPa and maximum yielding strength is 660 MPa. This high value indicates the potential for yielding or plastic deformation under the given load conditions. If this value approaches or exceeds the material's yield strength, the component could experience significant plastic deformation or failure. The maximum principal stress highlights areas of high tensile forces, while the von-Mises stress evaluates the risk of yielding. Ensuring that these stresses are within the material's strength limits is crucial for designing effective and safe E-glass bumpers. By carefully analyzing both stress measures, engineers can optimize the design to enhance performance and safety. The maximum equivalent stress is less than maximum yielding strength of materials(Harrison et al., 2020; Prabhakaran et al., 2012b; Safety et al., 1970). The comparison of total deformation of all models studied in this paper showed that Model D have the maximum deformation, Figure 4.25.

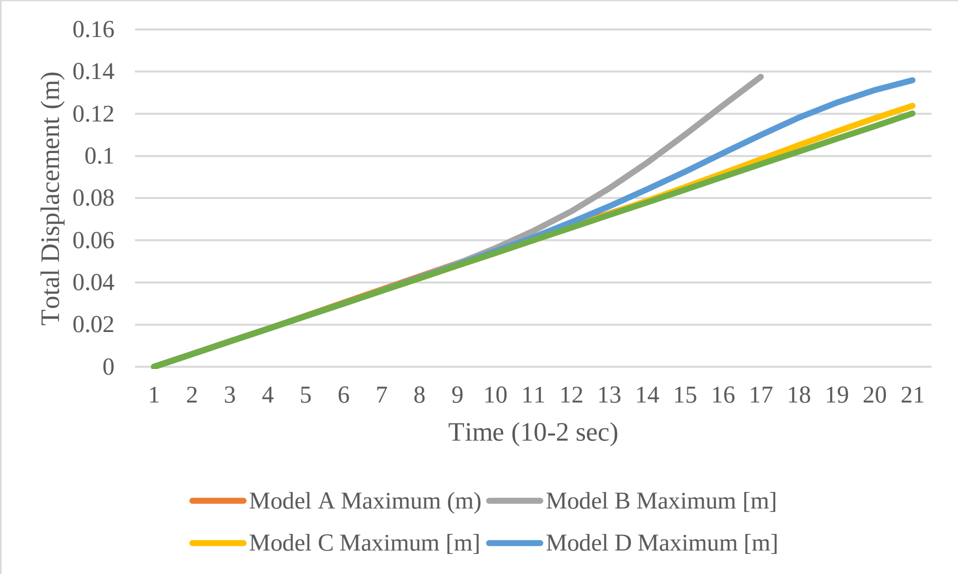

Figure 4.25: Comparison of total deformation of all models (Model A, B, C, and D)

The introduction of holes creates areas of stress concentration, making this model more prone to localized deformation around the holes. Crumple zones are designed to absorb energy by controlled deformation during impact. Thus, model “B” and “D” would likely exhibit greater total deformation than Models A or C, as the crumple zones deform intentionally to absorb energy. There's often a trade-off between total deformation and the ability to dissipate energy effectively. Reinforced models may transmit more force to surrounding areas, whereas crumple-zone models reduce transmitted force at the expense of higher deformation.

Model “A” likely has a steady, moderate reaction force as it lacks advanced energy-dissipating features like holes or reinforcements. Force is distributed relatively evenly across the structure, figure 4.26. The presence of holes creates localized areas of higher stress concentration, potentially resulting in sharper peaks or fluctuations in the reaction force graph. Model B might exhibit higher peak forces compared to Model A. Crumple zones are designed to absorb energy, which can lower the reaction force overall. The graph for model C may show a gradual rise and fall in force, with lower peaks compared to Models A and B, reflecting the controlled energy absorption. Figure 4.27. Reinforcement structures enhance stiffness and strength in model “D”, which typically results in a more stable and consistent reaction force graph. Peaks are likely lower than Model “B” (reduced stress concentration) but higher than Model “C” (due to less energy absorption).

