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Design and Comparative Evaluation of Electric Two-Wheeler Chassis Using Alternative Materials

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Abstract — The chassis frame is one of the most important structural components of an electric bike, as it supports the vehicle's overall weight and ensures rider safety under various operating conditions. This study investigates the structural behavior of an electric bike chassis subjected to different loading scenarios, including static and dynamic loads. Various analytical and numerical techniques are reviewed to evaluate chassis performance and identify opportunities for weight reduction without compromising structural integrity. The main objective of this work is to enhance the existing chassis design through suitable modifications that improve strength, stability, and overall vehicle efficiency. Reducing the weight of the chassis can contribute significantly to better energy utilization, improved handling characteristics, and enhanced vehicle performance. To achieve this objective, structural analyses such as stress and displacement evaluations were carried out using different engineering materials, namely Mild Steel, Aluminum Alloy, and Stainless Steel. The chassis geometry was developed using Computer-Aided Design (CAD) software CATIA, while structural simulations were performed using Fusion 360 and ANSYS. The Finite Element Analysis (FEA) approach was adopted to predict the mechanical response of the frame under applied loads and boundary conditions. Parameters such as Von Mises stress, total deformation, and factor of safety were considered to assess the suitability of each material for electric bike applications. With increasing concerns regarding environmental pollution and dependence on fossil fuels, electric vehicles have emerged as a sustainable transportation solution. Electric bikes, in particular, offer advantages such as reduced emissions, lower operating costs, and improved energy efficiency. Therefore, designing a lightweight yet durable chassis is essential for maximizing the performance and reliability of these vehicles. In this study, an electric bike frame was designed and analyzed using alternative materials to compare their structural performance. Static structural and torsional analyses were conducted to examine the frame's ability to withstand operational and impact loads. The selected materials were evaluated based on their strength-to-weight ratio, deformation characteristics, and overall structural behavior. The results demonstrate that the proposed chassis design is capable of sustaining expected service loads while maintaining safety and durability requirements. The findings of this research provide useful insights for the development of lightweight, cost-effective, and high-performance electric bike chassis systems for future transportation needs.

Keywords— Electric Bike (E-bike), Chassis Frame, Finite Element Analysis (FEA), Static Structural Analysis, Material Selection, Strength-to-Weight Ratio, Swing Arm Design, CATIA, Fusion 360, ANSYS, Aluminum Alloy, Stainless Steel, Mild Steel, Carbon Fiber, Von Mises Stress, Total Displacement, Factor of Safety, CAD Modeling, Rhombus Swing Arm, Weight Reduction.

I. INTRODUCTION

Electric vehicles (EVs) have emerged as a critical solution to global environmental concerns, offering a cleaner alternative to conventional internal combustion engine (ICE) vehicles. The demand for electric mobility solutions has surged over the past decade, significantly transforming urban mobility through the widespread adoption of electric bikes. E-bikes offer an eco-friendly, cost-effective alternative for short-distance travel.

However, rapid growth introduces the challenge of designing a chassis capable of supporting the performance and structural demands of electric powertrains. The bike's frame acts as its foundation, holding and supporting the entire weight of the vehicle, including the battery, motor, and suspension system.

1. Problem Statement

The design of an EV chassis faces several significant challenges:

- Excessive Weight: A heavier chassis increases energy consumption, thereby reducing the bike's range, acceleration, and handling performance.
- Stress Concentration and Fatigue: Continuous exposure to vibrations and road impacts can lead to micro-cracks, fatigue failure, and a reduced lifespan.
- Material Selection and Cost: High-performance materials can be expensive and pose manufacturing limitations (e.g.,

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welding or molding difficulties), limiting their viability for mass production.

2. Objectives

The core objectives of this research include:

- Studying the working and design procedure of an automobile chassis.
- Investigating the forces and loads acting on the chassis.
- Preparing a 3D CAD model of the chassis.
- Performing Finite Element Analysis (FEA) on the chassis using different materials.
- Conducting a comparative analysis to determine the optimal material and design (including swing arm geometry).

II. LITERATURE REVIEW

Malikasab Bagawan, M. Vamsi Krishna et.al.(2023): has worked on the structural design and performance evaluation of an electric motorcycle chassis frame. The study aims to enhance the frame's strength-to-weight ratio, ensuring safety and durability while accommodating the unique requirements of electric power-trains. Finite Element Analysis (FEA) was employed to simulate various loading conditions and optimize the frame's design.To design and create a lightweight chassis compared to conventional ones which was also sturdy, safe, and cost-effective.

Ansh Mehra, Ripanjot Singh et.al.(2022): has worked on to design and analysis of a chassis for a two-wheeler using different materials available in the market.The research aims to develop a robust and efficient electric bike chassis by employing advanced design and analysis techniques. The process involves creating a 3D model of the chassis using Solid-Works and performing static structural analysis using ANSYS software to evaluate its strength and stability under various loading conditions.

Fahim Foysal Arnob, Md. Shahnewaz Khan et.al.(2022): has research on the triangular structure was used as the basis of the design since this concept provides the best structural strength.the fabricated chassis were compared with numerical results obtained from the state of the art FEA Software,This research focuses on the design, fabrication, and analysis of an electric bike chassis, aiming to provide a sustainable and efficient alternative to traditional fossil fuel-powered vehicles. The study emphasizes the importance of chassis design in ensuring the structural integrity and performance of electric bikes.

Michal Mihálik a, et.al.(2021):This research focuses on the development of a compact, self- balancing electric vehicle designed for short-distance urban transportation. The vehicle's primary control system is based on a microcontroller from Atmel Corporation, utilizing a PID (Proportional- Integral-Derivative) controller to maintain balance. The design emphasizes achieving an optimal balance between cost and quality.

Gupta & Mehta (2021):has worked on on FEA-based optimization techniques such as topology optimization and size optimization for designing lightweight and strong chassis. The study demonstrates how FEA can be used to reduce material usage without compromising the safety and functionality of the chassis.

Bhatia & Singh (2021):This study explores how reducing the weight of the chassis positively impacts the overall range and efficiency of electric vehicles. The authors show that using lightweight materials like carbon fiber composites significantly improves energy consumption, leading to an extended range per battery charge.

Naresh Kumar Konada, Koka Naga Sai Suman(2020): has worked on composite material with proper fabrication methodology can replace the metals used in E Bike technology and produce higher stiffness to weight ratio, lower deformation and with stand higher loads closer to metals.This research investigates the structural performance of an electric bike (e-bike) chassis under static and impact loading conditions. The study aims to evaluate alternative materials for the chassis frame to enhance performance and sustainability.

