ISLAMIC UNIVERSITY OF TECHNOLOGY

ORGANIZATION OF ISLAMIC COOPERATION

IMPACT ANALYSIS ON CAR BUMPER TO ENHANCE PASSENGER SAFETY

A Thesis submitted in partial fulfilment of the requirement for the degree of
Bachelor of Science in Mechanical Engineering

Authored by:

KAZI FORHAN NADIM EZAZ
Student ID: 180011122

MOHAMMAD SAKIB UL ABRAR
Student ID: 180011120

RIDOWAN ISLAM PRANTO
Student ID: 180011112

Supervised by:

PROF. DR. MD. ZAHID HOSSAIN
Dean, Faculty of Engineering and Technology (FET)
Islamic University of Technology (IUT)

Department of Mechanical and Production Engineering (MPE)
Islamic University of Technology (IUT)

MAY 2023

CERTIFICATE OF RESEARCH

The thesis titled **IMPACT ANALYSIS ON CAR BUMPER TO ENHANCE PASSENGER SAFETY”** submitted by **KAZI FORHAN NADIM EZAZ** (180011122), **MOHAMMAD SAKIB UL ABRAR** (180011120), **RIDOWAN ISLAM PRANTO** (180011112) has been accepted as satisfactory in partial fulfilment of the requirement for the Degree of Bachelor of Science in Mechanical Engineering on May, 2023.

Supervisor

Zahid Hossain

PROF. DR. MD. ZAHID HOSSAIN
Dean, Faculty of Engineering and Technology (FET)
Islamic University of Technology (IUT)

Head of the Department

PROF. DR. MD. ANAYET ULLAH PATWARY
Department of Mechanical and Chemical Engineering (MCE)
Islamic University of Technology (IUT)

DECLARATION

This is hereby declared that this thesis entitled **IMPACT ANALYSIS ON CAR BUMPER TO ENHANCE PASSENGER SAFETY”** is an authentic report of our study carried out as requirement for the award of degree B.Sc. in (Mechanical Engineering) at Islamic University of Technology, Gazipur, Dhaka, under the supervision of **DR. MD. ZAHID HOSSAIN**, Professor, Department of Mechanical and Production Engineering, IUT during August 2022 to May 2023.

The matter embodied in this thesis has not been submitted in part or full to any other institute for award of any degree.

Signature of the Authors

Forhan Nadim
05-06-23

Kazi Forhan Nadim Ezaz
Student No: 180011122

05-06-2023

Mohammad Sakib Ul Abrar
Student No: 180011120

05.06.23

Ridowan Islam Pranto
Student No: 180011112

Signature of the Supervisor

Zahid Hossain

PROF. DR. MD. ZAHID HOSSAIN
Dean, Faculty of Engineering and Technology (FET)
Islamic University of Technology (IUT)

ACKNOWLEDGEMENTS

We would like to thank Allah (SWT) first of all for giving us the patience, potential and blessings to enable the completion of this thesis, and this would not have been possible without His mercy and generosity. We would like to thank our respected supervisor Prof. Dr. Md. Zahid Hossain, Dean, Faculty of Engineering Technology (FET) for his guidance, motivation and patience throughout the research period. We highly appreciate his enthusiasm and willingness to spend his time and wisdom for the care of his students throughout the academic year. Apart from him and would like to thank each and every faculty of our department of mechanical and production engineering for their knowledge assistance motivation and care throughout the study period. We are extremely grateful to have been privy to his sincere advices and earnest support. We would also want to express our gratitude to our parents for the crucial role they played in enabling us to grow up in a home that emphasized moral principles and was filled with love, respect, and religious sentiment, all of which allowed us to advance in life. Without the support of the aforementioned individuals, it would not have been possible for us to finish our study, thus we are very grateful to them. Despite our greatest efforts to complete this thesis flawlessly, we sincerely regret any errors that may have occurred.

ABSTRACT

This thesis explores the modification of automotive bumpers to improve impact resistance. The study focuses on developing a three-layer bumper design with a spring-supported system and employing single materials for simplicity and cost-effectiveness. Through the use of SOLIDWORKS and ANSYS, finite element method (FEM) and structural analysis were conducted to evaluate different material combinations. The design was assessed based on the average von Mises stress at the impact region, ensuring it did not exceed the material's yield strength, while prioritizing configurations with the lowest stress and highest displacement. The research findings demonstrate that the proposed multi-layer bumper design with the spring-supported system offers enhanced impact resistance compared to conventional designs, providing valuable insights for optimizing bumper performance and contributing to automotive safety advancements.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 Introduction

There has been a worldwide uptick in vehicle-related accidents during the last decade. The World Health Organization (WHO) has identified road traffic accidents as a main cause of mortality worldwide. It is estimated that 1.35 million individuals died in traffic-related incidents in 2018, with many more injured. More people living in metropolitan areas, more people owning cars, and more people using cellphones and other mobile devices while driving have all contributed to the increase in accidents. There has been an upsurge in accidents due to many factors, including insufficient infrastructure, bad road conditions, and slack enforcement of traffic rules and regulations. Better infrastructure, more driver education, increased traffic enforcement, and public awareness efforts to encourage safer driving practices are all necessary to solve this problem. But there are other ways to decrease the number of accidents or minimize the Impact of accidents. Car bumper is one of them that helps to reduce the Impact of an accident. The purpose of a car bumper is to shield the passengers of the vehicle from harm in the case of a collision. They are often composed of plastic, steel, or aluminum and are intended to absorb the force of a collision, minimizing damage to the car and the possibility of injury to the occupants. The speed and angle of the accident, the weight and size of the involved cars, the material and design of the bumper itself, and other factors can all affect how effective bumpers are. The study of automotive bumper crashworthiness through computer modelling and testing has gained popularity in recent years. In order to improve some regions and create new bumper materials and designs that might increase crash safety, this research intends to assess how well various bumper designs function in various collision scenarios. In this thesis, finite element analysis (FEA) and physical testing are used to analyze the crashworthiness of automobile bumpers. The research focuses on examining the performance of various bumper designs under low-speed Impact scenarios, evaluating the effect of bumper materials and design elements on crash safety, and suggesting novel design concepts that can enhance bumper performance.

1.1 Introduction to Car Bumper

Bumpers on automobiles are an essential component of the vehicle since they serve various purposes. They are intended to absorb the force of low-speed crashes and protect both the passengers of the vehicle and the car itself from harm. Plastic, aluminum, steel, fiber-glass, and fiberglass-reinforced plastic are just some of the materials that may be used to make bumpers. Bumpers are made from components that have been selected for their high levels of strength and durability as well as their capacity to absorb energy. Bumpers have seen a number of design changes throughout the years, with the most recent versions featuring a lower profile and a more streamlined appearance for improved aerodynamics.

Bumpers are normally attached to the front and back of a vehicle and serve as the primary protective mechanism in the event that the vehicle is involved in an accident. They are intended to distort upon Impact, so absorbing and dispersing the energy of the collision throughout the structure of the bumper. This energy absorption serves to minimize the force of the collision, which in turn helps to reduce the likelihood that the passengers of the car may sustain injuries. When a vehicle is involved in an accident, bumpers play an essential part in preventing damage to the vehicle's other vital components, such as the engine and gearbox, which are both vulnerable to destruction.

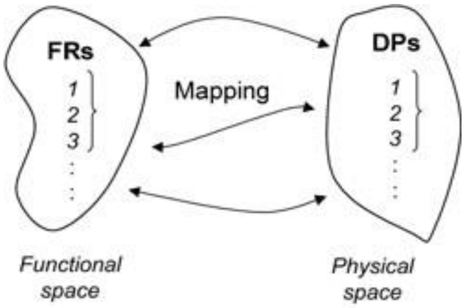
Figure 1.2 Commonly Used Car Bumpers

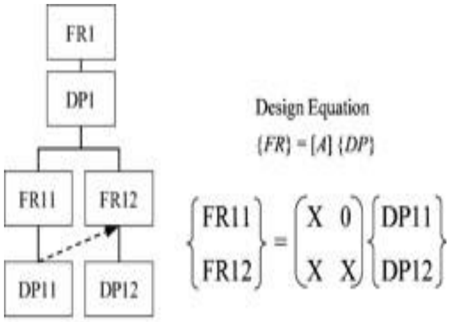
The significance of bumper systems for passenger cars in the prevention or reduction of physical damage sustained by the front or rear ends of passenger motor vehicles in the case of a collision. The bumper system is intended to provide protection for a variety of components, including the hood, the trunk, the grill, and different pieces of safety-related equipment including headlights, parking lights, and taillights. The design of the automobile bumper has to be lightweight while also provide enough protection for the vehicle's occupants. The purpose of bumpers on automobiles has changed significantly over the years, with an increased focus placed on striking a certain equilibrium between stiffness, strength, and the ability to absorb energy. Stiffness is essential because the design of the bumper must bend under load within the restrictions of the vehicle design. Energy absorption is also essential because it helps limit the amount of Impact force that is delivered to the surrounding rails and the vehicle frame. The car industry is now focusing its attention on developing bumper systems that are both lighter and safer. [1]

1.2 Car Bumper Manufacture and Use

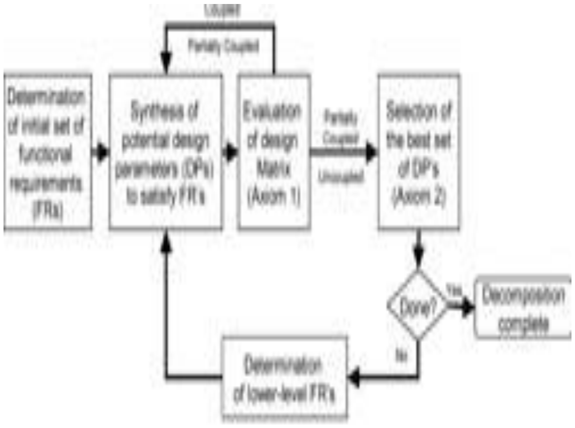
The method that is used to manufacture automobile bumpers changes based on the kind of material that is used, the design of the bumper, and the quantity of bumpers that are manufactured. Injection molding is one of the most popular processes used for the production of plastic bumpers, whereas blow molding is the technique of choice for the production of hollow plastic bumpers. Thermoforming is another method that may be used in the production of plastic bumpers of a wide variety of forms and dimensions. In addition, manufacturers make use of a variety of building techniques and materials. One example of this is the sandwich construction method, which includes stacking multiple materials to provide increased durability and strength.

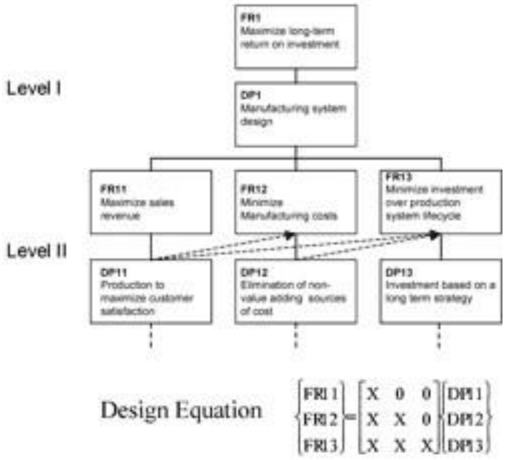
The use of a novel strategy for the conversion of polymer waste, more especially bumpers from automobiles, into carbon-based nano-materials with added value by the utilization of catalytic pyrolysis using TiO2 nanoparticles as the catalyst. The final product will undergo a number of characterizations and tests of its nanostructure and physical characteristics, including as XRD, SEM, and Raman spectroscopy, with the intention of determining its level of quality and how well it functions after it has been manufactured. There is a significant possibility that high-quality carbon nano-materials may be produced by the use of TiO2 nanoparticles as a catalyst for the pyrolysis of waste polymer. [2] The bumper beam is an essential part of vehicle safety because it deflects and absorbs the force of Impact caused by crashes. Because of increased safety rules and stringent environmental guidelines, the design of the bumper has grown more complicated. The bumper has to be flexible enough to absorb low-speed accidents without injuring passengers or occupants, but it also needs to be rigid enough to absorb high-speed Impacts without causing damage. Validation of the reinforcing beam must be accomplished using FEA as well as experimental testing since it is crucial to the safety of the structure. Careful design and study of useful factors may maximize the material's strength while simultaneously lowering its weight and expanding its potential application of recyclable resources. The effectiveness of product development may be improved by conducting a study of effective parameters. Significant design factors in bumper beam manufacture include cross-section, longitudinal curvature, fastening technique, rib thickness, and strength. [3]

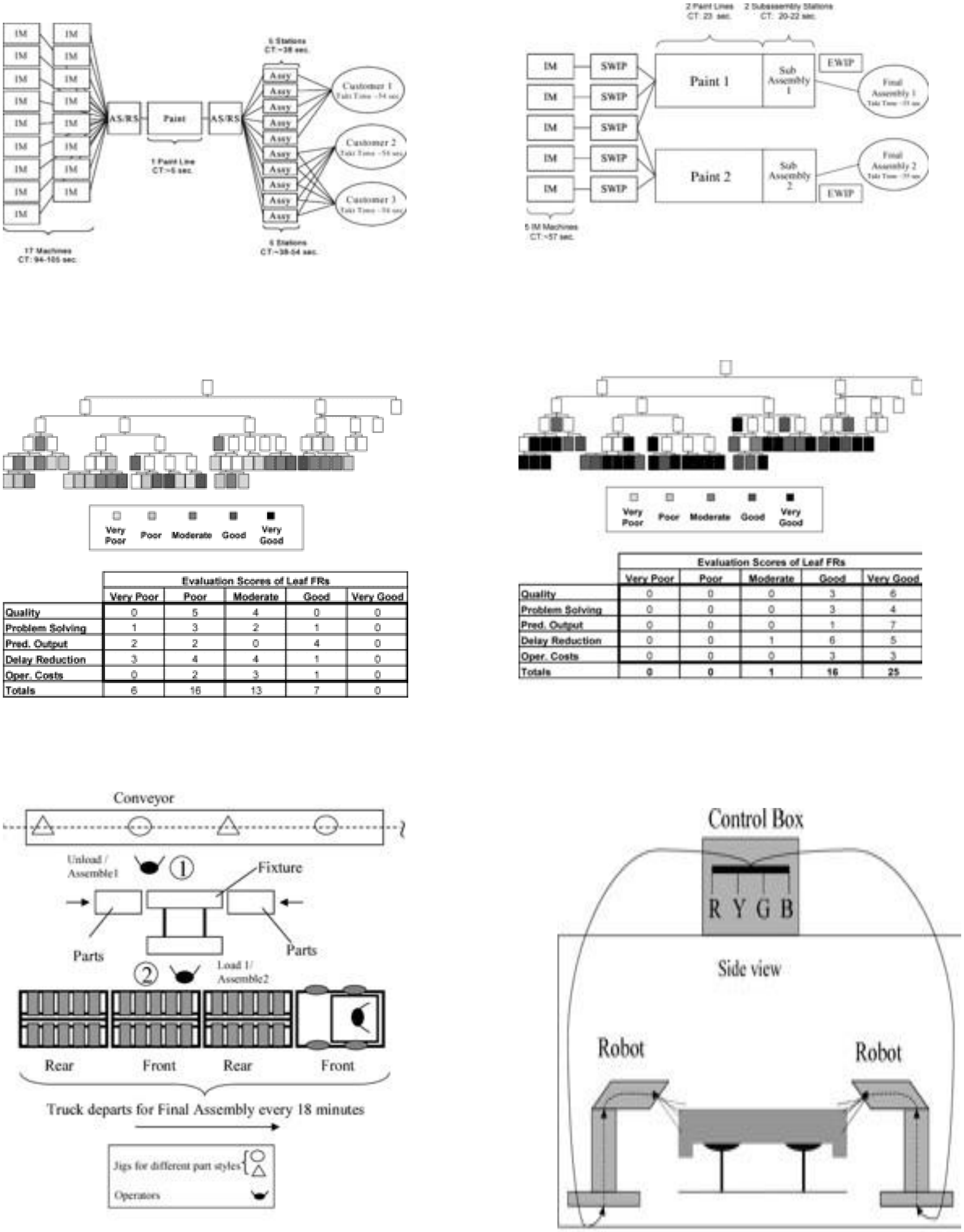




decomposition.







	Evaluation Scores of Leaf FRs				
	Very Poor	Poor	Moderate	Good	Very Good
Quality	0	5	4	0	0
Problem Solving	1	3	2	1	0
Pred. Output	2	2	0	4	0
Delay Reduction	3	4	4	1	0
Oper. Costs	0	2	3	1	0
Totals	6	16	13	7	0

	Evaluation Scores of Leaf FRs				
	Very Poor	Poor	Moderate	Good	Very Good
Quality	0	0	0	3	6
Problem Solving	0	0	0	3	4
Pred. Output	0	0	0	1	7
Delay Reduction	0	0	1	6	5
Oper. Costs	0	0	0	3	3
Totals	**0**	**0**	**1**	**16**	**25**

Figure 1.3 Manufacturing System Design of Automotive Bumper Manufacturing [4]

Plastic is increasingly used in the construction of current automobile bumper systems, which offers a number of benefits, both aesthetically and practically, to car designers and drivers. These bumpers may be constructed from a wide range of materials, and some of them can even be strengthened to provide Impact resistance comparable to that of metal while yet being easier and cheaper to repair. They expand at the same pace as metal bumpers and do not need the use of any extra fittings in order to remain in place. In addition, many plastic items are recyclable, giving producers an opportunity to utilize excess material in a manner that is both efficient and affordable. [5]Additionally, we may employ composite materials that are created from the fibers of okra and bananas. Because of the environmental advantages, cost-effectiveness, and renewability of these bio composites, they are gaining a growing amount of popularity in a variety of sectors. Strength and stiffness may be added to materials by the use of natural fibers as reinforcement; this makes the materials acceptable for use in structural applications. According to the information presented in the article, lignocellulosic fibers from less common plants, such as banana and okra, may have use as a reinforcement for polymer composites. Additional study is required to understand the mechanical and thermal characteristics of these materials before they may be used in practical application. [6] The use of thermoplastics made from natural fibers in the automobile sector, more especially for the development of bumpers. Natural fibers provide a number of benefits that typical reinforcing materials do not, including lower costs, the capacity to be renewed and recycled, and the ability to break down naturally. In most cases, bumpers are not intended to serve as structural components for the purpose of protecting the occupants of the vehicle; rather, their primary function is to shield the body of the vehicle and any safety-related components from damage in the event of low-speed crashes. The article also discusses research that examined several composites for bumper pallets, such as glass fiber, synthetic glass fibers, and jute fiber. Jute fiber was shown to be the most effective material. [7]

After the bumpers have been made, they are fitted onto the vehicle's front and back ends in the appropriate locations. The method of installation may vary based on the make and model of the automobile, but in most cases, it requires fastening the bumper to the underside of the chassis of the vehicle. During typical usage, bumpers are subjected to a variety of loads and Impacts, including being involved in small accidents when parking, travelling on rough roads, and being exposed to severe weather conditions. In addition to this, they are obliged to comply with the safety requirements established by regulatory agencies, which might differ from area to region.

1.3 Challenges of Car Bumper

The design of car bumpers must overcome a number of obstacles, such as striking a balance between safety and cost, conforming to regulatory standards, and reducing their negative influence on the environment. The safety of bumpers is an extremely important issue, and manufacturers are obligated to guarantee that their products can properly absorb Impact in the event of an accident while also reducing the likelihood that passengers would sustain injuries. Because bumpers need to be reasonably priced for both manufacturers and customers, cost is another important factor to take into account. This may be a tricky balancing act since using better quality materials and production procedures might result in the bumpers having a higher price tag.

Because the regulations may be difficult to understand and the requirements might differ from one place to another, it can be challenging for manufacturers to assure compliance. For instance, in the United States, the National Highway Traffic Safety Administration (NHTSA) is in charge of establishing safety standards for bumpers and mandates that cars satisfy certain requirements for Impact resistance. Through a process known as type approval, the European Commission is responsible for regulating the safety of vehicle components within the European Union. This includes the safety of bumpers.

In conclusion, environmental considerations include the reduction of the usage of materials that are damaging to the environment as well as the development of manufacturing methods that are environmentally sustainable. Plastic is not biodegradable and may contribute to pollution; hence, its usage in automobile bumpers has been criticized for the effect it has on the environment. Plastic does not break down easily. In an effort to lessen the damage that automobile bumpers do to the natural world, its manufacturers are looking at developing bumpers made of bioplastics and natural fibers, among other alternatives. In addition, eco-friendly production practices including recycling and cutting down on waste are two more ways to assist reduce the negative effects that automobile bumpers have on the surrounding environment.

1.4 Literature Review

Composite materials have received a lot of attention recently in the automobile sector due to their potential for weight reduction, enhanced performance, and environmental advantages. Several studies have assessed the viability of employing composite materials for several automobile applications, including bumper beams, according to a study of the literature.

For instance, the utilization of composites reinforced with natural fibers in bumper beam applications has been investigated in [8]. According to the study, natural fiber composites might provide the car industry with a green and affordable option since they have mechanical qualities that are equal to those of conventional materials

The performance of hybrid composite bumper beams comprised of a mix of carbon and glass fibers was examined in another study [9]. According to the study, hybrid composite bumper beams outperformed conventional steel bumper beams in terms of Impact resistance and energy absorption.

Recent study on these earlier investigations has been done by analyzing the utilization of carbon fiber composite material for an automobile's frontal bumper beam [10]. Using finite element analysis, the designed bumper beam was examined. Moreover, its performance was compared to that of bumper beams made of conventional steel.

According to the study's findings, the carbon fiber composite bumper beam was stiffer and lighter than the steel bumper beam, which may have improved handling and fuel economy. Better Impact resistance and energy absorption properties of the composite material, which are essential for safety in a collision scenario, were also present. The results of this study are in line with those of other investigations that have shown potential advantages of employing composite materials in automotive applications. However, further study is needed to solve challenges like cost and production feasibility before the material can be extensively used in the automobile sector. The use of composite materials in the automobile sector is generally viewed as a promising field of research, and the results of this study add to the expanding body of information on this subject. [10]

There has been more attention in recent years on making automobiles safer, particularly in the event of a head-on collision. Computer models and modelling have been used a lot to figure out how the parts of a car behave when it crashes. One of these modelling tools is ANSYS, which is a finite element analysis (FEA) software that can be used to model and study how buildings behave under different loads. [11]

In their study they used ANSYS to look at the features of frontal car crashes. At first, they explained ANSYS is and how it can be used to model crash situations. Then, they talk about how the study was done. ANSYS was used to model a car and a frontal crash with a rigid block was simulated. [12]

In the paper, the results of the modelling are shown, including how the structure of the car changed, how stress and strain were spread among the different parts of the car, and how much energy the car took in during the crash. The authors also compare their simulation results to actual data from other studies [13] [14] and find that the two sets of data agree well.

Overall, the study uses ANSYS to give a full description of what happens in a front-end car crash. The writers show how the software can be used to model complicated crash scenarios and give information about how car structures behave during a crash. The results of this study could help improve the way cars are built so that passengers are safer in the event of a crash.

Injuries and deaths globally are most frequently caused by automobile accidents. The bumper assembly is one of the most crucial parts of a car's safety system since it's made to deflect Impact energy and save the occupants. The performance of bumper assemblies during a collision has recently been extensively studied using computer simulations and modelling methodologies. [15] [16]

In a number of research, the performance of automobile bumper assemblies during a collision was analyzed using ANSYS. [17] These experiments have demonstrated the potential use of ANSYS as a tool for developing and improving bumper assemblies' crashworthiness. [18]

A passenger automobile bumper assembly's accident analysis using ANSYS is presented in a recent study. The bumper assembly was initially modeled and then analysis was done using ANSYS which was a low-speed Impact test. The simulation's outcomes revealed the patterns of deformation in the bumper structure, the distribution of stress and strain among its various parts, and the amount of energy absorbed during the collision. Additionally, the authors examined experimental data from other research and found that their simulation results and those data often agreed. [19]

The studies may help improve bumper assembly design and increase passenger safety in the case of a low-speed accident. The methods and findings of the authors might serve as the foundation for more auto safety research.

Typically, lightweight, high-strength materials like aluminum, steel, and composites are used to create automotive bumper beams. The selection of a bumper beam's material is influenced by a number of variables, including price, weight [20]

In a recent automobile bumper beam analyzing study they relied on mild steel for their bumper beam since it was relatively strong and cost-effective. [21] On the usage of alternative materials for vehicle bumper beams, several investigations have been done. For instance, in [20] the author used FEA simulations to examine the performance of bumper beams made of aluminum and carbon fiber-reinforced polymer (CFRP). When compared to aluminum and mild steel bumper beams, they discovered that CFRP bumper beams had a greater capacity to absorb energy.

In another study, the author looked at the usage of multi-material bumper beams consisting of steel, aluminum, and CFRP. They discovered that when compared to traditional bumper beams made of a single material, hybrid bumper beams were lighter and better at absorbing energy. [22]

Selecting the right material for automobile bumper beams is essential for assuring the protection of the car's occupants in the event of a low-speed frontal collision. While aluminum and composites have shown encouraging results in enhancing the energy-absorbing capacity of bumper beams, mild steel remains a popular material because to its low cost and high strength. To investigate the possibility of multi-material bumper beams for the best performance, more study might be done.

One of the key elements of a vehicle's suspension system are coil springs, and proper design and analysis are critical to guaranteeing both performance and safety. In another study they used finite element analysis (FEA) software to design and analyses coil springs for a car. [23]

FEA has been used in several research to develop and analyze coil springs. They looked at how a coil spring's design elements, such as the number of turns, wire diameter, and coil diameter, affected both its static and dynamic qualities. They discovered that the performance of the spring was most significantly Impacted by the wire diameter. [24]

The design of a coil spring for a passenger automobile was optimized using FEA in a different work. To reduce the weight of the spring while maintaining the necessary spring rate and deflection, they altered the spring's composition, wire diameter, and coil diameter. [25]

Additionally, in another paper they carried out a comparison of the functionality of helical and conical coil springs in a vehicle's suspension system. In comparison to helical springs, they discovered that conical springs performed better in terms of weight, stiffness, and fatigue life. [26]

In conclusion, the design and analysis of coil springs in vehicles using finite element analysis (FEA) is a key component of the optimization process for the suspension system. The performance of the spring can be significantly influenced by design considerations such as the wire diameter, the coil diameter, and the material choice. The configuration of the coil spring, whether it is helical or conical, can also have an effect on the performance of the suspension system as a whole.

1.5 Objective and Aim

By doing the design optimization of car bumpers and finding the best possible design that can withstand more deformation as well as less stress possession within maximum yield strength limit, the purpose of this study is to improve the performance of a passenger car bumper under crash at varying speed, thereby increasing the passenger safety. This will be accomplished by improving the performance of a passenger car bumper under crash at varying speed. Along with making changes to the existing design, we also attempted to include a range of materials into the design of the bumper. This was done in addition to bringing changes to the existing design. By incorporating a sandwich model into the bumper shell, we will be able to perform structural analysis using a wide range of material combinations in order to identify the one that yields the best results at a given speed. This will allow us to determine the optimal material combination. The purpose of this work is to create prospects for additional research and development in the field of vehicle engineering, such as a cost and feasibility analysis of the proposed model and material. The modelling of the car bumper and the simulations itself were both carried out with the assistance of specialized software applications. Our improved sandwich model has been developed with the intention of possessing reduced von misses stress and maximal deformation in the event of a sudden crash while travelling at a given speed.

2 Methodology

The primary objective of this study is to look at how car bumpers behave structurally when they are hit at low speeds. In this study, the bumper models will be made with SolidWorks, and meshing and structural analysis will be done with ANSYS. The models of the bumpers are designed in SolidWorks, which lets us to have precise control over factors like the shape, size, and material qualities. The bumper models are then imported into ANSYS to build and analyze the structure. Several cross-sectional designs are taken into account in this work. In their work, they have modelled and simulated eight different cross-sectional shapes. For the purpose of validating this work, we modeled and did simulations on the five best designs, which were (a) Open hat section, (b) Rolled form section, (c) C section, (d) Rectangle Section, and (e) Open B section [reference]. The results of the simulations are collected and analyzed to find out how the bumpers behave in low-speed crashes. In this study, finite element analysis (FEA), which is a numerical way to solve hard structure problems, was used to look at the data. ANSYS has a full set of FEA tools that can be used to model, analyze, and show the results of simulations. ANSYS is used to look at the simulation data and figure out how much stress, strain, deformation, and displacement the bumper models experience during low-speed crashes. When SolidWorks is used to create the bumper models and ANSYS is used for meshing and structural analysis, it is possible to get a complete understanding of how car bumpers behave when they encounter Impacts at low speeds.

