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Comparative Analysis of Electric Bike Chassis Using Different Materials

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***Abstract*—The chassis frame is the primary structural member of an electric bike (e-bike); it carries the battery, motor, suspension and rider and must remain safe under static and dynamic loads. This paper presents a comparative finite element analysis (FEA) of an e-bike chassis made of aluminum alloy, stainless steel and mild steel, with the aim of identifying a lightweight yet durable design. The chassis was modeled in CATIA and analyzed in Fusion 360 and ANSYS for loads of 1667.7 N, 2354.4 N and 3041.1 N, corresponding to one, two and three riders. Von Mises stress, total displacement, equivalent strain and factor of safety (FoS) were compared. All three materials remain safe at the heaviest load (FoS ≥ 1.6); stainless steel gives marginally lower stress and higher FoS, whereas aluminum alloy has by far the highest strength-to-weight ratio. A swing arm study of hollow and rhombus sections in structural steel and carbon fibre shows that the rhombus design deforms least. The findings support the development of lightweight, cost-effective e-bike chassis.**

***Index Terms*—Electric bike, chassis frame, finite element analysis, static structural analysis, material selection, strength-to-weight ratio, swing arm, CATIA, Fusion 360, ANSYS, von Mises stress, factor of safety.**

I. INTRODUCTION

Electric vehicles (EVs) have emerged as a critical solution to global environmental concerns, offering a cleaner alternative to conventional internal combustion engine vehicles. Demand for electric mobility has surged over the past decade, and e-bikes in particular have become an eco-friendly and cost-effective option for short-distance urban travel.

This rapid growth demands a chassis that can meet the performance and structural requirements of an electric powertrain. The frame is the foundation of the bike: it holds and supports the entire weight of the vehicle, including the battery, motor and suspension, so its design directly affects range, handling and rider safety.

1 Problem Statement

The design of an EV chassis faces several challenges. Excessive weight increases energy consumption and reduces range, acceleration and handling. Stress concentration and fatigue caused by continuous vibration and road impact can lead to micro-cracks, fatigue failure and reduced life. Material selection and cost is also critical, because high-performance materials are expensive and bring manufacturing limitations such as welding or molding difficulties, restricting their use in mass production.

2. Objectives

The objectives of this research are to: (1) study the working and design procedure of an automobile chassis; (2) investigate the forces and loads acting on the chassis; (3) prepare a 3D CAD model of the chassis; (4) perform FEA on the chassis using different materials; and (5) carry out a comparative analysis to determine the optimal material and design, including the swing arm geometry.

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II. Literature Review

Bagawan et al. [1] studied the structural design and performance of an electric motorcycle chassis frame, aiming to improve the strength-to-weight ratio while ensuring safety and durability for electric powertrains; FEA was used to simulate loading conditions and optimize a lightweight, sturdy, safe and cost-effective frame. Mehra et al. [2] designed a two-wheeler chassis using different available materials, creating a 3D model in SolidWorks and evaluating strength and stability through static structural analysis in ANSYS. Arnob et al. [3] adopted a triangulated structure as the basis of an e-bike chassis because of its structural strength, and compared the fabricated chassis with numerical FEA results, stressing the role of chassis design in structural integrity. Mihálik et al. [4] developed a compact, self-balancing electric vehicle for short urban trips, using a PID controller to maintain balance with an emphasis on cost–quality balance. Konada and Suman [5] analyzed an e-bike chassis under static and impact loads and found that properly fabricated composites can replace metals, giving a higher stiffness-to-weight ratio, lower deformation and comparable load capacity. Further FEA-based chassis studies cover electric motorcycle, hybrid e-bike, ladder-frame and eco-car designs [6]–[10].

Gupta and Mehta [11] applied FEA-based topology and size optimization to design lightweight, strong chassis with less material and no loss of safety. Bhatia and Singh [12] showed that reducing chassis weight, for example with carbon-fibre composites, improves energy consumption and extends range per charge, and Kumar et al. [13] likewise stressed weight reduction for performance, range and efficiency while preserving structural integrity and comfort. Patil and Joshi [14] reviewed the use of FEA to predict stress distribution, deformation and fatigue life of EV chassis. Sharma and Kapoor [15] used a multi-criteria decision-making approach to compare steel, aluminum and composites on mechanical properties and cost, and concluded that composites give the best balance of performance and weight. Chen and Xie [16] studied the fatigue behavior of composite chassis under cyclic loading and emphasized long-term durability, while Kumar and Rai [17] examined the environmental impact of composites and their potential for recycling and reuse. Building on these works, the present study compares conventional metals under identical loading conditions.