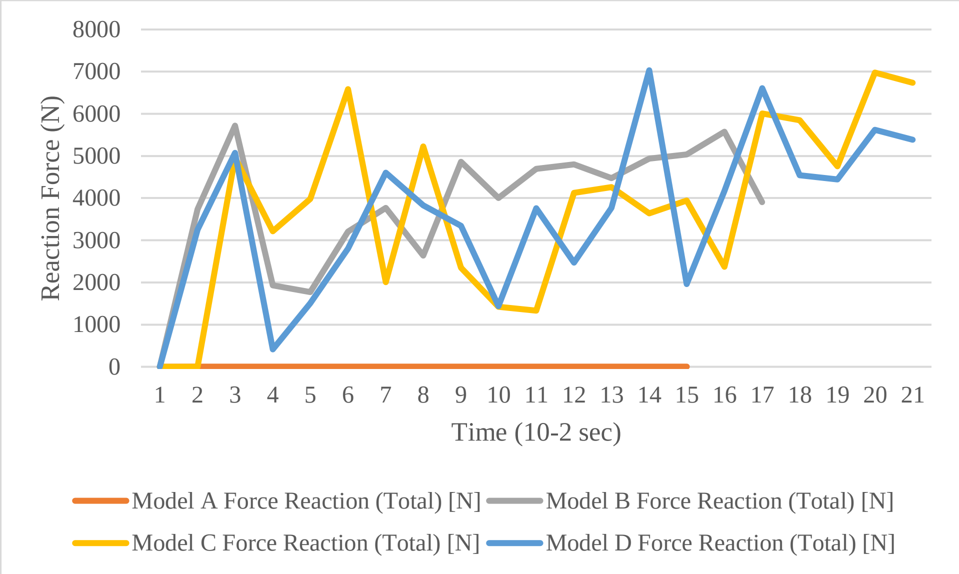

Figure 4.2: Comparison of total reaction forces of all models (Model A, B, C, and D)

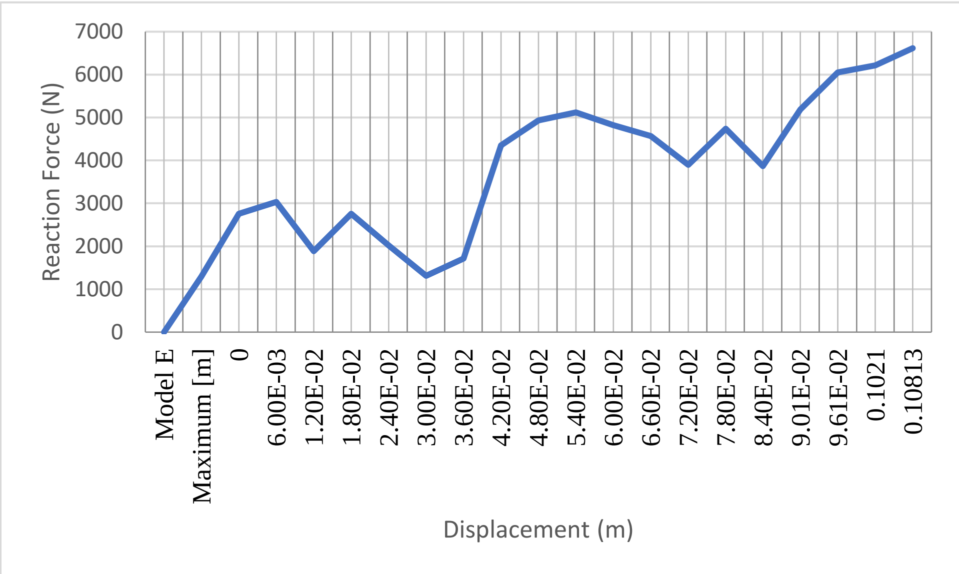

Figure 4.27: Force vs displacement curve of Model "D"

The force vs displacement curve shows that, at the start, there is a steep linear increase in force with displacement. This represents the elastic behavior of the material and structure, where deformation is proportional to applied force, Figure 4.27. Due to robust reinforcements, the curve would show a higher force capacity before significant deformation occurs, indicating improved resistance to displacement compared to less reinforced models.