2.1 Validation of Previous Work

2.1.1 Impact Mechanics

The entire body of a passenger car functions in the same way as a chassis. Because of this, the structure of the body is constructed in such a way that it should be able to convey all of the body's energy. When a vehicle is in the running state, it has some kinetic energy; however, if an accident causes the vehicle to come to a stop, at which point it has zero velocity and therefore zero kinetic energy, the vehicle does not have any kinetic energy. Following a very modest speed reduction trend and in a pattern that is virtually same, the kinetic energy should be zero in order to reduce the number of injuries. It is important that the frontal structure absorb all of the kinetic energy that is transferred to it during a frontal collision. [27] In this study, we take a specific mass of automobile along with the bumper, and we hit the car at various speeds with a bumper that is not moving. Consideration is given to speeds of 10, 15, 20, 25, and 30 kilometers per hour. The pressure that is exerted on the bumper may be determined by first calculating the forces that will be correspondingly exerting on it at each speed and then deriving that pressure from those calculations. In our simulation, we've chosen these particular numbers for pressure. The results of the calculations that were done in order to determine the pressure are shown below.

Mass of the vehicle with bumper (without passenger) = 1400 kg

Mass of five people (average) = 300kg

Total Weight (including passenger) = 1400 + 300 = 1700kg

Frontal surface area of Bumper = 80910 mm^2

Now, the equation of motion is,

$$v = u + at \tag{1}$$

Assuming that the car hits another identical one and it will stop in 0.1 s.

Deceleration of the car is given by,

$$a = (u - v)/t \tag{2}$$

Force acting during collision is given by,

$$F = ma \tag{3}$$

Where, v = final velocity of the car in m/s

u = initial velocity of the car in m/s

t = time after which vehicle stopped in seconds

F = Impact force

Pressure acted on the bumper

$$P = F/A \tag{4}$$

Where A is the surface area of collision on bumper beam. Bumper beam load calculations are shown in the Table

Table 2.1.1 Load on Bumper Beam Impact Region

Car speed (km/h)	Velocity (m/s)	Deceleration (m/s^2)	Force (N)	Pressure (N/mm^2)
10	2.77	27.7	47090	0.582
20	5.55	55.5	94444	1.167
30	8.33	83.3	141666	1.751

2.1.2 Modeling of Initial Design

The modeling of the bumper is done in SOLIDWORKS software. Bumper beam is considered as a shell part here. There is 2 support and the supports are solid. A 2D sketch of modeled bumper beam is shown in *Figure 2.1.2 (a)*.

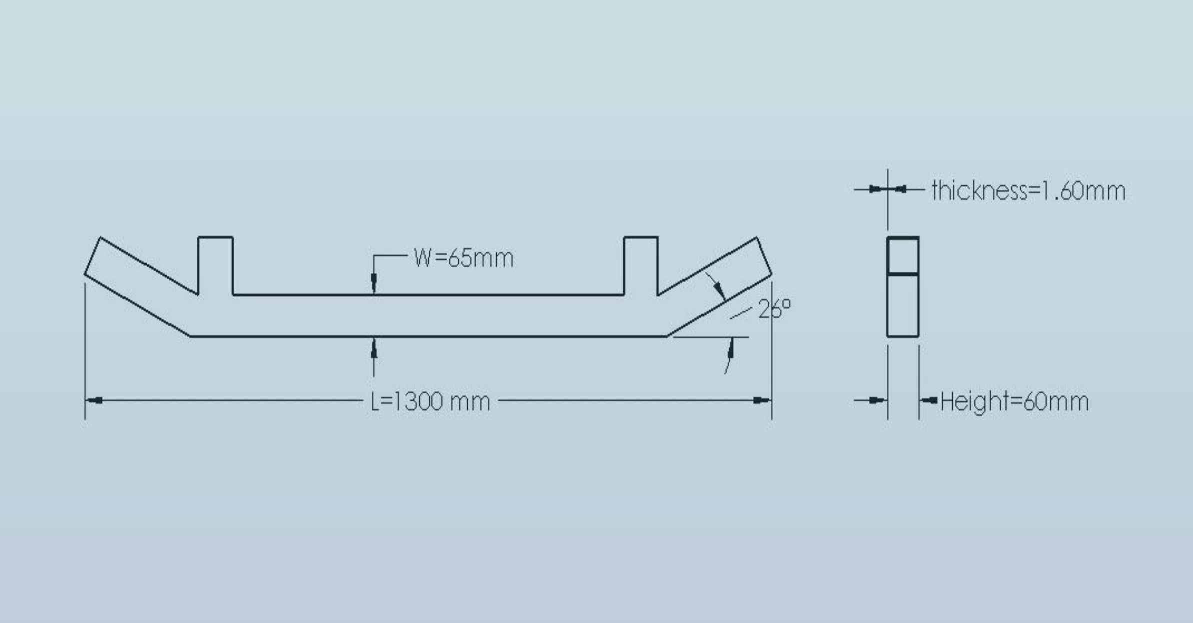


Figure 2.1.2 (a) Dimensions of Bumper Beam

Dimensional parameter of the bumper that were used to model the bumper is shown in *Table 2.1.2*. [27]

Table 2.1.2 Dimensional Parameter of Bumper Beam

Serial No.	Parameter	Description	Value
1.	L	Bumper beam length	1300 mm
2.	W	Bumper beam width	65 mm
3.	H	Bumper beam height	60 mm
4.	t	Bumper beam shell thickness	1.6 mm
5.	Ɵ	Bumper beam corner angle	26°

While modeling the bumper we have taken all the dimensions exactly as in Table 1. We modeled the five best designs, which were (a) Open hat section, (b) Rolled form section, (c) C section, (d) Rectangle Section, and (e) Open B section [27]. The isometric view of Bumper beam (rectangle section) and side view of each bumper is shown below

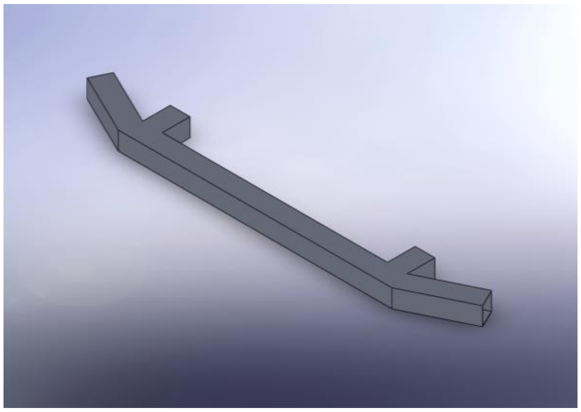


Figure 2.1.2 (b) Isometric View of Bumper Beam

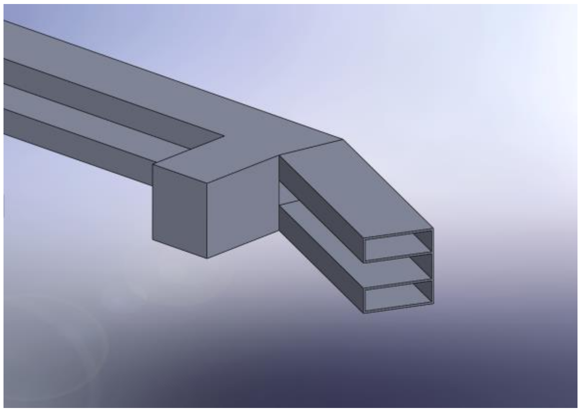


Figure 2.1.2 (c) Side view of Open B Sectioned Bumper Beam

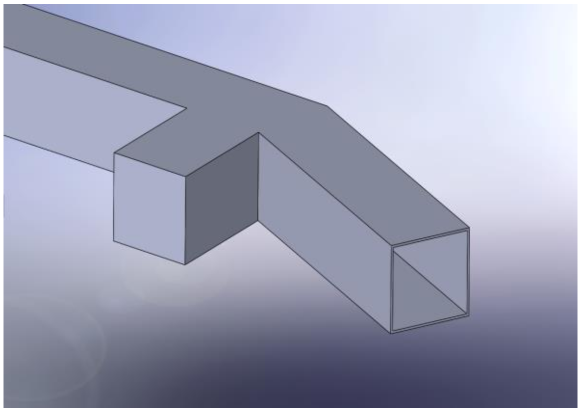


Figure 2.1.2 (d) Side view of the Rectangle Sectioned Bumper Beam

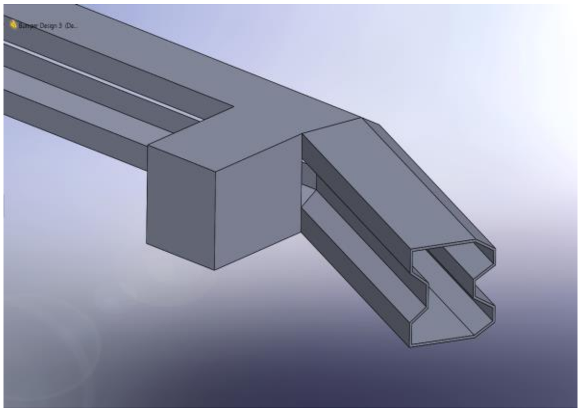


Figure 2.1.2 (e) Side view of the Rolled Form Sectioned Bumper Beam

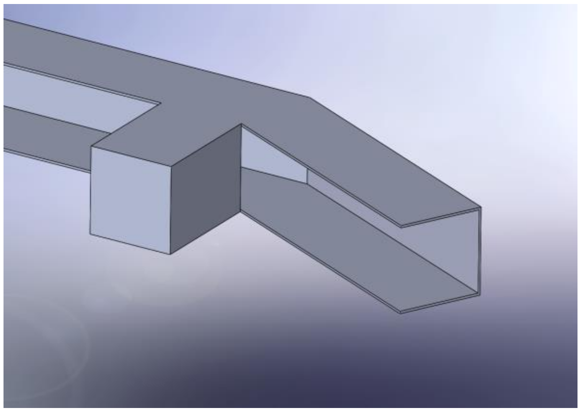


Figure 2.1.2 (f) Side View of C Sectioned Bumper Beam

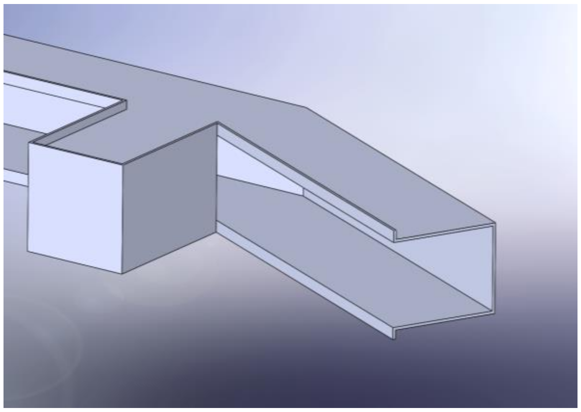


Figure 2.1.2 (g) Side View of Open Hat Sectioned Bumper Beam

2.1.3 Simulation

The simulation of the bumper beam is done using ANSYS software. The advanced Workbench tool has the capability to resolve dynamic as well as static structural problems. Here we make use of the static-nonlinear analysis. The carbon fiber composite material is considered for these designs of the bumper beam.

2.1.3.1 Finite Element Modeling

The construction of sub-blocks of the whole physical model is the core idea behind FEA, which stands for finite element analysis. To ensure that the findings of the analysis are reliable, it is necessary to connect the entirety of the sub-block to the remaining parts of the model. Node and element are both components of the subblock, but only node has the essential ability to estimate its displacement when it is exposed to an external load. As according to the following figure, the mesh was generated under ‘fine’ meshing to divide the whole bumper beam into small blocks of solids for the ease of calculations and simulations to be performed. A mesh of 4 millimeters in size was used for this bumper design.

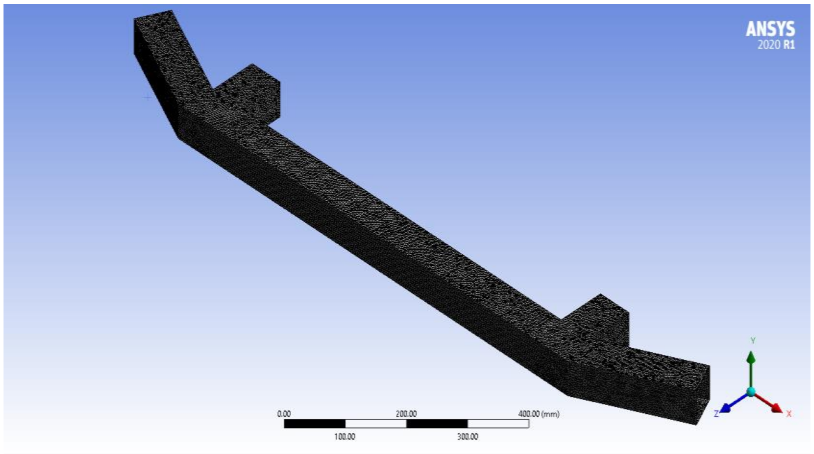


Figure 2.1.3.1 (a)Meshing of Rectangle Sectioned Bumper Beam

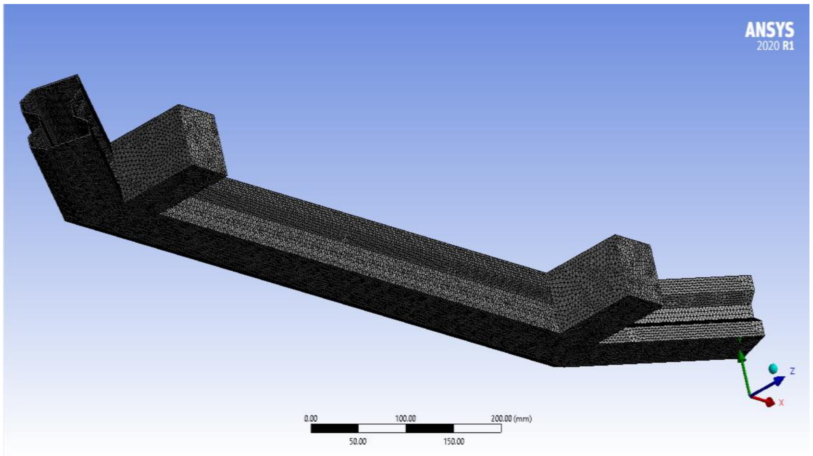


Figure 2.1.3.1 (b)Meshing of Rolled Form Sectioned Bumper Beam

2.1.3.2 Structural Analysis

To validate the previous work in our performed analysis we have calculated the overall displacement, maximum von misses stress, maximum von-misses stress and average von misses stress at Impact region. Also, the contribution that the supports and their reactions make to the calculation of the numerical simulation is significant. Within the scope of this work, fixed support is integrated into both of the bumper's extremities.

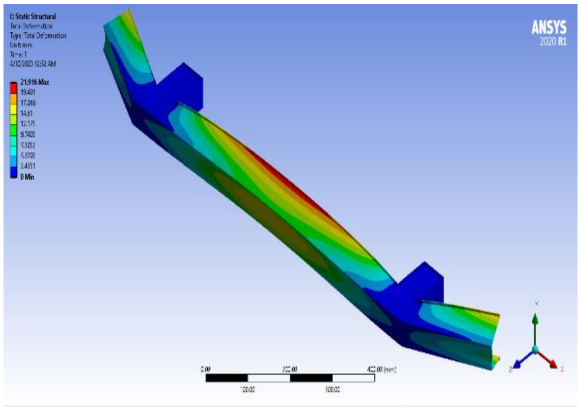


Figure 2.1.3.2 (a) *Total Deformation of Open Hat Section*

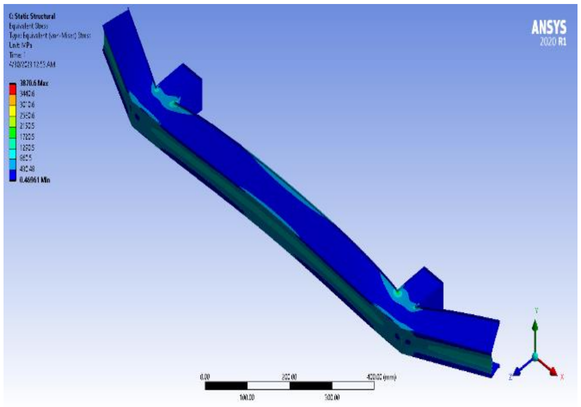


Figure 2.1.3.2 (b) *Stress Distribution of Open Hat Section*

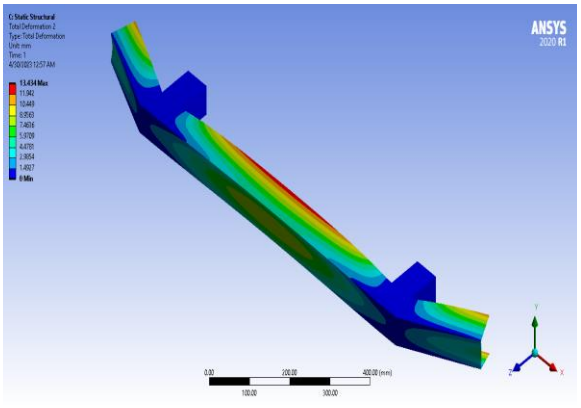


Figure 2.1.3.2 (c) *Total Deformation of C Section*

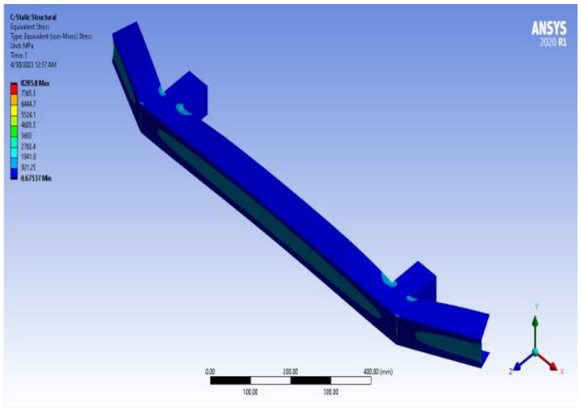


Figure 2.1.3.2 (d) *Stress Distribution of C Section*

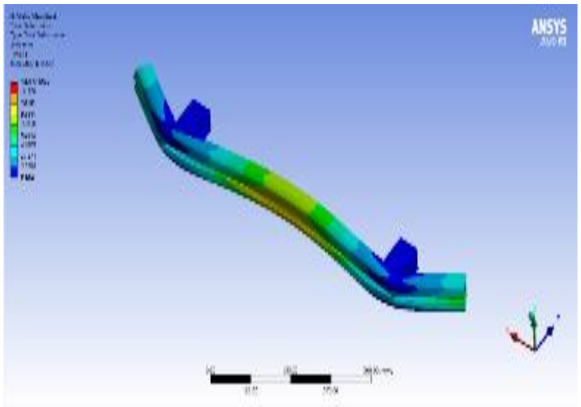


Figure 2.1.3.2 (e) *Total Deformation of Rolled Form Section*

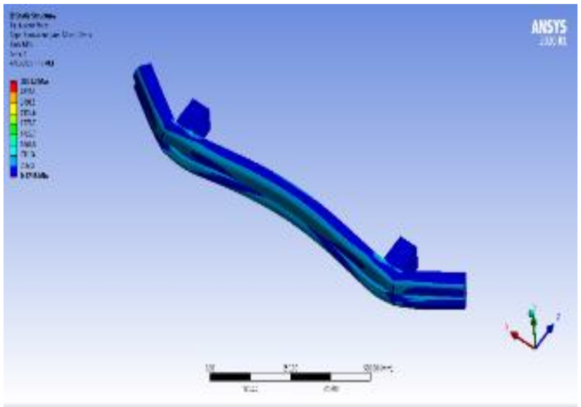


Figure 2.1.3.2 (f) *Stress Distribution of Rolled Form Section*

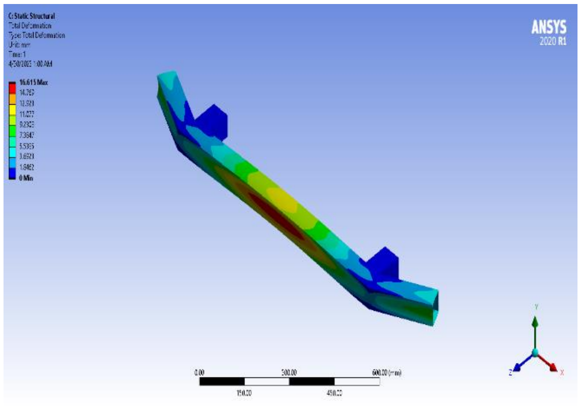


Figure 2.1.3.2 (g) *Total Deformation of Rectangle Section*

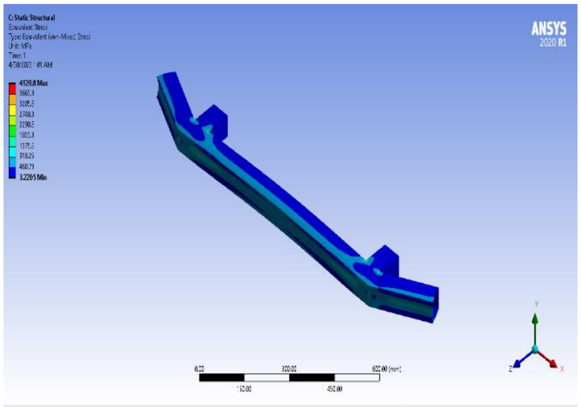


Figure 2.1.3.2 (h) *Stress Distribution of Rectangle Section*

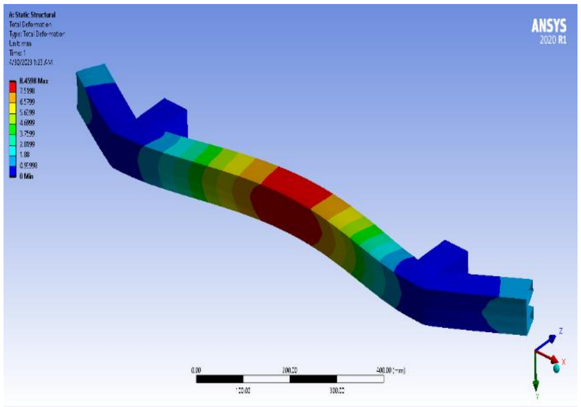


Figure 2.1.3.2 (i) *Total Deformation of Open B Section*

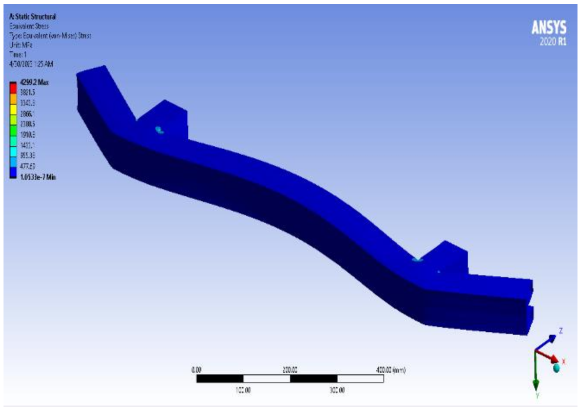


Figure 2.1.3.2 (j) *Stress Distribution of Open B Section*

The stress and displacement that were induced by the low-speed (30 km/h) Impact test on the five different designs that were investigated can be seen in the figures that have been provided above. The amount of stress and displacement that was generated to its maximum is shown by the red color, while the least amount of stress and displacement is shown by the blue color. The results of Impact tests conducted at 10, 20, and 30 kilometers per hour are presented in Tables 4–6. These tables detail the stresses and displacements that were found for each of the five designs that were taken into consideration. After performing Impact test, it has been found that the *Open Hat Section* is delivering the best results giving minimum average von misses stress under yield strength limit and maximum deformation. Our results also satisfied the results that were found in previous study [27]

Table 2.1.3.2 (a) Stress and Displacements induced at 10 kmph.

Design	Cross section	Max Von Misses Stress Observed (MPa)	Max Von Misses Stress Observed at Impact region (MPa)	Average Von Misses Stress Observed at Impact Region (MPa)	Maximum Displacement (mm)
Bumper 1	Open Hat Section	1094.7	373.02	205.02	7.271
Bumper 2	C Section	2785.0	561.07	297.98	13.602
Bumper 3	Rolled Form Section	736.65	383.13	124.82	4.5986
Bumper 4	Open B Section	1429	140.52	71.051	2.8119
Bumper 5	Rectangle Section	1369.6	397.93	203.94	5.5529

Table 2.1.3.2 (b) Stress and Displacements induced at 20 kmph.

Design	Cross section	Max Von Misses Stress Observed (MPa)	Max Von Misses Stress Observed at Impact region (MPa)	Average Von Misses Stress Observed at Impact Region (MPa)	Maximum Displacement (mm)
Bumper 1	Open Hat Section	2046.1	710.31	355.97	11.283
Bumper 2	C Section	5584.4	1125	597.49	18.69
Bumper 3	Rolled Form Section	2134.9	893.87	257.6	9.3787
Bumper 4	Open B Section	2865.3	281.76	142.47	5.683
Bumper 5	Rectangle Section	2746.4	788.34	408.94	11.074

Table 2.1.3.2 (c) Stress and Displacements induced at 30 kmph.

Design	Cross section	Max Von Misses Stress Observed (MPa)	Max Von Misses Stress Observed at Impact region (MPa)	Average Von Misses Stress Observed at Impact Region (MPa)	Maximum Displacement (mm)
Bumper 1	Open Hat Section	3870.6	1131.3	560.71	14.85
Bumper 2	C Section	8379	1688	896.49	28.65
Bumper 3	Rolled Form Section	3203.3	1341.2	386.52	14.072
Bumper 4	Open B Section	4299.2	422.76	213.76	8.4598
Bumper 5	Rectangle Section	4120.8	1182.8	613.61	16.615

2.2 Material Characteristics

a) Magnesium AZ31B

Magnesium AZ31B is a lightweight magnesium alloy that has a high strength and may be utilized in the production of automotive bumpers. This material is produced by mixing magnesium with trace quantities of aluminum, zinc, and manganese to create a compound that, once cured, is very resistant to corrosion, in addition to having high levels of strength and durability.

The fact that magnesium AZ31B is rather lightweight is one of the most significant benefits associated with utilizing it for automobile bumpers. Because magnesium is so much lighter than steel and other metals, it has the potential to significantly improve both the fuel efficiency and performance of a vehicle. Furthermore, magnesium is highly malleable, which enables it to be formed into complex shapes and designs, which can allow for greater design flexibility. Magnesium can be found in nature in the form of magnesium oxide.

The fact that magnesium AZ31B is resistant to corrosion is yet another benefit of employing this material for automotive bumpers. Magnesium is inherently resistant to rust and other types of corrosion, which may enhance the bumper's lifetime and minimize the frequency with which it has to be maintained or replaced. Magnesium can also help lower the cost of doing so. However, magnesium bumpers do have some disadvantages. To begin, magnesium is a more costly substance than other common metals and metal alloys such as steel and aluminum. In addition, magnesium is a highly reactive element, which means that it may corrode or deteriorate over time if it is not adequately coated or protected. This can be prevented by applying an appropriate coating. In conclusion, magnesium is one of the elements that might be more problematic to weld than other materials, which can make repairs more complex.

In general, the use of magnesium AZ31B as a material for the production of automobile bumpers might be an alternative that is durable, lightweight, and resistant to corrosion. Because of its low weight, versatility in design, and resistance to corrosion, it is a material that is often selected. However, while deciding which material to employ, the cost of the material, how reactive it is, and how difficult it is to weld are all factors that should be addressed.