III. Methodology

The research followed the structured approach shown in Fig. 1: (1) determination of the problem and objectives, which fixes the scope of the comparison; (2) a literature survey of existing EV chassis design methods; (3) 3D modeling of the chassis frame in CAD software; (4) analysis of different materials by FEA to simulate the structural behavior under predefined loads; and (5) comparison of total displacement, equivalent von Mises stress and factor of safety, followed by conclusions.

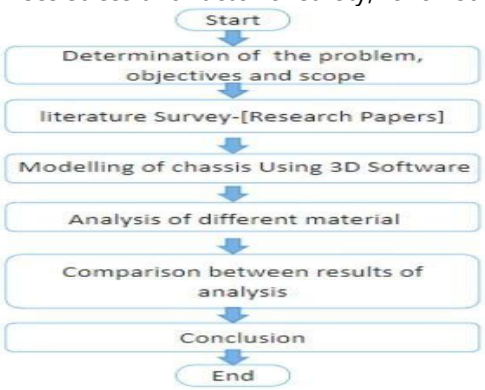


Fig. 1. Research methodology.

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IV. 3D Model of the Chassis

The solid model of the chassis frame (Fig. 2) is a 3D CAD representation, created in CATIA, that defines the geometry, dimensions and structural layout of the chassis. It forms the foundation of the vehicle and supports the major components such as the motor, battery, suspension and rider.



Fig. 2. Solid model of the chassis frame.

V. ANALYSIS OF DIFFERENT MATERIALS

1. Material Selection and Properties

The load-withstanding capacity of an automobile depends primarily on the material selected. Aluminum alloy, stainless steel and mild steel were assigned to the frame; their properties are listed in Table I. The ratio of yield strength to density, a measure of strength-to-weight performance, is included for comparison.

Table I Material properties

Material	Density (kg/m³)	E (GPa)	ν	Yield (MPa)	UTS (MPa)	Yield/density (kN·m/kg)
Aluminum alloy	2700	68.9	0.33	275	310	101.9
Stainless steel	8000	193	0.30	250	540	31.3
Mild steel	7850	220	0.275	207	345	26.4

2. Loads, Boundary Conditions and Meshing

The boundary conditions are given in Table II. The front and rear parts of the frame were fixed, and the baseline load of 1667.7 N was applied for the single-rider case. The loads were calculated from the approximate bike weight of 100 kg plus one, two or three riders of 70 kg each, giving 1667.7 N, 2354.4 N and 3041.1 N (Table III). The loads applied on the chassis are shown in Fig. 3.

Table II Boundary conditions

Fixed position	Front and back part of the frame
Load applied	1667.7 N (single rider)
Material of frame	Aluminum alloy, stainless steel, mild steel
Meshing	Parabolic mesh; 124,201 nodes and 62,445 elements

Table III Load calculation

Case	Bike (kg)	Riders (kg)	Total (kg)	Load (N)

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Case	Bike (kg)	Riders (kg)	Total (kg)	Load (N)
One rider	100	70	170	1667.7
Two riders	100	140	240	2354.4
Three riders	100	210	310	3041.1

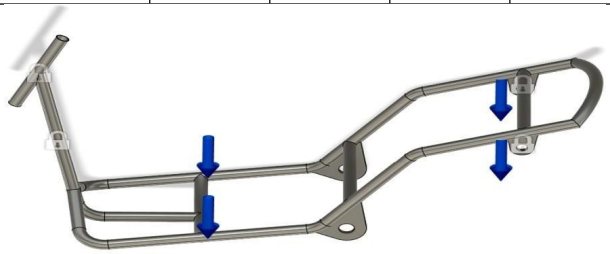


Fig. 3. Loads applied on the chassis frame.

3. Structural Analysis

FEA is commonly used in chassis design to simulate how forces, vibrations and stresses affect the frame. The model is divided into a mesh of small elements, each analyzed individually to determine the behavior of the whole structure under different load conditions. The key steps are: model creation (3D model in CAD software such as SolidWorks or CATIA); mesh generation (subdividing the model into small elements); boundary conditions (constraints at the wheel and motor mounts); material selection; load application based on real-world scenarios such as rider weight, road bumps and braking; and analysis of stress, deformation and strain. The chassis frame was solved in Fusion 360 and the swing arm in ANSYS.