Kumar et al. (2020): he study on the importance of reducing chassis weight in electric vehicles (EVs) to improve performance, range, and energy efficiency. It highlights the need for structural integrity, comfort, and performance as primary factors in chassis design. It also emphasizes the role of composite materials in reducing weight while maintaining strength.

Patil& Joshi (2020):his review covers the use of Finite Element Analysis (FEA) to simulate the structural behavior of EV chassis under various load conditions. It outlines the advantages of using FEA in predicting stress distribution, deformation, and fatigue life, which aids in optimizing chassis design for safety and performance.

Sharma &Kapoor (2020): his research investigates the selection of optimal materials for electric bike chassis, using a multi-criteria decision-making (MCDM) approach. The authors

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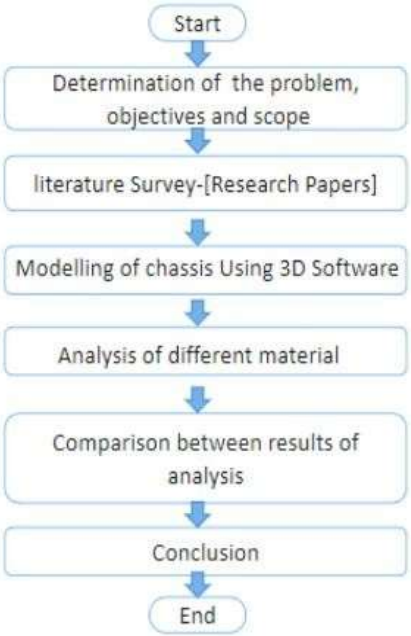
compare steel, aluminum, and composites based on their mechanical properties and cost, concluding that composites offer the best balance of performance and weight reduction for EV chassis.

Chen &Xie (2020):This paper focuses on the fatigue behavior of composite materials used in electric vehicle chassis. It discusses the cyclic loading conditions that the chassis undergoes and how FEA simulations help predict fatigue failure. The study emphasizes the need to assess long-term durability for safety and performance.

Kumar &Rai (2020): has worked on the environmental impact of using composite materials in EV chassis, highlighting the potential for recycling and reuse of composites. The authors argue that composites can offer sustainable solutions when considering the entire lifecycle, from manufacturing to disposal.

III. METHODOLOGY

The research methodology follows a structured approach:



- Determination of Problem & Objectives: Establishing the scope of the comparative analysis.
- Literature Survey: Reviewing existing methodologies in EV chassis design.
- 3D Modeling: Developing the solid model of the chassis frame using CAD software. The model defines the geometry and structural layout required to support major components like the motor, battery, and rider.
- Analysis of Different Materials: Utilizing FEA software (ANSYS) to simulate the structural behavior of the chassis under predefined loads.
- Comparison of Results: Evaluating parameters like total displacement, equivalent Von Mises stress, and factor of safety.

3d Model of Chassis

Fig.3 shows the solid model of the chassis frame is a 3D computer-aided design (CAD) representation that defines the geometry, dimensions, and structural layout of the chassis. It serves as the foundation for the vehicle, supporting all major components such as the motor, battery, suspension, and rider.



Fig.3-Solid model of chassis frame

IV. ANALYSIS OF DIFFERENT MATERIALS

Loading and boundary conditions applied on frame for performing static analysis

Table.1-boundary conditions

Fixed Position	Front and Back Part of the frame
Load applied on Frame	Total 1667.7 N
Material of Frame	Aluminum Alloy,Stainless Steel,Mild Steel
Type of Meshing	Parabolic coarse fine mesh having 124201 n odes and 62445 elements.

Type of Meshing Parabolic coarse fine mesh having 124201 n odes and 62445 elements.

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Material Selection and Properties

Table.2-Material Properties

Material	Density (kg /m3)	Youngs Modulus	Poissons Ratio	Yield Stength	Ultimate Tensile Strength
Aluminum Alloy	2700	68.90 GPa	0.33	275 MPa	310 MPa
Stainless Steel	8000	193 GPa	0.30	250 MPa	540 MPa
Mild Steel	7850	220 GPa	0.275	207 MPa	345 MPa

Loads applied & Meshing on Chassis

Load Calculations-

Table.3-Load Calculations

Sr.No.	Approx.Bike weight in kg	Weight of Single ,Two and Third person in kg	Total weight in kg	Total weight in N
1	100	70	170	1667.7
2	100	140	240	2354.4
3	100	210	310	3041.1

Loads applied on the chassis frame for static analysis



Fig.4-Loads applied on the chassis

Chassis Structural Analysis

Once the basic parameters are determined, the chassis must undergo rigorous structural analysis to ensure that it can withstand all expected loads and conditions.

Finite Element Analysis (FEA)

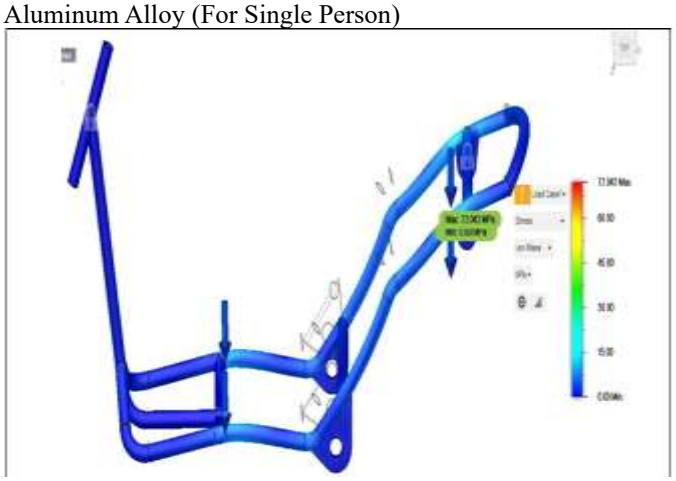
FEA is commonly used in chassis design to simulate and analyze how forces, vibrations, and stresses affect the frame. The model is broken down into a mesh of smaller elements, each of which is analyzed individually to determine how the entire structure behaves under different load conditions.

