International Conference on Social Science & Humanities Trends

International Journal for Research Trends in Social Science & Humanities

Aug 2026

ISSN: 2584-2455

Structural and Dynamic Analysis of a Lightweight Electric Vehicle Chassis Using Finite Element Analysis

Abhinav Singh Dangi[1], Dr. Arun Kumar Yadav[2]

[1,2]Department of Mechanical Engineering, Dr. A. P. J. Abdul Kalam University, Indore, India

Abstract- The increasing demand for sustainable and energy-efficient transportation has accelerated the development of lightweight electric vehicles. Among the major structural components of an electric vehicle, the chassis plays a critical role in ensuring vehicle strength, stability, safety and dynamic performance. This study focuses on the structural and dynamic analysis of a lightweight electric vehicle chassis using Finite Element Analysis (FEA), investigating the effect of lightweight chassis design on stress distribution, deformation, vibration characteristics and overall vehicle performance. Lightweight materials and optimised structural configurations are considered to reduce vehicle mass while maintaining sufficient stiffness and crashworthiness, and static structural analysis and dynamic analysis are examined for evaluating chassis behaviour under different loading and operating conditions. Twelve studies published between 2013 and 2025 are reviewed and organised into three themes covering lightweight chassis design, lightweight materials with multi-material optimisation, and structural optimisation with crash performance. The reviewed evidence is consolidated into comparative tables that map each study to its vehicle class, method, principal finding and limitation, alongside a specification of the analysis types applied in lightweight chassis development and an assessment of vehicle class coverage across the corpus. Five research gaps are identified and mapped to corresponding research directions. The findings indicate that lightweight chassis optimisation improves energy efficiency, reduces structural stress concentration and enhances vehicle stability without compromising safety, and that Finite Element Analysis is an effective tool for designing lightweight and durable chassis systems for sustainable transportation.

Keywords- Electric vehicle; lightweight chassis; finite element analysis; structural analysis; dynamic analysis; chassis optimisation; stress analysis; lightweight materials; vehicle stability; energy efficiency.

I. Introduction

Electric vehicles have emerged as one of the most effective solutions for reducing environmental pollution, greenhouse gas emissions and dependence on fossil fuels. The rapid advancement of battery technologies and sustainable transportation systems has increased demand for efficient and lightweight electric vehicles. Among the factors affecting electric vehicle performance, vehicle weight is one of the most important parameters because it directly influences energy consumption, battery efficiency, acceleration, handling and driving range.

The chassis is the primary load-carrying structure of an electric vehicle and supports major components such as the battery pack, motor, suspension system, steering mechanism and passenger cabin. The design of a lightweight and structurally efficient chassis is therefore essential for improving vehicle performance and safety. However, reducing chassis weight should not compromise structural strength, stiffness, durability or crashworthiness, and advanced structural analysis and optimisation methods are consequently required in modern electric vehicle design.

Finite Element Analysis has become one of the most widely used techniques for evaluating chassis behaviour under various loading conditions. It allows engineers to analyse stress distribution, deformation, vibration response and dynamic characteristics of chassis structures before physical manufacturing. Through structural and dynamic analysis, designers can identify high-stress regions, optimise material distribution and improve chassis performance while minimising overall weight.

Lightweight materials such as aluminium alloys, high-strength steel and composite materials are increasingly used in electric vehicle chassis systems to achieve better strength-to-weight ratios. Topology optimisation and advanced design approaches have further enabled the development of lightweight chassis structures with improved rigidity and energy efficiency.

1. Objectives and Contributions of this Study

The main objective of this study is to perform structural and dynamic analysis of a lightweight electric vehicle chassis using Finite Element Analysis, evaluating the mechanical behaviour of the chassis under different loading conditions and investigating the effectiveness of lightweight design strategies in improving structural performance, stability and energy efficiency. The study makes four contributions. First, it consolidates twelve studies into a structured thematic review supported by comparative tables rather than narrative description alone. Second, it specifies the analysis types applied in lightweight chassis development, stating what each evaluates and which output quantities it produces, so that the distinction between structural and dynamic analysis is made concrete. Third, it assesses the vehicle classes represented in the corpus and the transferability of their findings, which matters because load cases and duty cycles differ substantially between vehicle types. Fourth, it identifies five research gaps and maps each explicitly to a corresponding research direction.