In the automotive sector, magnesium alloys have been under consideration because of their potential to enable lightweight design, reduce energy consumption, and cut emissions of greenhouse gases. Magnesium alloys have been used in new products by major leading vehicle manufacturers to replace steels and aluminum due to their extremely high ratio of strength to density. These magnesium alloys have also been employed in novel applications. Because of their hexagonal close packed (HCP) crystal structure and strong basal crystallographic roughness from the rolling process, the magnesium alloy sheets (AZ31B) display different mechanical reactions when compared to steel and aluminum sheets. Additionally, the magnesium alloy sheets have a highly anisotropic property. According to the results of the tests conducted by Kelley and Hosford (1968), this also leads to a significant tension/compression asymmetry. To completely understand the magnesium alloy sheets' extensive mechanical characteristics, additional studies under a variety of stress circumstances are required. [28]

b) Aluminum Alloy Body

When compared to materials like steel or plastic, using an aluminum alloy body to make a car bumper can have a number of benefits. To begin with, the aluminum alloy bumper would weigh less than the steel one. Given the growing awareness of the need to reduce our carbon footprint, this can help increase the vehicle's overall fuel efficiency. Second, the bumper would last longer without rusting or otherwise degrading because to the corrosion-resistant properties of aluminum alloy. The bumper may last longer without needing maintenance or replacement. Third, aluminum alloy has strong energy absorption qualities, so the bumper can effectively absorb the Impact of a collision and limit the possibility of damage to the rest of the car or injuries to passengers. An automobile bumper made of aluminum alloy has several benefits, but it also has some possible downsides. One issue is that it may make the car more costly to produce than it would be with other materials. In the case of an accident, aluminum alloy may be more challenging to repair than other materials, which may increase repair periods or costs.

Aluminum alloy has numerous desirable properties for use in automobile bumpers, including low weight, resistance to corrosion, and the ability to absorb Impact energy. The choice to employ this material, however, should be grounded in a careful consideration of its possible advantages and downsides.

Aircraft designers are always on the lookout for high-performance materials that may be used to create structures that are both inexpensive and resilient against wear and tear. Al-Li alloys for heavy structure, high-strength plate and extrusions for wings, and innovative monolithic and aluminum-fiber laminates for fuselages are just some of the new and developing materials that are meeting their demands. Aluminum alloys are being increasingly used in the automobile industry due to their low cost and positive Impact on fuel efficiency. Corrosion resistance and mechanical qualities are also important considerations for automotive usage. Fenders, hoods, and other "hang-on" parts often have formability as their limiting mechanical attribute. Dent resistance at a thickness that is cheaper than steel's is a necessity, so is strength. Alloys with excellent formability in the T4 temper that age harden during the paint bake process were developed since formability is often reduced with increased yield strength. 2008, 6111, and 6016 are currently competing with alloys like 6009 and 6010. The materials used in the construction of the body must be able to absorb Impact force and fail safely in the event of a collision. Die casting of Al-Si-Mg alloys is being done for such components of a car's space frame. Thin 6XXX extrusions, which must combine formability, strength, ductility, and the ability to bend plastically upon Impact, are bonded to the ductile die castings. A new 7XXX alloy provides a superior mix of qualities if present alloys prove insufficient for future demands; this is especially important for bumpers, which must combine strength and acceptable formability. [29]

c) Carbon Fiber Composite Body

The use of carbon fiber for bumpers has a number of distinct benefits over more conventional materials. Because carbon fiber is both lightweight and strong, it can be used to significantly reduce the curb weight of the vehicle, which in turn improves the vehicle's overall performance and efficiency. Second, in the event of a collision, the carbon fiber can effectively absorb the Impact forces, hence reducing the likelihood that the people within the vehicle would be hurt. Because carbon fiber has a natural resistance to corrosion, it has a longer lifespan compared to other materials, which is great for the budget of a bumper. It is important to point out that the manufacturing and maintenance costs of carbon fiber are higher than those of certain other materials. As a result, one has to do an exhaustive cost-benefit analysis prior to deciding whether or not to equip an automobile bumper with carbon fiber.

The goal of greater energy efficiency by the automotive industry is now confronted with the formidable obstacle of lightweighting as one of its primary challenges. The amount of petrol that vehicles use and the pollution that they produce are important problems. Increasing a vehicle's fuel economy may be accomplished in the most efficient manner by reducing the weight of the vehicle's components. Research and development activities have been very beneficial to the development of lightweight materials since they have helped to reduce their manufacturing costs, boost their recyclability, make it easier to incorporate them into vehicles, and improve their fuel economy. As worries about both weight and safety become more prevalent, there is a growing need for a new generation of materials. The greatest lightweight potential can be achieved using carbon fiber reinforced plastic, which may be used to bring lightweight ideas to reality. When compared to a number of conventional metals, plastic reinforced with carbon fiber performs superiorly in terms of stiffness, strength, and resistance to fatigue. The use of carbon fiber reinforced plastic in the automotive industry has a variety of practical uses, including a reduction in weight, an improvement in crashworthiness, a reduction in the number of components, an increase in durability and toughness, and an improvement in aesthetic appeal. Carbon fiber reinforced plastic is a versatile composite that has found broad usage in a variety of industries, including the aircraft industry, the sports equipment industry, the oil and gas industry, and the automotive industry, to mention just a few. [30]

When compared to more traditional materials such as steel or plastic, the use of composites in the manufacturing of car bumpers offers a number of benefits that cannot be found with these other options. The formation of a new material with improved properties may be accomplished by fusing together two or more constituents, which is how composites are made. Composite materials, for example, may be designed to match the demands of a car bumper by being low in weight without losing strength or corrosion resistance. This is possible because composite materials are made up of many layers of different materials. It is possible to customize composites to fulfil particular needs by selecting the proper mix of components, which may include fiberglass, carbon fiber, or Kevlar, for example. It's possible that composite bumpers, which are produced from these materials, are lighter and stronger than traditional bumpers, which would be beneficial to the overall performance of the vehicle. When it comes to the ability to absorb energy, composite bumpers are better than traditional bumpers. This translates to less damage being done to the vehicle and the people inside of it in the event of an accident.

Automobile bumpers made of composite materials provide an increased level of protection against the weather and corrosion. As a result of this, composite bumpers may have a longer lifespan than their metal equivalents, which means they will need less repairs or replacements over time. In addition, the looks of the vehicle may be improved by the manufacturer by molding composite materials into a variety of unique forms and sizes. Composite materials have the potential to provide numerous advantages, but they also have several drawbacks that might be an issue. When composite materials are utilized for vehicle components rather of the more cost-effective metals or plastics, the price of the vehicle may go up. In addition, repairs on composite bumpers may be more difficult and may need the use of specialist equipment as well as in-depth industry expertise. When utilized in the manufacturing of automotive bumpers, composite materials provide a number of benefits, including decreased weight, enhanced strength, resistance to corrosion, and design freedom. However, before making a decision to use composite materials, it is important to consider the benefits and drawbacks of this option and have a complete understanding of what is involved.

Emissions from petrol and efficiency in the use of gasoline are two key challenges in the contemporary world. Improving a vehicle's gas economy may be accomplished most successfully by reducing the amount of weight carried by its various components. Between the two parts, the bumper is the one that carries the most weight. To ensure that the safety of the vehicle is not compromised in any way, we need to employ composite materials for the bumper. Polymer composite materials have been used in the automotive sector for many decades; however, broad acceptance of these materials has been impeded by both financial and technical barriers. As a result of the many favorable properties that reinforced composites possess, they are often used. These characteristics include high specific tensile and compressive strengths, electrical conductivity that can be modified, a low coefficient of thermal expansion, a good fatigue resistance, and the ability to construct sophisticated form materials. They have taken the place of older, more conventional building materials such as steel, wood, and aluminum in the modern world. Although glass-fiber-reinforced polymers are the predominant material used in the automotive industry, other polymer composites, such as carbon-fiber-reinforced polymers, glass-fiber-reinforced polypropylene, and glass-fiber vinyl ester sheet molding compound (SMC), show considerable potential. The applicability of polymer composites to the field of vehicle bumpers is the major topic of this article. Studies of the properties of composite materials that have been published in academic literature reveal that these materials have much greater potential than the conventional materials that are now used in the production of automobile bumpers. The aerospace and chemical industries, wind power plants, sports equipment, marine transportation, and the maritime industry are other typical sectors of use. [31]

d) <u>Commercial Steel Bare / CS</u>

When it comes to the manufacture of car bumpers, one tried-and-true approach that has shown to be both cost-effective and long-lasting is the use of commercial steel in the manufacturing process. Because it is durable, has a long lifespan, and can withstand significant amounts of Impact pressure, commercial steel is an excellent material for the construction of automotive bumpers. As a result of its low cost, widespread availability, and ease of manipulation into a diverse range of bumper sizes and forms, it is an excellent material for use in the manufacturing of bumpers in large quantities. Unfortunately, the use of commercial steel bumpers comes with a few drawbacks that should be considered. To begin, they greatly increase the weight of the vehicle in comparison to lighter options like as aluminum or composites, which may have a detrimental Impact on the vehicle's overall performance as well as its fuel efficiency. Steel bumpers corrode quickly, which shortens the amount of time they may be used and makes it necessary to do maintenance and replacements on a more consistent basis.

In contrast to composite bumpers, steel bumpers are not as effective at distributing the force of contact, which means that in the event of an accident, it is possible for there to be more severe injuries or even fatalities. In addition, the manufacture of steel bumpers may be wasteful of natural resources due to the high energy and material needs of the material itself. For the most part, commercial steel is the material of choice for the production of car bumpers because of its high strength and durability, together with its low cost. On the other hand, because to its higher weight, susceptibility to corrosion, and absence of energy absorption, it is often considered to be a less attractive material than composites or aluminum. After carefully weighing all of the potential benefits and drawbacks of using commercial steel, the only time this kind of steel should be used is when it is absolutely necessary.

The term "cold-rolled steel" (CS) refers to a kind of steel that is often utilized by automobile manufacturers in the fabrication of bumpers. The steel that goes into CS is given a treatment at room temperature, which is what gives it its silky smooth and consistently even surface. This material is a wonderful option for bumpers because of how easily it can be made to seem like the body of the car. Because of its strength and durability, CS is an excellent material for use in the construction of automotive bumpers. Because of its great strength and resistance to the severe Impact forces that vehicle bumpers are subjected to, CS is an excellent choice of material for automobile bumpers. CS bumpers are very long-lasting and need very little maintenance or replacement. This is mostly due to the material's resistance to rust and corrosion.

Because it is not expensive and can be obtained in a variety of locations, CS is a material that is advantageous to use for automobile bumpers. CS is widely accessible from a wide number of suppliers, and it is often less expensive than alternatives such as aluminum or composites. It's possible that this may be a viable solution for businesses who need to mass-produce bumpers while keeping prices as low as possible. The use of CS bumpers does, however, come with a number of important downsides. To begin, they are heavier than alternatives like as aluminum or composites, which may bring about a decrease in the overall performance of the vehicle as well as the mileage it achieves per gallon of petrol. Additionally, the potential for damage to the vehicle or its occupants in the event of a collision is increased due to the fact that CS bumpers are not as effective as bumpers made of other materials, such as composites, in terms of absorbing the force of the Impact. Because of its relatively cheap price and long-lasting nature, composite sheet (CS) might be an advantageous material for manufacturers to employ in the construction of automotive bumpers. On the other hand, as a result of its greater weight and worse energy absorption, it is often considered to be a less attractive material than composites or aluminum. It is essential to make sure that all of the possible benefits and drawbacks of CS are taken into consideration before making a decision to put it into practice.

By raising the strength of a steel sheet, it may be possible to decrease the amount of weight a vehicle weighs while simultaneously enhancing the resilience of the vehicle in the event of a collision. Although ultra-high-strength steel sheets of the 980 to 1,180MPa class have been used on a limited scale for members where high strength is required, such as bumpers and door beams, the majority of the steel sheets used for main structural members have had a tensile strength of up to 440 to 590MPa. This is because bumpers and door beams are relatively small in comparison to the size of the main structural members. In recent years, ultra-high-strength steel sheets have become more popular as a means of reducing the overall weight of motor vehicles. The use of ultra-high-strength steel sheets in the class 980MPa in the structural components of a vehicle seat is a novel application that is being lobbied for. But an ultra-high-strength steel sheet has a low formability, so it can't be easily used for a variety of different auto parts. This limits its applicability. In light of this, Nippon Steel Corporation developed three distinct types of ultra-high-strength steel sheets in order to provide a wide range of options according to the characteristics required for fabricating various car components. These sheets include one with excellent total elongation, another with enhanced local elongation for intensive bending deformation, and a third that combines the two characteristics in a balanced manner. This research analyzes the qualities of three different variants of 980MPa class cold-rolled steel sheet and presents some case studies demonstrating how these materials may be used in the construction of vehicle seat structures [32]

e) Glass-mat thermoplastic (GMT)

Glass-mat thermoplastic, or GMT for short, is a composite material often utilized in the production of automobile bumpers. GMT is a strong, lightweight, and Impact- and wear-resistant material created by mixing short glass fibers with a thermoplastic resin. The capacity of GMT to absorb energy upon Impact is a major benefit when used in automobile bumpers. GMT bumpers are designed to absorb and disperse Impact energy, protecting the vehicle and its occupants from harm. Furthermore, GMT is corrosion-resistant, making it an ideal material for automobile bumpers.

The design flexibility of GMT is another benefit when used for automobile bumpers. Due to GMT's malleability, manufacturers may be able to create bumpers that are tailored to individual vehicle makes and models. The many color options for GMT mean that further painting or finishing is often unnecessary. There are, however, drawbacks to using GMT bumpers. To begin with, they may be more costly than alternatives like as steel or aluminum. Maintenance and repair costs may also rise if you use GMT since it is more difficult to fix than other materials. In sum, GMT offers manufacturers a robust, lightweight, and adaptable choice for bumper construction. It is often used because of its Impact-absorbing properties, resistance to corrosion, and adaptability in design. However, the price may be more than that of other materials, and fixing GMT bumpers might be tricky. Prior to deciding to implement GMT, it is important to weigh all of the advantages and disadvantages of doing so.

Automakers are motivated to create lightweight automobiles by the rising global difficulties of improving fuel efficiency and reducing emissions of greenhouse gases. Vehicle performance (including crashworthiness and Impact resistance) and recycling rates may both improve if weight is reduced. Creating high-performance lightweight materials by finding alternatives to heavy metals like steel and cast iron is one approach. Fiber-reinforced plastics (FRP) composite, a lightweight material, is one way to cut down on fuel use and greenhouse gas emissions. However, one of the critical factors affecting its structural application is the damage of FRP composite under Impact loading. During a collision, the bumper beam plays a crucial role in absorbing the shock of the Impact. Many industries, including the transportation sector, have made extensive use of polymer composites. Using high-strength glass fibers as the reinforcing element in the polymer composite to create an automobile bumper beam is the primary focus of this work.

Mechanical functionality and production methods are covered. it is visible that GRP has more potential in the automotive sector than traditional materials like vehicle bumper beams. [33]

f) Sheet Molding Compound (SMC)

Sheet molding compound, sometimes known as SMC, is a kind of composite material that is frequently used in the production of automobile bumpers. SMC is a material that is strong, lightweight, and resistant to Impact and wear. It is produced by mixing a polyester resin, chopped glass fibers, and other additives, which results in a material that has these characteristics.

The capacity of sheet molding compound (SMC) to absorb Impact energy is one of the key benefits of employing this material for automobile bumpers. SMC bumpers have the ability to properly disperse and absorb the energy that is generated by a collision, which may lessen the danger of harm to the vehicle or the occupants within. since of its resistance to corrosion, sheet molding compound (SMC) is an excellent choice for the construction of automobile bumpers since it is long-lasting and robust.

The flexibility of design offered by SMC makes it an attractive material for use in automobile bumpers. Because of the ease with which it can be molded into a variety of forms and sizes, SMC can enable producers to build bumpers that are tailored to the specifications of individual vehicle models. SMC is also available in a variety of colors, which helps cut down on the amount of extra painting or finishing that has to be done.

However, SMC bumpers do have certain downsides. To begin, they have the potential to be more costly than other materials like as steel or aluminum. In addition, SMC may be more challenging to repair than other materials, which may result in an increase in the costs associated with maintenance and repairs.

In general, the use of SMC by automobile manufacturers as a material for the production of vehicle bumpers may be a choice that is robust, lightweight, and adaptable. Because of its resistance to corrosion, its capacity to absorb energy in the event of a collision, and the diversity of its design, it is a popular option. SMC bumpers, on the other hand, are be difficult to repair and may come at a greater initial cost than bumpers made of other materials. A comprehensive examination of the costs and advantages, as well as any possible downsides or limits, should provide the foundation for making a choice about the utilization of SMC.

g) Steel Bare / EG – HF 80Y 100T

Steel Bare/EG-HF 80Y 100T is a kind of high-strength steel that is often used in the production of automobile bumpers. This form of steel is known as "bare." When low-carbon steel is combined with trace levels of alloying metals like manganese and chromium, the resulting material has a higher resistance to corrosion. The end product is a material that is tough, long-lasting, and resistant to Impact as well as wear.

It is possible to use high-strength steel for automobile bumpers because of its capacity to absorb Impact energy, which is one of the key benefits of employing this material. Steel bumpers have the ability to properly disperse and absorb the energy that is generated after a collision, which may lessen the danger of harm to the vehicle or the occupants within. In addition, when compared to other materials such as aluminum or composites, steel is one of the least costly options, which makes it an attractive choice for companies who produce automobiles.

The adaptability of high-strength steel in terms of design is an additional benefit of using this material for automobile bumpers. Because it is so malleable, steel can be easily fashioned into a wide variety of shapes and sizes, which enables manufacturers to create bumpers that are tailored to the specifications of individual vehicle models. In addition, steel is simple to weld, which makes it a convenient material for making repairs and performing maintenance.

However, steel bumpers do have some disadvantages. To begin, they may be heavier than other materials, which may have an adverse effect on the efficiency with which gasoline is used and the performance of the vehicle. In addition, steel is vulnerable to corrosion, which may shorten the lifetime of the bumper and make it less effective.

When it comes to the production of automobile bumpers, the use of high-strength steel might be a choice that provides benefits in terms of strength, durability, and cost-effectiveness. Because of its adaptability in design, its capacity to absorb energy after an Impact, and the simplicity with which it can be repaired, it is a popular option. When deciding which material to employ, however, the weight of the material as well as how susceptible it is to corrosion should be taken into consideration.

h) Aluminum 2024 – T86

Aluminum 2024-T86 is a high-strength aluminum alloy that is most often used in the aerospace sector. However, it is also a material that may be utilized in the production of automobile bumpers. After the addition of copper and various other alloying elements to aluminum, this material is produced. The final product is one that is resistant to corrosion, in addition to being strong and lightweight.

The fact that aluminum 2024-T86 is so much lighter than other metals make it an attractive material for use in automobile bumpers. Aluminum is a large amount lighter than steel and other metals, which may lead to improvements in both the fuel economy and performance of a vehicle. In addition, aluminum is very malleable, which means that metal can be molded into intricate forms and patterns. This property enables aluminum to provide more versatility in terms of design.

The fact that aluminum 2024-T86 is resistant to corrosion is yet another benefit of choosing this material for automotive bumpers. Because aluminum is naturally resistant to rust and other forms of corrosion, using bumpers made of aluminum can lengthen their lifespan and reduce the frequency with which they need to be maintained or replaced.

However, there are a few drawbacks associated with aluminum bumpers. To begin, the price of aluminum might be higher than the price of alternative materials such as steel or composites. Aluminum, on the other hand, is not as robust as certain other materials, which means that it is more likely to sustain damage in the event of a collision.

Automobile manufacturers have the option of employing aluminum 2024-T86 to create automobile bumpers, which has the benefits of being robust, lightweight, and resistant to corrosion. Because of its low weight, versatility in design, and resistance to corrosion, it is a material that is often selected. However, when deciding which material to use, the cost of it as well as the fact that it has a lower strength should be taken into consideration.

i) **Copper**

Copper's special qualities make it an excellent choice for certain spring designs. Copper's ability to efficiently carry electricity stems from its high electrical conductivity. Due to their high electrical conductivity, copper springs are ideal for use in electrical connections and other similar uses. Because copper does not corrode or oxidize easily like other materials do, copper springs can also serve as a more reliable electrical connection.

Copper also has excellent corrosion resistance, meaning metal will not deteriorate when exposed to water or other corrosive elements. This makes copper springs a viable option for uses where durability or resistance to corrosion is paramount, such as in industrial or marine settings.

However, copper may not be the best option for all types of springs, despite its unique properties that make it useful in certain applications. Because of its low stiffness and strength, copper is not as widely employed as metals like steel or titanium in the production of springs. Because of this, the amount of force or deformation that copper springs can bear before being irreversibly deformed is reduced, which reduces their potential usefulness and longevity.

Although there are applications where the properties of copper springs make them a good choice, in most cases, other materials with greater strength and durability, such as steel or titanium, are likely to be a better choice.

The miniaturization of electronic equipment has placed new demands on copper alloys, which have traditionally been used as spring materials in electromechanical systems. The first is the need for materials with better elastic capabilities, which will allow these miniaturized electronics to withstand the greater working loads and temperatures. Since these devices have tighter operating margins, the second issue is better methods for characterizing the spring properties of design interest. The elastic characteristics of copper alloys are discussed, along with some of the newer alloys, processing processes, and strengthening mechanisms being used to achieve these results. It is shown that thermomechanical processing is an excellent method for strengthening a range of copper alloys to high values. The elastic characteristics of spring materials are addressed, and new techniques for characterizing these qualities are contrasted with the more conventional approaches based on tension testing. [34]

3 Design Modifications and Optimizations

The design shown in *Figure 2.1.2 (g)* was used for the finite element model (FEM), and then a structural analysis was performed by applying pressure to the region where the bumper is Impacted. Open hat section design of the bumper yielded the best results, with the lowest average Von Misses Stress and the highest displacement. Despite the fact that the previous design achieved the best results out of all of the cross-sectional area designs, there were no adjustments made to the position of the bumper support bar. The design of the support leg and bar has therefore been modified slightly, but the cross-sectional area of the bumper beam has remained the same. In the beginning, the distances between the supports were adjusted in such a way that in one condition, the supports were placed at a distance of 6 centimeters from the corner, in another condition, the supports were placed at a distance of 13 centimeters from the corner, and in the final condition, the supports were placed at the same distance as in the original design. In addition to this, another design with three supports was selected, and the supports were evenly placed within each other beginning at the corner. Again, each of the designs had two distinct kinds of support cross sections: one kind featured a solid cross section, while the other type featured shelled cross sections. The overall design can be understood by referring to the figures that are presented below.

The all of the following designs the dimension of bumper beam is kept same as before as in *Table 2.1.2.* A new dimension of bumper support bar is introduced here in shelled cross-sectional model. The thickness of the shell here is taken as 1 centimeter.

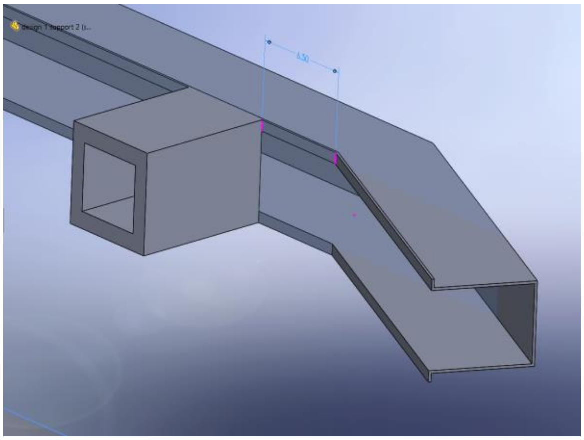


Figure 3 (a) 2 Support (shelled) at 6 cm distance from corner

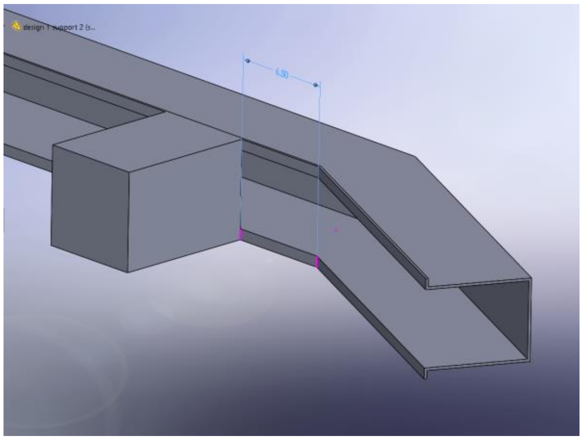


Figure 3 (b) 2 Support (solid) at 6 cm distance from corner

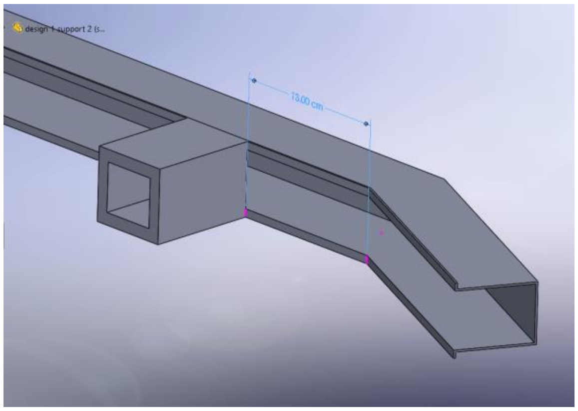


Figure 3 (c) *2 Support (shelled) at 13 cm distance from corner*

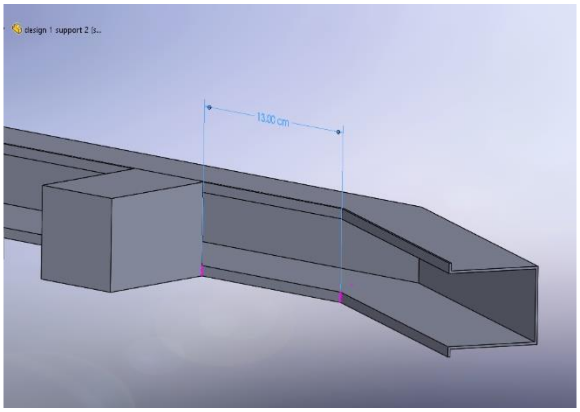


Figure 3 (d) *2 Support (solid) at 13 cm distance from corner*

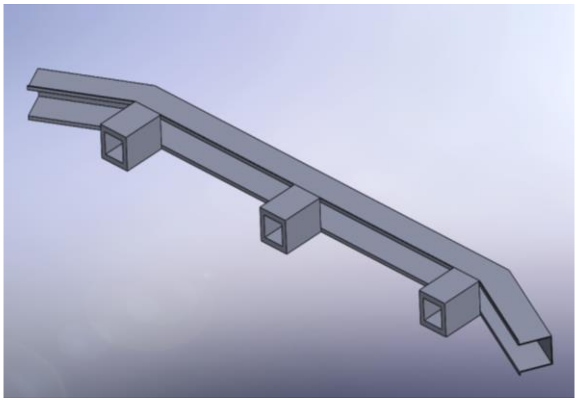


Figure 3 (e) *3 Support (shelled) at equal distance from corner*

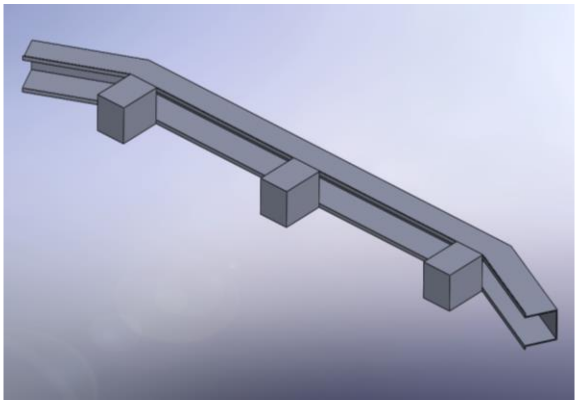


Figure 3 (f) *3 Support (solid) at equal distance from corner*

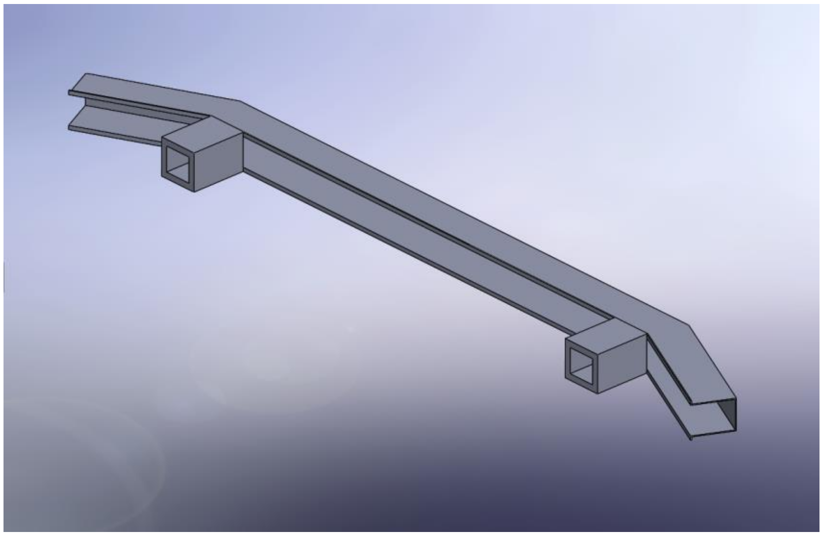


Figure 3 (g) *2 Support (shelled) placed at corner*

Following the modeling of the previous designs, tests with a similar format but limited to a crash analysis at a speed of 30 kilometers per hour were carried out. The material that is being used is still a carbon fiber composite. The layout that produced the greatest results was selected, and it will be put through more testing. FEM and structural analysis were performed in the Impact zone, which had a pressure of 1.751 MPa uniformly distributed throughout it. For each of the bumper models, the meshing process was carried out using a size of 4 millimeters, and Figure 3(a) displays the fine meshing of the bumper with three supports. The static structural behavior and total deformation of a few different designs are depicted in Figure 3, from a to g. The conclusive findings are presented in Table 3 below.