Key FEA Steps

- Model Creation: The 3D model of the chassis is created, often using CAD software like Solid- works or CATIA.
- Mesh Generation: The chassis model is subdivided into a mesh of small elements for easier analysis.
- Boundary Conditions: Constraints are applied to simulate fixed points (e.g., where the frame mounts to the wheels and the motor).
- Material selection-The material selection of an automobile plays a vital role for giving strength to the automobile. The load with standing capability primarily depends on the selection of materials.
- Load Application: Loads are applied to the model based on real-world scenarios, such as rider weight,road bumps, braking forces, and wind resistance.
- Analysis: The software calculates the stress, deformation,strain etc...

Static Analysis Results

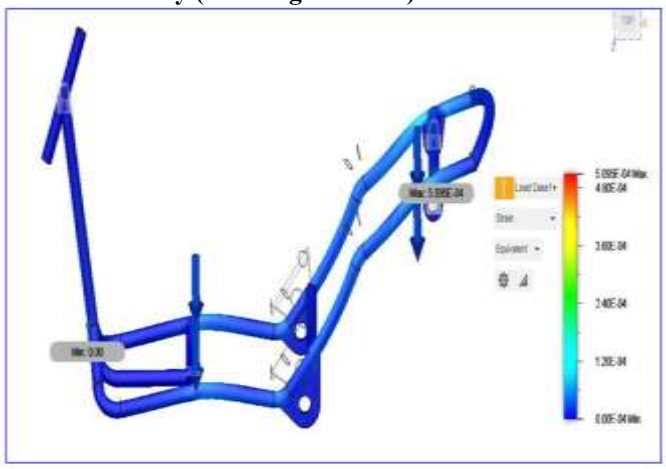
Aluminum Alloy (For Single Person)



(a) Total Displacement

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Aluminum Alloy (For Single Person)



(c)Equivalent Strain

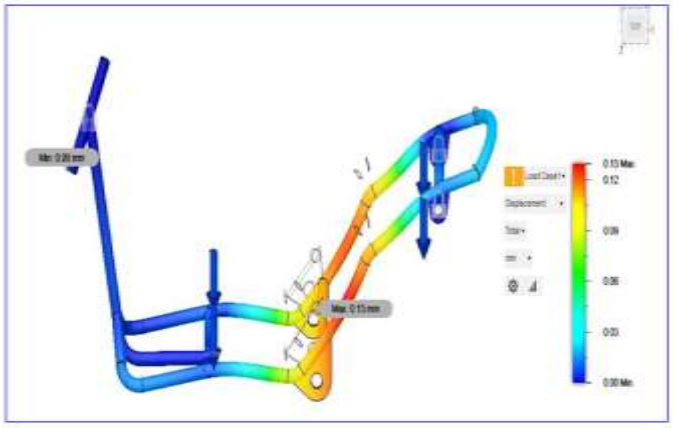
Fig.c shows When a load of 1667.7 N was applied,the equivalent strain was 0.0005095.

(d)Factor of Safety

Fig.d shows When a load of 1667.7 N was applied, the factor of safety was 2.873.

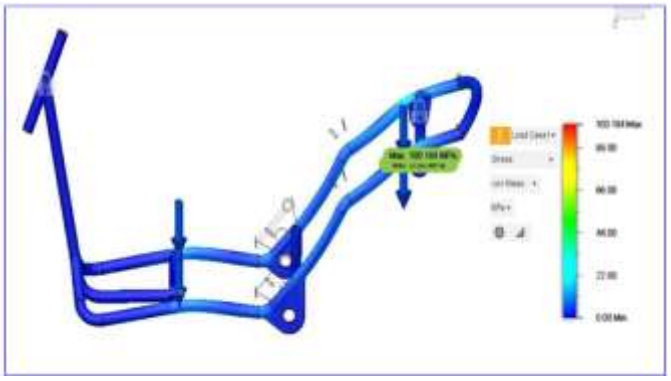
Fig.6.1a,b,c,d-Static Analysis Results Al ((For Single Person)

Aluminum Alloy (For Two Person)



(a) Total Displacement

Fig.a shows an increased load of 2354.4 N, the total displacement rose to 0.13 mm,



(b) Equivalent Von Mises stress

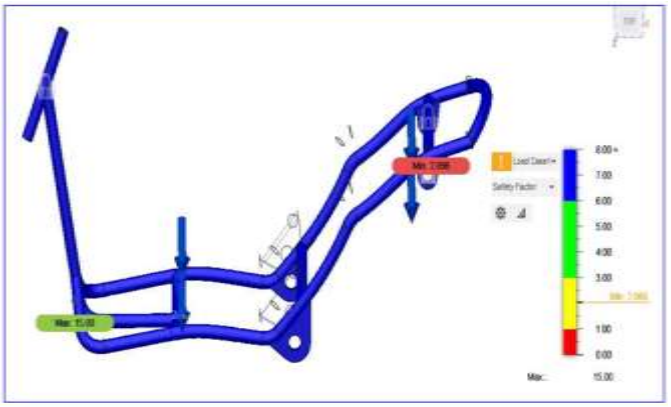
Fig.b shows an increased load of 2354.4 N,the equivalent Von Mises stress reached 100.184 MPa,

Aluminum Alloy (For Two Person)



(a) Equivalent Strain

Fig.c shows an increased load of 2354.4 N,the equivalent strain increased to 0.0007076.



(b) Factor of Safety

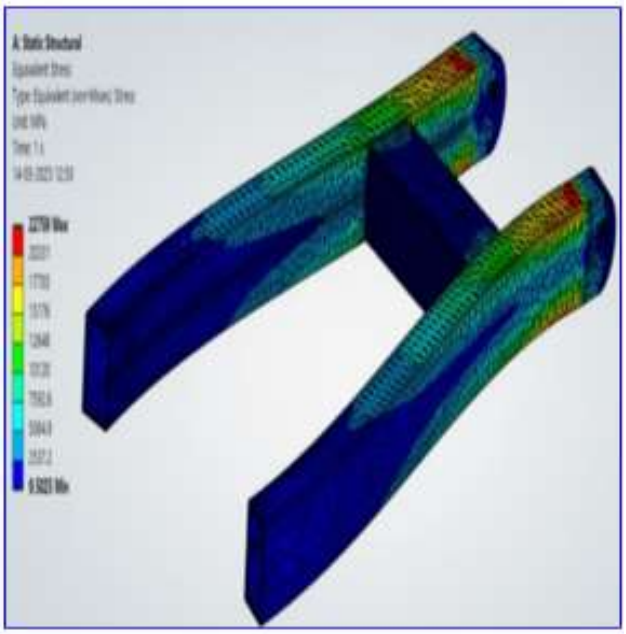
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Fig.d shows an increased load of 2354.4 N,the factor of safety decreased to 2.066. Fig.7.a,b,c,d-Static Analysis Results Al ((For Two Person)

