International Journal of Engineering, Science and Humanities

An international peer reviewed, refereed, open access journal

Impact Factor: 8.3 www.ijesh.com ISSN: 2250 3552

Lightweight Materials for Electric Vehicle

Dr. Pallavi Dikkar[1]

[1]Assistant Proffesor, MCT'S Rajiv Gandhi Institute of Technology, Mumbai.

Pallavi.dikkar@mctrgit.ac.in

Sarvesh Sawant[2]

[2]MCT'S Rajiv Gandhi Institute of Technology, Mumbai.

.sarveshsawant22012007@gmail.com

Hardik[3]

[3]MCT'S Rajiv Gandhi Institute of Technology, Mumbai.

antispirial@gmail.com

Abstract:

The rapid adoption of electric vehicles (EVs) relies on overcoming challenges in driving range, cost, and energy efficiency, with lightweight materials playing a crucial role. Reducing vehicle mass directly improves performance, increasing driving range by about 8–10% for every 10% weight reduction. A multi-material approach combining Advanced High-Strength Steels (AHSS), aluminum alloys, magnesium alloys, and polymer composites offers the best results. Aluminum is widely used due to its balance of strength and cost, while Carbon Fiber Reinforced Polymers (CFRP) provide greater weight savings but are expensive and difficult to recycle. Although light weighting enhances range, performance, and enables battery downsizing, challenges such as high material costs, manufacturing complexity, and recycling issues remain.

Keywords:

Lightweight materials, Electric vehicles, Aluminum, AHSS, Magnesium, CFRP, Weight reduction, Battery efficiency, Driving range, Composites

1.Introduction

The global shift toward sustainable transportation has significantly increased the development and adoption of electric vehicles (EVs). Unlike conventional internal combustion engine vehicles, electric vehicles operate using electric motors powered by rechargeable battery systems. With growing environmental concerns and the need to reduce greenhouse gas emissions, EVs have emerged as a cleaner and more energy efficient alternative for modern transportation. One of the major challenges in electric vehicle design is improving driving range and overall efficiency. Since EVs rely entirely on battery power, vehicle weight plays a crucial role in determining performance, acceleration, and energy consumption. Heavier vehicles require more energy to move, which directly reduces battery efficiency and driving range. Therefore, reducing vehicle weight has become a key engineering strategy in EV development. Lightweight materials such as aluminum alloys, high strength steel, magnesium alloys, and carbon fiber composites are increasingly being used in electric vehicle manufacturing. These materials offer high strength to weight ratios, improved durability, and better structural performance compared to traditional materials. By replacing heavier components with lightweight alternatives, manufacturers can enhance battery performance, increase range, and improve vehicle safety.

2.Literature Review

The transition from Internal Combustion Engine (ICE) vehicles to Electric Vehicles (EVs) has highlighted a significant challenge: Battery Weight. Current lithium-ion battery packs add approximately 400kg to 600kg to a vehicle's curb weight. Literature suggests that for every 10% reduction in vehicle weight, the driving range increases by approximately 6–8%. 2.1 Aluminum and Advanced High-Strength Steel (AHSS) Recent studies by the International Aluminum Institute (2024) indicate that aluminum is the most preferred material for EV chassis because it is 30-40% lighter than traditional steel. However, research by the World Auto Steel organization argues that Advanced High-Strength Steel (AHSS) remains more cost-effective and has a lower carbon footprint during the manufacturing phase compared to aluminum. 2.2 Magnesium Alloys and Composites Research into Magnesium alloys shows they are 33% lighter than aluminum, but their application is limited due to high corrosion rates and manufacturing costs. Furthermore, Carbon Fiber Reinforced Polymers (CFRP) have been identified in the literature as the "ultimate" lightweight material. While CFRP offers the highest strength-to-weight ratio, current research focuses on reducing its high production cost to make it viable for mass-market EVs beyond luxury models like the BMW i3. 2.3 Impact on Battery Efficiency Schmitt et al. (2025) demonstrated that light weighting does not just improve range; it allows for "secondary weight saving." By reducing the body weight, engineers can use smaller motors, smaller brakes, and smaller battery packs to achieve the same performance, creating a positive cycle of efficiency.

