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Design Optimisation And Impact Analysis Of Car Body Structure Using Ansys

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***Abstract*— The performance of the vehicle can be optimized by various means, one such method is by reducing the weight to increase its performance. With the recent development in the field of composites it is evident that composite materials can be the best alternative material to reduce the weight but we must also be careful to maintain its strength. The research and development over Composite materials have benefited greatly as they have higher strength and lower weight, more recyclable. In this thesis, a car body structure is designed using CATIA V5 software and a comparative Computer-aided engineering analysis for its crash worthiness is done using ANSYS workbench. The main advantage of CAE is the car body structure can be tested in various fields for optimum performance and durability of the component without actual manufacturing of the original component. The car body structure is implemented with four different materials such as Structural Steel, Magnesium Alloy, Titanium Alloy, Carbon Fiber Reinforced Polymer Materials and analyzed of its crash worthiness by impact analysis. The weight of the car body is being optimized by optimization technique for mass reduction without compromising the stiffness and durability of the structure. The CAE analysis and weight reductions are done in ANSYS workbench software. The results will be compared and discussed with the equivalent stress and total deformation value to find out the better materials that reduces weight and withstands stiffness and durability.**

***Keywords*— Impact Analysis, Car body structure, CATIA V5, ANSYS workbench Material comparison.**

1. INTRODUCTION

A car is a widely used mode of transportation designed for the efficient and safe movement of people and goods on roads. With advancements in technology, modern cars are equipped with features that enhance comfort, performance, and most importantly, safety. As traffic density increases and road safety becomes a growing concern, understanding the effects of collisions has become crucial.

Impact analysis, also known as crash analysis, is the study of how a vehicle behaves during a collision and the forces exerted on its structure and occupants. It involves simulations, crash tests, and analytical techniques to assess vehicle safety and improve design. This analysis plays a key role in reducing fatalities and injuries, shaping safety regulations, and guiding the development of safer vehicles.

1.1 Importance of Crashworthiness Analysis

- Passenger Safety: Prevents severe injuries by dissipating crash energy.
- Force Transmission Reduction: Minimizes the transfer of high impact energy to passengers.
- Optimized Structure: Reduces weight while ensuring high strength and impact resistance.
- Simulation-Based Testing: Eliminates the need for expensive physical crash tests and facilitates improved design iterations.

2. LITERATURE REVIEW

2.1 Introduction

The study of car crash analysis is crucial for enhancing vehicle safety, minimizing accident severity, and improving overall transportation systems. This research draws from various books, journal publications, and technical reports to provide a comprehensive understanding of crash dynamics, material behavior, and impact resistance. The primary objective of this literature review is to present relevant background information on the factors influencing car crashes, with a special focus on material properties, structural integrity, and crashworthiness which are discussed in the sections 2.1.1Studies on Automotive Structural Materials, 2.1.2 Studies on Lightweight Alloys and Hybrid Materials ,2.1.3. Studies on Crashworthiness of Electric Vehicle Body Structures, 2.1.4. Studies on Finite Element Analysis (FEA) for Crash Testing, 2.1.5. Studies on Energy Absorption and Impact Resistance, 2.1.6. Studies on Optimization Techniques in Vehicle Design.

2.1.1 Studies on Automotive Structural Materials

Andrew Hickey and Shoaping Xiao (2017), these studies focus on high strength steel and aluminum for impact performance. Sai Kiran (2017); these studies focus on trade-offs in strength, ductility, and corrosion resistance. J. Santhakumar (2020); these studies highlight the shift from steel to high-performance materials. V. Sivarama Krishna (2024), these studies focus on comparing materials based on performance, crash behavior, and cost.

2.1.2 Studies on Lightweight Alloys and Hybrid Materials:

Andrew Hickey and Shaoping Xiao (2017), these studies focus on lightweight alloys and hybrids for reducing weight while maintaining crash resistance. Sai Kiran (2017); these studies highlight aluminum, magnesium, and CFRP for strength and efficiency. J. Santhakumar (2020); these studies focus on aluminum alloys, composites, and joining methods for safety and cost. P. Sandeep Raj (2024), these studies focus on AA7075, AA6061, and hybrids for fuel efficiency, corrosion resistance, and crashworthiness.