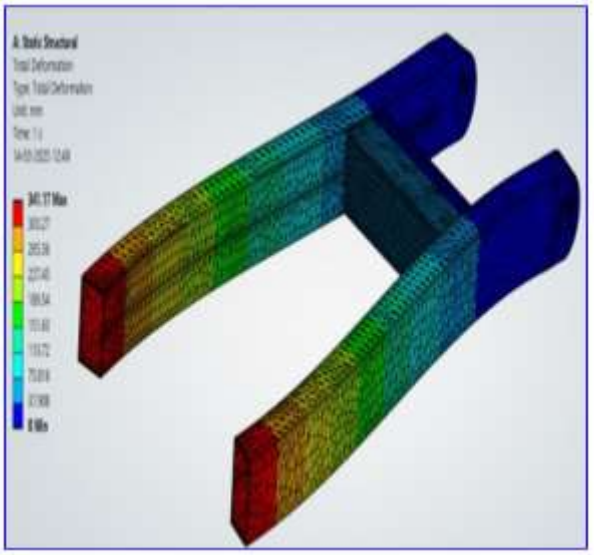
Static Structural Analysis of Swing Arm Hollow With Structural Steel



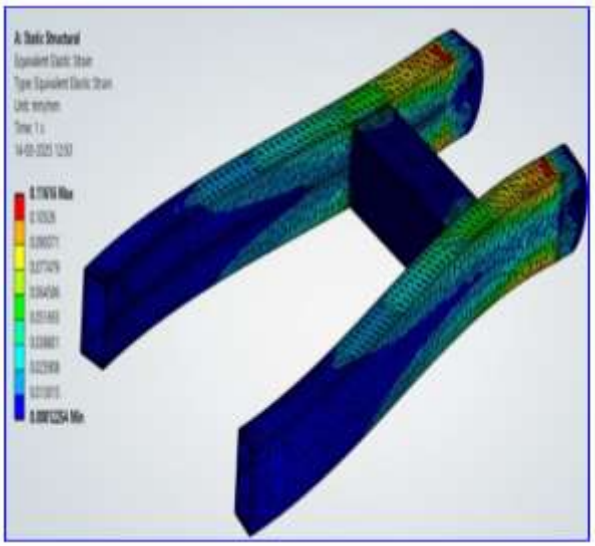
(a)Material Selection



(b)Equivalent Von Mises stress



(c)Total Deformation



(d)Equivalent strain

Fig.10.1a,b,c,d-Static Analysis Results of Hollow With Structural Steel

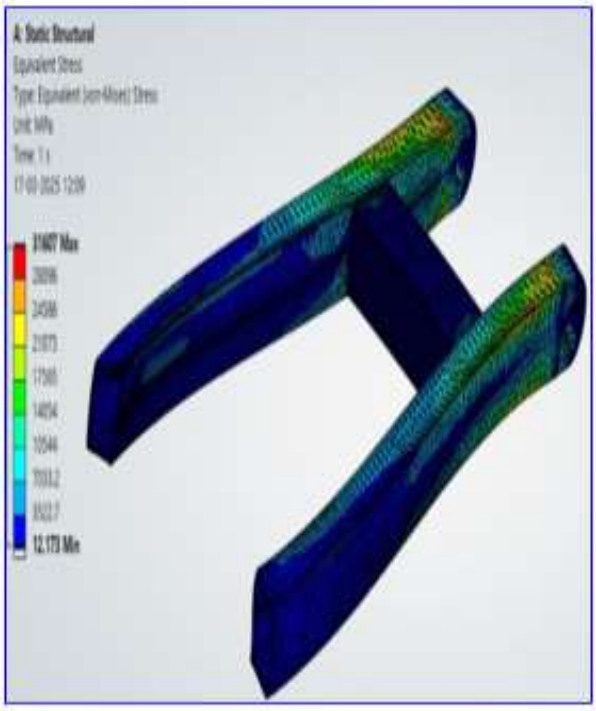
Fig.10.1 shows under the given loading conditions, the Structural Steel chassis exhibited a total deformation of 341.17 mm, an equivalent Von Mises stress of 22,759 MPa, and an equivalent strain of 0.11616 mm, indicating high stiffness and excellent resistance to deformation.

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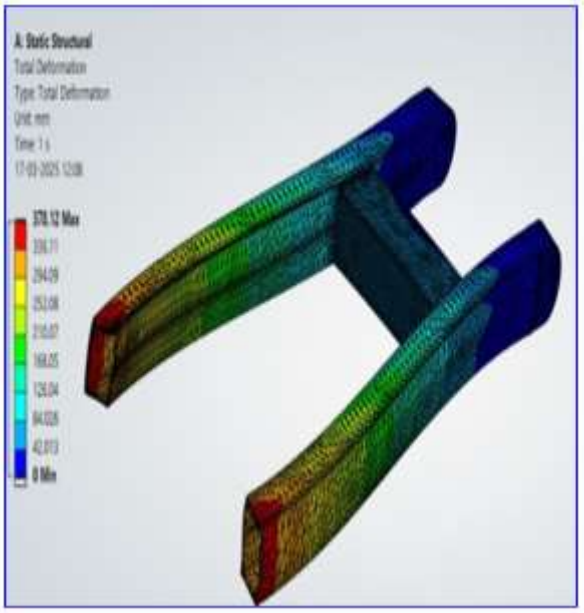
Hollow With Carbon Fibre