2. Organisation of the Paper

Section 2 reviews the literature across three themes and consolidates it in comparative tables. Section 3 sets out the identified research gaps. Section 4 concludes, and Section 5 details future work.

II. LITERATURE REVIEW

1. Lightweight Chassis Design in Electric Vehicles

Lightweight chassis design plays a major role in improving the efficiency and performance of electric vehicles, since reducing chassis weight decreases energy consumption, improves acceleration and increases driving range. Selem (2022) designed a light chassis for an urban electric vehicle and showed that such vehicles require compact lightweight structures providing sufficient strength while maintaining stability and passenger safety.

Several researchers have focused on lightweight chassis structures for competition and commercial electric vehicles. Tsirogiannis, Stavroulakis and Makridis (2019) applied finite element modelling and structural analysis to a Shell Eco Marathon competition chassis to evaluate strength and deformation characteristics under different loading conditions. Pang and Chun (2023) investigated trellis frame structures for electric scooters because of their high stiffness and reduced structural mass, and Zhang et al. (2021) showed that lightweight frame structures for low-load electric vehicles achieve improved load distribution and reduced stress concentration through optimised structural design.

Crashworthiness is another important factor in chassis development, since lightweight systems must provide adequate impact resistance and occupant protection during collisions. Li et al. (2019) applied robust design optimisation to improve both crash performance and structural reliability while reducing overall vehicle weight. De et al. (2020) demonstrated in the context of hybrid truck chassis design that lightweight structures can perform effectively under multiple road conditions and loading constraints, which is significant because it tests lightweight structures against varying rather than single load cases.

Figure 1: Lightweight chassis design approaches for electric vehicles

Figure 1 illustrates different lightweight chassis structures used in electric vehicles, including urban EV chassis, trellis frame structures and low-load vehicle frames. It highlights the relationship between reduced chassis weight, improved load distribution, enhanced vehicle stability and increased driving efficiency, and presents the role of crashworthiness and structural reliability in lightweight chassis development.

2. Lightweight Materials and Multi-Material Optimisation

The selection of suitable lightweight materials is critical for electric vehicle chassis development. Singh (2024) reviewed lightweight metals and alloys in electric vehicle manufacturing and reported that aluminium alloys, magnesium alloys and high-strength steel are commonly used because they provide better strength-to-weight ratios than traditional steel materials.

Composite materials have also gained attention in electric vehicle body and chassis structures. Liu et al. (2013) showed that carbon twill weave fabric composites offer excellent lightweight properties and high structural stiffness in body applications, reducing vehicle weight significantly while maintaining crash resistance and durability. Durgam et al. (2021) conducted experimental and numerical studies of chassis materials under various loading conditions, highlighting the importance of material testing and structural validation in material selection. Theirs is the only study in the corpus to combine physical testing with simulation for material characterisation, which makes it particularly relevant to the validation gap identified in Section 3.

Ju (2025) proposed a multi-material optimisation system that combines different materials in specific regions according to stress and performance requirements, allowing structural efficiency, manufacturability and cost to be optimised simultaneously. This represents a conceptual advance over single-material substitution, since it treats material assignment as a spatially varying design variable rather than a global choice. Ha-Upala et al. (2021) demonstrated through a simple lightweight design for small electric vehicles that low-cost materials and simplified structures can improve accessibility and mobility for elderly users, showing that lightweighting also serves objectives beyond efficiency.

Figure 2: Lightweight materials and multi-material optimisation in EV chassis

Figure 2 presents various lightweight materials used in electric vehicle chassis manufacturing, including aluminium alloys, magnesium alloys, high-strength steel and carbon fibre composites. It also demonstrates the concept of multi-material optimisation, where different materials are combined according to structural stress requirements, explaining how material optimisation improves structural efficiency, durability, manufacturability and vehicle performance while reducing overall weight.

3. Structural Optimisation and Crash Performance Analysis

Structural optimisation techniques are widely used in chassis development to achieve weight reduction without compromising safety and durability. Finite Element Analysis is among the most commonly used methods for analysing stress distribution, deformation and structural performance under different loading conditions, and Tsirogiannis et al. (2019) used it to identify high-stress regions and support the development of optimised lightweight designs.

Topology optimisation has become an advanced technique for lightweight electric vehicle development. Liu et al. (2025) applied topology optimisation to a frame-type aluminium body while explicitly considering crash performance, demonstrating significant reductions in body mass while preserving structural integrity during crash conditions. Including crash performance as a constraint within the optimisation, rather than checking it afterwards, is methodologically stronger than sequential treatment.