2.1.3 Studies on Crashworthiness of Electric Vehicle Body Structures:

Andrew Hickey and Shaoping Xiao (2017), these studies focus on battery protection and cabin integrity in EV crashes.Sai Kiran et al. (2017); these studies focus on reinforced enclosures and advanced crumple zones. Santhakumar (2020); these studies focus on multi-material design and weight distribution. P. Sandeepraj (2024), these studies focus on lightweight composites and reinforced frames for EV safety.

2.1.4 Studies on Finite Element Analysis (FEA) for Crash Testing:

Andrew Hickey and Shaoping Xiao (2017), these studies focus on FEA for simulating crashes, predicting deformation, and validating models. Sai Kiran (2017); these studies focus on accurate crash models to reduce testing and improve design. J. Santhakumar (2020); these studies focus on behavior prediction and model validation. P. Sandeep Raj (2024), these studies focus on stress analysis, energy absorption, and mesh optimization.

2.1.5 Studies on Energy Absorption and Impact Resistance:

Andrew Hickey and Shaoping Xiao (2017), these studies focus on crumple zones and bumpers to reduce crash forces. Sai Kiran (2017); these studies focus on foam inserts and improved materials for better impact resistance. J. Santhakumar (2020); these studies focus on honeycomb structures and layered composites for energy absorption. P. Sandeep Raj (2024), these studies focus on CFRP and aluminum honeycomb to enhance passive safety.

2.1.6 Studies on Optimization Techniques in Vehicle Design:

Andrew Hickey and Shaoping Xiao (2017), these studies focus on optimizing crashworthiness and reducing weight. Sai Kiran et al. (2017); these studies focus on balancing cost, strength, and safety using CAD tools. Santhakumar (2020); these studies focus on using AI to enhance strength and meet crash standards. P. Sandeepraj (2024), these studies focus on AI and multi-objective optimization for safer, cost-effective vehicle design.

3. METHODOLOGY

The methodology adopted in this project involves analyzing and optimizing the crashworthiness of an automotive body structure using Finite Element Analysis (FEA) in ANSYS as shown in Fig.3.1. It integrates advanced materials, dynamic simulations, and optimization techniques to enhance vehicle safety and structural performance. Key crash parameters such as deformation, stress distribution, and failure modes are evaluated under varying impact speeds, angles, and barrier types to simulate real-world conditions. By comparing traditional and advanced materials, the study aims to achieve a balance between safety, weight reduction, and cost-effectiveness, contributing to the development of safer and more efficient vehicle designs.

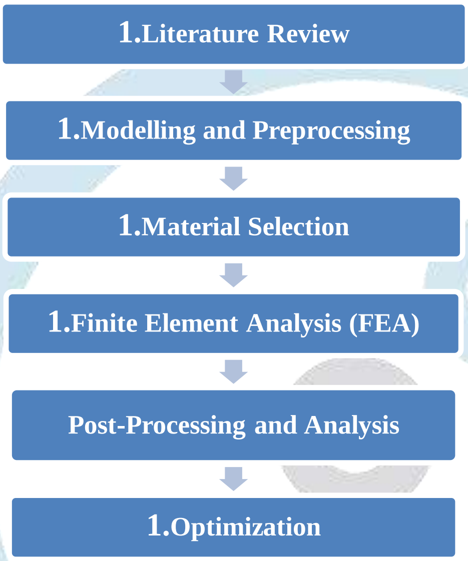

Fig.3.1 Flow Chart of Methodology Adopted

3.1 Problem Definition

Automotive crashes present a major risk to passenger safety, highlighting the need for improved vehicle structures that can effectively absorb impact energy. While traditional materials like steel and aluminum are commonly used, emerging composite materials and high-strength alloys offer potential for better crash performance.This study focuses on comparing the crash behavior of various materials to identify the most suitable option for enhancing vehicle safety.

3.2 Model Specification

The Car model which is used in this present analysis is of Renault Megane E-Tech Electric (2022).