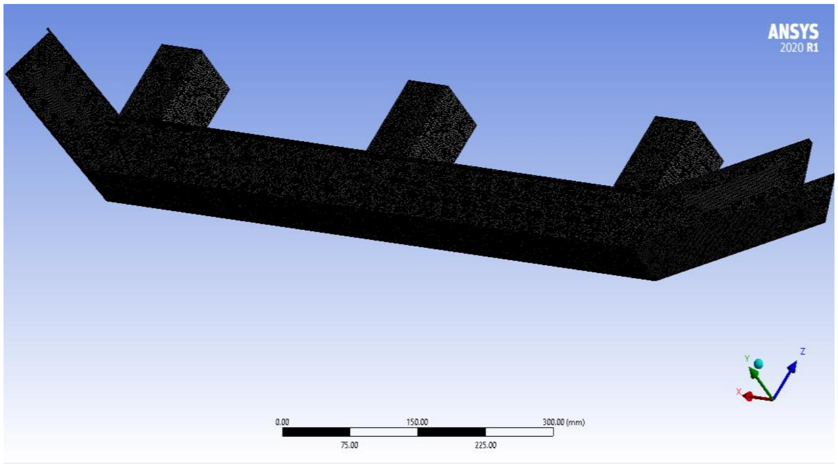


Figure 3 (h) Meshing of Modified Design with 3 (Three) Support Leg

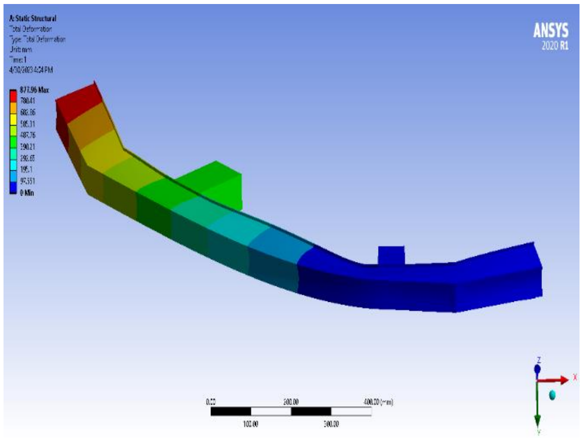


Figure 3 (i) Total Deformation of Solid Support Two Leg at 13 Centimeter from Corner

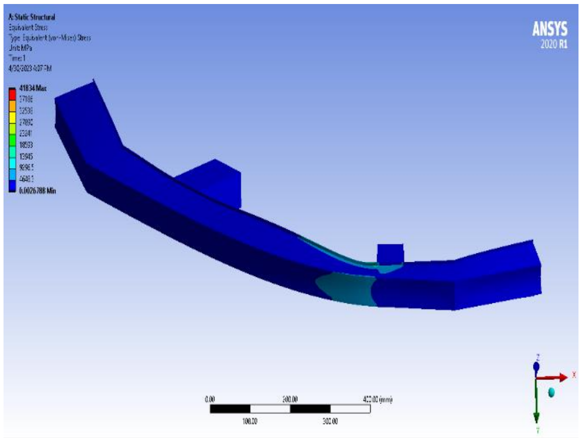


Figure 3 (j) Stress Distribution of Solid Support Two Leg at 13 Centimeter from Corner

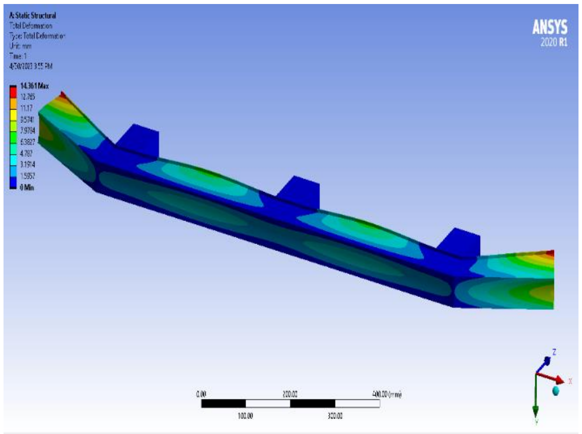


Figure 3 (k) Total Deformation of Shelled Support Three Leg at Equal Distance

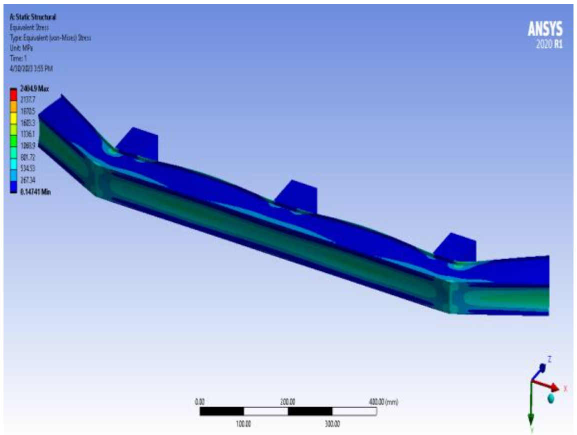


Figure 3 (l) Stress Distribution of Shelled Support Three Leg at Equal Distance

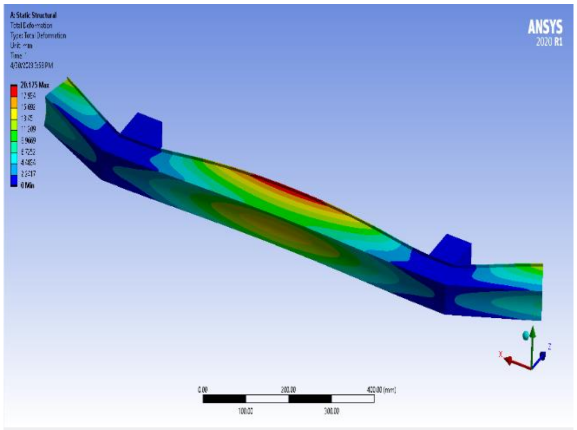


Figure 3 (m) Total Deformation of Shelled Support Two Leg at Corner

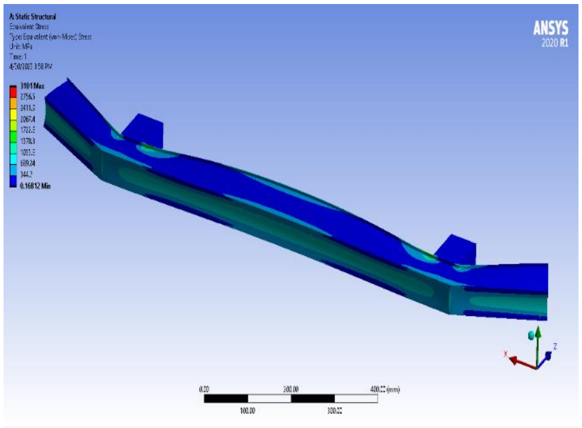


Figure 3 (n) Stress Distribution of Shelled Support Two Leg at Corner

Table 3 Average Von Misses Stress and Displacement Results of Different Modified Design

Design Modifications	Max Von Misses Stress Observed (MPa)	Max Von Misses Stress Observed at Impact region (MPa)	Average Von Misses Stress Observed at Impact Region (MPa)	Maximum Displacement (mm)
2 Support (shelled) distance as paper	3101.1	1041.6	525.6	15.166
2 Support (shelled) at a distance of 6.5 cm from corner	2493.1	1123.71	590.71	20.215
2 Support (shelled) at a distance of 13 cm from corner	5240.7	590.71	667	30.582

2 Support (solid) at a distance of 6.5 cm from corner	2467	1123.3	590.69	20.165
2 Support (solid) at a distance 13 cm from corner	3208.6	1041.2	568.54	20.141
3 Support (Shelled) Distance Equally Spaced	2404.9	1046.5	476.72	14.361
3 Support (Solid) Distance Equally Spaced	2305.9	1046.1	476.87	14.317

It can be shown that the Bumper with shelled support and initial distances provides the best results, with the highest displacement of 15.166 mm and a comparatively low average von misses stress at Impact region of 525.6 MPa. Additionally, it does not cross the Yield Strength of Carbon fiber Composite, which is 570 MPa. Hence this design will now be used for further modifications and be tested with different materials.

4 Final Modified Design

In the prior chapter, several distinct design approaches were utilized. Both shelled and solid supports were utilized, and various distances from the corner of the bumper were employed for the supports. One of these designs also features an additional support that was added later on. In the end, after doing structural analysis, it was determined that the design incorporating shelled supports at starting distances i.e., placed at corner produced the greatest potential outcomes. This design will undergo more revisions as a result of the selection.

4.1 Design Modification

As the final step of our design process, we opted on a sandwich-style form for the bumper beam. The bumper of this particular model is composed of three distinctive layers, as shown in *Figure 4.1(a)*. In our model we've developed every one of the layers is identical in thickness. Copper springs, in addition to this, are frequently used in automobiles and other vehicles because of their ability to absorb the stress that is created by bumps and wrecks on the road. The same result can be accomplished by installing a spring made of copper alloy within the shelled supports in order to create the same effect. Copper springs, which are more often located in suspension systems, are going to be repurposed for use in bumpers so that their performance can be tested. This will be done in order to ensure that the performance of the copper springs is not compromised. This particular spring has been constructed in such a way that it will easily slide into place within the support leg shell that the bumper has. Additional study will now make use of many of the different kinds of resources that were covered in *Chapter 2.2*. After the preliminary tests have been completed, the materials that have proven to be the most successful will be selected. Then, the three-layer design will be applied to the process of evaluating various combinations of these materials in order to determine whether or not the results have improved. First, we are going to make all three layers out of the same material, and then we are going to apply a sandwich configuration to the bumper beam layers, which will have alternating layers of different materials. The bumpers will continue to have the same parameters as before. The beam's previous thickness, which was 1.6 millimeters, has been split up into three layers in an equal manner. Table 4.1 presents the values for each parameter that can be found on the spring, which is a newly included component of the bumper beam.

Table 4.1 Parameters of Spring Element

Serial No.	Parameter	Description	Value
1.	l	Spring Length	91 mm
2.	D	Mean Coil Diameter	53.6 mm
3.	d	Wire diameter	3.2 mm
6.	p_1	End Coil Pitch	3.5 mm
7.	p_2	Middle Coil Pitch	20 mm
4.	n_t	Number of total Coils	7
5.	n_a	Number of active Coils	4

The design of the 3 Layer bumper with spring is shown in the following figures. Separate angle views of the spring have been shown in following figures.

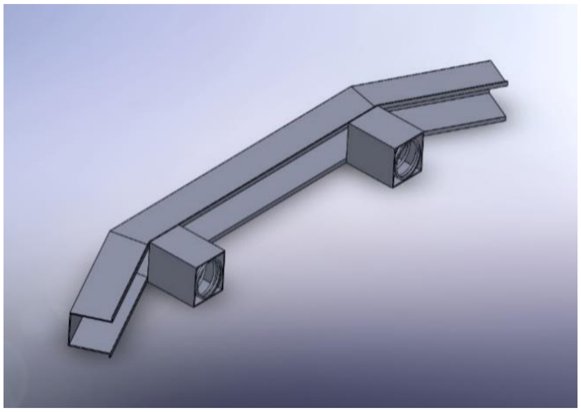


Figure 4.1 (a) Isometric View of 3 Layer Bumper Beam

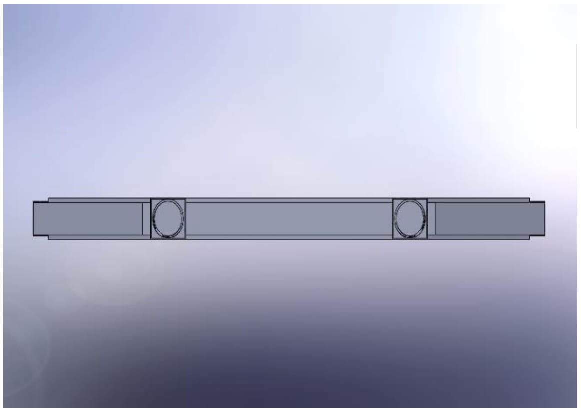


Figure 4.1 (b) Rear View of Bumper Beam

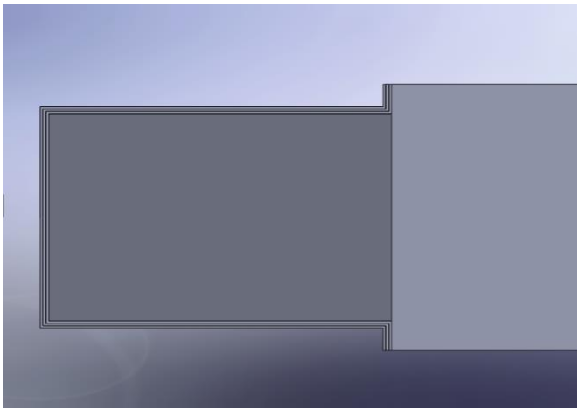


Figure 4.1 (c) Side View of Bumper Beam

Figure 4.1 (d) Spring Element that is being used inside support leg shell

4.2 Simulation

The design was first created in Solid Works, then following that, it was imported into the ANSYS program. ANSYS It is necessary to make use of a technique known as meshing, which is both powerful and flexible, in order to generate meshes of a high quality for engineering simulations involving intricate geometries. It provides users with a wide selection of meshing tools and methodologies, which enables them to design meshes that are tailored to the specific needs of their simulation. In addition to being able to construct meshes for multi-body parts, assemblies, and enormous models consisting of millions of pieces, it can import geometry from a variety of CAD file types.

4.2.1 Finite Element Modeling

The Impact mechanics subtopic mentioned in *Chapter 2.1.1* will be used in this section again. Now we will be taking speeds of 10,15,20,25,30 KMPH. The same mass of car and bumper will be used and the Speeds will be converted to pressure which will act on the Bumper as shown in *Figure 4.2.1(a).*

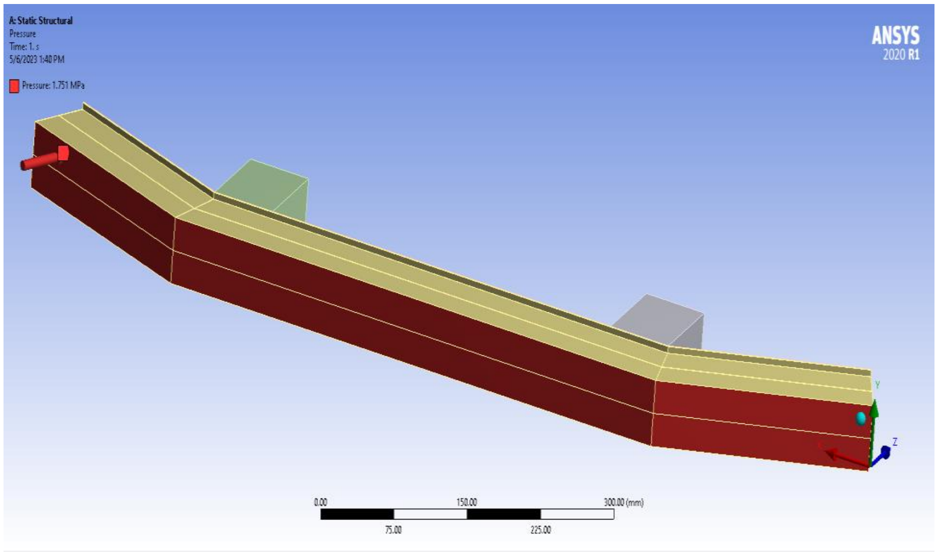


Figure 4.2.1 (a) Impact Mechanics on Bumper Beam

The following *Table 4.2.1* gives the finalized pressure values acting on the Bumper.

Table 4.2.1 Impact Pressure on Car Bumper at Varying Speed

Car speed (km/h)	Velocity (m/s)	Deceleration (m/s^2)	Force (N)	Pressure (N/mm^2)/MPa
10	2.77	27.7	47090	0.582
15	4.17	41.7	70890	0.876
20	5.55	55.5	94444	1.167
25	6.94	69.4	117980	1458
30	8.33	83.3	141666	1.751

While doing the meshing in ANSYS, the mesh sizing can be select accordingly to carry out more accurate analysis. Also, it’s tough sometimes to take the mesh size to small due to the design complexity. In this design 4-millimeter mesh sizing was used in the design and *Figure 4.2.1(b)* shows the meshing of bumper beam final design.

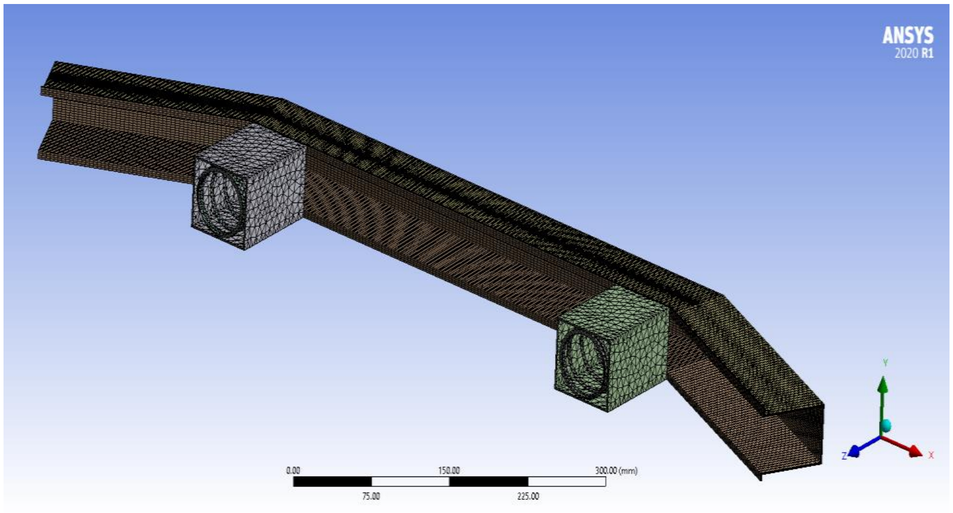


Figure 4.2.1 (b) Isometric View of Bumper Final Design’s Meshing

4.2.2 Structural Analysis

Finally, the Impact test was carried out using Static Structural of ANSYS. The performance and durability of the bumper under various loading circumstances can be better understood thanks to the static structural analysis of a car bumper model using ANSYS software. This study is essential to ensuring that the bumper can resist crashes and Impacts with the least amount of harm to the car and its occupants. Measuring the displacement of the bumper model in response to a predetermined load is part of the complete deformation study. This study enables engineers to pinpoint bumper components that are highly deformed and at risk of failure or structural damage.

Calculating the maximum stresses that can exist in the bumper model under a given load is the goal of the Equivalent Von Miss Stress study. This research is crucial for locating bumper components that are under significant stress, which might eventually cause failure or fatigue. Engineers may optimize the bumper's design to make sure it can resist Impacts and crashes without suffering structural damage by studying the stress distribution in the bumper. Following *Figure*

4.2.2 (a) to Figure 4.2.2 (f) shows the Total Deformation and Stress Distribution tests for different materials at 30 KMPH while same material was considered for all the layers of the bumper beam.

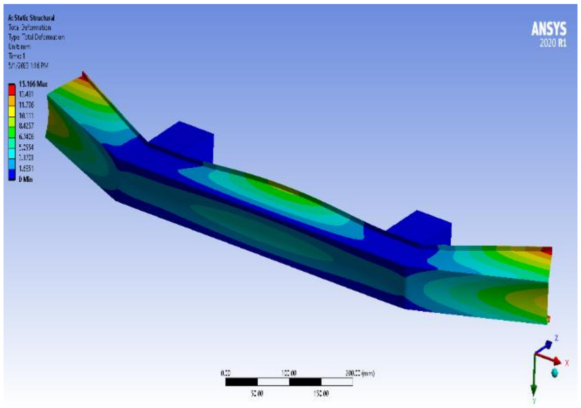


Figure 4.2.2 (a) Total Deformation of Carbon Fiber

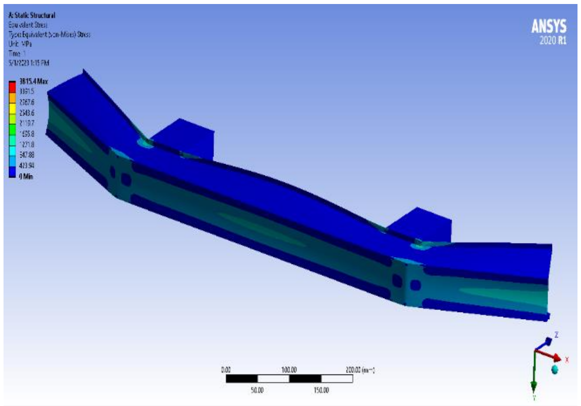


Figure 4.2.2 (b) Stress Distribution of Carbon Fiber

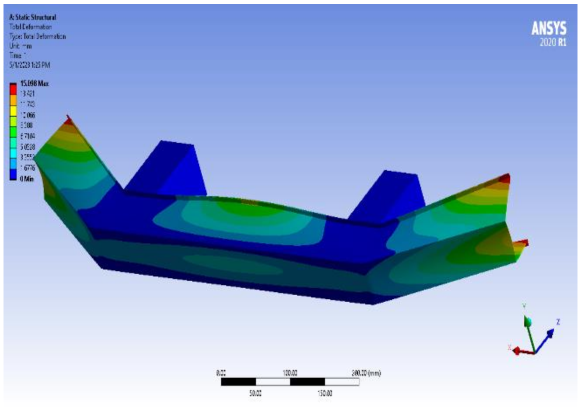


Figure 4.2.2 (c) Total Deformation of Aluminum 2024-T86

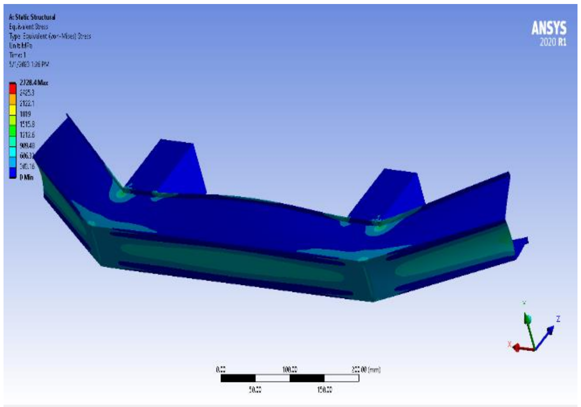


Figure 4.2.2 (d) Stress Distribution of Aluminum 2024-T86

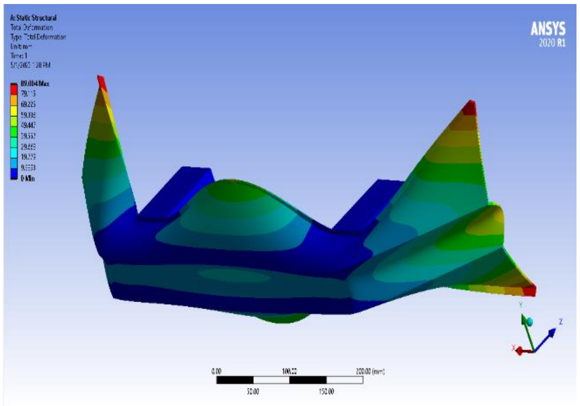


Figure 4.2.2 (e) Total Deformation of GMT

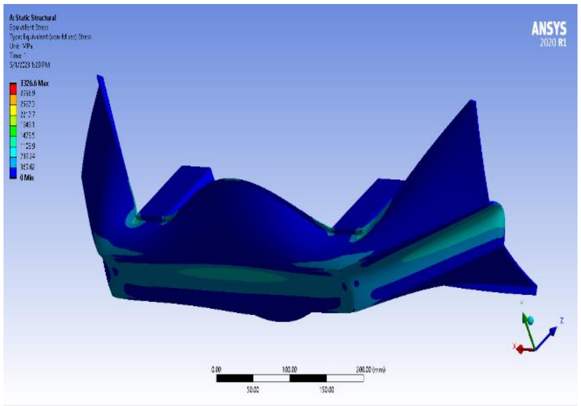


Figure 4.2.2 (f) Stress Distribution of GMT

In following Tables and Figures results of individual material used in 3 layer and their total stress and total displacements curves are shown at different speeds.

The results of the Impact tests are given in the following table.