Crashworthiness analysis is an important aspect of structural optimisation because lightweight chassis structures must absorb impact energy effectively and protect passengers during collisions. Li et al. (2019) used robust optimisation based on six-sigma design approaches to improve crash reliability and reduce design uncertainty, improving both safety performance and manufacturing quality. Their explicit treatment of uncertainty distinguishes this study from deterministic optimisation approaches elsewhere in the corpus.

De et al. (2020) showed that optimised lightweight structures improve vehicle durability and dynamic stability under multiple road conditions, and Zhang et al. (2021) showed that optimised frame structures for low-load electric vehicles deliver improved performance with reduced material usage. Structural optimisation and crash analysis are therefore essential for developing lightweight, safe and durable electric vehicle chassis systems.

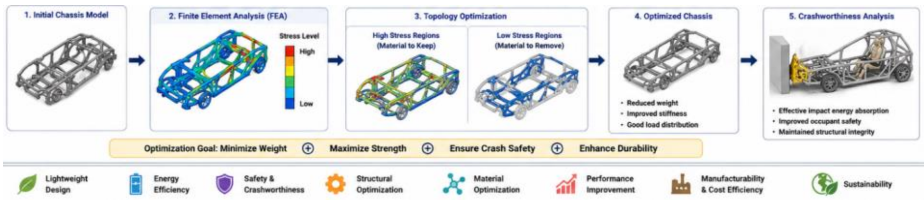

Figure 3: Structural optimisation and crashworthiness analysis of electric vehicle chassis

Figure 3 illustrates the structural optimisation process of an electric vehicle chassis using Finite Element Analysis and topology optimisation methods. It identifies high-stress and low-stress regions within the chassis structure and shows how unnecessary material is removed to achieve lightweight design, and demonstrates crashworthiness analysis, impact energy absorption and improved passenger safety during collision conditions while maintaining structural stiffness and durability.

4. Consolidated Summary of the Reviewed Literature

Table 1 organises the reviewed studies by theme, and Table 2 compares each study on vehicle class, method, principal finding and the limitation it leaves unresolved. The limitation column reflects the assessment of this study rather than statements made by the original authors.

Table 1: Thematic organisation of the reviewed literature

Theme	Analytical focus	Studies	Count
T1. Lightweight chassis design	Chassis configuration, frame structures and load distribution across vehicle types	Selem (2022); Tsirogiannis et al. (2019); Pang & Chun (2023); Zhang et al. (2021); De et al. (2020)	5

Theme	Analytical focus	Studies	Count
T2. Lightweight materials and multi-material optimisation	Material selection, composite structures, material testing and spatially varying material assignment	Singh (2024); Liu et al. (2013); Durgam et al. (2021); Ju (2025); Ha-Upala et al. (2021)	5
T3. Structural optimisation and crash performance	Topology optimisation with crash constraints and robust optimisation under uncertainty	Li et al. (2019); Liu et al. (2025)	2

Table 2: Comparative summary of the reviewed studies

Study	Vehicle class	Method	Principal reported finding	Limitation for structural and dynamic analysis
Selem (2022)	Urban electric vehicle	Light chassis design	Compact lightweight structures maintain strength and stability	Design-stage study; dynamic behaviour not evaluated
Tsirogiannis et al. (2019)	Competition (Shell Eco Marathon)	Design, modelling and finite element analysis	FEA identifies strength and deformation characteristics	Competition duty cycle differs from road vehicle loading
Pang & Chun (2023)	Electric scooter	Trellis frame structural analysis	Trellis frames deliver high stiffness at reduced mass	Two-wheeler geometry; limited transfer to four-wheel chassis
Zhang et al. (2021)	Low-load electric vehicle	Lightweight frame design	Optimised frames improve load distribution and reduce stress concentration	Low-load case; higher payload conditions untested
De et al. (2020)	Hybrid truck	Design under multiple road conditions	Lightweight structures perform under varied road and load constraints	Commercial vehicle scale; passenger EV transfer partial
Singh (2024)	General EV manufacturing	Review of lightweight metals and alloys	Alloys provide superior strength-to-weight ratios	Review only; no structural case evaluated
Liu et al. (2013)	Electric vehicle body	Carbon twill weave composite design	Composites reduce weight while retaining stiffness and crash resistance	Body structure rather than chassis frame; composite cost not addressed