VI. RESULTS AND DISCUSSION

1. Static Analysis of the Chassis Frame

For the aluminum alloy frame under the single-rider load of 1667.7 N (Fig. 4), the equivalent strain was 5.095×10^{-4} and the FoS was 2.873, with a maximum von Mises stress of 72.042 MPa. When the load was increased to 2354.4 N (Fig. 5), the total displacement rose to 0.13 mm, the stress to 100.184 MPa and the strain to 7.076×10^{-4}, while the FoS decreased to 2.066.



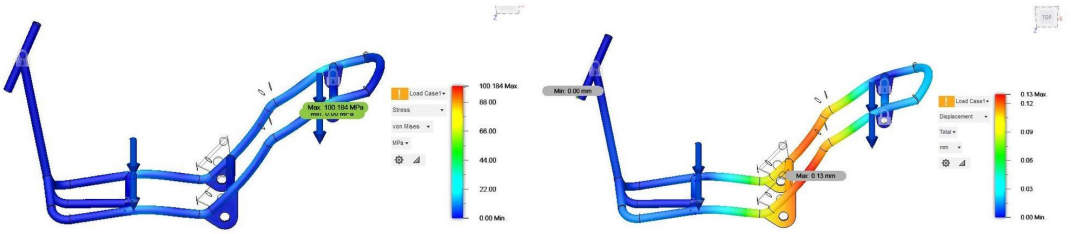
(a) Equivalent von Mises stress (b) Equivalent strain (c) Factor of safety

Fig. 4. Static analysis results for the aluminum alloy frame, single rider (1667.7 N).

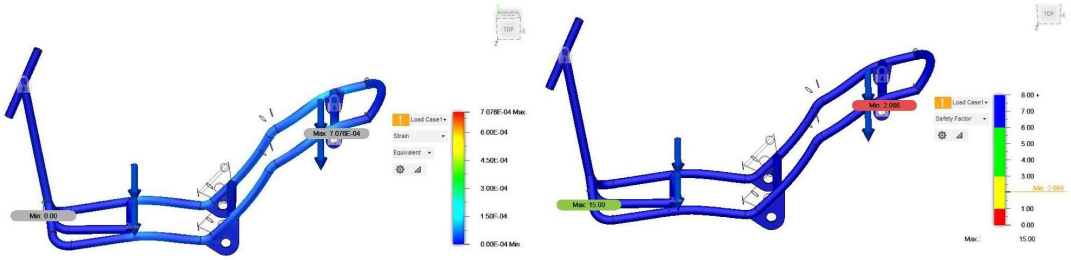
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(a) Equivalent von Mises stress (b) Equivalent strain (c) Factor of safety



(a) Equivalent von Mises stress (b) Total displacement



(c) Equivalent strain (d) Factor of safety

Fig. 5. Static analysis results for the aluminum alloy frame, two riders (2354.4 N).

Table IV lists the results for all three materials and loads, and Fig. 6 compares them graphically. Stress, displacement and strain increase almost linearly with load, while the FoS falls from about 2.9 to about 1.6 as the load rises from 1667.7 N to 3041.1 N. The three materials behave very similarly, with stress differing by less than 1 %. Stainless steel gives the lowest stress and highest FoS at every load (for example 128.099 MPa and 1.616 at 3041.1 N), whereas mild steel has the lowest FoS (1.605 at 3041.1 N). Displacement is 0.096 mm at 1667.7 N and 0.163 mm at 3041.1 N for all three materials.