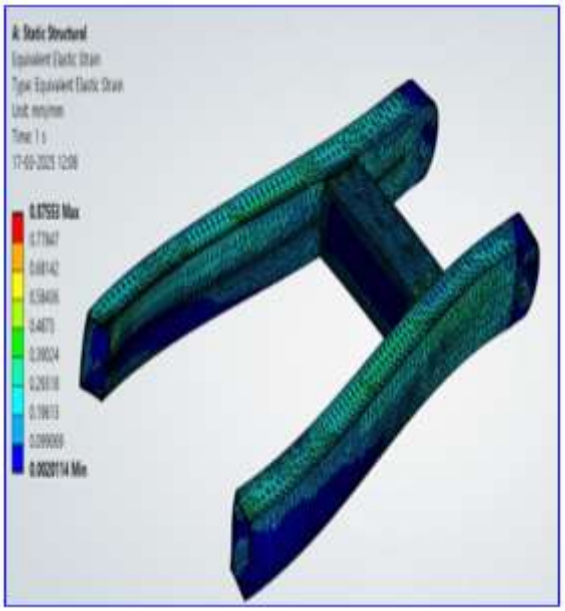
(a)Material Selection



(b)Equivalent Von Mises stress



(c)Total Deformation



(d) Equivalent strain

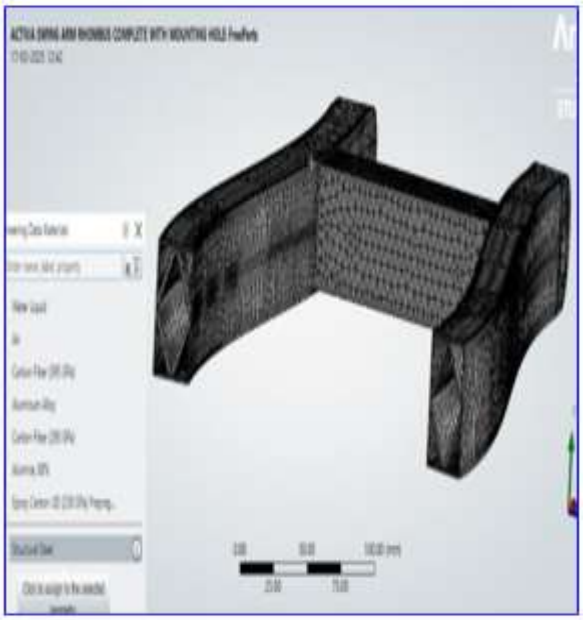
Fig.10.2a,b,c,d-Static Analysis Results of Hollow With Carbon Fibre

Fig.10.2 shows under the applied loading conditions, the Carbon Fiber chassis exhibited a total deformation of 378.12 mm, an equivalent Von Mises stress of 31,607 MPa, and an

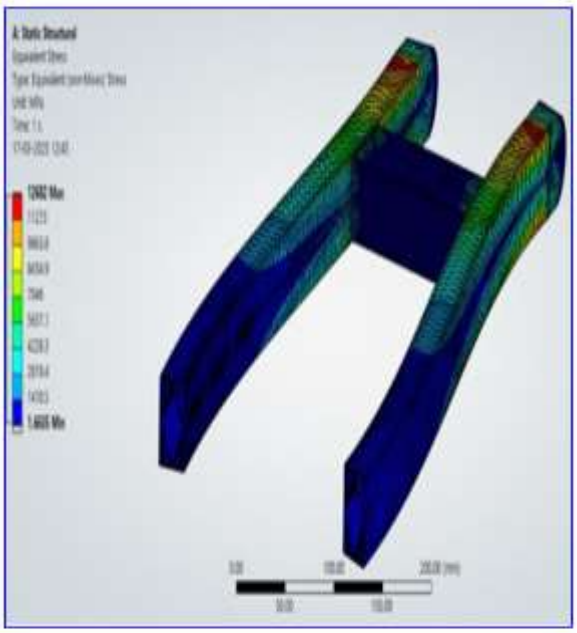
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equivalent strain of 0.87553 mm, indicating excellent strength and high elasticity, making it well-suited for lightweight and performance-driven electric vehicle designs.