Study	Vehicle class	Method	Principal reported finding	Limitation for structural and dynamic analysis
Durgam et al. (2021)	EV chassis materials	Experimental and numerical material studies	Material testing and validation are essential to selection	Material-level; full chassis dynamic response not analysed
Ju (2025)	EV chassis	Multi-material optimisation system	Regional material assignment optimises efficiency, cost and manufacturability	Optimisation framework; manufacturing of multi-material joints not addressed
Ha-Upala et al. (2021)	Small EV for elderly users	Simple lightweight design approach	Low-cost simplified structures improve accessibility	Simplified design; limited structural evaluation reported
Li et al. (2019)	Electric vehicle	Six-sigma robust design optimisation	Robust optimisation improves crash reliability under uncertainty	Crash-focused; vibration and fatigue behaviour not covered
Liu et al. (2025)	Pure EV aluminium frame body	Topology optimisation with crash constraints	Mass reduction achieved while preserving crash integrity	Static and crash cases; operational dynamic response not evaluated

Three observations follow from Table 2. First, the corpus is dominated by static and crash analysis: no reviewed study evaluates operational vibration response, modal behaviour or fatigue under service loading, which is precisely the dynamic dimension this work addresses. Second, only Durgam et al. (2021) reports physical experimental work alongside simulation, so the validation gap identified in Section 3 is evidenced by the corpus itself. Third, the twelve studies span urban cars, competition vehicles, scooters, low-load vehicles, small mobility vehicles and hybrid trucks, so findings must be read against the load case and duty cycle of each vehicle class rather than transferred directly, as Table 4 sets out.

5. Analysis Types in Lightweight Chassis Development

Table 3 specifies the analysis types applied across the corpus, stating what each evaluates, the principal output quantities it produces and the studies that report it. Setting these out separately makes the distinction between structural and dynamic analysis concrete and shows where the current literature concentrates.

ISSN: 2584-2455

Table 3: Analysis types applied in lightweight chassis development

Analysis type	What it evaluates	Principal output quantities	Reported in
Static structural analysis	Chassis response to steady applied loads such as payload, battery mass and mounting reactions	Stress distribution, deformation, stiffness	Tsirogiannis et al. (2019); Zhang et al. (2021); Selem (2022)
Topology optimisation	Material layout that satisfies stiffness requirements at minimum mass	Optimised material distribution, mass reduction	Liu et al. (2025)
Multi-material optimisation	Assignment of different materials to regions according to local stress demand	Regional material selection, cost and manufacturability trade-off	Ju (2025)
Crashworthiness analysis	Structural response and energy absorption during impact	Impact energy absorption, intrusion, occupant protection measures	Li et al. (2019); Liu et al. (2025)
Robust and uncertainty-based optimisation	Sensitivity of performance to variation in design and manufacturing parameters	Reliability indices, design margins	Li et al. (2019)
Multi-condition load analysis	Structural behaviour across varying road and loading scenarios	Comparative stress and durability across load cases	De et al. (2020)
Experimental material and structural testing	Physical verification of predicted material and structural behaviour	Measured strength, stiffness and validation error	Durgam et al. (2021)
Dynamic and vibration analysis	Modal behaviour, vibration response and ride stability under operating conditions	Natural frequencies, mode shapes, vibration amplitude	Not addressed in the reviewed corpus

The final row states the position plainly: dynamic and vibration analysis is absent from the reviewed corpus even though several studies note its importance. This is the strongest single justification for the present study, since it establishes the gap from the literature itself rather than by assertion.

6. Vehicle Class Coverage of the Reviewed Corpus

Because load cases, duty cycles and design constraints differ substantially between vehicle types, Table 4 states the vehicle class of each study and assesses how directly its findings transfer to a compact passenger electric vehicle chassis.