Research/Org	Focus Material	Key Finding
Intl.Aluminum Institute	Aluminum Alloy	40% weight saving compared to mild steel
B-pillar & passenger cage	Press-hardened AHSS (22MnB5	Better crash resistance and lower production cost
Roof structure	CFRP	High weight reduction but high repair cost
Battery floor protection	AHSS / Aluminum skid plates	Excellent for engine cradles but prone to corrosion

3. Aim of the Study

3.1 Primary Objective The main goal of this research is to evaluate the role of advanced lightweight materials in the structural design and performance of Electric Vehicles (EVs). This report aims to identify how weight reduction directly influences battery efficiency and driving range.

3.2 Specific Research Goals

- **Comparative Analysis:** To compare the physical properties (density, tensile strength, and durability) of Aluminum, Advanced High-Strength Steel (AHSS), Magnesium, and Carbon Fiber.
- **Performance Evaluation:** To analyze the "Secondary Weight Saving" effect, where reducing body weight allows for smaller, lighter batteries and motors.
- **Sustainability Assessment:** To examine the recyclability and environmental impact of these materials compared to traditional mild steel.
- **Cost-Benefit Analysis:** To determine the economic feasibility of using expensive composites like Carbon Fiber in mass-market electric cars.

4. METHODOLOGY

4.1 Research Design

This report adopts a Descriptive and Comparative Research Design. Due to the technical nature of the topic, the study focuses on a systematic review of existing engineering data and automotive industry standards. The goal is to evaluate the trade-offs between material weight, mechanical strength, and production cost.

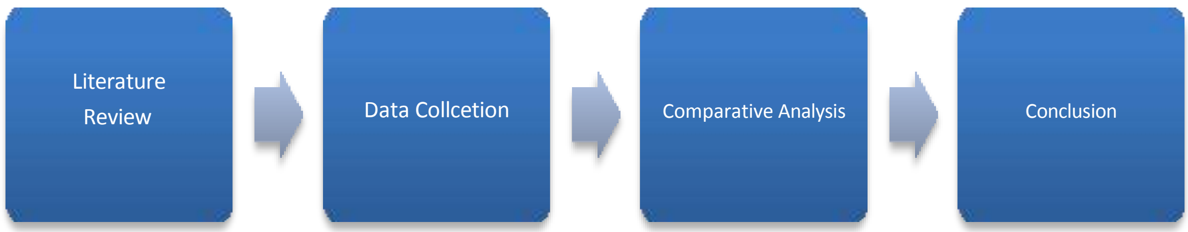
4.2 Data Collection Sources

- To ensure high technical accuracy, data was gathered from the following professional sources:
- Peer-Reviewed Journals: Materials Science and Engineering (Elsevier), Springer, and IEEE Xplore.
- Industry Reports: Technical white papers from Tesla, Inc., BMW Group, and the International Aluminum Institute.
- Material Databases: MatWeb and ASM International for precise density (g/cm^3) and tensile strength (MPa) values.

4.3 Evaluation Parameters

1. The materials selected for this study (Aluminum, High-Strength Steel, Magnesium, and Carbon Fiber) were analyzed based on a specific set of criteria essential for Electric Vehicle (EV) manufacturing:
2. Mass Reduction Potential: The percentage of weight saved when replacing traditional mild steel.
3. Specific Strength: The strength-to-weight ratio, determining the safety-to-mass efficiency.
4. Cost-to-Weight Ratio: Evaluating if the weight saved justifies the increase in manufacturing price.
5. Environmental Impact: Assessing recyclability and the carbon footprint of the material production phase.

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open access journal
Impact Factor: 8.3 www.ijesh.com ISSN: 2250 3552



5. TYPES OF MATERIALS

5.1 Aluminum Alloys

Aluminum is the most widely adopted lightweight material in the EV industry due to its excellent balance between cost, weight, and manufacturability.