CHAPTER FIVE

CONCLUSION AND RECCOMENDATIONS

5.1 Conclusions

In conclusion, the stress analysis and total deformation results for the different models of the Minidor Bajaj bumper at a velocity of 20 km/hr. provide valuable insights into how each model reacts to dynamic loads and impacts.

- Model "A", showed a maximum total stress of 715.85 MPa and a minimum of 1.1363 MPa. The maximum total deformation was 84.35 mm, with notable differences in directional deformation across the bumper and maximum Contact Energy is 137.22J, Internal Energy is 118.00J and also Maximum Reaction Force 3.15KN.
- Model "B", with a rectangular point-out shape, experienced a maximum total stress of 719.73 MPa and a maximum total deformation of 137.55 mm and maximum Contact Energy is 288.73J, Internal Energy is 282.25J and also Maximum Reaction Force 5.72KN.
- Model "C", featuring a circular point-out design, had a maximum stress of 665.45 MPa and a maximum deformation of 123.80 mm. and maximum Contact Energy is 293.63J, Internal Energy is 292.18J and also Maximum Reaction Force 6.97KN.
- Model "D", with a circular point-in shape, exhibited a maximum stress of 647.69MPa and a maximum deformation of 135.93 mm. and maximum Contact Energy is 397.43J, Internal Energy is 394.90J and also Maximum Reaction Force 7.03KN.The stress levels were below the material's yield strength, ensuring the bumper's safety and reliability under dynamic conditions.

The comparison of E-glass and steel bumpers in automotive engineering has shown that E-glass bumpers offer several advantages over traditional steel bumpers. The E-glass bumper's ability to absorb and distribute impact forces is demonstrated by lower stress levels and less deformation under the same loading circumstances. The E-glass bumper's ability to regain its normal shape with little damage was demonstrated by the fact that its overall distortion was far less than that of the steel bumper.

Additionally, compared to its steel predecessor, the E-glass bumper is far lighter, which enhances vehicle handling and fuel economy. The E-glass bumper's strength and durability in actual collision situations were highlighted by the performance analysis, which showed a greater factor of safety when compared to the steel bumper.

In comparison to conventional steel bumpers, the composite E-glass bumper offers better performance characteristics, less deformation, and efficient stress distribution, making it an appropriate material for bumper fabrication overall. These results highlight how crucial it is to choose the appropriate materials for automobile design in order to guarantee the best possible safety and performance for both cars and their occupants.

5.2. Recommendations

The use of Model "D," which has a circular point-in shape and a maximum stress below the material's yield strength, is advised based on the analysis results for the various Minidor Bajaj bumper models at a speed of 20 km/hr. This ensures safety and dependability under dynamic conditions.

Additionally, the automotive engineering comparison between steel and E-glass bumpers emphasizes the benefits of E-glass bumpers, such as decreased stress, less deformation, and increased fuel efficiency because of their lighter weight.

Therefore, when compared to conventional steel bumpers, the usage of E-glass bumpers may offer improved performance characteristics and increased safety for both cars and occupants. In order to improve overall safety and efficacy in actual impact situations, these aspects must be taken into account when choosing materials for bumper production.

5.3. Future Work

The design and analysis of bumpers for Minidor Force Bajaj were the main topics of this study. Although the thesis offered insightful information about the material performance and structural effectiveness of bumper designs, there are still a number of issues that need more research:

- Future research could concentrate on experimental crash tests to validate the simulation results, even though finite element analysis was used to assess the bumper's performance. Tests of this kind would yield empirical information to improve the bumper design even more.
- Examining how the bumper might be integrated with other safety systems, like crumple zones or energy absorbers, could improve overall vehicle safety and occupant protection.
- Cost-benefit analysis may be used in future studies to assess the feasibility of large-scale implementation of the suggested bumper designs.