Table IV Static analysis results for all materials

Material	Load (N)	Disp. (mm)	Stress (MPa)	Strain ($\times 10^{-4}$)	FoS
Aluminum alloy	1667.7	0.096	72.042	5.095	2.873
	2354.4	0.130	100.184	7.076	2.066
	3041.1	0.163	128.451	9.124	1.612
Stainless steel	1667.7	0.096	71.823	5.078	2.882
	2354.4	0.129	100.113	7.072	2.068
	3041.1	0.163	128.099	9.124	1.616
Mild steel	1667.7	0.096	72.297	5.109	2.836
	2354.4	0.130	100.707	7.110	2.055
	3041.1	0.163	128.938	9.096	1.605

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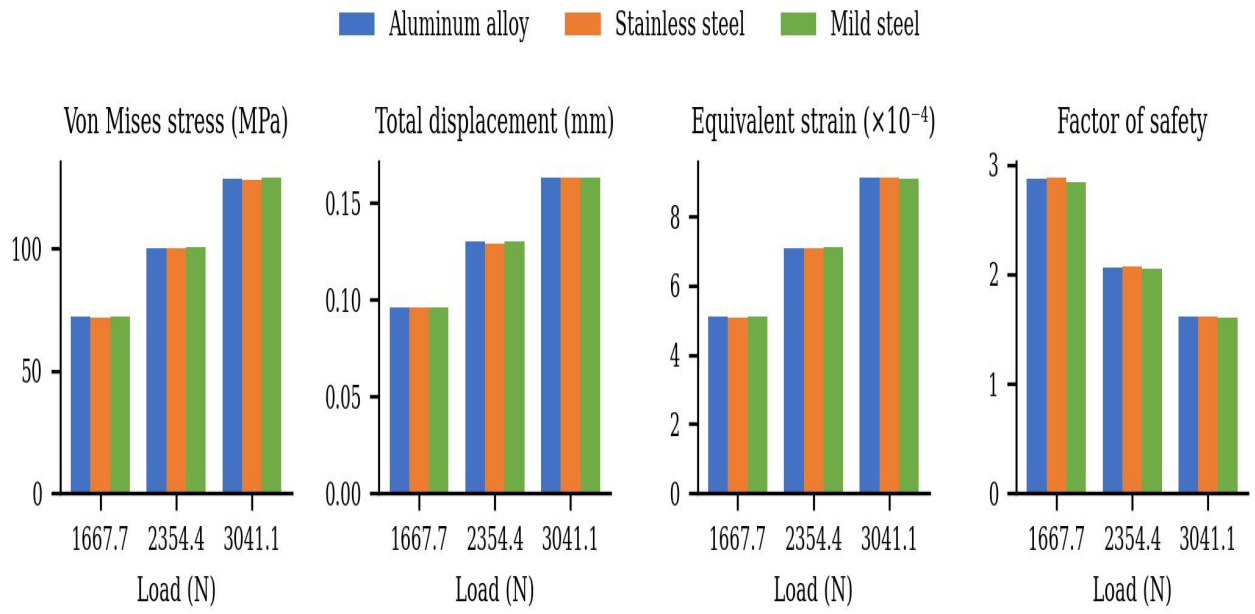


Fig. 6. Comparison of von Mises stress, displacement, strain and factor of safety for the three materials.

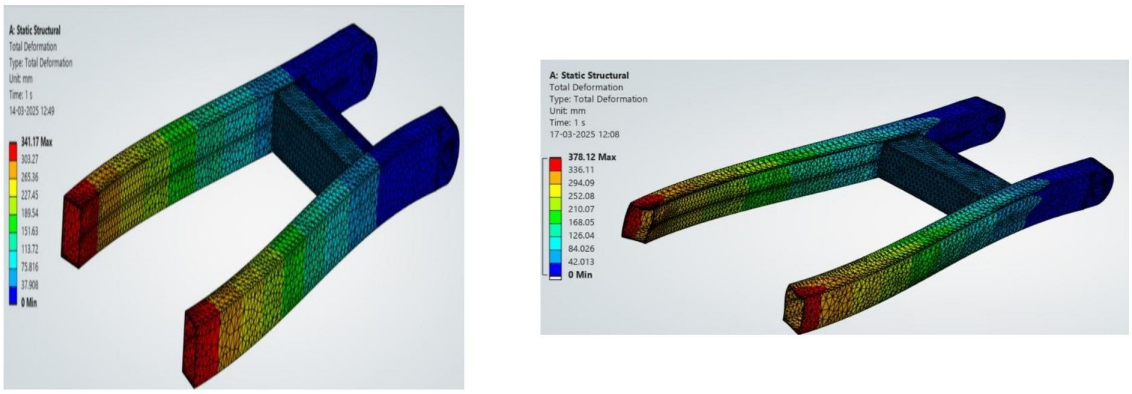
2 Static Analysis of the Swing Arm

Two swing arm designs, hollow and rhombus, were analyzed in ANSYS using structural steel and carbon fibre. The total deformation, equivalent stress and equivalent strain are given in Table V and shown in Figs. 7–9. For the hollow design, structural steel showed a total deformation of 341.17 mm, an equivalent stress of 22,759 MPa and a strain of 0.11616; carbon fibre showed 378.12 mm, 31,607 MPa and 0.87553. For the rhombus design, structural steel showed 200.05 mm, 12,682 MPa and 0.06978, and carbon fibre showed the lowest deformation of all cases (165.06 mm) with 20,893 MPa and a strain of 0.29175.