- Properties: Low density, high corrosion resistance, and high thermal conductivity.
- Mass Reduction: Replacing traditional steel with aluminum can reduce component weight by 30–50%.
- EV Application: Primarily used in body panels, chassis structures, and battery enclosures (to help dissipate heat).

5.2 Advanced High-Strength Steel (AHSS)

AHSS allows engineers to meet strict safety standards while using thinner, lighter components compared to conventional mild steel.

- Properties: Multi-phase microstructure (e.g., Dual Phase steel) offering tensile strengths from 440 MPa to over 1000 MPa.
- Mass Reduction: Typically offers a 15–25% weight saving.
- EV Application: Used in "crash management" zones, such as B-pillars and side- impact beams, to protect the battery pack and passengers.

5.3 Magnesium Alloys

Magnesium is the lightest of all structural metals, making it highly attractive for non- structural and semi-structural EV parts.

- Properties: Extremely low density ($\approx$ 1.8 g/cm^3), 33% lighter than aluminum and 75% lighter than steel.
- Mass Reduction: Can achieve weight savings of 30–70%.
- EV Application: Common in steering wheels, seat frames, and gearbox housings. Its high damping capacity also helps reduce vehicle noise and vibration.

5.4 Carbon Fiber Reinforced Polymers (CFRP)

CFRP represents the pinnacle of lightweighting technology, offering the highest strength-to-weight ratio available.

- Properties: Consists of carbon fibers embedded in a resin matrix; it is non-corrosive and has excellent fatigue resistance.
- Mass Reduction: Offers a massive 50–70% weight reduction over traditional steel.
- EV Application: High-end EV "safety cells" (e.g., BMW i3) and roof structures. However, high production costs and recycling difficulties remain the primary challenges for mass-market

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open access journal
Impact Factor: 8.3 www.ijesh.com ISSN: 2250 3552

adoption.

6. ANALYSIS (Continued)

6.1 Cost-Benefit Analysis of Lightweight Materials

The adoption of lightweight materials in EVs involves a careful trade-off between higher upfront material and manufacturing costs versus long-term savings in energy, battery sizing, and operational efficiency. The decision is driven not just by engineering performance but by the total cost of ownership across the vehicle's lifetime.

Material cost to save 1 kg (compared to conventional steel):

AHSS: $1–3/kg saved — lowest cost, reuses existing stamping infrastructure

Aluminum alloys: $3–6/kg saved — moderate cost, new tooling and joining equipment needed

Magnesium alloys: $8–15/kg saved — high cost, requires controlled casting environments

GFRP: $5–10/kg saved — moderate-high, longer cycle times in production

CFRP: $30–60/kg saved — very high, requires autoclaves or resin transfer moulding (RTM)

Break-even analysis — 200 kg weight reduction using aluminum:

Additional material + manufacturing cost: approximately ■70,000–■1,00,000 per vehicle

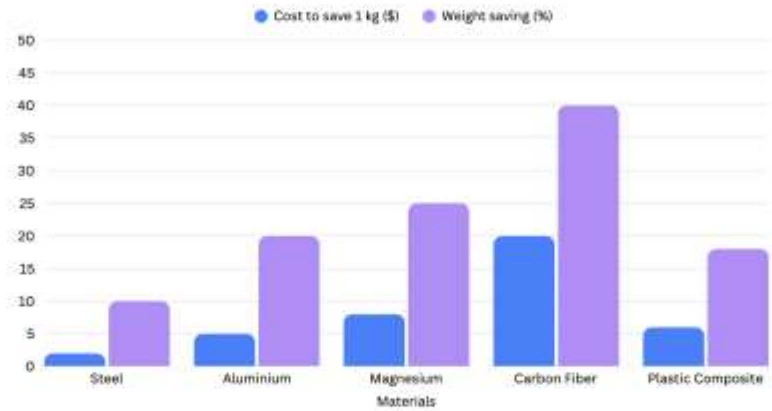
Electricity savings over 1,50,000 km lifetime: approximately ■1,10,000–■1,80,000

Net benefit: positive return over vehicle lifetime — making aluminum the most commercially viable option for mass-market EVs

For CFRP, the additional cost is $6,000–$12,000 per vehicle with only $1,500–$2,500 in energy savings — meaning it only makes financial sense in high-performance or premium EVs where buyers pay for performance rather than running cost savings.