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Appendix

Gabaasaa Istaastiksii Balaa Tiraafikaa Qaaj/Poo/Bu/ Magaalaa Asallaa

Kan Baatii 11(Kudha tokko) Bara 2012

Guyyaa Poo/H-436-1-15

Lakk 15-10-2011

Kom/Poo/Oromiyaatti

Damee Qorannaa yakkaa fi Murtee Haqaa Keenisisaatif

Finfinee

Dhimmii isaa ,- Gabaasa Istaatiksii Balaa Tiraafikaa Kan Waggaa Bara 2012 hojjechuun isiini erguu ilaala.

Akkumma mata duree irratti ibsamuuf yaalamectti gabaasa hojii **Istaatiksi Balaa Tiraafikaa** kan **Waggaa Bara 2012** Qaj/Poo/Bu/Mas/Asalla hojjechuudhan x/y gagecsituu kana taana kan isiini erginee ta'u keenya kabajaadhaan isiin yaadachifnaa.

" Nagaa Wajiin"

Taayyee Alamuu

G/Insp.

Tim Istaafi Is/Yakka Qaj/Po/Ma Aslla

Bara 2012 kessattii Gosa Konkolaataa Balaa Geesisanii Akka Magaalaa Asallaatii

Lakk.	Miidhaa Balaan kan Geesise	1 Biskiletti	2 Awutomobili	3 Pikapi	4 Kan Fe'insa kuntala >11 Caaluu	5 Bottee	6 Taaksii (MInidore Bajaj Force)	7 Kan Ummataa Nama >4 Caaluu	8 Gaarii	Walii Qabaa
1	Du'a	0	1	0	1	0	3	2	0	7
2	Midhamaa Ciimaa	0	0	0	1	0	2	1	0	4
3	Midhamaa Salphaa	0	0	1	0	0	0	0	1	3
Walii Qabaa		0	1	1	2	0	5	3	1	13

Gabaasaa Istaastiksii Balaa Tiraafikaa Qaaj/Poo/Bu/ Magaalaa Asallaa

Kan Baatii 11(Kudha tokko) Bara 2013

Komishiin Poolisii Oromiyaatti Qajeelcha... Poolisii Bulmaagastaa Asallaa
የኦሮሚያ ፖሊስ ኮሚሽን ... ፖሊስ መምሪያ

Lakk PMA/538/J·15/13

Guyyaa 28/09/13

Kom/Po/Oromiyaatti

Damee Qor/Yak/fi Mu/Ha/Keenisisaatif

Finfinee

Dhimmii ;- Gabaasa istaastiksii Ballaa Ab/Ad/Ho/Qo/Ya/fi Mu/Ha/
Ke/Qa/Po/Bu/Ma/Asallaa kanbaatii 11 Bara 2013 kan illaaluu ta'a

Kunis akkumaan armaan olitii ibsamuu dhaaf yaalameetii Gabaasa istaastiksi Ballaa Ad/Qo/Ya/fi Mu/Ha/Keenisisaa Qa/Po/Bu/Mag/Asallaa kan baatii 11 Bara 2013 keessatti hojiiwaan hojjetamee qopheesuu Xalaya a gageesitu kanaan kan isiinif ergine ta'u isaa kabajaa dhaan isiini ibsina.

Nagaa Wajiin "

28/9/2013

Ababaa Waldee

Inisp.

Hoj/Istaastksii

Bara 2013 kessattii Gosa Konkolaataa Balaa Geesisanii Akka Magaalaa Asallaatii

Lakk.	Miidhaa Balaan kan Geesise	1 Biskiletti	2 Awutomobili	3 Pikapi	4 Kan Fe'insa kuntala >11 Caaluu	5 Bottee	6 Taaksii (MInidore Bajaj Force)	7 Kan Ummataa Nama >4 Caaluu	8 Gaarii	Walii Qabaa
1	Du'a	0	1	1	0	0	4	1	0	7
2	Midhamaa Ciimaa	0	1	0	1	0	2	1	0	5
3	Midhamaa Salphaa	0	1	1	0	0	0	0	0	2
Walii Qabaa		0	3	2	1	0	6	2	0	14