TABLE -3.1 Car body specifications as shown in Fig. 3.2

Car Body Specifications	Values
Length	4,372mm
Width	1,874mm
Height	1,445mm
Wheelbase	2,669mm

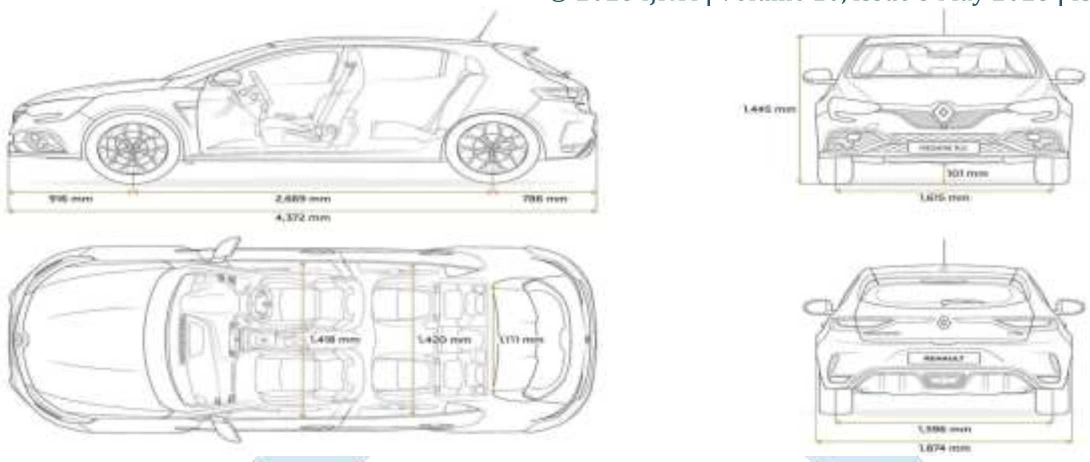

Fig.3.2 Dimensions of Car Body Specifications

4. MODELLING AND ANALYSIS

4.1 Design of Car Body Using CATIA V5

A 3D model of the Car Body with given specification was drawn using CATIA V5 with the dimensions shown in the Fig. 4.1.

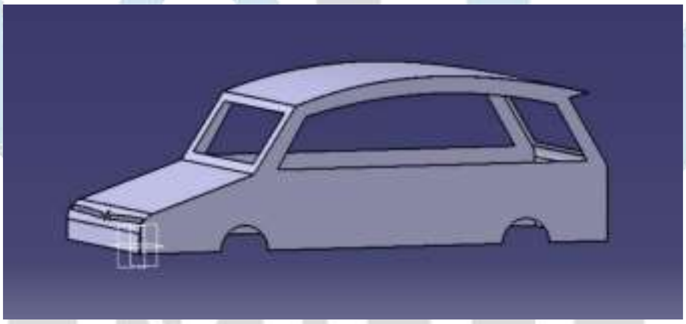

Fig. 4.1 Car Body Model from CATIA V5

4.2 ANSYS Workbench Overview

ANSYS Workbench was used for simulation to evaluate crashworthiness under different impact conditions. The steps followed in ANSYS Workbench include:

- Defining Engineering Data.
- Importing Geometry.
- Generating Mesh.
- Applying boundary conditions and forces.
- Running simulation and analyzing results.

Type of Analysis : Impact Analysis

4.2.1 Engineering Data

Engineering Data in ANSYS is a crucial part of the simulation process. It's where you define the properties of the materials you'll be using in your model. Think of it as giving ANSYS the "ingredients" it needs to understand how your materials will behave under different conditions as shown in below tables 4.1,4.2,4.3,4.4,4.5.