Table 4.2.2 (a) Stress and Displacements induced at 10 kmph

Material of Bumper Body	Max Von Misses Stress Observed (MPa)	Max Von Misses Stress Observed at Impact region (MPa)	Average Von Misses Stress Observed at Impact Region (MPa)	Maximum Displacement (mm)
Magnesium body	1072.1	373.55	155.14	7.982
Aluminum Body	906.8	371.8	154.5	5 .00
Carbon Fiber Body	1268.2	352.6	166.11	5.041
Commercial Steel bare CS	1140.2	370.87	156.58	1.808
GMT	1105.7	375.92	153.85	29.583
SMC	1075.8	372.39	155.68	17.973
Steel Bare/ EG – HF 80Y 100T	1140.7	370.88	156.58	1.7469
Aluminum 2024 – T86	1097	372.54	155.69	5.0769

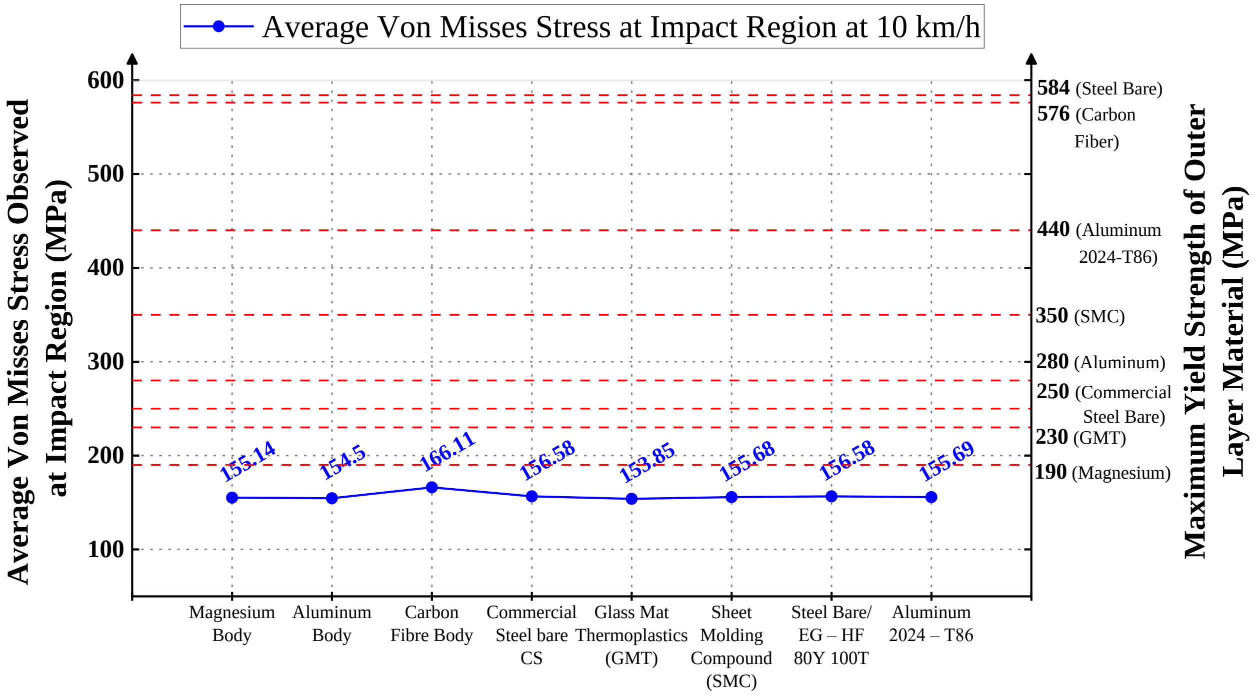


Figure 4.2.2 (a) Total Stress Curve at 10 kmph

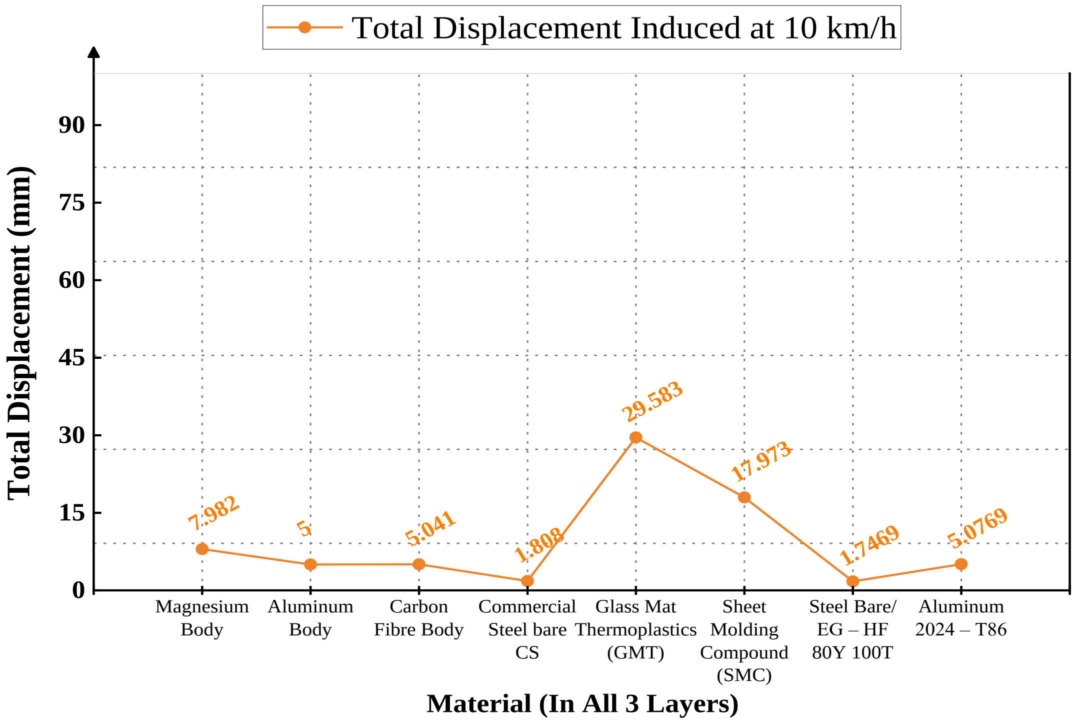


Figure 4.2.2 (b) Total Displacement Curve at 10 kmph

Following table and figures shows the result of Impact test at 15 kmph.

Table 4.2.2 (b) Stress and Displacements induced at 15 kmph

Material of Bumper Body	Max Von Misses Stress Observed (MPa)	Max Von Misses Stress Observed at Impact region (MPa)	Average Von Misses Stress Observed at Impact Region (MPa)	Maximum Displacement (mm)
Magnesium body	1608.2	560.32	232.72	11.982
Aluminum Body	1360.3	557.74	231.76	7.5276
Carbon Fiber Body	1902.3	528.9	249.16	7.5615
Commercial Steel bare CS	1710.3	556.31	234.88	2.712
GMT	1658.5	563.88	230.77	44.375
SMC	1613.7	558.58	233.52	26.96
Steel Bare/ EG – HF 80Y 100T	1711	556.31	234.87	2.6204
Aluminum 2024 – T86	1645.4	558.81	233.53	7.6154

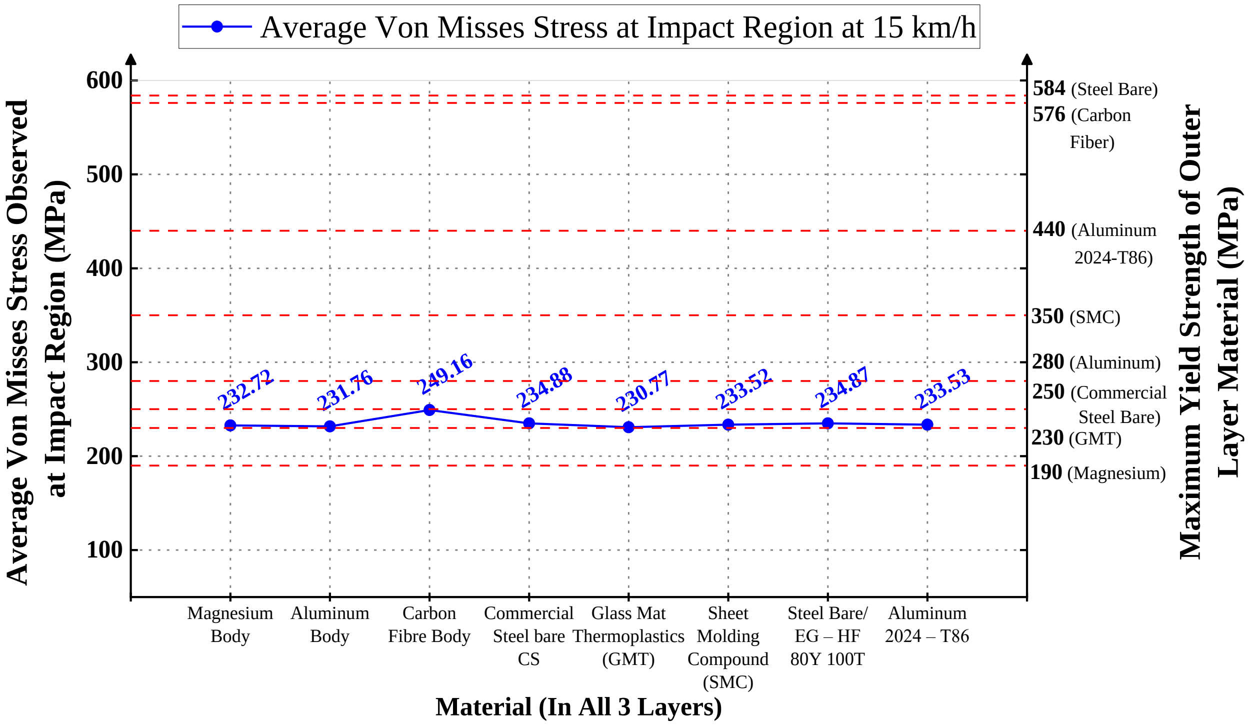


Figure 4.2.2 (c) Total Stress Curve at 15 kmph

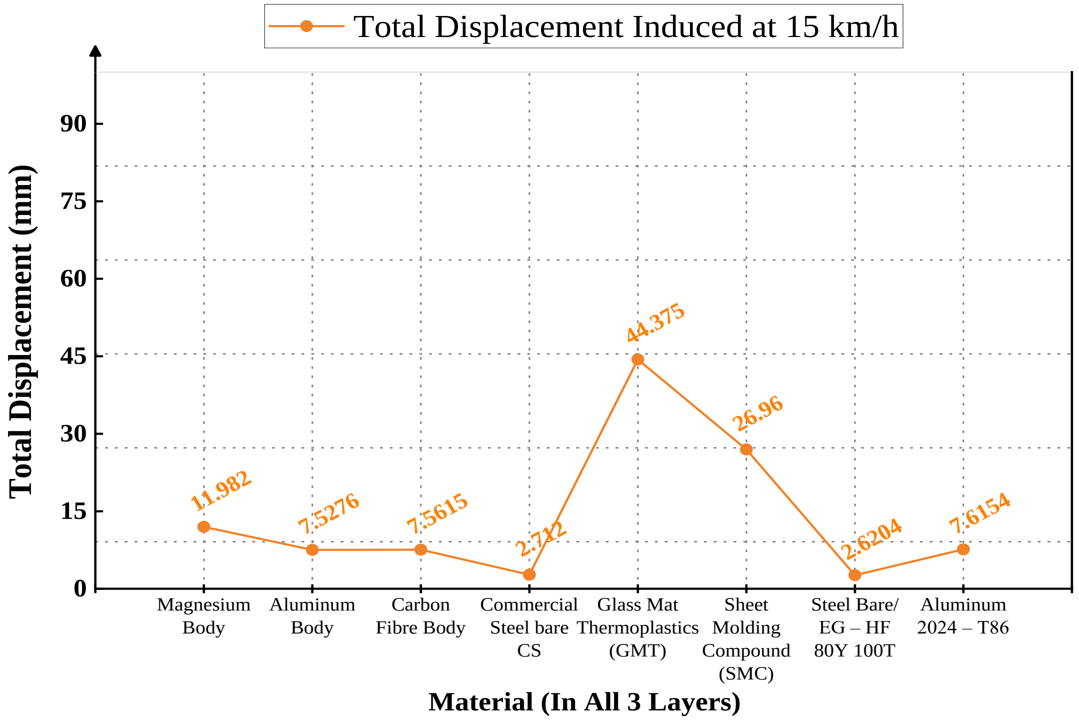


Figure 4.2.2 (d) Total Displacement Curve at 15 kmph

Following table and figures shows the result of Impact test at 20 kmph.

Table 4.2.2 (c) Stress and Displacements induced at 20 kmph

Material of Bumper Body	Max Von Misses Stress Observed (MPa)	Max Von Misses Stress Observed at Impact region (MPa)	Average Von Misses Stress Observed at Impact Region (MPa)	Maximum Displacement (mm)
Magnesium body	2149.8	749.02	311.09	16.018
Aluminum Body	1818.4	745.56	309.81	10.063
Carbon Fiber Body	2542.9	707.02	333.07	10.108
Commercial Steel bare CS	2286.3	743.65	313.98	3.6254
GMT	2217.1	753.78	308.49	53.319
SMC	2157.2	746.69	312.16	36.039
Steel Bare/ EG – HF 80Y 100T	2287.4	743.66	313.97	3.5029
Aluminum 2024 – T86	2199.6	747.01	312.18	10.18

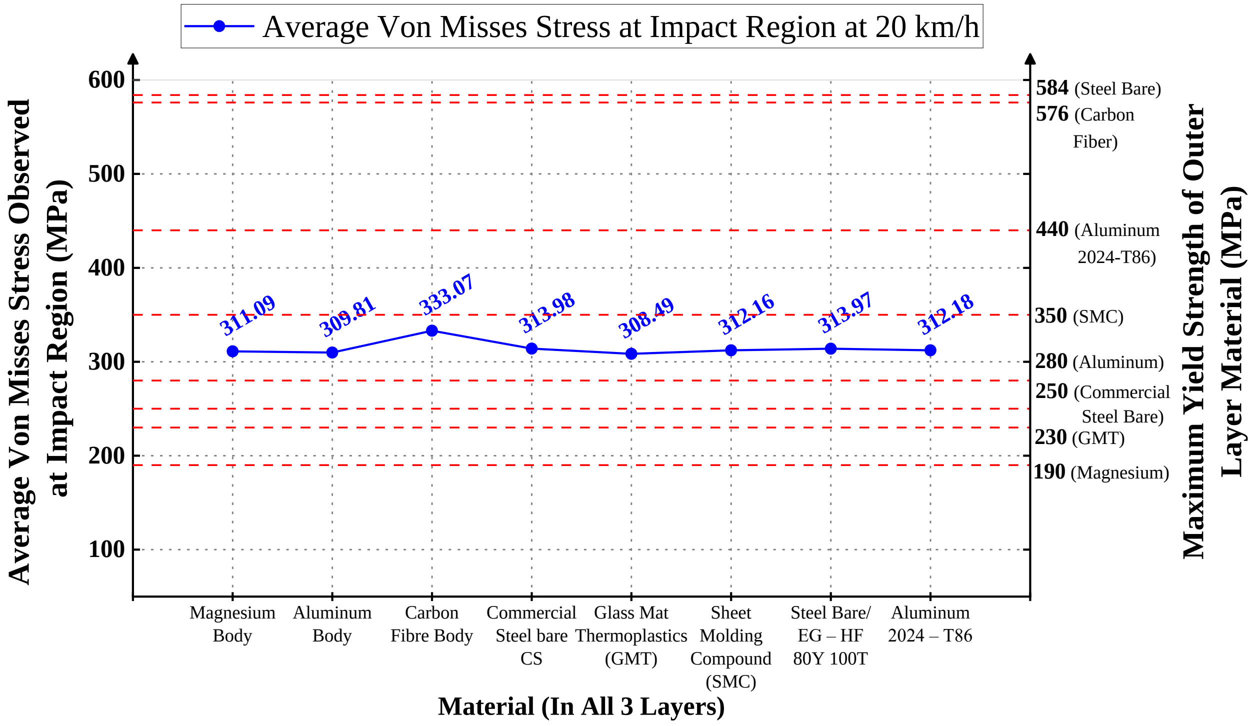


Figure 4.2.2 (e) Total Stress Curve at 20 kmph

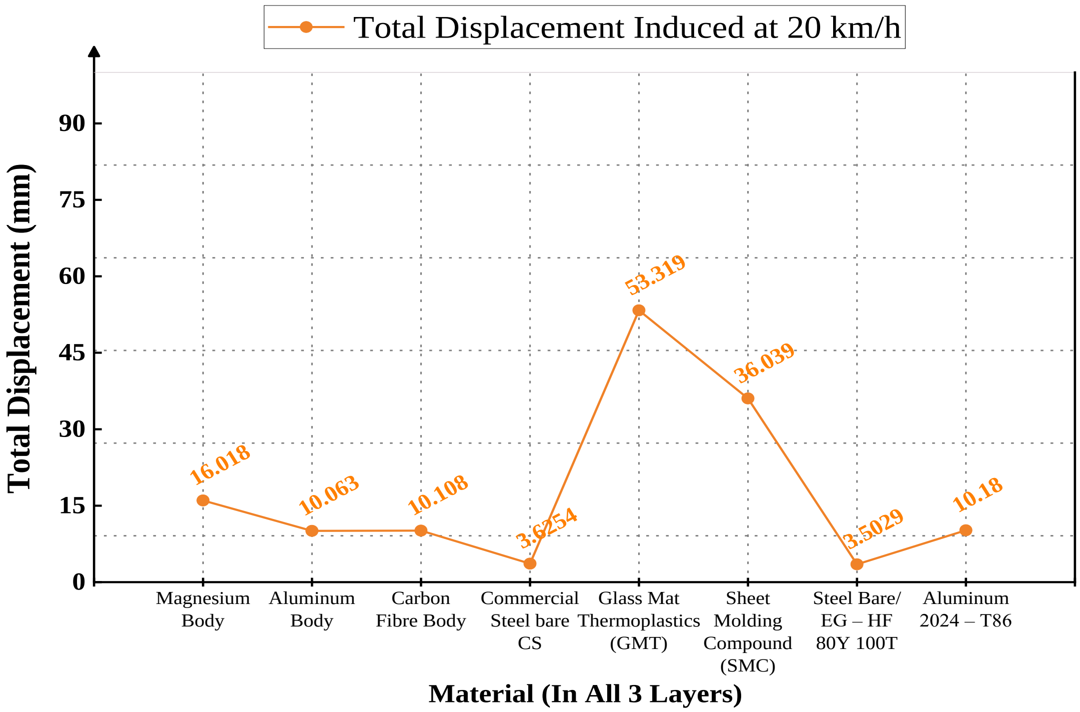


Figure 4.2.2 (f) Total Displacement Curve at 20 kmph

Following table and figures shows the result of Impact test at 25 kmph.

Table 4.2.2 (d) Stress and Displacements induced at 25 kmph

Material of Bumper Body	Max Von Misses Stress Observed (MPa)	Max Von Misses Stress Observed at Impact region (MPa)	Average Von Misses Stress Observed at Impact Region (MPa)	Maximum Displacement (mm)
Magnesium body	2687.75	936.456	388.925	20.03
Aluminum Body	2273.4	932.13	387.34	12.58
Carbon Fiber Body	3179.15	883.91	416.41	12.637
Commercial Steel bare CS	2858.35	929.725	392.54	4.5325
GMT	2771.85	942.44	385.68	71.0715
SMC	2696.95	933.545	350.26	45.0565
Steel Bare/ EG – HF 80Y 100T	2859.7	929.73	392.53	4.3815
Aluminum 2024 – T86	2749.95	933.505	376.09	12.727

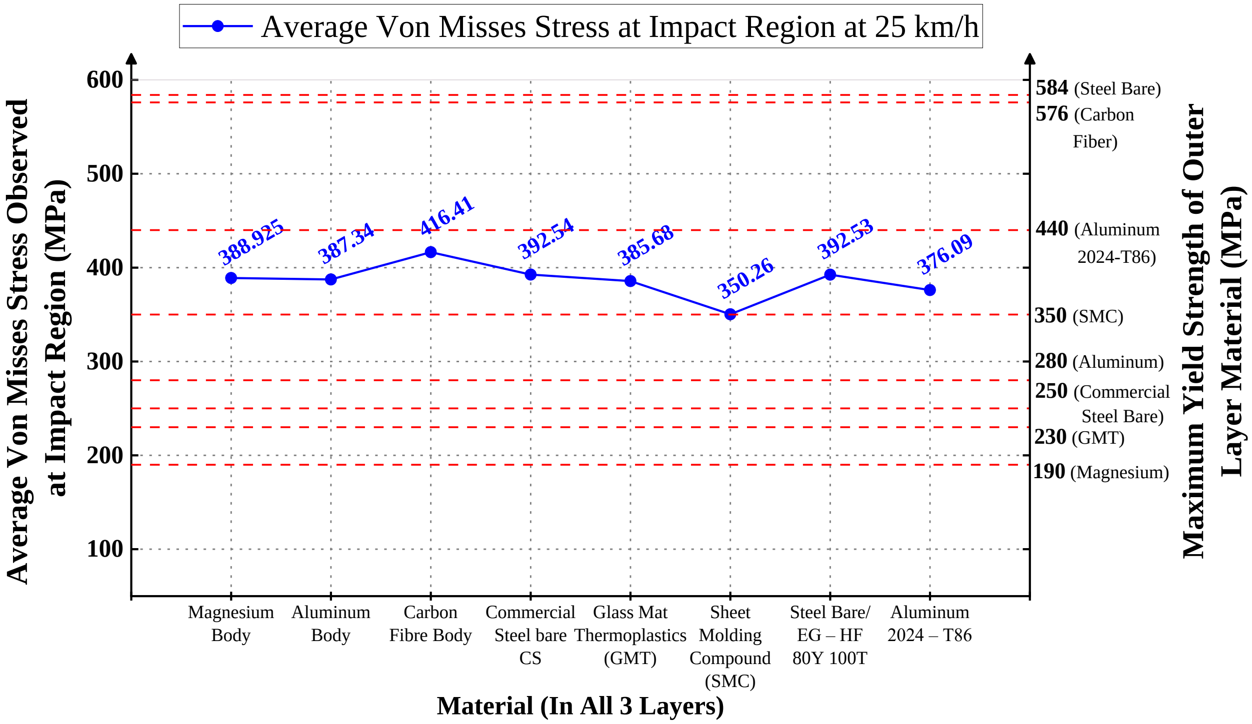


Figure 4.2.2 (g) Total Stress Curve at 25 kmph

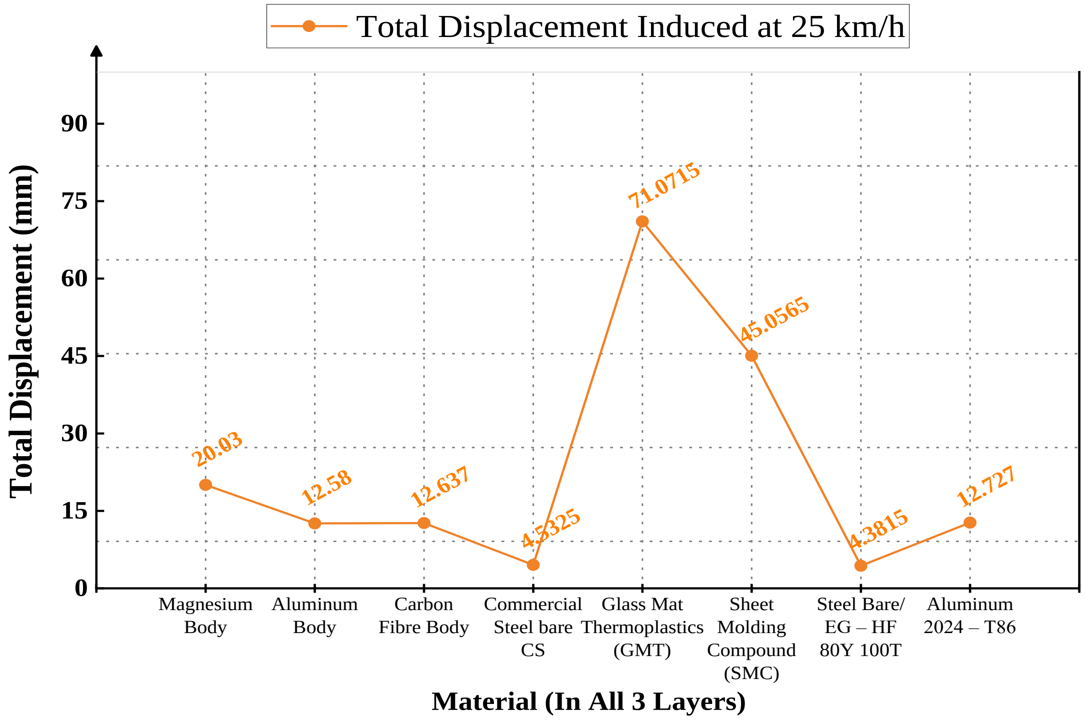


Figure 4.2.2 (h) Total Displacement Curve at 25 kmph

Following table and figures shows the result of Impact test at 30 kmph

Table 4.2.2 (e) Stress and Displacements induced at 30 kmph

Material of Bumper Body	Max Von Misses Stress Observed (MPa)	Max Von Misses Stress Observed at Impact region (MPa)	Average Von Misses Stress Observed at Impact Region (MPa)	Maximum Displacement (mm)
Magnesium body	3225.7	1123.9	466.76	24.033
Aluminum Body	2728.4	1118.7	464.84	15.098
Carbon Fiber Body	3815.4	1060.8	499.76	15.166
Commercial Steel bare CS	3430.4	1115.8	471.1	5.4396
GMT	3326.6	1131.1	462.87	89.004
SMC	3236.7	1120.4	468.38	54.074
Steel Bare/ EG – HF 80Y 100T	3432	1115.8	471.09	5.26
Aluminum 2024 – T86	3300.3	1120.8	440	15.274

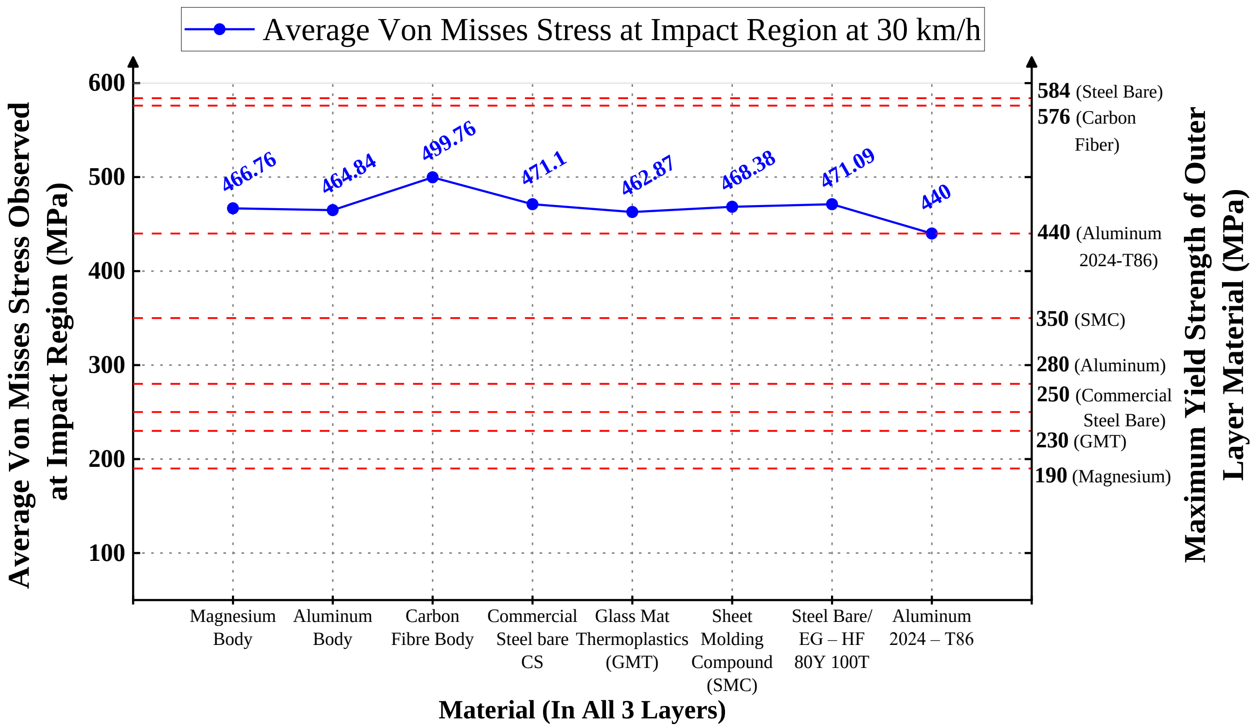


Figure 4.2.2 (i) Total Stress Curve at 30 kmph

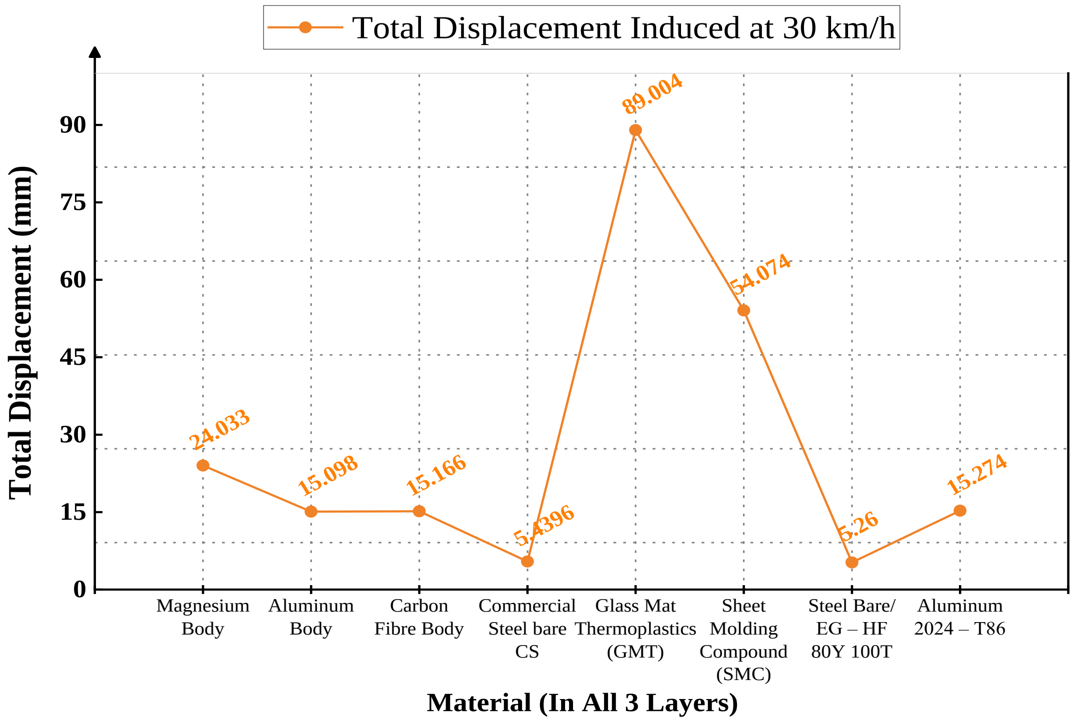


Figure 4.2.2 (j) Total Displacement Curve at 30 kmph

Different materials reacted differently during the crash analysis, as revealed by the tests. At 10 kilometers per hour, none of the materials exceed their Sy Value in the Impact region when compared to the usual Von Miss stress. The optimal outcome is achieved at 15 km/h GMT, causing a significant deformation of 44.375 mm. The average Von Miss stress is also lower than its Sy value, measuring at 240 MPa. Both commercial steel and magnesium reach their Sy values when subjected to an average Von Miss stress, while moving at a speed of 15 kilometers per hour. The SMC performs best for us at a speed of 20 km/h, with a deformation of 36.039 mm and an average Von Miss stress value below the SMC's Sy value of 350 MPa. The Sy values of the Aluminum body and GMT intersect at an average Von Miss stress when travelling at a speed of 20 kilometers per hour. At 25 kilometers per hour, only the materials mentioned do not exceed their Yield Strength (Sy) limits. At a speed of 20 kilometers per hour, the SMC experiences a deformation of 36.039 mm. However, the average Von Miss stress in the impact area remains below its Sy value of 330 megapascals. The SMC crosses its Sy for the average Von Miss Stress in the Impact Region at a speed of 25 kilometers per hour. Carbon fiber and Aluminum 2024-T86 perform best when combined, achieving a deformation of 15.166 mm and 15.274 mm, respectively, at a speed of 30 km/h. The Von Miss stress in the Impact region of these materials does not seem to be exceeded even at a speed of 30 kilometers per hour. Aluminum 2024-T86 has a value of 440 MPa, whereas carbon fiber has a value of 576 MPa. The material called Steel Bare/EG - HF 80Y 100T meets the requirements and has a Sy value of 584 MPa. It calculates a displacement of only 5.26 mm.