Table 4: Vehicle class coverage and transferability

Vehicle class	Studies	Transferability to a compact passenger EV chassis
Urban and compact electric vehicles	Selem (2022); Ha-Upala et al. (2021)	Direct; comparable scale, payload and duty cycle
Low-load electric vehicles	Zhang et al. (2021)	High; similar structural scale with lighter loading assumptions
Pure electric vehicle body and frame	Liu et al. (2025); Liu et al. (2013)	High; frame and body structures with passenger vehicle load cases
Competition vehicles	Tsirogiannis et al. (2019)	Partial; extreme efficiency focus and atypical duty cycle
Two-wheeled electric vehicles	Pang & Chun (2023)	Partial; frame concept transfers, geometry and load path do not
Commercial and hybrid trucks	De et al. (2020)	Partial; multi-condition method transfers, structural scale does not
Material and method studies without a fixed vehicle class	Singh (2024); Durgam et al. (2021); Ju (2025); Li et al. (2019)	General; applicable across classes as design methods rather than designs

Five studies transfer directly or with high confidence, three transfer only partially, and four are class-independent method contributions. The evidential base for compact passenger vehicle chassis design is therefore adequate but narrower than the corpus size suggests, and results drawn from scooters, trucks and competition vehicles should be treated as methodological rather than quantitative precedents.

III. RESEARCH GAP

Several studies have addressed lightweight electric vehicle chassis design and structural optimisation using Finite Element Analysis, investigating lightweight materials, topology optimisation methods and crashworthiness analysis for improving electric vehicle performance. Despite this progress, five research gaps remain. They are stated below and mapped to corresponding research directions in Table 5.

First, many existing studies concentrate on static structural analysis and weight reduction without giving sufficient attention to the combined structural and dynamic behaviour of lightweight chassis systems. As Table 3 shows, dynamic and vibration analysis is absent from the reviewed corpus entirely.

Second, limited research has been conducted on the integrated analysis of stress distribution, deformation, vibration characteristics and dynamic stability under practical operating conditions. Most studies address either lightweight material selection or structural optimisation individually, while fewer investigate the combined influence of lightweight materials and dynamic loading on chassis performance.

Third, there is a lack of comprehensive experimental validation for lightweight chassis systems. Many studies rely primarily on numerical simulation without considering real-world road conditions, vibration effects, fatigue behaviour and long-term structural durability.

Fourth, the influence of lightweight chassis design on ride comfort, handling stability and energy efficiency has not been fully explored, so the vehicle-level consequences of structural decisions remain largely unquantified.

Finally, limited studies address lightweight chassis development for compact urban electric vehicles and low-cost transportation systems, where both structural efficiency and manufacturability are important considerations.

There is therefore a need for further research on lightweight electric vehicle chassis systems combining structural optimisation, dynamic analysis, lightweight materials and practical design constraints. This study aims to address these gaps by performing detailed structural and dynamic analysis of a lightweight electric vehicle chassis using Finite Element Analysis to evaluate stress behaviour, deformation characteristics, vibration response and overall structural performance.

Table 5: Research gaps mapped to corresponding research directions

No.	Identified research gap	Corresponding research direction
G1	Dynamic and vibration behaviour not analysed alongside static performance	Modal and vibration analysis reported together with static stress and deformation results
G2	Material selection and structural optimisation treated separately	Coupled studies evaluating material choice and structural configuration under dynamic loading
G3	Limited experimental validation of simulation results	Physical testing covering vibration response, fatigue behaviour, crash performance and durability
G4	Vehicle-level consequences unquantified	Assessment of ride comfort, handling stability and energy efficiency arising from chassis design
G5	Compact urban and low-cost vehicles under-represented	Chassis studies targeted at compact urban EVs with manufacturability and cost constraints included

IV. CONCLUSION

This study investigated the structural and dynamic analysis of a lightweight electric vehicle chassis using Finite Element Analysis. The research highlighted the importance of lightweight chassis design in improving electric vehicle efficiency, stability and structural performance, since lightweight systems reduce overall vehicle mass, resulting in lower energy consumption, improved battery efficiency and enhanced driving range.

Finite Element Analysis proved to be an effective tool for evaluating stress distribution, deformation, stiffness and vibration characteristics of the chassis structure under different loading conditions. The analysis demonstrated that optimised lightweight designs can maintain structural integrity and safety while reducing unnecessary material usage, and that lightweight materials and optimised structural configurations contribute to improved load distribution and reduced stress concentration.

Three observations emerged from the comparative synthesis. Dynamic and vibration analysis is absent from the reviewed corpus even though several studies note its importance, which establishes the need for this work from the literature itself rather than by assertion. Only one reviewed study reports physical experimental work alongside simulation, so the validation gap is likewise evidenced by the corpus. And the twelve studies span vehicle classes from scooters to hybrid trucks, so their findings should be treated as methodological rather than quantitative precedents for compact passenger vehicle design.