The rhombus design therefore gave lower deformation, stress and strain than the hollow design in both materials. Carbon fibre combined with the rhombus section reduced deformation by about 18 % relative to structural steel in the same section, showing its suitability for lightweight, performance-oriented electric vehicle designs. The absolute stress values in Table V are used here for relative comparison between the designs.

Design	Material	Def. (mm)	Stress (MPa)	Strain (mm/mm)
Hollow	Structural steel	341.17	22,759	0.11616
Hollow	Carbon fibre	378.12	31,607	0.87553
Rhombus	Structural steel	200.05	12,682	0.06978
Rhombus	Carbon fibre	165.06	20,893	0.29175

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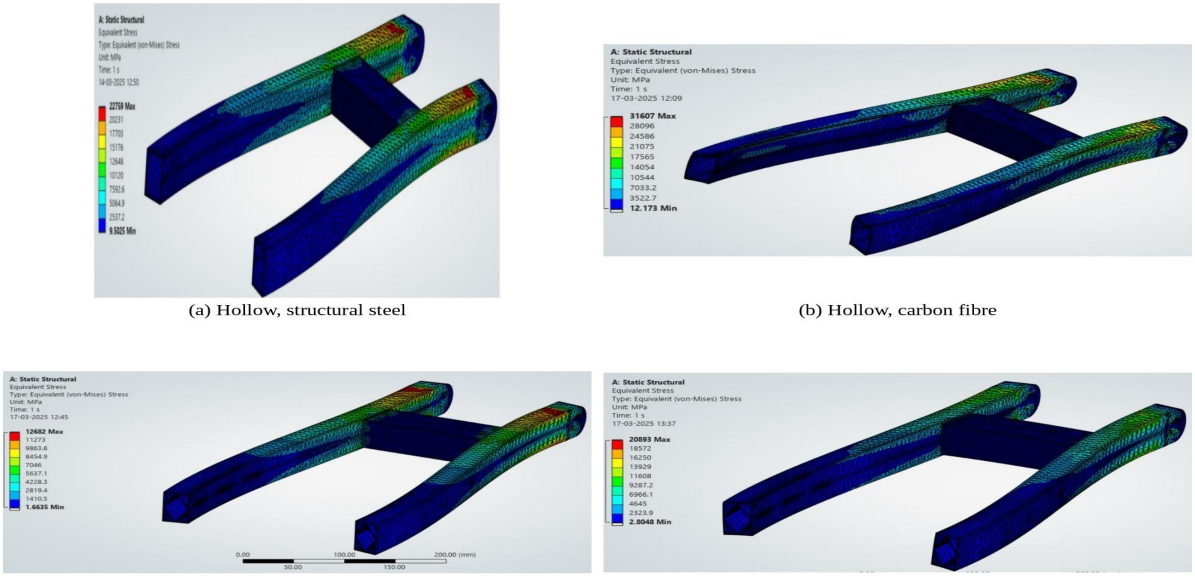
(a) Hollow, structural steel

(b) Hollow, carbon fibre

(c) Rhombus, structural steel

(d) Rhombus, carbon fibre

Fig. 7. Total deformation of the swing arm: hollow and rhombus designs in structural steel and carbon fibre.