GMT and SMC are two materials that produce excellent results, alongside Carbon Fiber and Aluminum 2024-T86. The four chosen materials will be used to create a three-layer bumper model. Different combinations of these materials will be tested to determine which combination performs the best.

4.3 Sandwich Model Analysis

The Finite Element Modelling (FEM) and structural analysis will now be performed on the Sandwich model or the 3 Layer Model shown in *Figure 4.1(a)*. The four materials were chosen based on the results of the tests carried out in the section before this one. Following the completion of the previous tests, the following materials- Carbon Fiber composite, Aluminum 2024-T86, GMT, and SMC- were chosen for further evaluation, and the same tests will now be carried out on the combination of these materials.

4.3.1 Carbon Fiber with Aluminum 2024-T86 Sandwiched

Table 4.3.1 (a) Impact Results of Carbon Fiber with Aluminum 2024-T86 Sandwich Model

Impact Speed (kmph)	Max Von Misses Stress Observed (MPa)	Max Von Misses Stress Observed at Impact region (MPa)	Average Von Misses Stress Observed at Impact Region (MPa)	Maximum Displacement (mm)	Average Von Misses Stress Observed at Middle layer (MPa)
10	1208.4	353.59	167.07	5.0425	54.943
15	1815.5	531.30	251.035	7.65	82.65
20	2423.1	709.01	335	10.11	110.17
25	3029.4	886.56	418.8	12.64	137.74
30	3635.7	1063.8	502.65	15.171	165.3

Figure 4.3.1(a) and *Figure 4.3.1(b)* depicts the total deformation of the object as well as the von Miss stress when the object is moving at a speed of 30 kilometers per hour respectively. Both the average Von Misses stress observed at impact region and the average Von Misses stress observed at middle layer show that the Sy of carbon Fiber and Aluminum 2024-T86 does not cross itself respectively. This produces somewhat better results than the carbon fiber composite on its own, which gave us 15.166 millimeters, while this gives us 15.55 millimeters when tested for a crash at 30 km per hour.

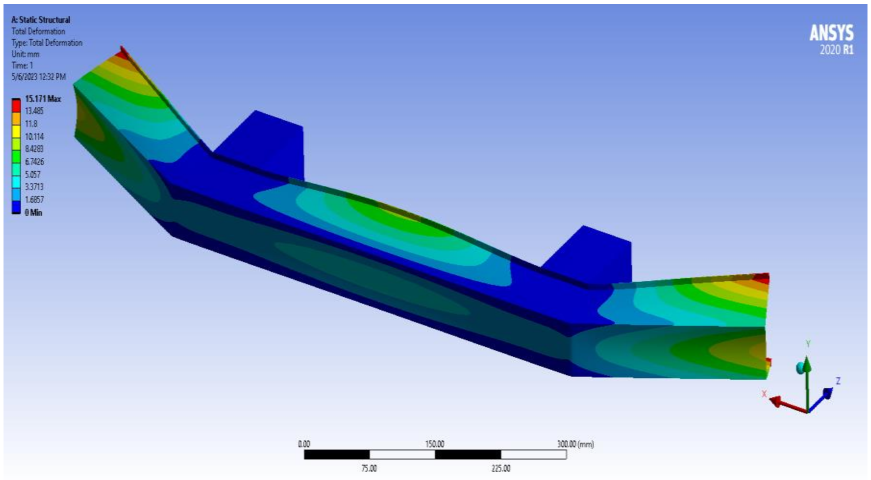


Figure 4.3.1 (a) Total Deformation of Carbon Fiber with Aluminum 2024-T86 Sandwiched at 30 kmph

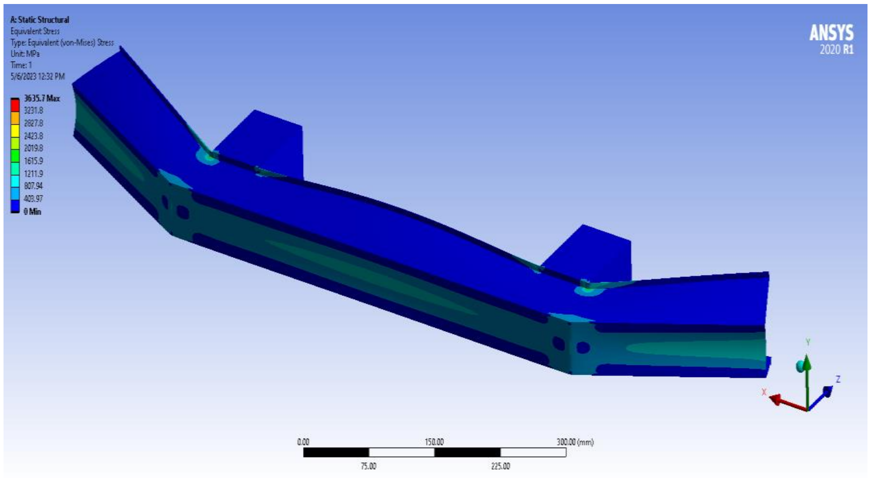


Figure 4.3.1 (b) Equivalent Von Misses Stress of Carbon Fiber with Aluminum 2024-T86 Sandwiched at 30 kmph

4.3.2 Aluminum 2024-T86 with Carbon Fiber Sandwiched

Table 4.3.2 (a) Impact Results of Aluminum 2024-T86 with Carbon Fiber Sandwich Model

Impact Speed (kmph)	Max Von Misses Stress Observed (MPa)	Max Von Misses Stress Observed at Impact region (MPa)	Average Von Misses Stress Observed at Impact Region (MPa)	Maximum Displacement (mm)	Average Von Misses Stress Observed at Middle layer (MPa)
10	1133.8	371.25	154.44	5.0542	57.246
15	1703.6	557.8	231.5	7.12	86.02
20	2273.5	744.41	309.68	10.134	114.79
25	2842.4	930.6	754.33	12.67	142.6
30	3411.2	1116.9	444.65	15.206	170.5

As a result of this combination, the average Von Misses stress observed at impact region and the average Von Misses stress observed at middle layer demonstrate that the Sy of carbon fiber and Aluminum 2024-T86 does not cross itself respectively. *Figure 4.3.2(a)* and *Figure 4.3.2(b)* depicts the total deformation of the object as well as the von Miss stress when the object is moving at a speed of 30 kilometers per hour respectively. This offers results that are slightly better than those produced by the and Aluminum 2024-T86 on its own, which gave us 15.244 millimeters, while this gives us 15.888 millimeters when tested for a crash at 30 kmph.

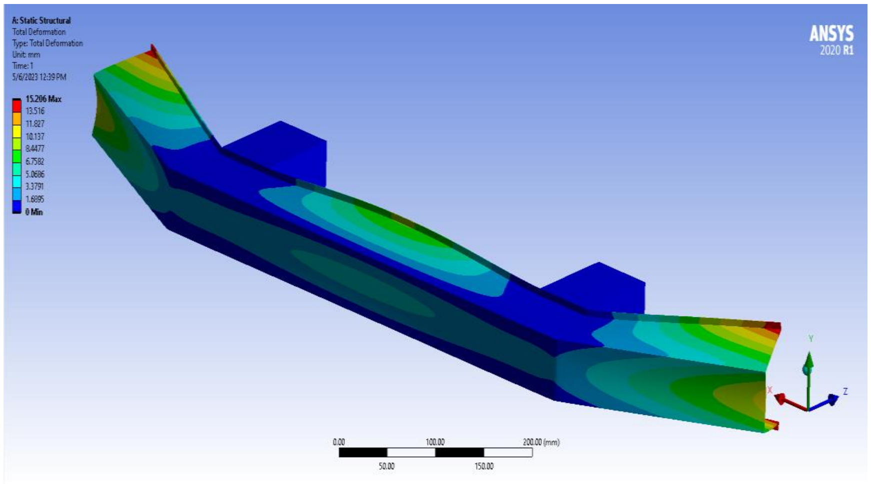


Figure 4.3.2 (a) Total Deformation of Aluminum 2024-T86 with Carbon Fiber Sandwiched at 30 kmph

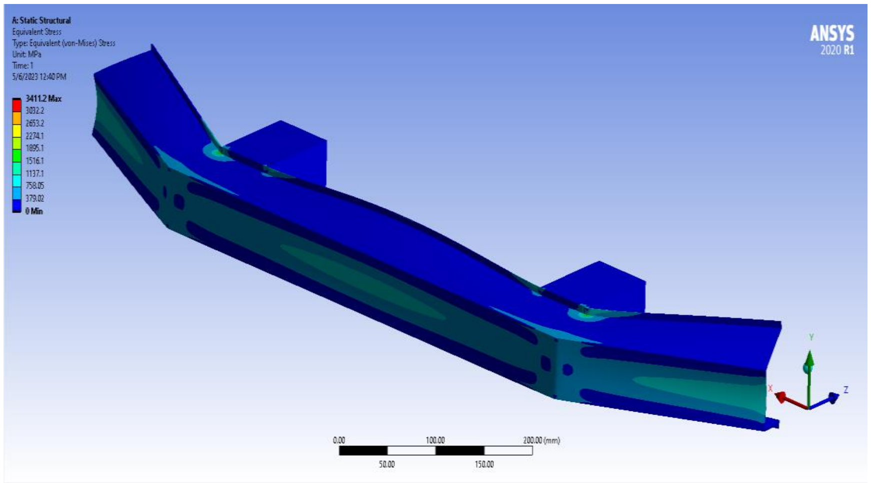


Figure 4.3.2 (b) Equivalent Von Misses Stress of Aluminum 2024-T86 with Carbon Fiber Sandwiched at 30 kmph

4.3.3 Aluminum 2024-T86 with GMT Sandwiched

Table 4.3.3 (a) Impact Results of Aluminum 2024-T86 with GMT Sandwich Model

Impact Speed	Max Von Misses Stress Observed (MPa)	Max Von Misses Stress Observed at Impact region (MPa)	Average Von Misses Stress Observed at Impact Region (MPa)	Maximum Displacement (mm)	Average Von Misses Stress Observed at Middle layer (MPa)
10	1310.6	387.7	173.48	5.6119	13.32
15	1969.3	582.5	260.66	8.43	17.89
20	2628	777.4	347.85	11.253	22.55
25	3276.5	969.26	433.69	14.03	31.61
30	3943.1	1166.4	521.92	16.884	40.07

The average Von Misses Stress that was observed in the impact site demonstrates that the Sy of Aluminum 2024 T86 was crossed at the 30 km per hour collision in this particular composition of materials. The object experiences a complete deformation and a Von Misses stress when moving at a speed of 25 kilometers per hour, as shown in *Figure 4.3.3(a) and 4.3.3(b),* respectively. The total deformation is illustrated in these figures. These data are only applicable for impacts occurring at a speed of 25 kilometers per hour, and they create a tolerable deformation of 14.03 millimeters. This deformation is not significantly bigger than the deformation produced by simply Aluminum 2024-T86. In addition, the Sy of GMT has not yet crossed over into the middle layer for the average Von Misses stress that is being observed there. This may only be utilized for speeds up to 25 km per hour; any speeds higher than that makes it ineffective. Nevertheless, 2024-T86 Aluminum is better in its individual sense.

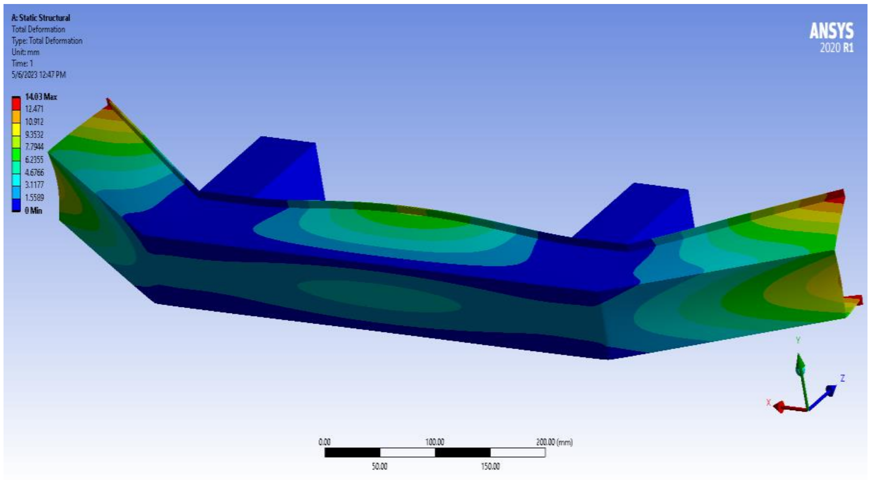


Figure 4.3.3 (a) Total Deformation of Aluminum2024-T86 with GMT Sandwiched at 25 kmph

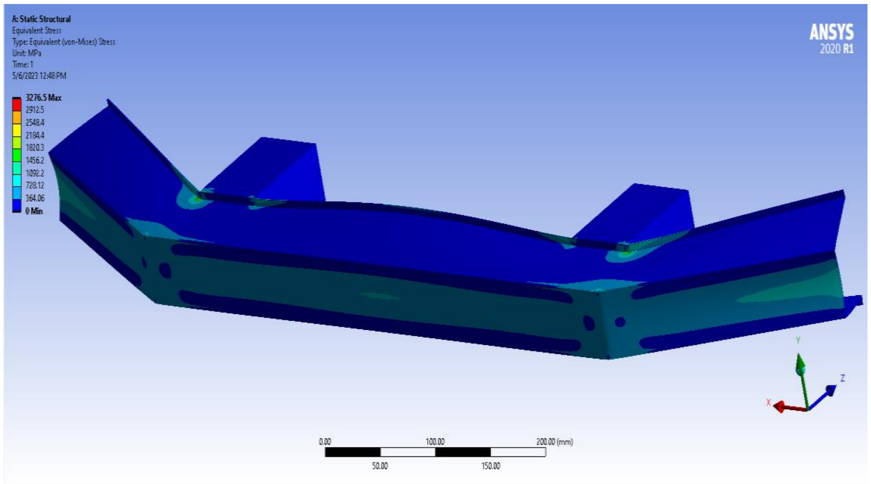


Figure 4.3.3 (b) Equivalent Von Misses Stress of Aluminum2024-T86 with GMT Sandwiched at 25 kmph

4.3.4 Aluminum 2024-T86 with SMC Sandwiched

Table 4.3.4 (a) Impact Results of Aluminum 2024-T86 with SMC Sandwich Model

Impact Speed (kmph)	Max Von Misses Stress Observed (MPa)	Max Von Misses Stress Observed at Impact region (MPa)	Average Von Misses Stress Observed at Impact Region (MPa)	Maximum Displacement (mm)	Average Von Misses Stress Observed at Middle layer (MPa)
10	1265.1	385.84	169.44	5.515	20.165
15	1900.9	579.75	254.6	8.29	28.67
20	2536.7	773.67	339.76	11.059	37.1901
25	3162.7	964.6	423.61	13.788	45.771
30	3806.1	1160.8	509.78	16.594	60.667

In this group of materials, the average von Misses stress at impact region shows that Aluminum 2024-T86 exceeds Yield Strength (Sy) at 30 kmph. *Figure 4.3.4(a) and 4.3.4(b)* show total deformation and von Miss stress at 25 kmph. These results apply solely to collisions at 25 km/h and produce a tolerable deformation of 13.788 millimeters. Aluminum 2024-T86 deforms similarly. SMC Sy has not yet reached the intermediate layer for the average von misses stress found there. It is not a viable solution for 30 kmph crashes as Aluminum 2024-T86 is better on its own but it can be used as an alternate for crashes till 25 kmph.

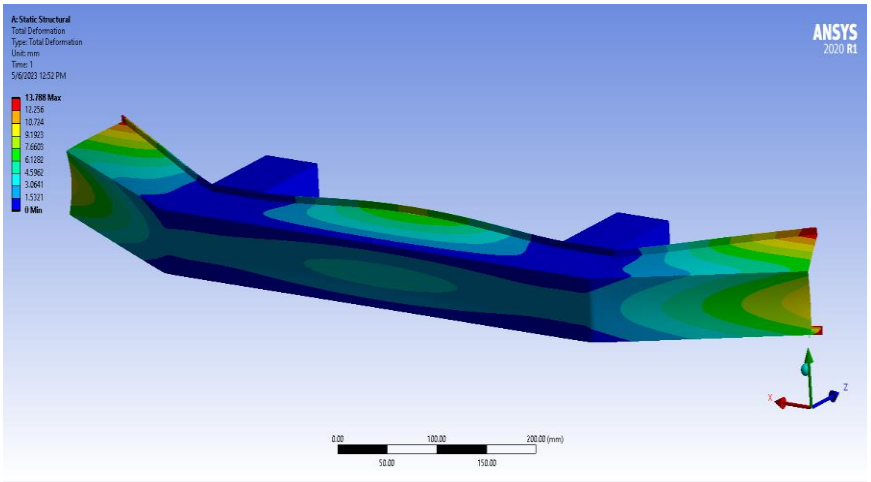


Figure 4.3.4 (a) Total Deformation of Aluminum2024-T86 with SMC Sandwiched at 25 kmph

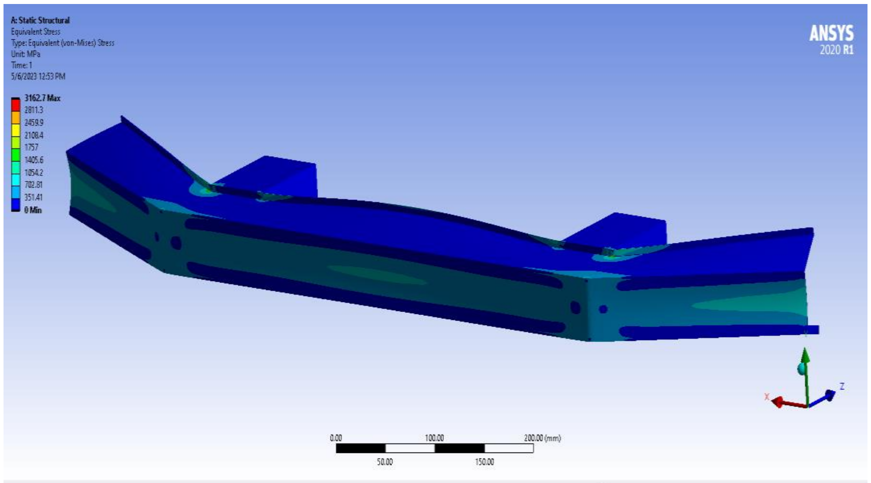


Figure 4.3.4 (b) Equivalent Von Misses Stress of Aluminum 2024-T86 with SMC Sandwiched at 25 kmph

4.3.5 GMT with Aluminum 2024-T86 Sandwiched

Table 4.3.5 (a) Impact Results of GMT with Aluminum 2024-T86 Sandwich Model

Impact Speed (kmph)	Max Von Misses Stress Observed (MPa)	Max Von Misses Stress Observed at Impact region (MPa)	Average Von Misses Stress Observed at Impact Region (MPa)	Maximum Displacement (mm)	Average Von Misses Stress Observed at Middle layer (MPa)
10	1749.8	306.72	116.28	21.499	156.72
15	2629.15	460.87	174.72	32.30	245.64
20	3508.5	615.02	233.15	43.109	334.56
25	4386.4	768.91	291.5	53.90	418.27
30	5264.3	922.79	349.83	64.682	501.98

The average von Misses stress that was observed at the impact region indicates that the Sy of GMT was crossed when this combination of materials was subjected to a collision travelling 30 km per hour. It also crosses the Sy of Aluminum 2024 T86 when it collides at 30 km per hour, as seen by the average von misses stress observed in the middle layer. When compared to the data for each GMT individual bumper, the average Von Misses Stress observed at the impact region crossed its Sy at a speed of 15 kilometers per hour. The addition of Aluminum 2024-T86 produces a workable product with an appropriate average stress and a very high displacement of 43.109 mm; as a result, the product may now induce a speed increase of 5 kilometers per hour. This could be a very useful alternative for collisions at modest speeds of up to 20 km per hour. The Total deformation as well as the von Miss stress that takes place as a result crash at a speed of 20 kilometers per hour is depicted in *Figure 4.3.5(a) and 4.3.5(b).*

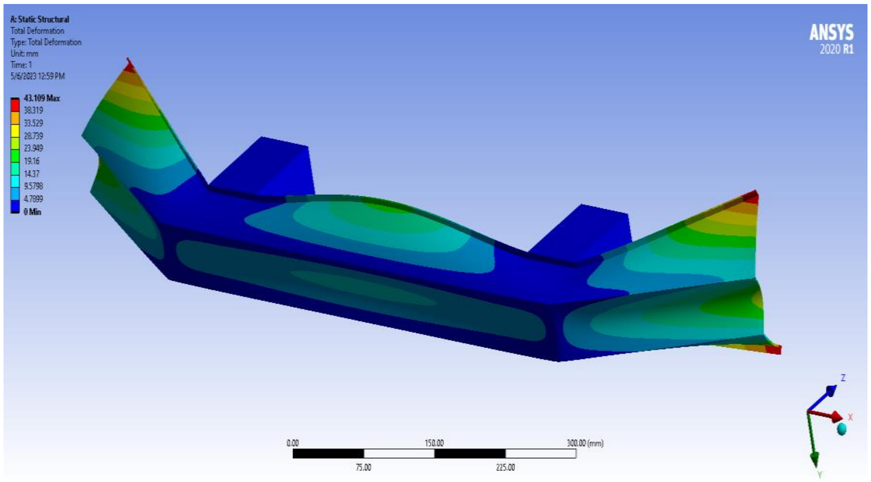


Figure 4.3.5 (a) Total Deformation of GMT with Aluminum 2024-T86 Sandwiched at 25 kmph

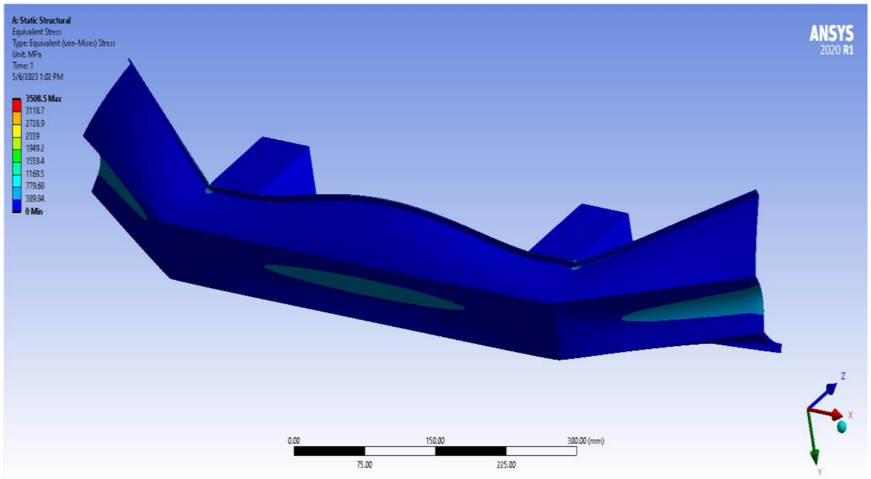


Figure 4.3.5 (b) Equivalent Von Misses Stress of GMT with Aluminum 2024-T86 Sandwiched at 25 kmph

4.3.6 SMC with Aluminum 2024-T86 Sandwiched

Table 4.3.6 (a) Impact Results of SMC with Aluminum 2024-T86 Sandwich Model

Impact Speed (kmph)	Max Von Misses Stress Observed (MPa)	Max Von Misses Stress Observed at Impact region (MPa)	Average Von Misses Stress Observed at Impact Region (MPa)	Maximum Displacement (mm)	Average Von Misses Stress Observed at Middle layer (MPa)
10	1410.8	333.38	130.62	14.85	127.11
15	2119.8	500.9	196.27	22.31	191.5
20	2828.9	668.48	261.92	29.777	254.87
25	3527.1	833.46	326.55	37.126	317.76
30	4244.6	1003.2	392.99	44.679	382.41

Using these components, the average Von Misses stress observed at impact region smashes through the Sy of SMC at 30 kmph. The Sy of Aluminum 2024-T86 did not reach the middle layer Von Misses stress. SMS crosses its Yield Strength (Sy) at 30 kilometers per hour and is viable under and equivalent to 25 kmph. It also lowers average stress and increases maximum displacement to 37.126 mm and 326.55 MPa. For crashes up to 25 kilometers per hour (approximately 16 miles per hour), this could be a useful option. *Figure 4.3.6(a) and 4.3.6(b)* show the total deformation and von Miss stress of a 25-kilometer-per-hour collision.