Properties of Materials Used in this Analysis:

a) Steel:

Table 4.1 Properties of Steel

Properties	METRIC	UNIT
Density	7850	kg/m^3
Young's modulus	200	Gpa
Poission's ratio	0.3	No unit
Yield strength	250	Mpa
Ultimate tensile strength	460	Mpa

b) Magnesium alloy:

Table 4.2 Properties of Magnesium alloy

Properties	METRIC	UNIT
Density	1800	kg/m^3
Young's modulus	45	Gpa
Poission's ratio	0.35	No unit
Yield strength	193	Mpa
Ultimate tensile Strength	255	Mpa

c) Titanium alloy:

Table 4.3 Properties of Titanium alloy

Properties	METRIC	UNIT
Density	4620	kg/m^3
Young's modulus	96	Gpa
Poission's ratio	0.36	No unit
Yield strength	930	Mpa
Ultimate tensile Strength	1070	Mpa

d) Carbon fiber reinforced polymer:

Table 4.4 Properties of CFRP

Properties	METRIC	UNIT
Density	1400	kg/m^3
Young's modulus	57	Gpa
Poission's ratio	0.005	No unit
Yield strength	530	Mpa

4.2.2 Import Geometry

Geometry import in ANSYS is a fundamental step in the simulation process. After assigning the materials, the car model is converted into STP file and imported into Ansys Workbench.

4.2.3 Meshing

Meshing is applied by using automatic mesh. Under mesh sizing, mesh was set to fine mesh to achieve accurate and precise results. Rather than using a fine mesh all over the components fine mesh was used at the area of stress concentration as shown in the Fig.4.2.

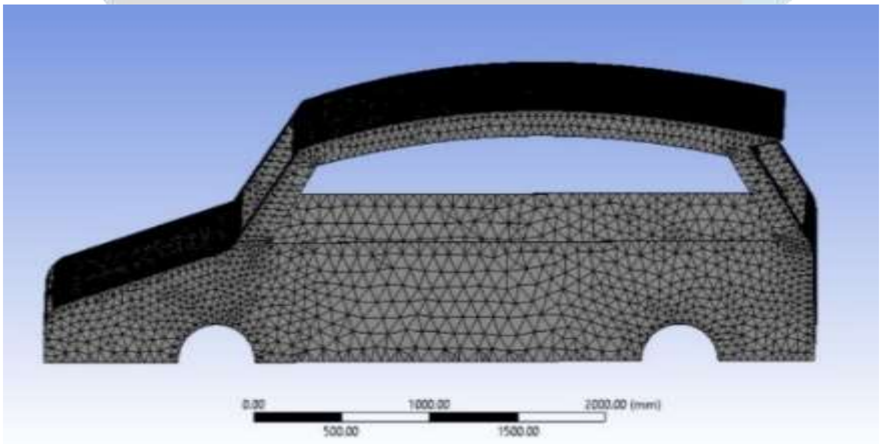

Fig. 4.2 Meshing of car body

4.2.4 Applying Boundary Conditions

In the analysis setting, fixed support is applied to the back wheels of car, so that the back wheels is constrained in all degrees of freedom and it would withstand different types of loads.

4.2.4.1 Case-1 Impact Analysis in Y-Direction for All Materials

In the analysis setting, a force of 14473N is assigned to the car structure in Y-direction and the time is 1 seconds as shown in the Fig. 4.3.

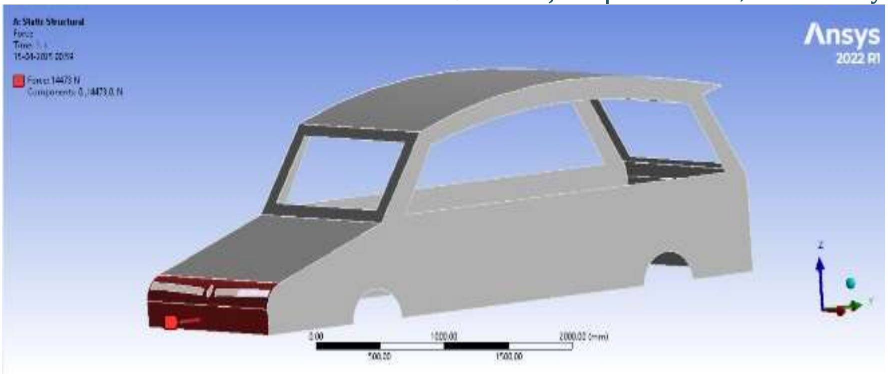

Fig.4.3 Force in Y-Direction

4.2.4.2 Case-2 Impact Analysis in -X-Direction for All Materials

In the analysis setting, a force of 14473N is assigned to the car structure in -X-direction and the time is 1 seconds as shown in the Fig.4.4.