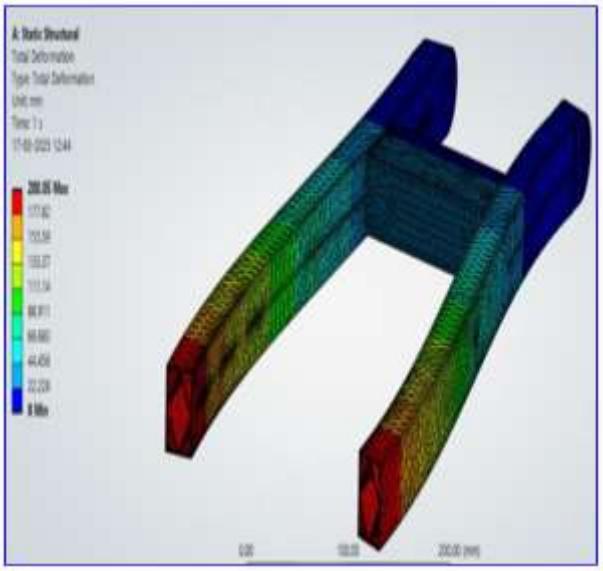
Rhombus With Structural Steel



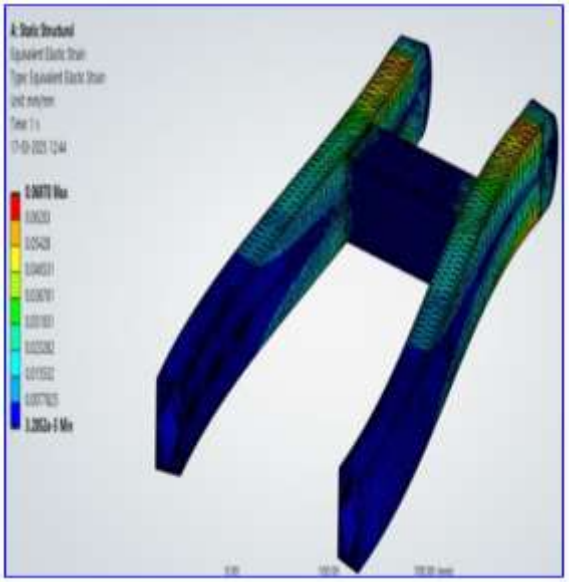
(a)Material Selection



(b)Equivalent Von Mises stress



(c)Total Deformation



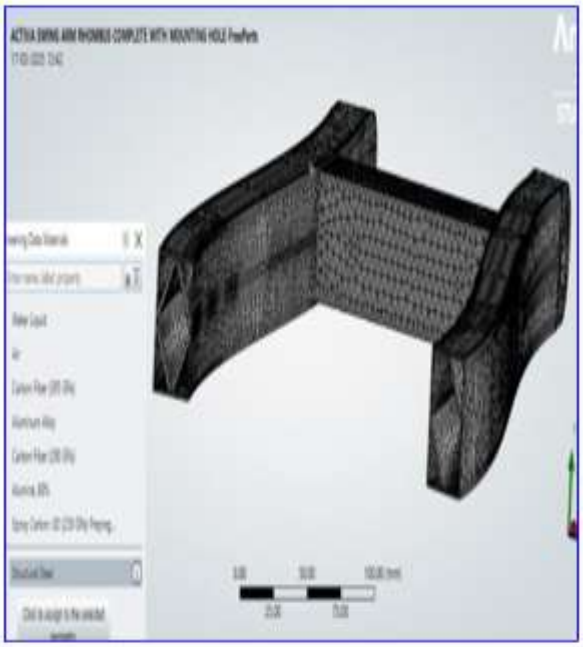
(d) Equivalent strain

Fig.11.1a,b,c,d-Static Analysis Results of Rhombus With Structural Steel

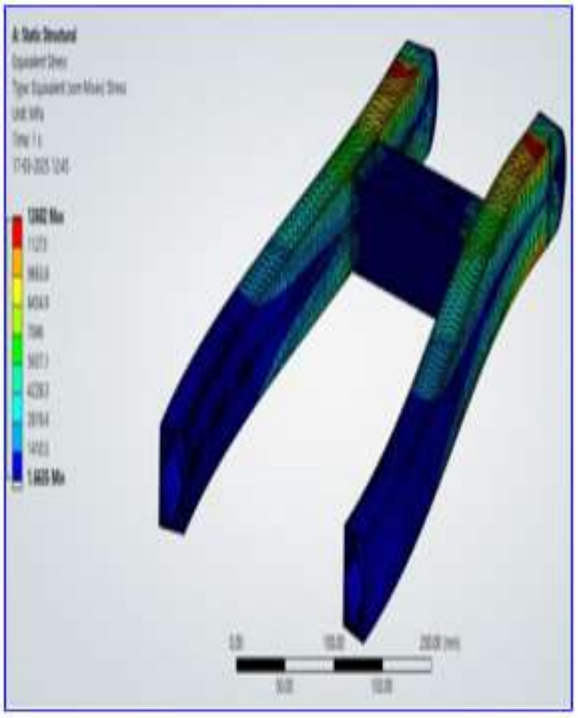
Fig.11.1 shows the Structural Steel chassis exhibited a total deformation of 200.05 mm, an equivalent Von Mises stress of 12,682 MPa, and an equivalent strain of 0.06978 mm, demonstrating excellent stiffness and resistance to both stress and strain.

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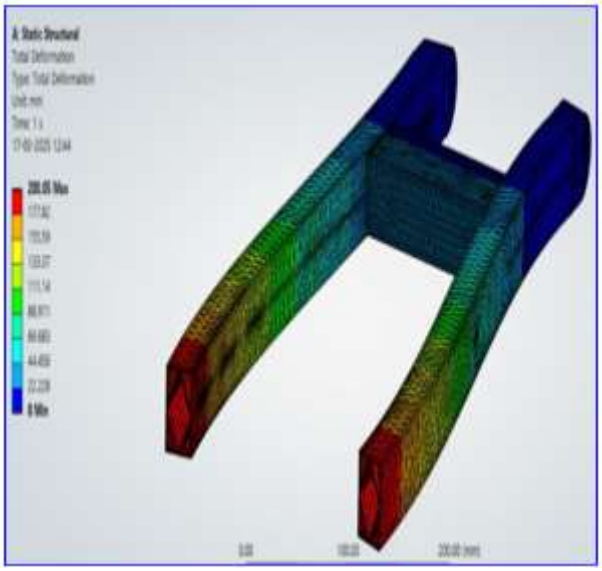
Rhombus With Carbon Fibre



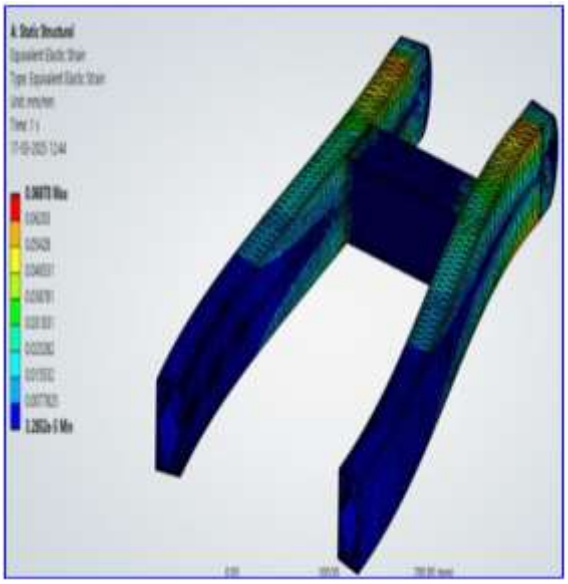
(a)Material Selection



(b) Equivalent Von Mises stress



(c)Total Deformation



(d)Equivalent strain

Fig.11.2a,b,c,d-Static Analysis Results of Rhombus With Carbon Fibre

Fig.11.2 shows the Carbon Fiber chassis recorded the lowest total deformation of 165.06 mm, the highest stress capacity at 20,893 MPa, and a strain of 0.29175 mm, showcasing superior strength-to-weight performance and high elasticity, ideal for advanced lightweight vehicle applications.

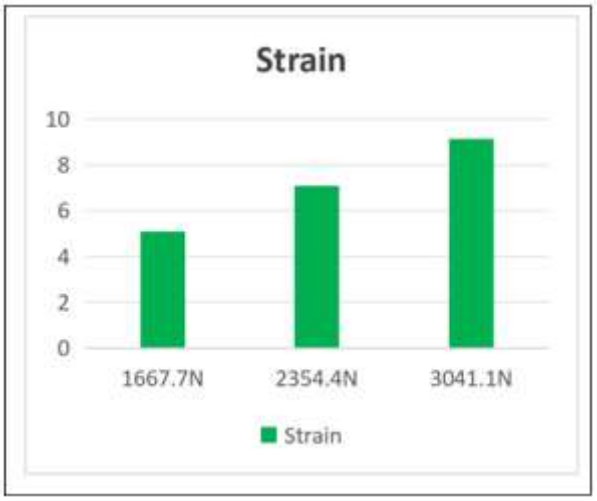
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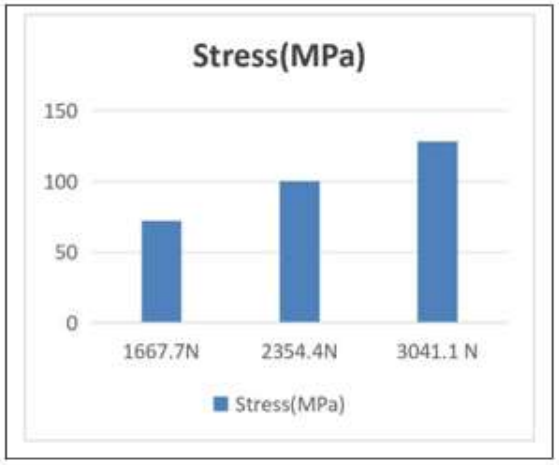
V. COMPARATIVE GRAPHICAL REPRESENTATION OF RESULTS