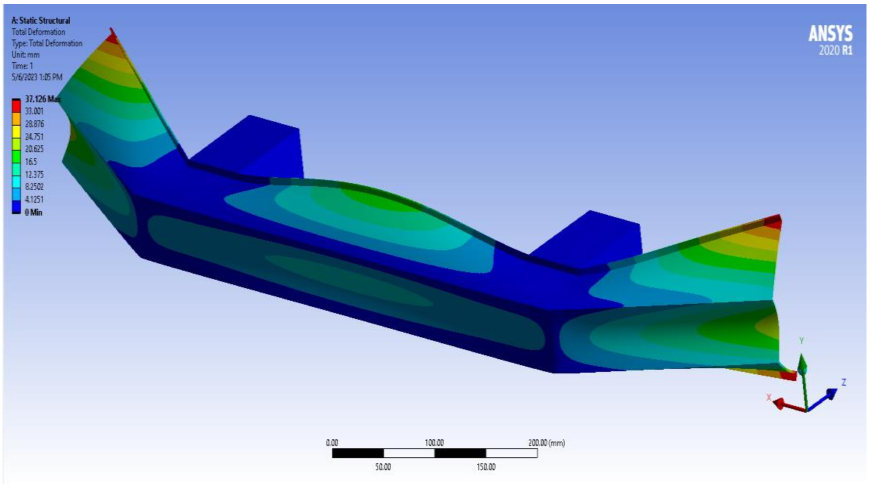


Figure 4.3.6 (a) Total Deformation of SMC with Aluminum 2024-T86 Sandwiched at 25 kmph

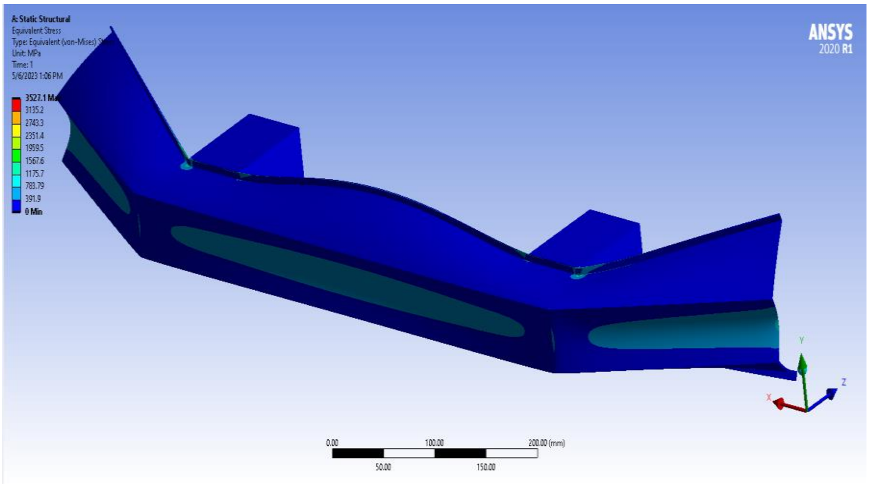


Figure 4.3.6 (b) Equivalent Von Misses Stress of SMC with Aluminum2024-T86 Sandwiched at 25 kmph

4.3.7 Carbon Fiber with GMT Sandwiched

Table 4.3.7 (a) Impact Results of Carbon Fiber with GMT Sandwich Model

Impact Speed (kmph)	Max Von Misses Stress Observed (MPa)	Max Von Misses Stress Observed at Impact region (MPa)	Average Von Misses Stress Observed at Impact Region (MPa)	Maximum Displacement (mm)	Average Von Misses Stress Observed at Middle layer (MPa)
10	1439.2	367.73	185.79	5.5797	13.44
15	2162.5	552.55	279.17	8.38	21.55
20	2885.9	737.36	372.54	11.188	29.66
25	3607.9	921.88	465.75	13.99	35.05
30	4330	1106.4	558.97	16.787	40.436

In conjunction with Glass Mat Thermoplastic (GMT), Carbon Fiber composite delivered the best results. Even in a collision travelling at 30 kilometers per hour, the average von misses stress observed in the impact region does not exceed the carbon fiber's Sy value when Carbon fiber and GMT are utilized. The observed value of the average von misses stress in the middle layer does not cross the Sy limit of GMT. The average stress is slightly higher here 558.67 MPa when compared to the results of the bumper that was just made of carbon fiber composite, but this is not a problem because it does not cross the Sy limit. Additionally, the maximum displacement is greater in this configuration, coming in at 16.787 mm. As a result, it is an appropriate choice for collisions with velocities in excess of 30 km per hour. The total deformation and the von Miss stress that arise as a result of a collision that takes place at a speed of 30 kilometers per hour are both depicted in *Figure 4.3.7 (a) and 4.3.7 (b)*, which is an illustration of what happens after a collision that takes place at such speed

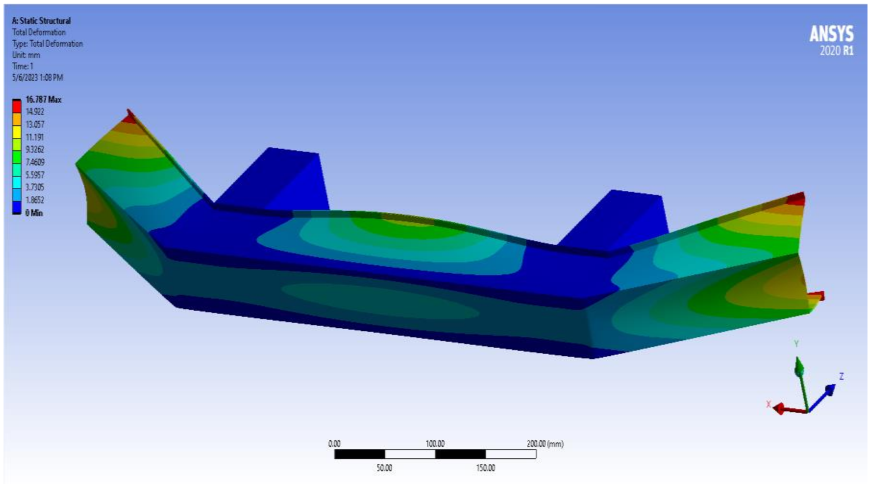


Figure 4.3.7 (b) Total Deformation Carbon Fiber with GMT Sandwiched at 25 kmph

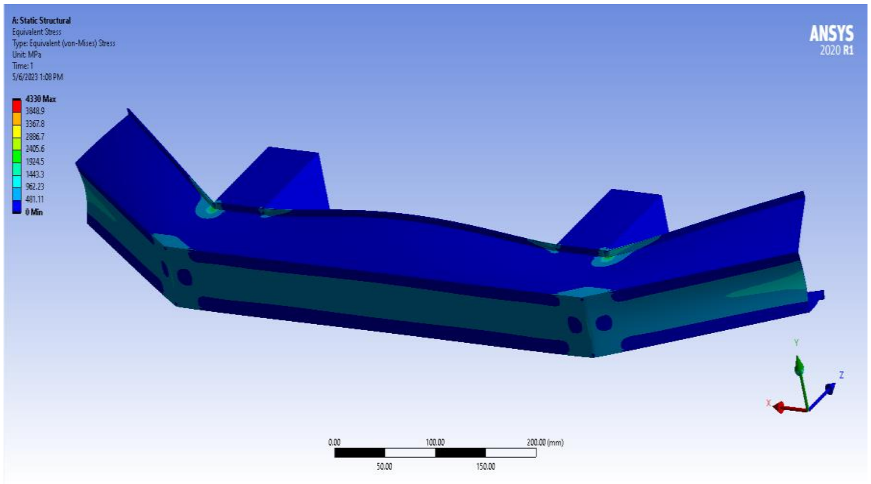


Figure 4.3.7 (b) Equivalent Von Misses Stress of Carbon fiber with GMT Sandwiched at 25 kmph

4.3.8 Carbon Fiber with SMC Sandwiched

Table 4.3.8 (a) Impact Results of Carbon Fiber with SMC Sandwich Model

Impact Speed (kmph)	Max Von Misses Stress Observed (MPa)	Max Von Misses Stress Observed at Impact region (MPa)	Average Von Misses Stress Observed at Impact Region (MPa)	Maximum Displacement (mm)	Average Von Misses Stress Observed at Middle layer (MPa)
10	1403.4	365.65	181.73	5.4877	20.004
15	2108.7	549.42	273.07	8.246	30.34
20	2814	733.18	364.41	11.004	40.651
25	3518.1	916.64	455.59	13.757	50.418
30	4222.2	1100.1	546.76	16.51	60.185

Carbon fiber composite, when used in conjunction with Sheet Molding Compound (SMC), produced the second-best overall performance. Even in a collision travelling at 30 kilometers per hour, the average von misses stress detected in the impact region does not surpass the Sy value of the carbon fiber when carbon fiber and SMC are used. This is the case even when compared to other materials. The average von misses stress in the middle layer has been measured, and the resulting value has not been found to exceed the Sy value of SMC. When compared to the results of the bumper that was only built of carbon fiber composite, the average stress is somewhat higher here 546.76 MPa; nevertheless, this is not a problem because it does not cross the Yield Strength (Sy) limit. Furthermore, the greatest displacement possible in this configuration is 16.51 millimeters, which is a significant increase from the previous value. As a consequence of this, it is an appropriate option for collisions with velocities that are greater than 30 km per hour. *Figure 4.3.8(a) and 4.3.8 (b)* depicts both the total deformation and the von Miss stress that occur as a result of a collision that takes place at a speed of 30 kilometers per hour. This figure is an illustration of what takes place after a collision that takes place at such a pace.

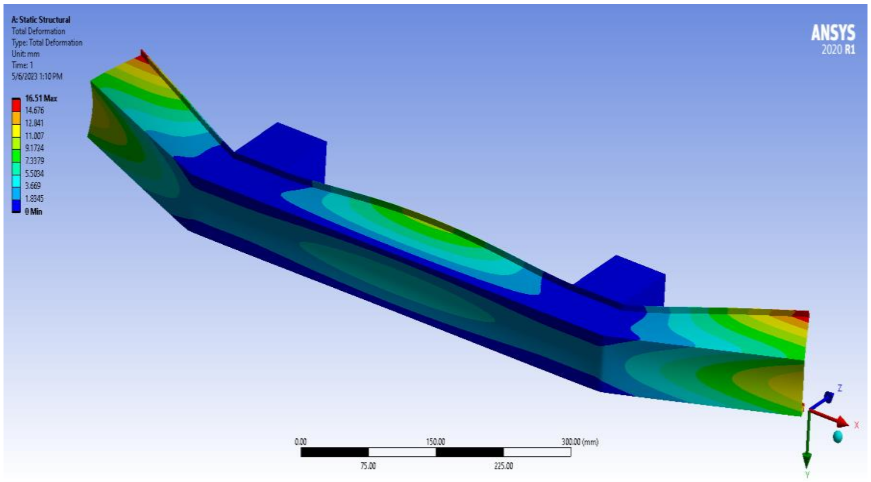


Figure 4.3.8 (a) Total Deformation Carbon Fiber with SMC Sandwiched at 30 kmph

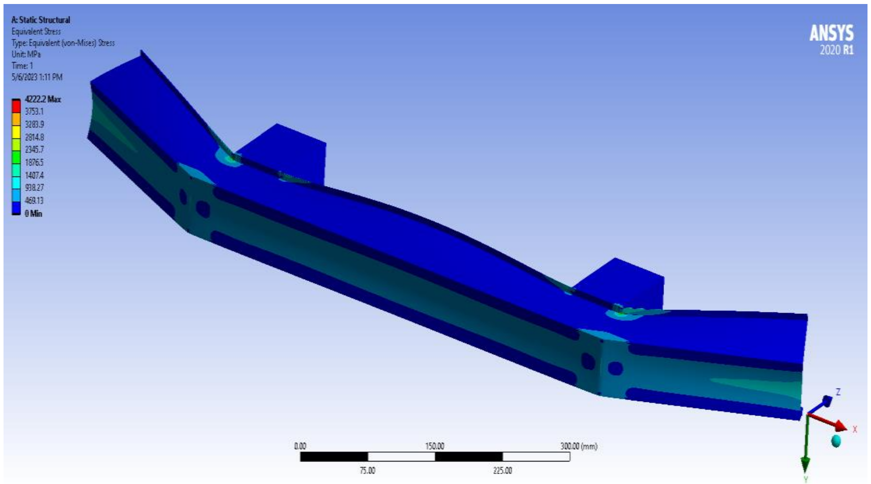


Figure 4.3.8 (b) Equivalent Von Misses Stress of Carbon fiber with SMC Sandwiched at 30 kmph

5 Results of Sandwich Model Analysis

In total, 48 tests of the Equivalent Von Misses Stress and Total Deformation Combination were carried out. At 30 km per hour, it was revealed that when only one type of material was examined, Aluminum 2024 T86 offered better results than Carbon Fiber did. It caused a larger deformation of 15.274 millimeters and lower average stress in the impact region, both of which were greater than those produced by carbon fiber. Based on the average Von Misses stress at the impact location and the maximum total displacements, our sandwich model analysis has shown that different compositions of material are producing better outcomes at particular speeds that has been taken into consideration for the analysis. The following figures not only provide a comprehensive analysis of the performance of various material compositions at a particular speed but also enable us to choose the material that delivers the optimal level of performance at that speed.

- **For Impact at 10 kmph**

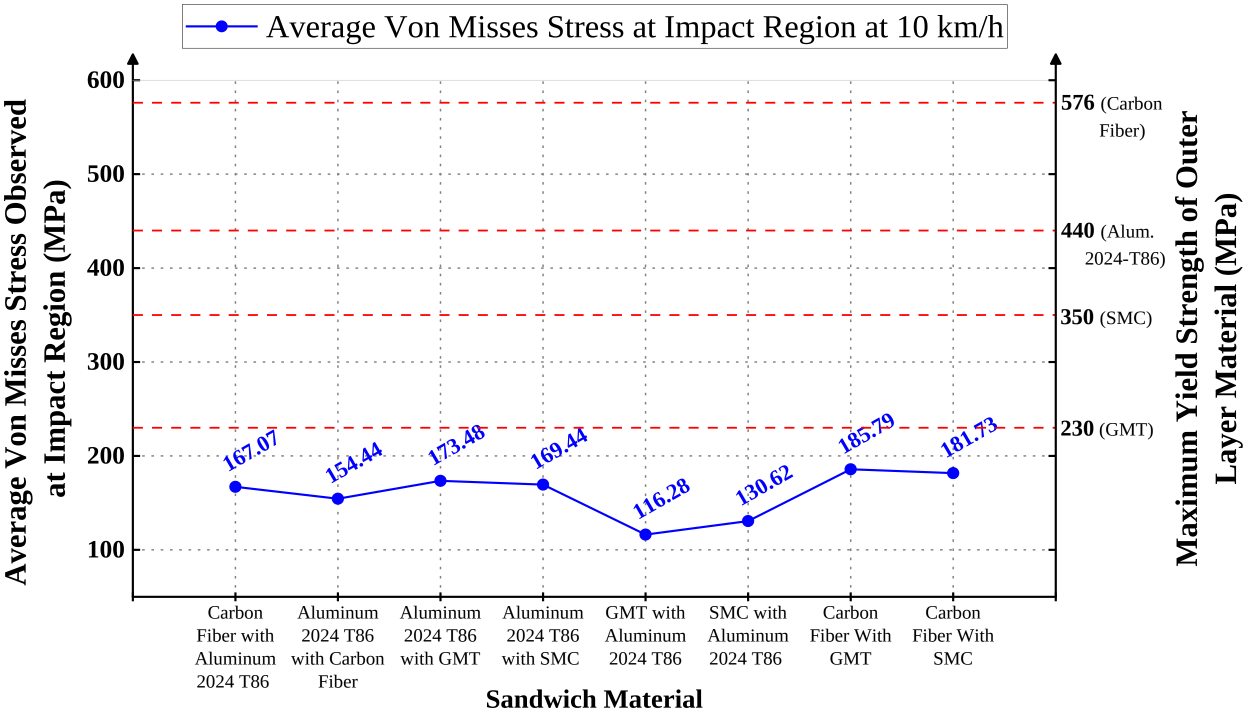


Figure 5.1 (a) Total Stress Curve for Sandwich Model at 10 kmph

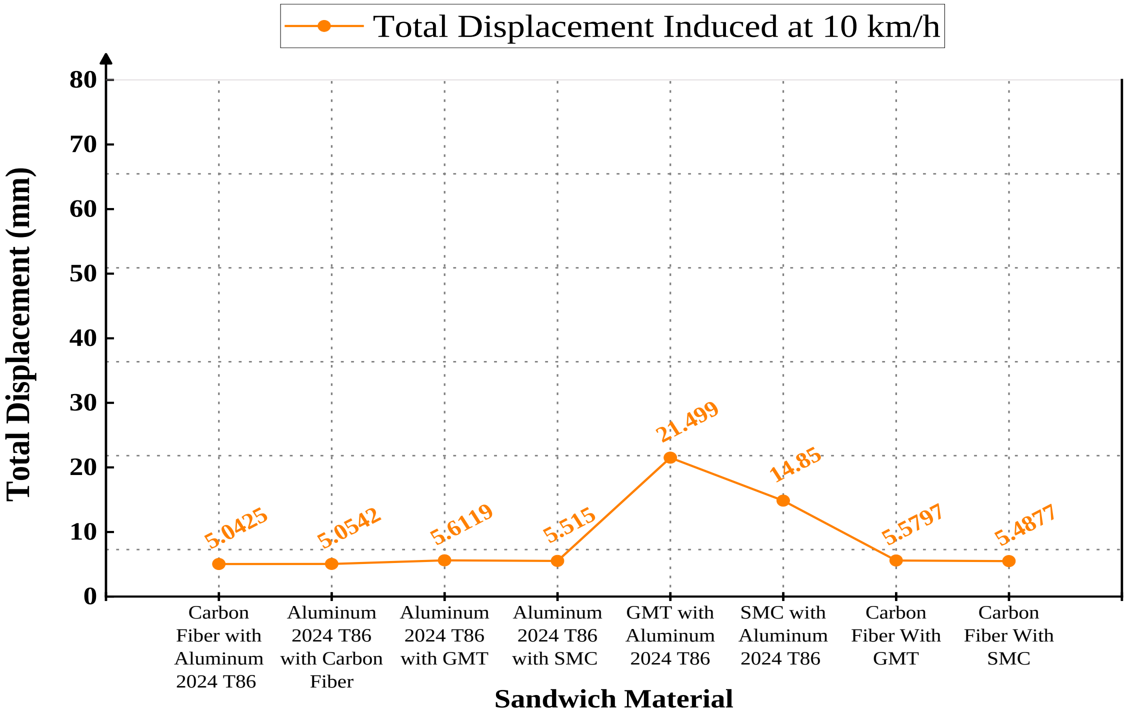


Figure 5.1 (b) Total Displacement Curve for Sandwich Material at 10 kmph

As we observe *Figure 5.1(a)*, we can see that an impact at 10 kilometers per hour causes each material combination to give us the acceptable amount of Von Misses stress at the impact region. This stress stands below the maximum yield strength of the materials. The sandwich model of the GMT with Aluminum 2024-T86 produces a maximum displacement of approximately 21.499 millimeters, as shown in *Figure 5.1(b)*. Next, we will move on to the discussion of this figure. Because of this, we are able to consider this particular combine of materials to have the best performance for this speed.

- **For Impact at 15 kmph**

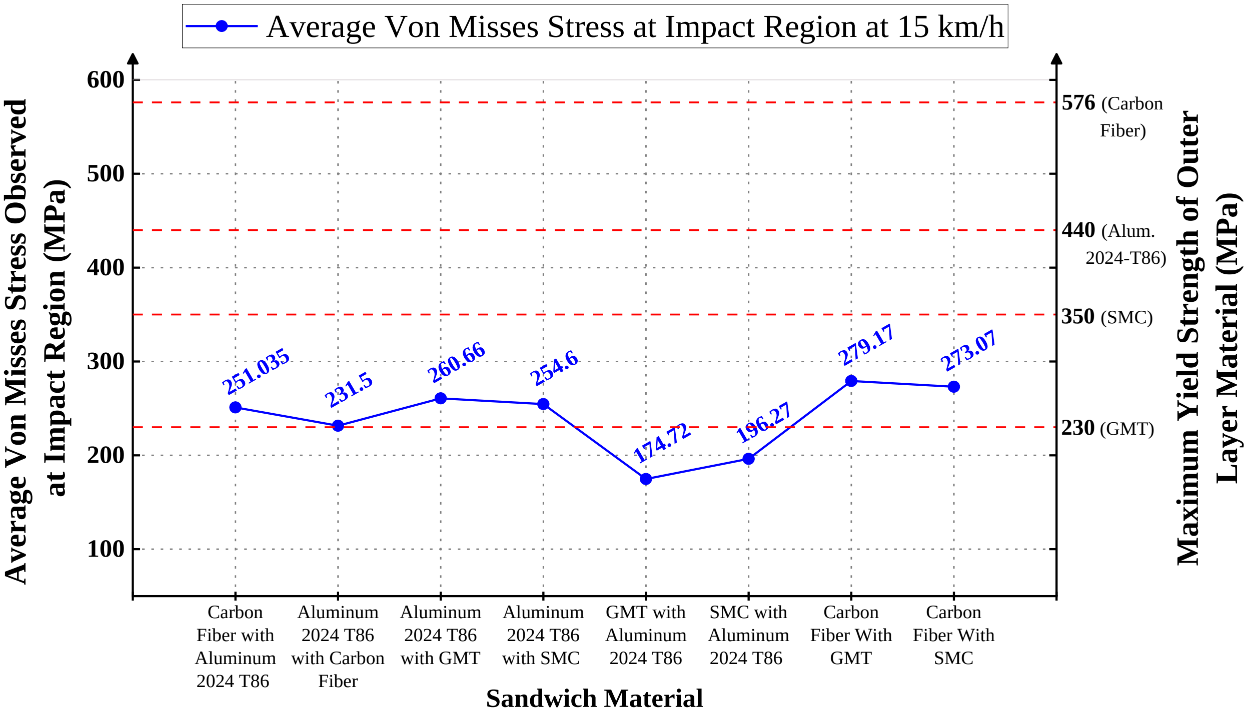


Figure 5.1 (c) Total Stress Curve for Sandwich Model at 15 kmph

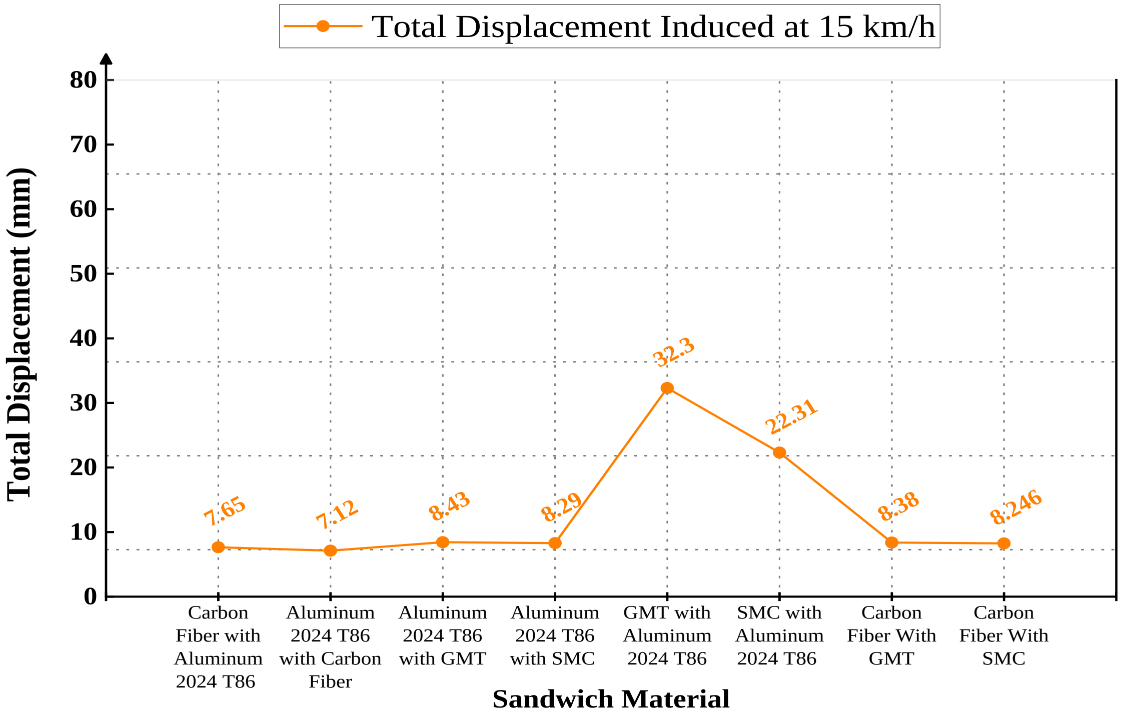


Figure 5.1 (d) Total Displacement Curve for Sandwich Material at 15 kmph

As we observe *Figure 5.1(c)*, we can see that an impact at 15 kilometers per hour causes each material combination to give us the acceptable amount of Von Misses stress at the impact region. This stress stands below the maximum yield strength of the materials. The sandwich model of the GMT with Aluminum 2024-T86 produces a maximum displacement of approximately 32.3 millimeters, as shown in *Figure 5.1(d)*. Next, we will move on to the discussion of this figure. Because of this, we are able to consider this particular combine of materials to have the best performance for this speed.

- **For Impact at 20 kmph**

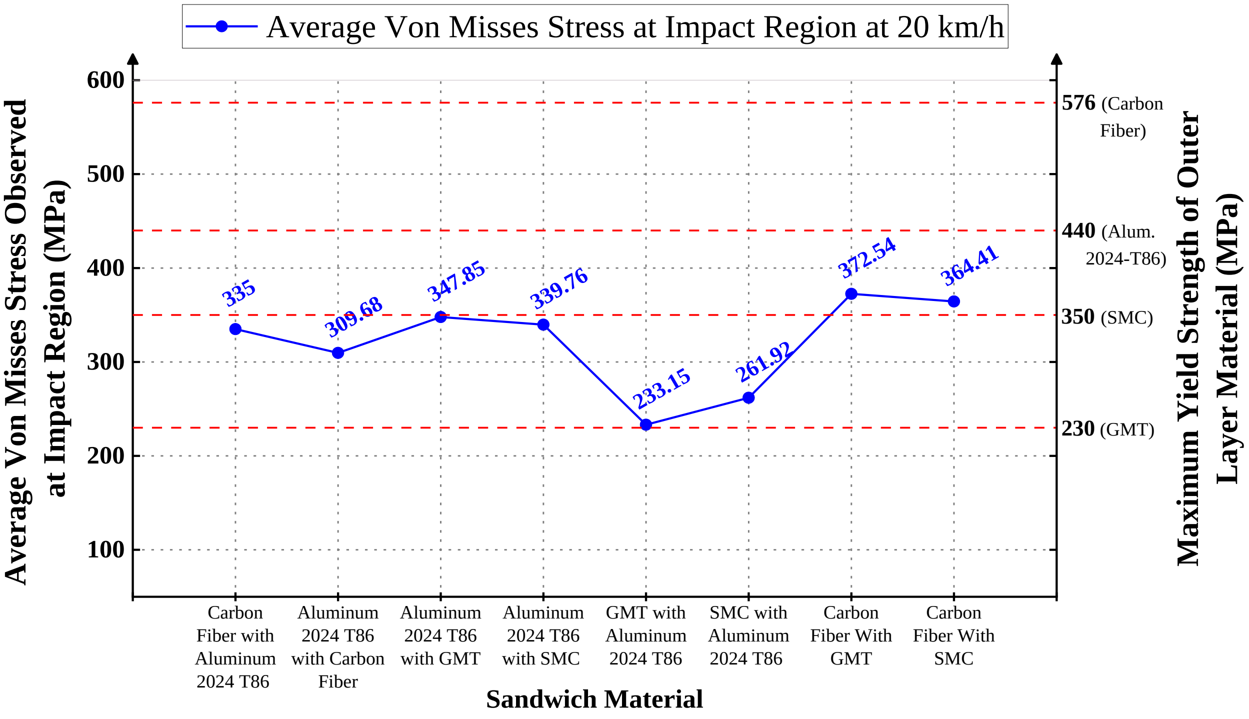


Figure 5.1 (e) Total Stress Curve for Sandwich Model at 20 kmph

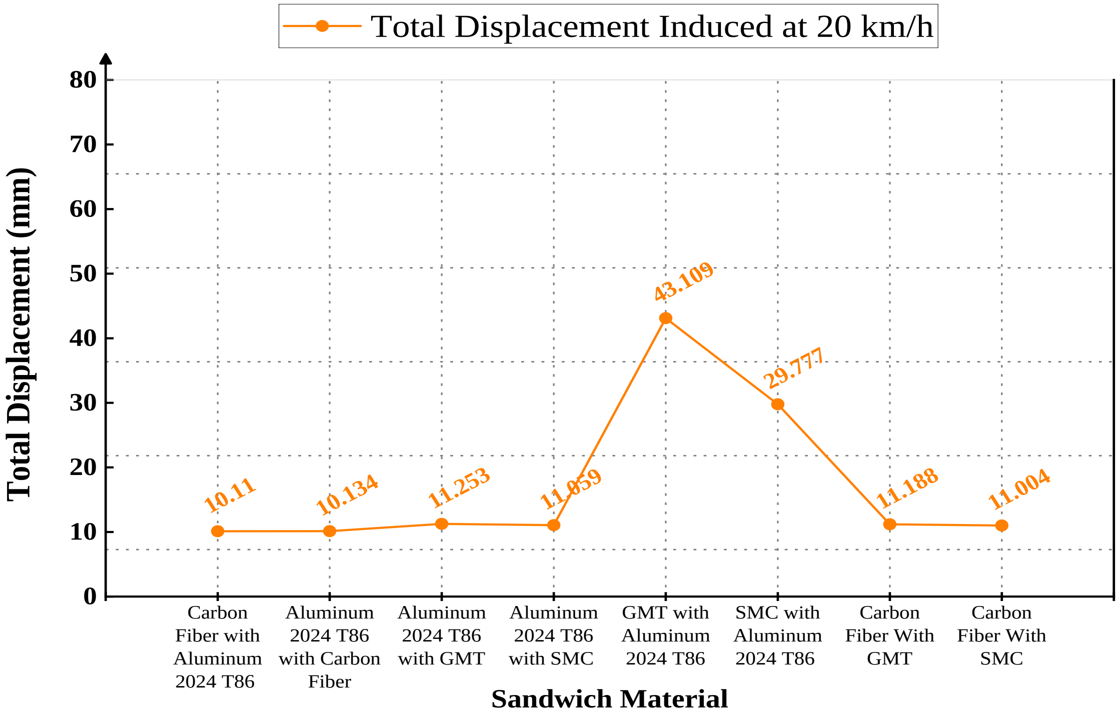


Figure 5.1 (f)   Total Displacement Curve for Sandwich Material at 20 kmph

As we observe *Figure 5.1(e)*, we can see that an impact at 20 kilometers per hour causes each material combination except GMT with Aluminum 2024-T86 is to give us the acceptable amount of Von Misses stress at the impact region. This stress stands below the maximum yield strength of the materials. As GMT with Aluminum 2024-T86 crosses the maximum Yield Strength Limit of GMT for this speed, so there will be plastic deformation on GMT layer of Bumper. Hence, we cannot choose this combination although it is giving us the maximum displacements of 43.109 millimeters. Following that sandwich model of the SMC with Aluminum 2024-T86 produces a second highest displacement of approximately 29.777 millimeters, as shown in *Figure 5.1(f)*. Next, we will move on to the discussion of this figure. Because of this, we are able to consider this particular combine of materials to have the best performance for this speed.