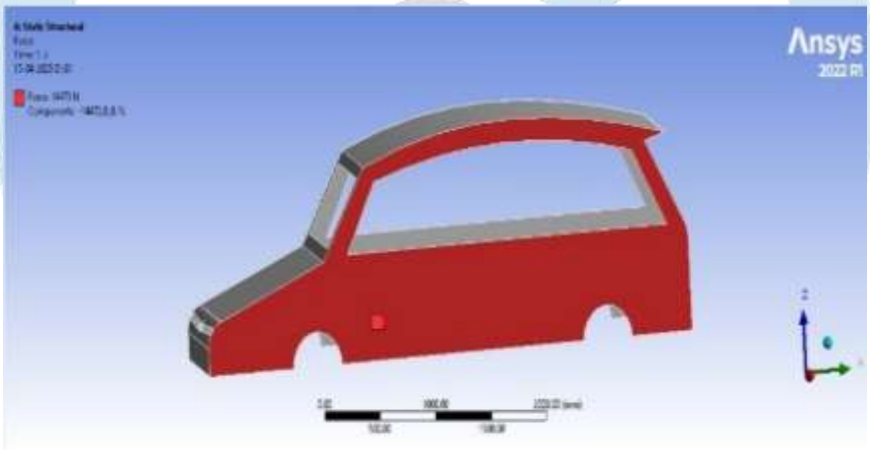

Fig.4.4 Force in -X-Direction

4.2.4.3 Case-3 Impact Analysis in -Y-Direction for All Materials

In the analysis setting, a force of 14473N is assigned to the car structure in -Y-direction and the time is 1 seconds as shown in the Fig.4.5.

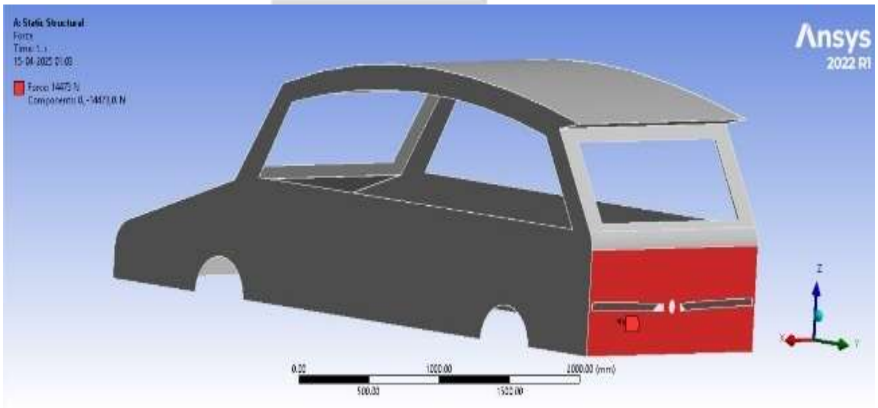

Fig.4.5 Force in -Y-Direction

5. RESULTS AND DISSCUSIONS

After performing impact analysis on various materials for car body applications, the results are summarized in Table 6.1, comparing structural steel, magnesium alloy, titanium alloy, and CFRP based on three key parameters: Equivalent stress, Total deformation, and Safety factor.

- Equivalent Stress: CFRP (2064.7 MPa) and titanium alloy (1633.4 MPa) show higher stress, indicating higher stiffness or heavier loading. Magnesium alloy and steel have lower stress, suggesting more flexibility.

- Total Deformation: Magnesium alloy and CFRP deform most (up to 456.18 mm), meaning they are less rigid. Titanium alloy deforms least (25.73 mm in Y), showing high stiffness.

- Safety Factor: Titanium alloy has the highest safety (up to 2.1). Magnesium alloy has the lowest, especially in Y-direction (0.11), making it less reliable.