(a) Hollow, structural steel

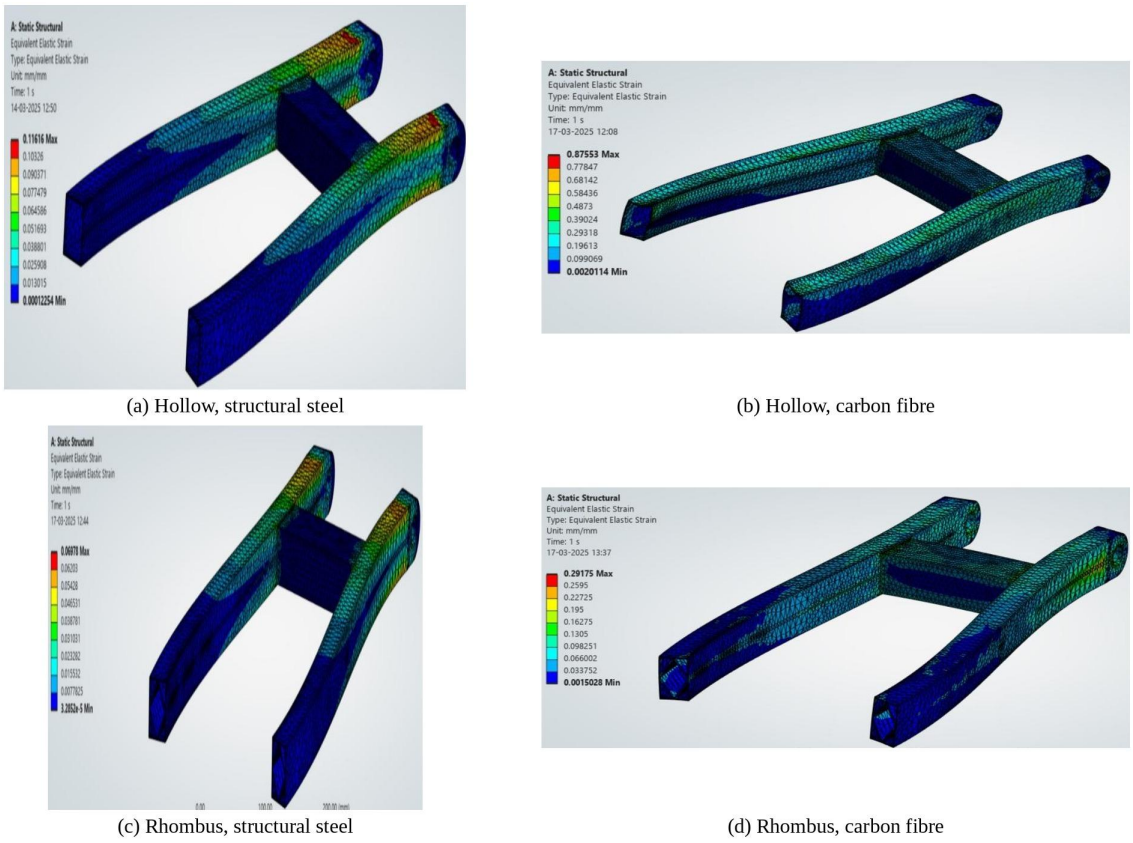
(b) Hollow, carbon fibre

(c) Rhombus, structural steel

(d) Rhombus, carbon fibre

Fig. 8. Equivalent (von Mises) stress of the swing arm: hollow and rhombus designs in structural steel and carbon fibre.

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(a) Hollow, structural steel

(b) Hollow, carbon fibre

(c) Rhombus, structural steel

(d) Rhombus, carbon fibre

Fig. 9. Equivalent elastic strain of the swing arm: hollow and rhombus designs in structural steel and carbon fibre.

VII. CONCLUSION

Static FEA of an e-bike chassis was carried out for aluminum alloy, stainless steel and mild steel under loads of 1667.7–3041.1 N, and the following conclusions are drawn:

1) All three materials carry the applied loads with FoS above 1.6 at the heaviest load, and the differences in stress, displacement and strain between them are marginal. A well-designed chassis shows minimal displacement, low strain and stress and a high FoS; on these criteria stainless steel is slightly better for chassis fabrication.

2) A high strength-to-weight ratio makes the chassis strong and robust while keeping it light, which improves performance and efficiency. Aluminum alloy has the highest strength-to-weight ratio (about 102 kN·m/kg against 31 and 26 kN·m/kg for stainless and mild steel).

3) The rhombus swing arm is safer than the hollow design, showing the lowest total deformation, equivalent stress and equivalent strain, and structural steel gave strong, robust behavior in both designs.

4) Stainless steel gives the heaviest structure, but thinner sections can be used to reduce weight if ductility and fatigue resistance remain adequate. For typical Indian road conditions a stronger, slightly heavier chassis is preferable to an ultra-light one, because it gives durability, lower maintenance and better load tolerance.

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