- **For Impact at 25 kmph**

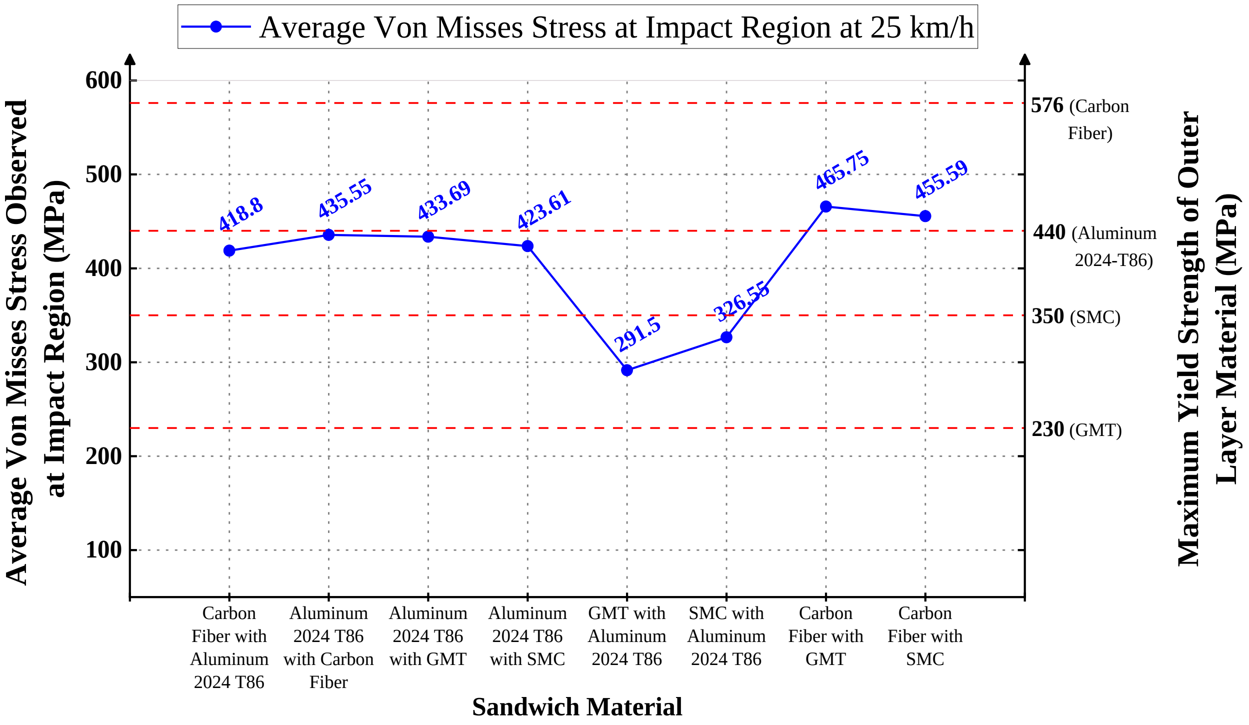


Figure 5.1 (g) Total Stress Curve for Sandwich Model at 25 kmph

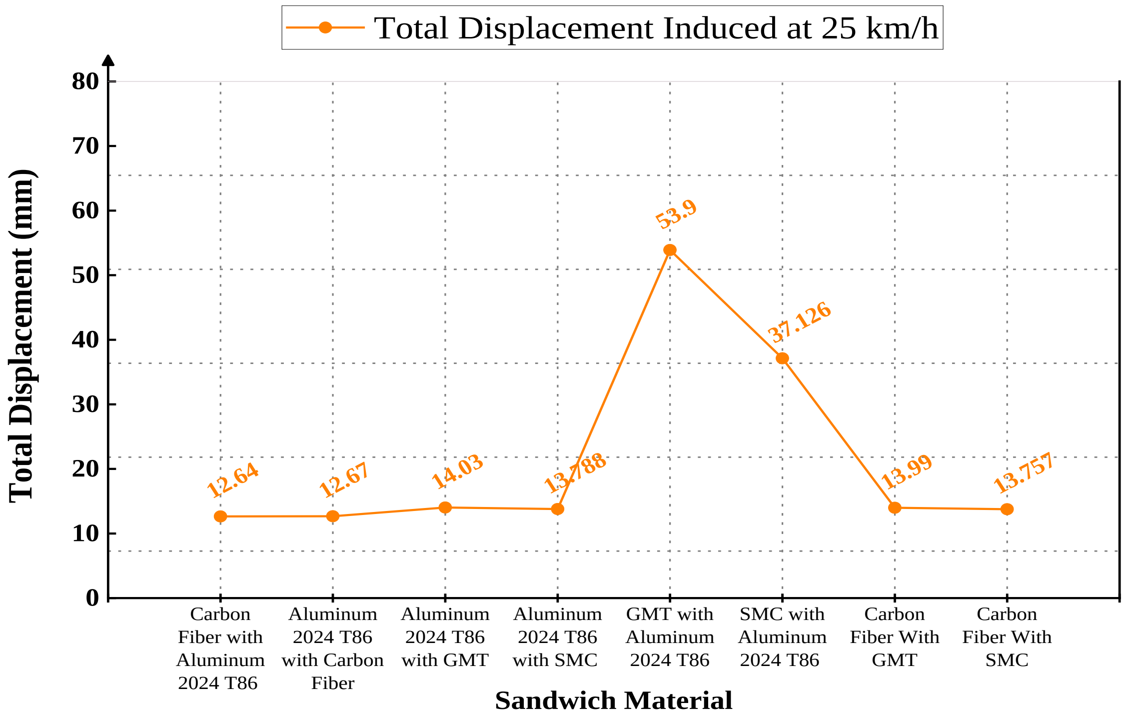


Figure 5.1 (h) Total Displacement Curve for Sandwich Material at 25 kmph

As we observe *Figure 5.1(g)*, we can see that an impact at 25 kilometers per hour causes each material combination except GMT with Aluminum 2024-T86 is to give us the acceptable amount of Von Misses stress at the impact region. This stress stands below the maximum yield strength of the materials. As GMT with Aluminum 2024-T86 crosses the maximum Yield Strength Limit of GMT for this speed, so there will be plastic deformation on GMT layer of Bumper. Hence, we cannot choose this combination although it is giving us the maximum displacements of 53.9 millimeters. Following that sandwich model of the SMC with Aluminum 2024-T86 produces a second highest displacement of approximately 37.126 millimeters, as shown in *Figure 5.1(h).* Next, we will move on to the discussion of this figure. Because of this, we are able to consider this particular combine of materials to have the best performance for this speed.

- **For Impact at 30 kmph**

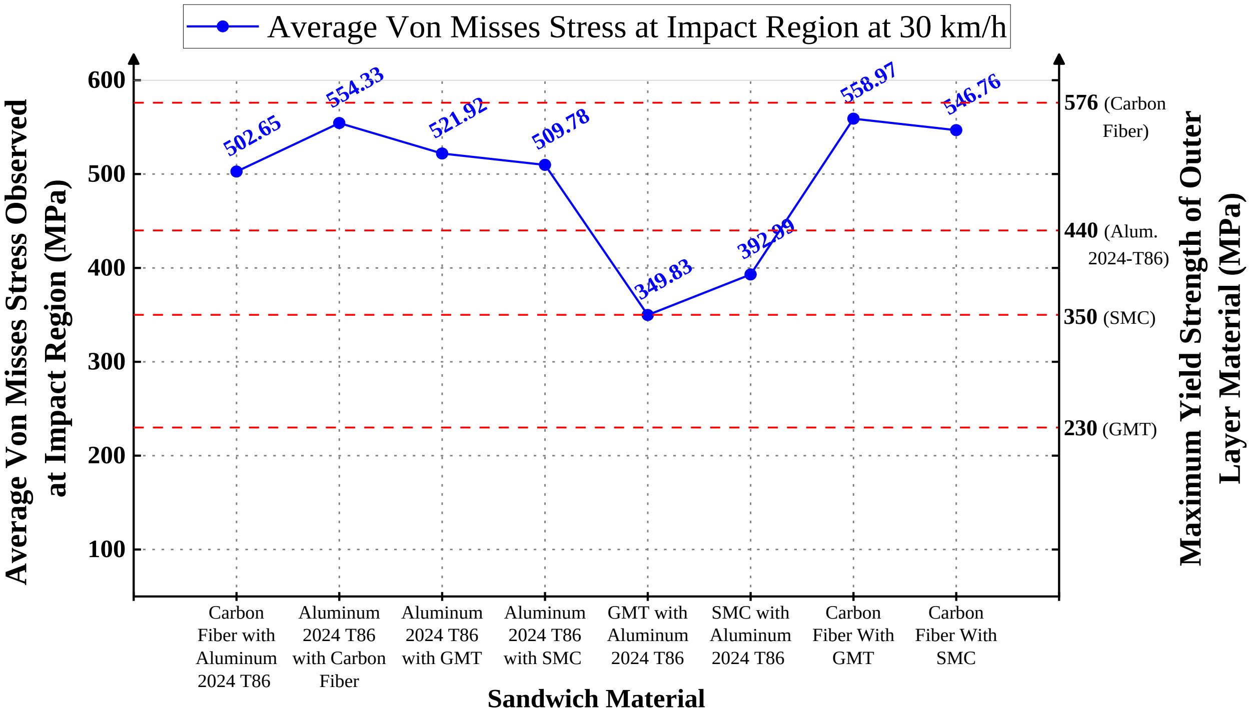


Figure 5.1 (i) Total Stress Curve for Sandwich Model at 30 kmph

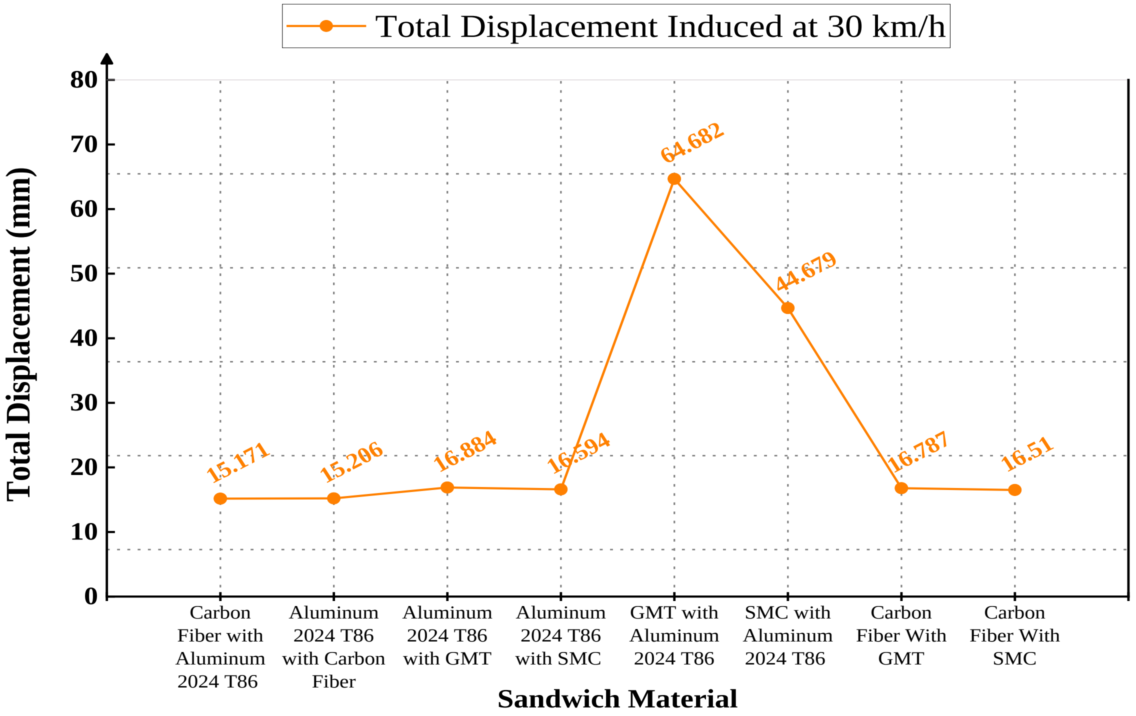


Figure 5.1 (j)   Total Displacement Curve for Sandwich Material at 30 kmph

As we observe *Figure 5.1(i)*, we can see that an impact at 30 kilometers per hour causes the combination of Carbon Fiber with Aluminum 2024-T86, Carbon Fiber with GMT and Carbon Fiber with SMC to give us the acceptable amount of Von Misses stress at the impact region. This stress stands below the maximum yield strength of the materials. Other than that rest of the material combinations has crossed the respective maximum yield strength limit of outer layer material at this speed. Hence, we cannot choose any of those combinations although they are giving us a fine amount of displacements. Following that among the sandwich model that are having Von Misses stress under the maximum limit, Carbon Fiver with GMT produces the highest displacement of approximately 16.79 millimeters, as shown in *Figure 5.1(j)*. Next, we will move on to the discussion of this figure. Because of this, we are able to consider this particular combine of materials to have the best performance for this speed.

Following on the above results comparison among material combinations for particular speeds, we have been able to select the best performing material for certain speeds. From the following *Figure 5.1(k)* and *Figure 5.1(l)* we get an idea about the material combination characteristics based on changes of Von Misses stress and Total Deformation at varying impact speeds.

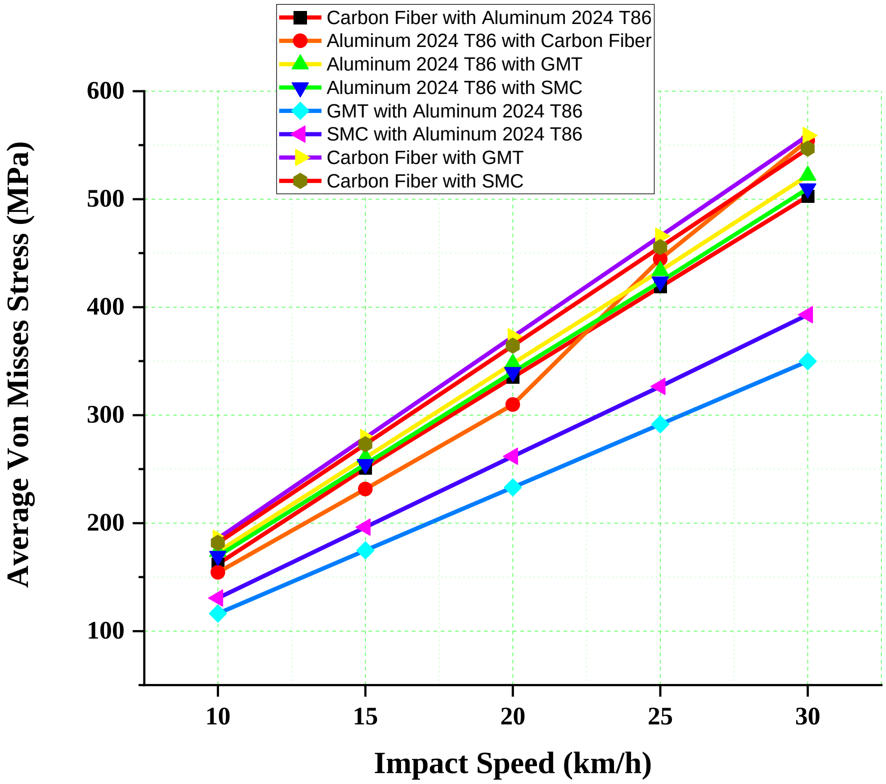


Figure 5.1 (k) *Combine Stress Curve for Sandwich Material*

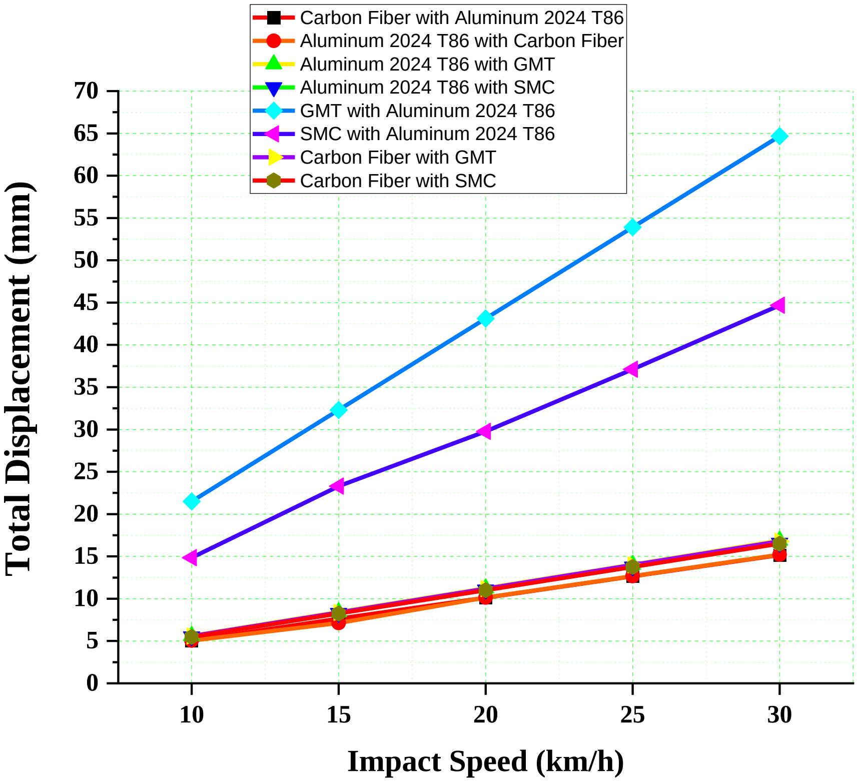


Figure 5.1 (l) *Combine Deformation Curve for Sandwich Material*

5.1 Conclusion

This study focused on improving the impact resistance of vehicle bumpers by making modifications to existing designs. The upgraded bumpers shown better resistance to damage and energy absorption capacities as a result of the introduction of a three-layer design and the incorporation of a spring-supported system. A comprehensive finite element method (FEM) and structural analysis were carried out using SOLIDWORKS and ANSYS. This allowed for the examination of a variety of material combinations, with particular attention paid to the average von Mises stress in the region of impact and the values of displacement. The research showed that the proposed multi-layer bumper design, when optimized with adequate material selections, efficiently alleviated excessive stress during collisions while retaining structural integrity. This was accomplished without compromising the integrity of the bumper's structure. It was discovered that Aluminum 2024-T86 may have been used as an alternative to Carbon Fiber in a single material combination for the bumper. The three-layer combination not only provided us with better outcomes, but it also provided us with better results when using Carbon fiber with GMT as the first viable alternative and using SMC with aluminum 2024-T86 as a second viable option. These combinations can be tried out for maximum efficiency in mass production. After that, a feasibility analysis can also be done, which is then followed by an experimental analysis in the lab. This research presents an innovative strategy for the design of bumpers as well as material optimization, both of which contribute to the progress of automobile safety. The findings have important practical significance for the automotive industry, as they provide direction for additional investigation and refinement in bumper modifications to improve overall vehicle crashworthiness and occupant safety.

5.2 Future Scopes

In order to improve passenger safety, we have investigated numerous potential avenues for further study. Mass optimization of the most promising findings so far is one possible direction. The bumper's performance can be improved while its weight is decreased by fine-tuning the design and materials. The vehicle's fuel economy and handling would both benefit from this. Cost analysis is another crucial factor. It would be possible to conduct a feasibility analysis for practical applications if a thorough examination of the chosen materials and their costs were conducted. This analysis would shed light on the financial feasibility and potential obstacles of rolling out the improved bumper design more broadly. The thesis also advises researching how and why bumpers for automated guided vehicles (AGVs) can be modified for industrial use. The use of AGVs is growing rapidly across industries, making it all the more important to improve their safety features. Putting into practice the results of this study on AGV bumpers would help make factories and warehouses safer places to work.

In conclusion, the paper's potential future directions include AGV bumper design application, cost analysis, and mass optimization. Additional progress in passenger safety and industry-specific applications could be made in these areas.

References

[1] J. L. J. W. D. Cochran, "Manufacturing System Design of Automotive Bumper Manufacturing," *Semantic Scholar,* 2001.

[2] A. A. A. Hanan H. Mohamed, "TiO2/carbon dots decorated reduced graphene oxide composites from waste car bumper and TiO2 nanoparticles for photocatalytic applications," *Arabian Journal of Chemistry,* pp. 3082-3091, January 2020.

[3] S. S. b. A. A. c. N. A. O. a. A. O. a. W. W. A. a. M.M. Davoodi a b, "Development process of new bumper beam for passenger car: A review," *ELSEVIER,* pp. 304-313, September 2012.

[4] P. S. B. N. Mr. Nitin S. Motgi, "Impact Analysis of Front Bumper," *International Journal of Engineering Trends and Technology (IJETT),* Dec 2013.

[5] *. S. C. A. Obumneme Onyedum1, "Comparative Mechanical Analysis of Okra Fiber and," *American Journal of Engineering, Technology and Society,* pp. 193-199, January 10, 2016.

[6] A. a. A. E. Olorunnishola, "A Comparative Analysis of a Blend of Natural Jute and Glass," *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE),* pp. 67-71, May. - June. 2018.

[7] P. K. Uddandapu, "Impact Analysis on Car Bumper by varying speeds using Materials," *International Journal of Modern Engineering Research ,* pp. 391-395, Jan-Feb. 2013.

[8] N. S. M. &. S. R. Chawla, "Natural fiber-reinforced composites for automotive applications," in *Handbook of natural fiber reinforced polymer composites (pp. 517-536)*, Woodhead Publishing., pp. 517-536).

[9] M. A. A.-S. H. &. A.-E. A. El-Sayed, "Hybrid composite bumper beam for automobiles," *International Journal of Engineering Science and Computing,* pp. 19945-19949, (2019).

[10] S. S. &. N. S. N. Godara, ". Analysis of frontal bumper beam of automobile vehicle by using carbon fiber composite material.," *International Journal of Mechanical and Production Engineering Research and Development,* pp. 845-852., 2021.

[11] A. B. Joshi, "A review of finite element method and its applications," *nternational Journal of Emerging Technology and Advanced Engineering,* pp. 282-287., 2016.

[12] S. S. R. C. &. S. S. K. Bhardawaj, "Analysis of frontal car crash characteristics using ANSYS," *International Journal of Engineering and Applied Sciences,* pp. 78-84., 2017.

[13] B. Y. J. C. Z. &. L. Z. Gao, "Simulation study on passenger car frontal impact with rigid barrier," in *Applied Mechanics and Materials*, 2013, pp. 398-401.

[14] Y. H. J. &. Z. K. Chang, "Analysis of the front-end structures of a passenger car under NCAP frontal impact using finite element simulation," *International Journal of Crashworthiness,* pp. 77-86., 2015.

[15] M. &. H. R. Ghorbel, "Development of a car bumper using finite element analysis.," *Journal of Mechanics Engineering and Automation,* pp. 47-52., 2014.

[16] S. N. S. H. S. &. K. K. Kim, "An investigation of the crashworthiness of a front bumper for pedestrian protection using FE analysis," *International Journal of Automotive Technology,,* pp. 253-258., 2016.

[17] Z. L. G. L. X. &. L. Y. Zhang, " Numerical analysis and design of an automobile bumper with the crash box by finite element method," in *In Proceedings of the International Conference on Mechanic Automation and Control Engineering*, 2011.

[18] A. G. M. D. E. &. K. V. Mamalis, "Crashworthiness design optimization of automotive bumper systems.," *Journal of Materials Processing Technology,* pp. 460-465., 2003.

[19] M. A. R. N. C. U. S. &. J. S. P. Basith, " Crash analysis of a passenger car bumper assembly to improve design for impact test," *Journal of Mechanical Engineering and Sciences,* pp. 5387-5397, 2019.

[20] Y. C. X. &. C. Y. Jiang, "Analysis of automotive bumper beam based on different materials using FEA," in *Materials Science Forum,*, 2015, pp. 105-110..

[21] J. A. M. &. K. M. S. Marzbanrad, " Design and analysis of an automotive bumper beam in low-speed frontal crashes," *Journal of Mechanical Science and Technology, ,* pp. 167-176, 2018.

[22] M. C. L. C. Y. &. L. H. J. Shih, "The design of a multi-material bumper beam using numerical and experimental analyses," in *Composite Structures*, 2018, pp. 30-41.

[23] A. K. M. K. &. K. H. H. AlSahlani, "Design and analysis of coil spring in vehicles using finite elements method," *Journal of King Saud University - Engineering Sciences,* pp. 375-382., 2018.

[24] H. J. J. J. H. &. L. C. H. Lee, "Design optimization of coil spring for automotive suspension system using Taguchi method and finite element analysis.," *International Journal of Precision Engineering and Manufacturing,* pp. 817-823., 2016.

[25] A. M. C. S. S. &. P. P. R. Patel, " Finite element analysis and optimization of coil spring of a passenger car," *International Journal of Innovative Research in Science, Engineering and Technology,* pp. 4524-4530, 2017.

[26] R. S. &. J. S. S. Kadam, "A comparative study of helical and conical coil springs in a passenger car," *Journal of Mechanical Science and Technology,* pp. 4969-4977, 2018.

[27] S. N. N. S.S. Godara, "Analysis of frontal bumper beam of automobile vehicle by using carbon fiber composite material," *Materials Today: Proceedings,* 2020.

[28] Y. J. ·. Y. Bai, "Experimental study on the mechanical properties of," *International Journal of Fracture ,* p. 25–48 , 2016.

[29] J. S. a. D. LEGE, "Advances in aluminium alloy products for structural applications in transportation," *Journal de Physique Archives,* vol. Volume 03, pp. C7-179 - C7-190, Novembre 1993.

[30] Z. A. 1. A. M. 2. A. F. J. 2. S. 3. P. 4. a. S. S. R. K. 3. Hossein Mohammadi 1, "Lightweight Glass Fiber-Reinforced Polymer Composite for Automotive Bumper Applications: A Review," *Polymers,* 2022.

[31] A. A. M. M. V. P. a. F. A. H Ahmad1, "A review of carbon fiber materials in automotive industry," 2020.

[32] A. S. John Alen1, "A Review on the Composite Materials used for Automotive Bumper in Passenger Vehicles," *International Journal of Engineering and Management Research,* pp. 98-101, 2014.

[33] T. N. H. T. K. G. K. YAMAZAKI*3, "Development of Ultra-High-Strength Cold-Rolled Steel," NIPPON STEEL TECHNICAL REPORT, 2003.

[34] T. Schlabach, "Copper Alloy Spring Materials and Spring Properties," *IEEE Transactions on Parts, Hybrids, and Packagin,* pp. 237 - 242, December 1973.