Material	Cost to Save 1 kg	Weight Saving vs Steel
AHSS	$1–3	20–35%
Aluminum Alloys	$3–6	40–50%
Magnesium Alloys	$8–15	50–65%
GFRP	$5–10	25–35%
CFRP	$30–60	50–70%

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open access journal
Impact Factor: 8.3 www.ijesh.com ISSN: 2250 3552



6.2 Safety and Structural Integrity

Light weighting cannot come at the expense of passenger safety. Modern EVs must comply with Euro NCAP, FMVSS (USA), and IIHS crash standards. Each material is strategically placed in the vehicle body based on its specific crash behavior and energy absorption characteristics.

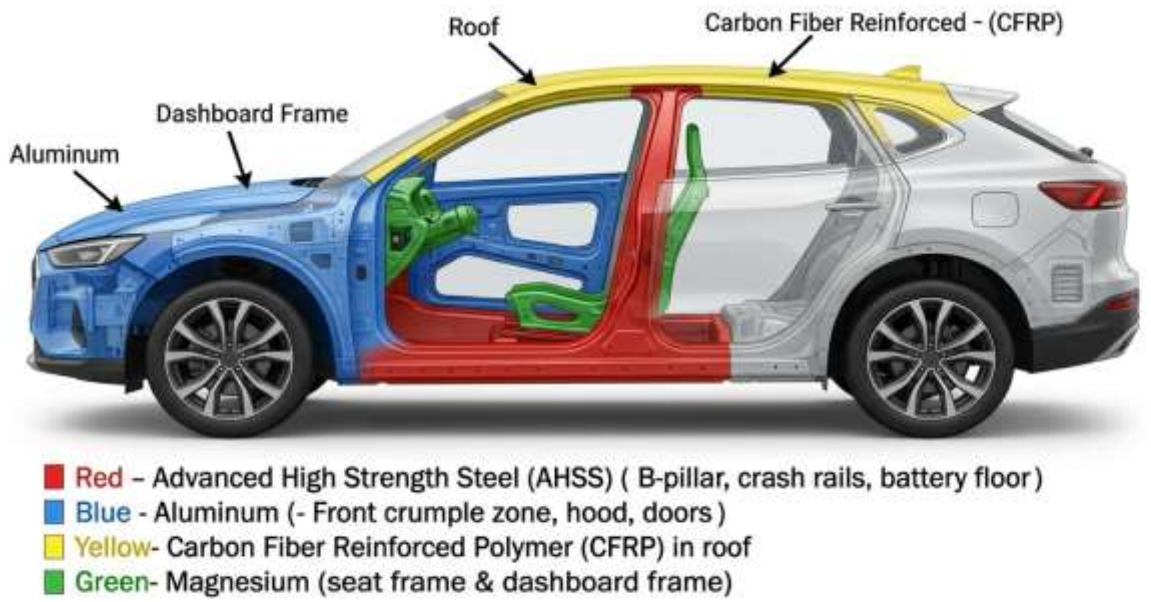
Crash zone to material mapping:

Crash Zone	Material Used	Reason
Front crumple zone	Aluminum extrusions	Progressive energy absorption through controlled folding. Audi e-t
B-pillar & passenger cage	Press-hardened AHSS (22MnB	T) ensile strength 1,500–2,000 MPa. Prevents cabin intrusion durin
Roof structure	CFRP	High specific stiffness resists rollover crushing at minimal weight.
Battery floor protection	AHSS / Aluminum skid plates	Shields battery pack from road debris. Tesla uses dedicated steel
Door beams	AHSS or Al extrusions	Resist side-pole impacts as per FMVSS 214 standard.