Table 5.1- Results for Impact Analysis

Materials	Direction	Equivalent stress (Mpa)	Total deformation (mm)	Safety factor
Structural steel	Y- direction	453.38	142.46	0.55
	-X- direction	1759.5	107.06	0.14
	-Y- direction	927.75	58.01	0.26
Magnesium alloy	Y- direction	439.35	56.54	0.43
	-X- direction	1657.9	421.16	0.11
	-Y- direction	888.45	227.24	0.21
Titanium alloy	Y- direction	435.26	25.73	2.1
	-X- direction	1633.4	191.28	0.5
	-Y- direction	877.29	101.08	1.6
CFRP	Y- direction	458.64	58.28	1.13
	-X- direction	2064.7	456.18	0.25
	-Y- direction	1054.7	249.86	0.50

- **Graphical Representation for Impact Analysis in All Directions:**

For Y-Direction:

The graph represents the variations of equivalent stresses, total deformation and safety factor in Y-direction for different materials i.e., Structural steel, Magnesium alloy, Titanium alloy and CFRP as shown in the Fig.5.1.

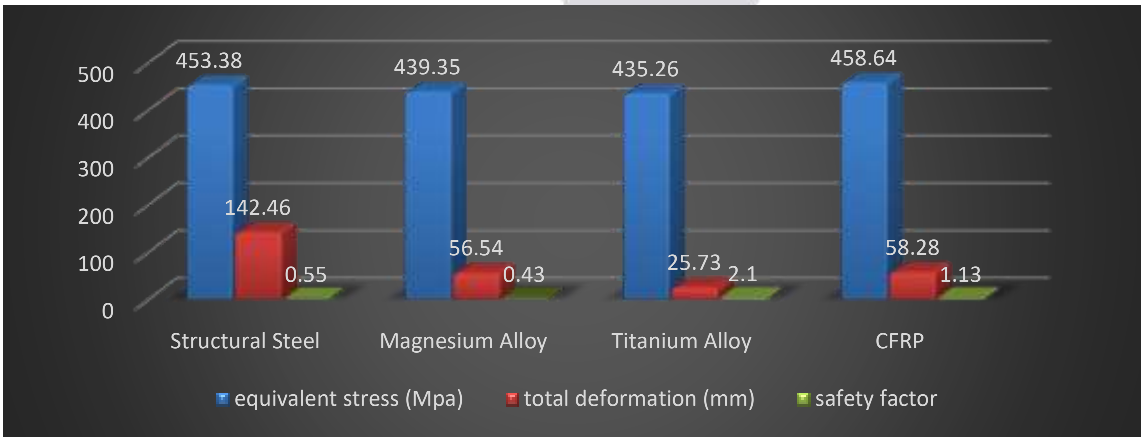

Fig.5.1 Impact Analysis in Y-Direction for All Materials

For -X-Direction

The graph represents the variations of equivalent stresses, total deformation and safety factor in -X-direction for different materials i.e., Structural steel, Magnesium alloy, Titanium alloy and CFRP as shown in the Fig.5.2.