Gabaasaa Istaastiksii Balaa Tiraafikaa Qaaj/Poo/Bu/ Magaalaa Asallaa

Kan Baatii 11(Kudha tokko) Bara 2014

Gabaasa Istaasitiksii balaa tiraafikaa baatii 11(kudha tokko) baraa hojii 2014

Lakk fmA/2121/1.15

Guyyaa 28/9/14

Qaaj/Muumee Poolisii Oromiyaatiif

Finfinee

Dhimmi isaa :- Gabasaa Istaasitiksii balaa tiraafikaa It/A/Dir/Ad/Ho/ Qoranna Yakkaa fi murtee

Haqaa Keenisisa Kan **baatii 11(kudha tokko)** Bara 2014 gunee Isiniif Erguu Ta'a

Akkumma mata duree irrati ibsamuuf yaalameeti gabaasa istaatiksi balaa tiraafikaa Akkaata formaatti Istaasitiksii balaa tiraafikaa gaafatuun yakkotaa baatii 11(kudha tokko) Bara 2014 keessati Akka Qa/Po/Bu/Mag/Asallaa tti rawwataman kan ibsuu waraqaa fuula ________ qabuu kana irratti gunnee xalayaa gaggeessituu kanaan isnii erguu keenya kabajaadhan ibsina.

"Nagaa Wajjiin"

Tashoomaa Guutaa

It/A/saajiin

Qind/Dok/Istaasitiksii yakka fi balaa Qaaj/poo/Bu/Mag/Asallaa

Bara 2014 kessattii Gosa Konkolaataa Balaa Geesisanii Akka Magaalaa Asallaatii

		1	2	3	4	5	6	7	8	
Lakk.	**Miidhaa Balaan kan Geesise**	**Biskiletti**	**Awutomobili**	**Pikapi**	**Kan Fe'insa kuntala >11 Caaluu**	**Bottee**	**Taaksii (MInidore Bajaj Force)**	**Kan Ummataa Nama >4 Caaluu**	**Gaarii**	**Walii Qabaa**
1	**Du'a**	0	0	0	2	0	4	1	0	**7**
2	**Midhamaa Ciimaa**	0	1	0	1	0	2	1	0	**5**
3	**Midhamaa Salphaa**	1	2	1	0	1	2	1	1	**9**
Walii Qabaa		**1**	**3**	**1**	**3**	**1**	**8**	**3**	**1**	**21**

Gabaasaa Istaastiksii Balaa Tiraafikaa Qaaj/Poo/Bu/ Magaalaa Asallaa

Kan Baatii 11(Kudha tokko) Bara 2016

Lakko PMA/517/1-11/16
Guyyaa 21/09/2016

Kutaa Istatiksii Yakka fi Balaa Tiraafikii Kom/ Pol/ Oromiyaa ttif

Finfinnee

Dhimmi;-Gabasaa Istaatiksii Balaa Tiraafikii Waggaa bara 2016 isiinii erguu ta'a.

Kunis akkumaan armaan olittii ibsamudhaf yalameetii gabaasaa Waggaa bara 2016 Kan Istaatiksii Balaa Tiraafikii hojiwwan gamma kannan hojatamaan xalayaa gageesituu Fuula ________ Of Keessaa qabu wal-qabsifnee kan isini ergii ta'uu kabajaan isiini hubachisnaa.

Nagaa Wajjiin

Xaahir Ismaa'il

Sajiin

Kutaa Xiqqaa Istaatiksii Balaa Tiraafikii

Bara 2016 kessattii Gosa Konkolaataa Balaa Geesisanii Akka Magaalaa Asallaatii

Lakk.	Miidhaa Balaan kan Geesise	1	2	3	4	5	6	7	8	Walii Qabaa
		Biskiletti	Awutomobili	Pikapi	Kan Fe'insa kuntala >11 Caaluu	Bottee	Taaksii (MInidore Bajaj Force)	Kan Ummataa Nama >4 Caaluu	Gaarii	
1	Du'a	0	2	1	2	0	5	4	0	14
2	Midhamaa Ciimaa	1	1	2	1	4	4	3	4	20
3	Midhamaa Salphaa	1	2	1	2	1	6	5	1	20
Walii Qabaa		2	5	4	5	5	15	13	5	54