Material	Tensile Strength (MPa)	Failure Mode
Mild Steel	270–370	Ductile, progressive
AHSS	600–2,000	Ductile, controlled
Aluminum 6xxx	200–350	Ductile, some tearing
CFRP	600–1,000	Brittle — needs crush initiators
Magnesium	180–280	Brittle

Note: CFRP's brittle failure mode requires special 'crush initiators' — geometric features that force progressive, controlled collapse rather than sudden CFRP.

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open access journal
Impact Factor: 8.3 www.ijesh.com ISSN: 2250 3552



6.3 Sustainability and Lifecycle Considerations

The environmental impact of lightweight materials must be assessed across three phases: production, use phase, and end-of-life. Only by examining all three phases can the true sustainability benefit of light weighting be established.

Production phase — Embodied energy and Cooper kg of material:

Material	Embodied Energy (MJ/kg)	CO■Emitted (kg/kg)
Recycled Steel	10–15	0.5–1.0
Virgin Steel	25–35	1.8–2.5
Recycled Aluminum	10–15	0.5–1.0
Virgin Aluminum	180–200	8–12
Magnesium (virgin)	350–400	18–22
CFRP	200–400	15–30
GFRP	50–100	3–7

Use phase savings: For a 200 kg weight reduction over 1,50,000 km EV lifetime — approximately 1,500–2,000 kWh of electricity is saved, avoiding roughly 600–900 kg of Coo at average grid mix. This comfortably offsets the extra production energy in most cases, meaning light weighting has a net positive environmental impact over the vehicle's life.

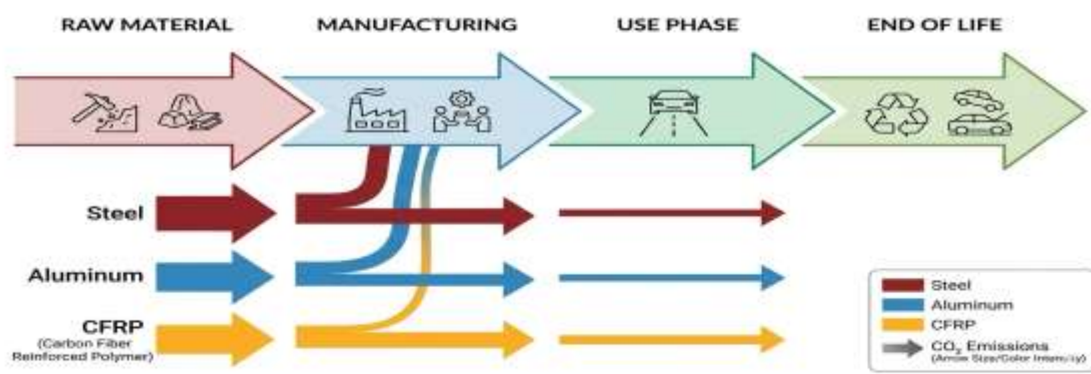
End-of-life recyclability rates:

Steel: ~90% recycling rate, well established globally, high scrap value

Aluminum: ~85% recycling rate, requires only 5% of original energy to recycle from scrap

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open access journal
Impact Factor: 8.3 www.ijesh.com ISSN: 2250 3552

Magnesium: ~50% recycling rate, needs inert atmosphere during processing to prevent oxidation
GFRP: ~20–30%, mostly downcycled to lower-grade filler material
CFRP: ~15–25%, pyrolysis and solvolysis can recover fibers but quality degrades significantly
Regulatory context: EU End-of-Life Vehicle (ELV) Directive mandates 85% reuse/recycling by vehicle weight. This puts pressure on CFRP-heavy designs unless carbon fiber recycling technology matures



7. RESULTS AND DISCUSSION

7.1 Comparative Material Performance Summary

The research identified that all four material families offer distinct advantages and limitations depending on the application. No single material is universally superior. The following consolidated table summarizes the key findings across all critical parameters for EV design:

Property	AHSS	Aluminum	Magnesium	GFRP	CFRP
Density (g/cm³)	7.8	2.7	1.8	1.8–2.0	1.5–1.6
Tensile Str. (MPa)	600–2,000	200–500	180–280	300–600	600–1,500
Weight Saving vs Steel	20–35%	40–50%	50–65%	25–35%	50–70%
Corrosion Resistance	Poor (needs coating)	Excellent	Poor	Excellent	Excellent
Relative Cost	Low	Moderate	High	Moderate-High	Very High
Recyclability	Excellent	Excellent	Moderate	Poor	Poor
Manufacturability	Excellent	Good	Moderate	Good	Poor

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open access journal
Impact Factor: 8.3 www.ijesh.com ISSN: 2250 3552

EV Adoption Level	High	Very High	Low	Moderate	Low–Moderate

Property	AHSS	Aluminum	Magnesium	GFRP	CFRP	Property
Density (g/cm³)	7.8	2.7	1.8	1.8–2.0	1.5–1.6	Density (g/cm³)
Tensile Strength (MPa)	800–2000	200–500	180–280	300–600	600–1500	Tensile Strength (MPa)
Weight Saving vs Steel	20–35%	40–50%	50–65%	25–35%	50–70%	Weight Saving vs Steel
Corrosion Resistance	Poor	Excellent	Poor	Excellent	Excellent	Corrosion Resistance
Relative Cost	Low	Moderate	High	Moderate-High	Very High	Relative Cost
Recyclability	Excellent	Excellent	Moderate	Poor	Poor	Recyclability
Manufacturability	Excellent	Good	Moderate	Good	Poor	Manufacturability
EV Adoption Level	High	Very High	Low	Moderate	Low–Moderate	EV Adoption Level

7.2 Real-World EV Case Studies

Tesla Model S — Aluminum-intensive architecture:

The Tesla Model S uses a predominantly aluminum body structure (5xxx and 6xxx series alloys). The body-in-white achieves approximately 40% weight reduction versus an equivalent steel structure. The chassis uses adhesive bonding and self-piercing rivets (SPR) throughout, eliminating traditional welding. The reinforced aluminum floor also doubles as structural protection for the battery pack. Despite carrying a 100 kWh battery pack, the vehicle achieves a range exceeding 600 km — a direct result of the lightweight architecture.

BMW i3 — CFRP and Aluminum hybrid:

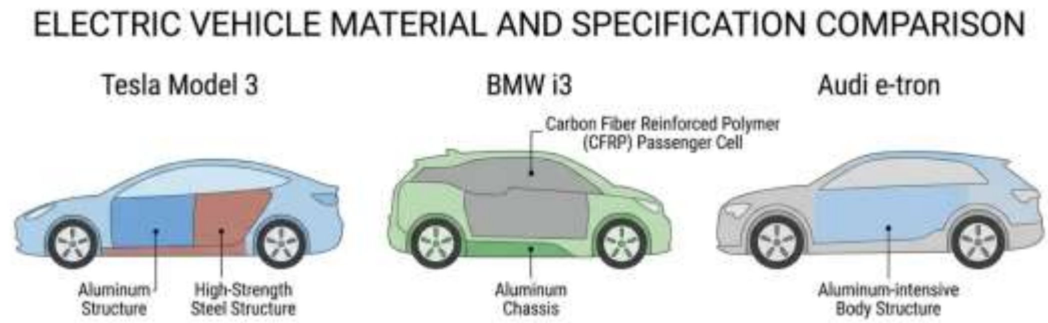
The BMW i3 is the most radical lightweighting experiment in mass-produced EVs. Its passenger cell (called the 'Life Module') is entirely made of CFRP, weighing approximately 150 kg compared to 350 kg for an equivalent steel structure — a saving of 200 kg in the cell alone. The drive module (chassis) is an aluminum space frame. Total weight saving versus conventional construction: 250–300 kg. The challenge: production cost is approximately $15,000 higher per vehicle, and only ~30,000 units per year were produced due to cost constraints. Despite limited commercial success, the i3 proved CFRP mass production is technically feasible.