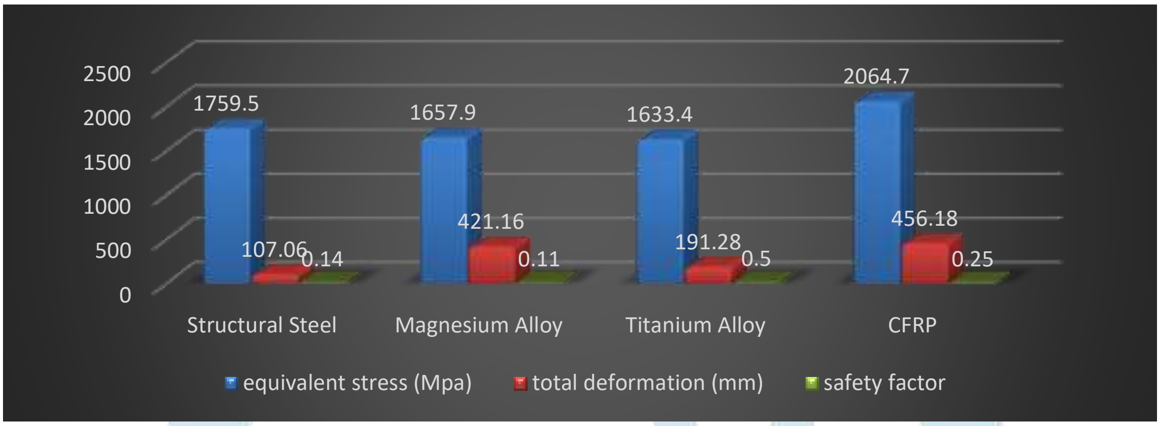

Fig.5.2 Impact Analysis in -X-Direction for All Materials

For -Y-Direction

The graph represents the variations of equivalent stresses, total deformation and safety factor in -Y-direction for different materials i.e., Structural steel, Magnesium alloy, Titanium alloy and CFRP as shown in the Fig.5.3.

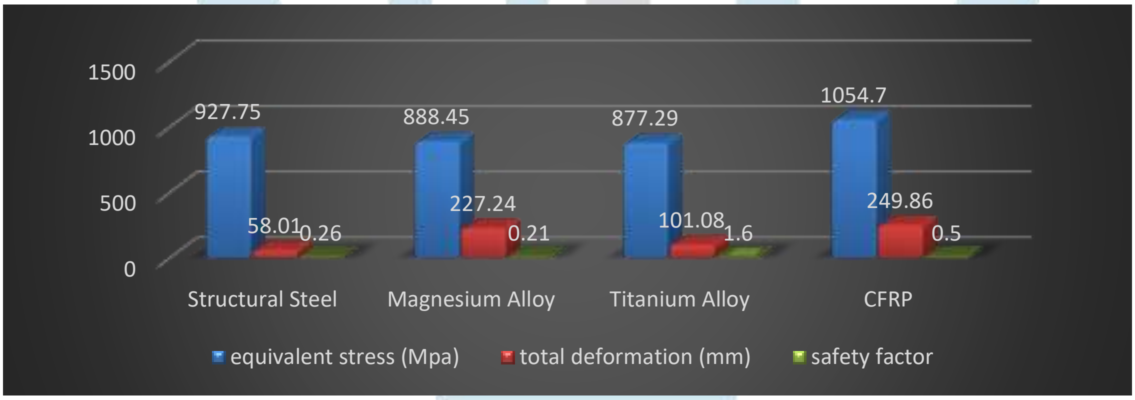

Fig.5.3 Impact Analysis in -Y-Direction for All Materials

6. CONCLUSION

1. Stress Analysis:

- X & Y Directions: Titanium alloy exhibits the least stress, indicating it distributes impact forces effectively.
- -Y Direction: CFRP (Carbon Fiber Reinforced Polymer) shows the least stress, followed closely by Titanium. This suggests CFRP is efficient in specific impact orientations but not universally the best.

2. Deformation Analysis:

- Least deformation: Structural steel, meaning it retains its shape best under impact but may be heavier.
- Second least deformation: Titanium, meaning it balances lightweight properties with impact resistance.

3. Factor of Safety (F.S):

- Titanium shows the best factor of safety, indicating superior overall strength and resistance to failure compared to the other materials.

Final Conclusion:

- Magnesium alloy is likely the weakest in this comparison due to lower strength and higher deformation.
- Structural steel is strong but heavy, making it less ideal for lightweight applications.
- CFRP is excellent for specific load directions (-Y) but may not be the best all-around material.
- Titanium alloy is the best overall material for impact resistance due to low stress, good deformation resistance, and high safety margin.

SCOPE OF FUTURE RESEARCH

- Integration of AI and machine learning for predictive crash simulations and material optimization.
- Development of advanced lightweight composites for better energy absorption and fuel efficiency.
- Use of real-time sensor data and digital twins to enhance crashworthiness in dynamic environments.
- Enhanced multi-material modeling techniques for accurate simulation of complex crash scenarios.
- Incorporation of sustainability factors by analyzing recyclable and eco-friendly materials under impact.

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