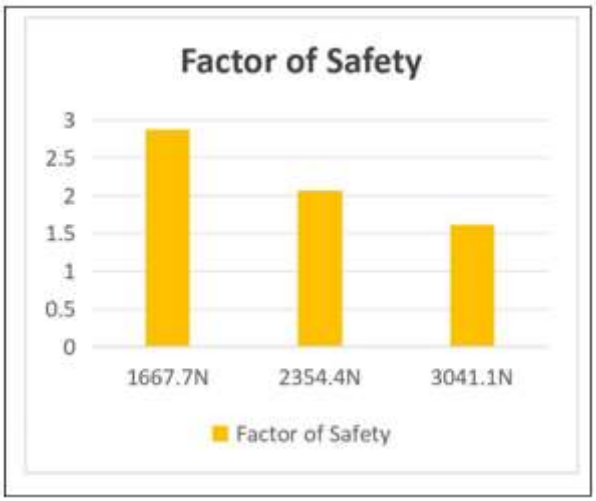
Static Analysis Results
Aluminum Alloy

Table 4-Static Analysis Results Aluminum Alloy

Load Applied	Stress(MPa)	Displacement(mm)	Strain	Factor of Safety
1667.7N	72.042	0.096	5.095 E-04	2.873
2354.4N	100.184	0.13	7.076 E-04	2.066
3041.1 N	128.451	0.163	9.124 E-04	1.612







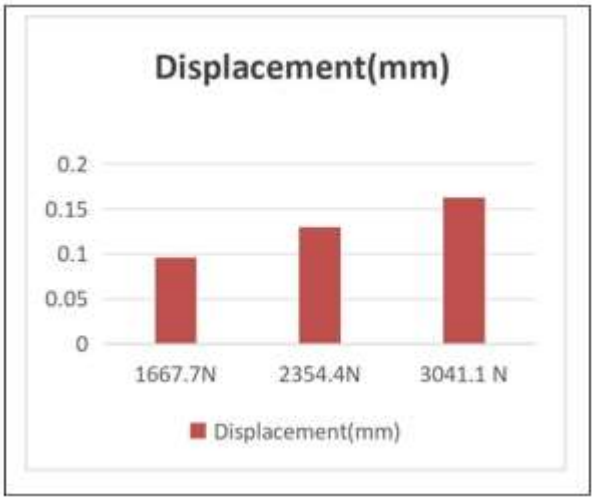


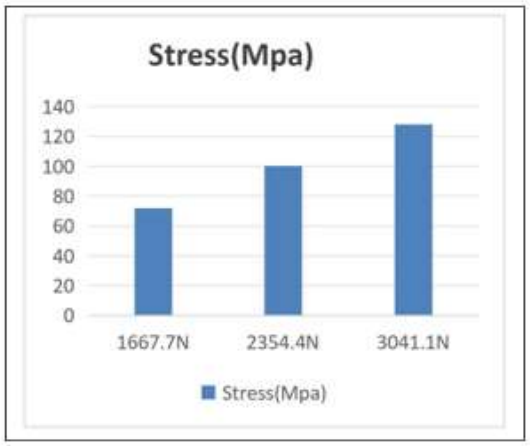
Fig Graphical Representation of Static Analysis Results Aluminum alloy

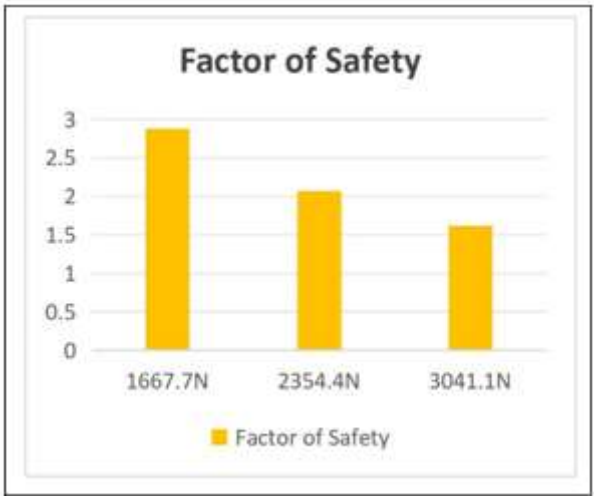
Stainless Steel

Table 5-Static Analysis Results Stainless Steel

Load Applied	Stress(MPa)	Displacement(mm)	Strain	Factor of Safety
1667.7N	71.823	0.096	5.078 E-04	2.882
2354.4N	100.113	0.129	7.072 E-04	2.068
3041.1 N	128.099	0.163	9.124 E-04	1.616

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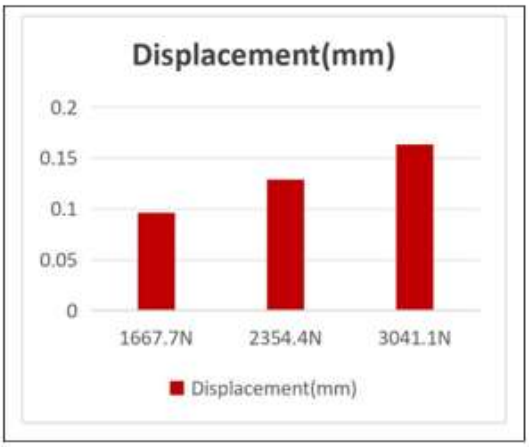
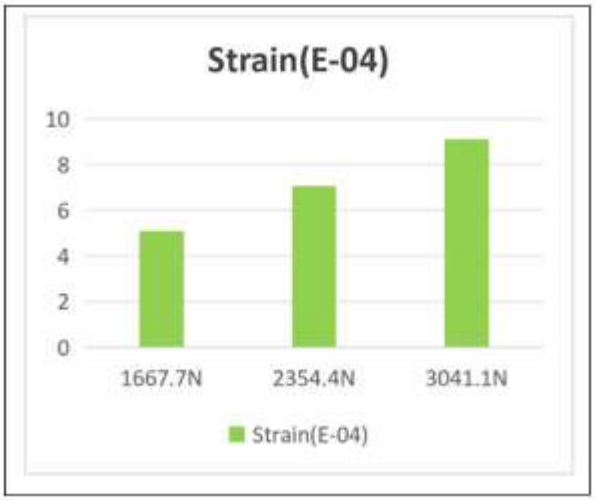