The study further showed that dynamic analysis is essential for understanding vibration behaviour, ride stability and structural response during vehicle operation, and that proper structural optimisation improves both static and dynamic performance while ensuring passenger safety and chassis durability. Overall, the research confirms that combining lightweight design principles, structural optimisation techniques and Finite Element Analysis can significantly improve the performance and sustainability of electric vehicle chassis systems.

Future Work

Future research can extend this study in several directions, presented here in order of priority. First, and most immediately, experimental validation of lightweight chassis designs should be undertaken under real driving conditions, with physical testing evaluating vibration response, fatigue behaviour, crash performance and long-term structural durability. This addresses the gap most clearly evidenced by the corpus itself. Second, advanced dynamic analysis should be performed under different road conditions, impact loads and suspension interactions to improve ride comfort and handling stability, extending the analysis beyond the static and crash cases that dominate the existing literature.

Third, multi-objective optimisation techniques considering weight reduction, crashworthiness, cost efficiency, manufacturability and sustainability should be applied so that competing design requirements are resolved within a single procedure rather than sequentially.

Fourth, advanced composite materials and hybrid material combinations should be investigated to achieve greater weight reduction while maintaining structural strength and manufacturability, with joint design for multi-material structures addressed explicitly.

Fifth, smart sensors and intelligent chassis monitoring systems should be integrated to enable real-time structural health monitoring and improved vehicle safety.

Finally, artificial intelligence and machine learning techniques may be integrated with Finite Element Analysis to develop automated lightweight chassis optimisation systems, reducing the manual iteration currently required in design exploration.

REFERENCES

1. Selem, A. T. (2022, September). Design of a light chassis for an urban electric vehicle. In The International Undergraduate Research Conference (Vol. 6, No. 6, pp. 1-6). The Military Technical College.
2. Li, Z., Duan, L. B., Cheng, A. G., Yao, Z. P., Chen, T., & Yao, W. (2019). Lightweight and crashworthiness design of an electric vehicle using a six-sigma robust design optimization method. Engineering Optimization, 51(8), 1393-1411.
3. Tsirogiannis, E. C., Stavroulakis, G. E., & Makridis, S. S. (2019). Electric car chassis for shell eco marathon competition: Design, modelling and finite element analysis. World Electric Vehicle Journal, 10(1), 8.
4. Liu, Q., Lin, Y., Zong, Z., Sun, G., & Li, Q. (2013). Lightweight design of carbon twill weave fabric composite body structure for electric vehicle. Composite Structures, 97, 231-238.
5. Durgam, S., Deshmukh, V. M., Jagtap, A. P., Sable, M. J., & Gawai, N. M. (2021, March). Experimental and numerical studies on materials for electric vehicle chassis. In IOP Conference Series: Materials Science and Engineering (Vol. 1126, No. 1, p. 012073). IOP Publishing.
6. Ha-Upala, N., Dangeam, S., Bhumkittipich, K., Apiratikul, P., & Bhumkittipich, P. (2021, October). Simple lightweight design of small electric vehicle for elderly society. In 2021 24th International Conference on Electrical Machines and Systems (ICEMS) (pp. 685-688). IEEE.
7. Zhang, J., Deng, Y., Zheng, B., & Qi, X. (2021). Lightweight design of low-load electric vehicle frame. Journal of Computational Methods in Science and Engineering, 21(2), 423-433.
8. Ju, Z. (2025, June). Research on multi-material optimization system in lightweight design of electric vehicle chassis. In 2025 IEEE 3rd International Conference on Image Processing and Computer Applications (ICIPCA) (pp. 948-953). IEEE.
9. Liu, B., Yang, J., Zhang, X., & Li, X. (2025). Topology optimization and lightweight platform development of pure electric vehicle frame-type aluminum body considering crash performance. Journal of Materials Engineering and Performance, 34(3), 2424-2434.
10. Pang, G. C., & Chun, T. W. (2023). An in-depth analysis of lightweight chassis design for electric scooters using trellis frame structures. Journal of Innovation and Technology, 2023.
11. Singh, R. (2024). Lightweight metals and alloys in electric vehicle manufacturing: Enhancing performance and efficiency. International Journal of Science and Research Archive, 13, 1735-1742.
12. De, S., Singh, K., Seo, J., Kapania, R. K., Ostergaard, E., Angelini, N., & Aguero, R. (2020). Lightweight chassis design of hybrid trucks considering multiple road conditions and constraints. World Electric Vehicle Journal, 12(1), 3.