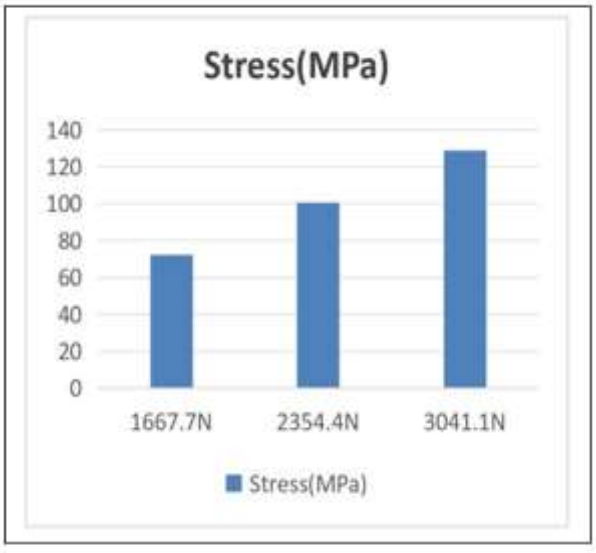
Fig.Graphical Representation of Static Analysis Results Stainless Steel

Mild Steel

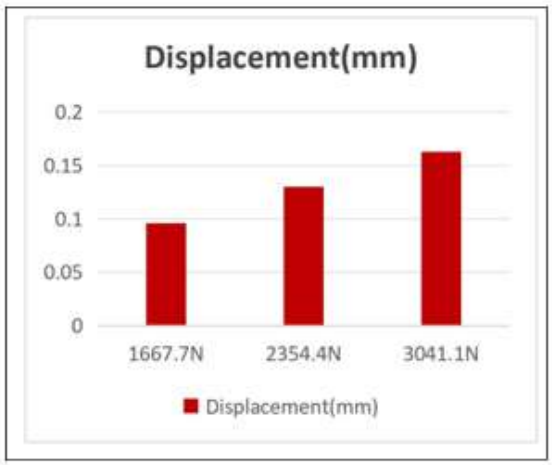
Table 6-Static Analysis Results Mild Steel

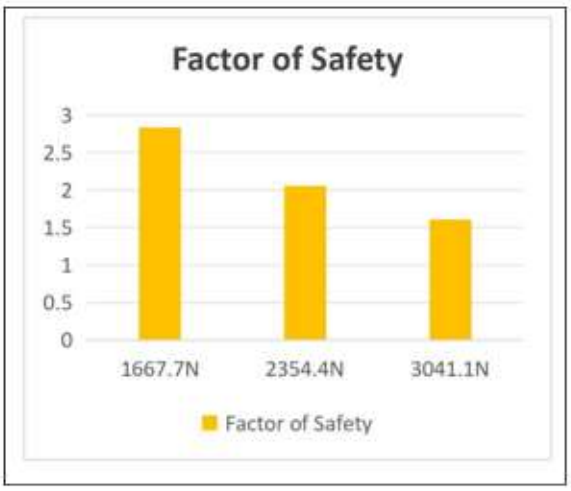
Load Applied	Stress(MPa)	Displacement(mm)	Strain	Factor of Safety
1667.7N	72.297	0.096	5.109 E-04	2.836
2354.4N	100.707	0.13	7.110 E-04	2.055
3041.1 N	128.938	0.163	9.096 E-04	1.605





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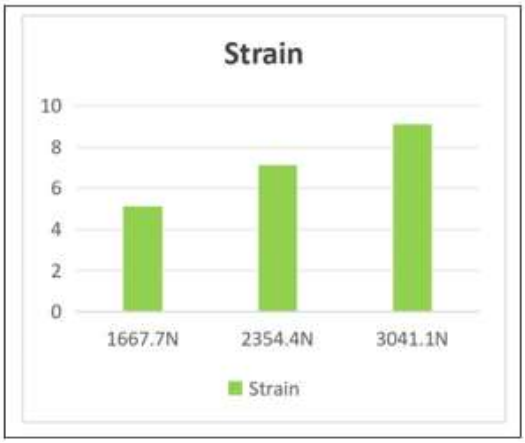


Fig Graphical Representation of Static Analysis Results Mild Steel

Values of Parameters for all materials under static load Analysis

Table 7-Values of Parameters for all materials under static load Analysis

Material	Load Applied	Total Displacement (mm)	Equivalent Von Mises stress (Mpa)	Equivalent Strain	Factor of Safety
Aluminum Alloy	1667.7N	0.096	72.042	0.0005095	2.873
	2354.4N	0.13	100.184	0.0007076	2.066
	3041.1 N	0.163	128.451	0.0009124	1.612
Stainless Steel	1667.7N	0.096	71.823	0.0005078	2.882
	2354.4N	0.129	100.113	0.0007072	2.068
	3041.1 N	0.163	128.099	0.0009124	1.616
Mild Steel					

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	1667.7N	0.096	72.297	0.0005109	2.836
	2354.4N	0.13	100.707	0.000711	2.055
	3041.1 N	0.163	128.938	0.0009096	1.605

VI.CONCLUSION

After performing static analysis on chassis frame by applying a load varying the materials of the bike Chassis, it was observed that...

- Well-designed chassis Material will exhibit minimal displacement, Lower equivalent strain A higher factor of safety, Lower equivalent stress.so per analysis Stainless Steel exhibit all above so its better for chassis fabrication.
- A higher strength to weight ratio is good for a Bike chassis.It means the chassis is strong and robust while also being lightweight,which leads to better performance and efficiency.so Aluminum Alloy have higher strength to weight ratio.
- As per Analysis of Swing Arm Rhombus design more safe as compared to Hollow design because total deformation,equivalent stress and equivalent strain show lowest value. and as per analysis structural Steel is is strong and robust which leads to better performance and efficiency.
- As per tensile test of above material Stainless Steel is good, but it become heaviest structure so we can use of thinner sections, reducing weight if ductility and fatigue resistance are adequate.

If you prioritize comfort and durability, stainless steel might be the better choice. For most Indian road conditions, a stronger, slightly heavier chassis is better than an ultra-lightweight one.It ensures durability, lower maintenance, and better load tolerance-crucial for long-term use.

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