Audi e-tron GT — Balanced multi-material strategy:

The Audi e-tron GT uses front aluminum castings and extrusions for the crumple zone, AHSS and ultra-high-strength steel for the passenger cage, aluminum sheet for hood and trunk, and optional CFRP roof

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open access journal
Impact Factor: 8.3 www.ijesh.com ISSN: 2250 3552

Kerb weight: 2,340 kg with a 93.4 kWh battery, range ~488 km. This represents current industry best- practice: a cost-optimized multi-material strategy that prioritizes each material where it performs best.



Vehicle	Weight	Battery Size	Range	Primary Material Strategy
Tesla Model 3	~1760 kg	60–82 kWh	~491 km	Aluminum + High-Strength Steel
BMW i3	~1365 kg	42 kWh	~246 km	CFRP + Aluminum
Audi e-tron	~2490 kg	95 kWh	~436 km	Aluminum-intensive body

7.3 Manufacturing and Integration Challenges

Multi-material EV body construction introduces joining and assembly challenges that do not exist in single- material steel bodies. These must be carefully engineered to ensure structural integrity, durability, and repairability over the vehicle's lifetime.

Joining methods used in multi-material EVs:

Self-Piercing Rivets (SPR): Joins aluminum-to-aluminum and aluminum-to-steel without pre-drilling. The rivet pierces and flares through the lower sheet. Fast cycle (~1 second/rivet) but requires access to both sides of joint.

Flow Drill Screws (FDS): Used where only one-sided access is available. The screw generates heat through friction, forming its own thread in the material below. Ideal for closed sections.

Structural Adhesive Bonding: Epoxy-based adhesives distribute load over a large area, reduce stress concentrations, and electrically isolate dissimilar metals to prevent galvanic corrosion. BMW uses ~130 meters of adhesive per i3 body shell.

Friction Stir Welding (FSW): Solid-state welding for aluminum-to-aluminum joints. No filler metal required, excellent joint strength, but requires heavy fixturing and high capital investment.

Galvanic corrosion challenge:

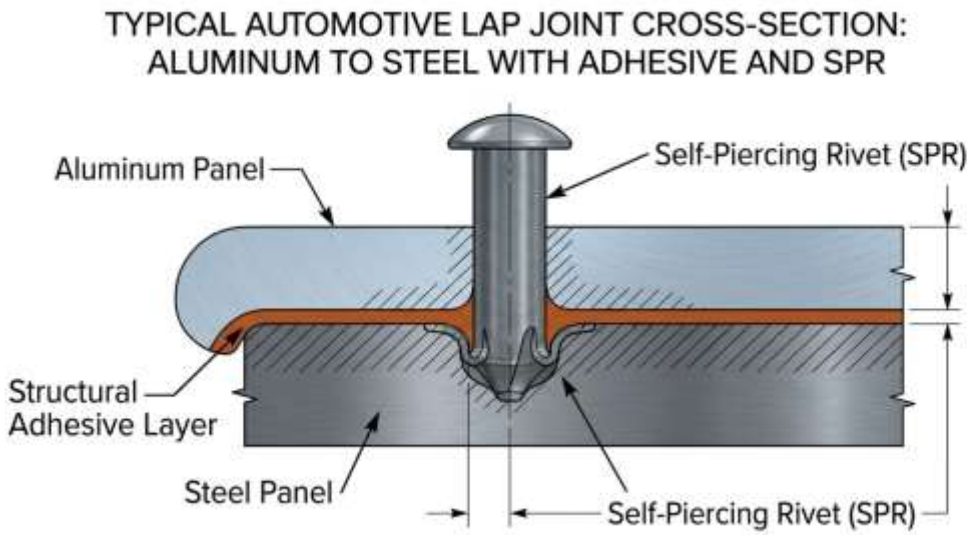
When aluminum and steel are in direct contact in the presence of moisture, the electrochemical potential difference (~0.5–1.0 V) causes accelerated corrosion of the aluminum. Solutions include

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open access journal
Impact Factor: 8.3 www.ijesh.com ISSN: 2250 3552

physical isolation with adhesive layers or polymer tapes, anodizing coatings, and sealant at all joints.

Thermal expansion mismatch:

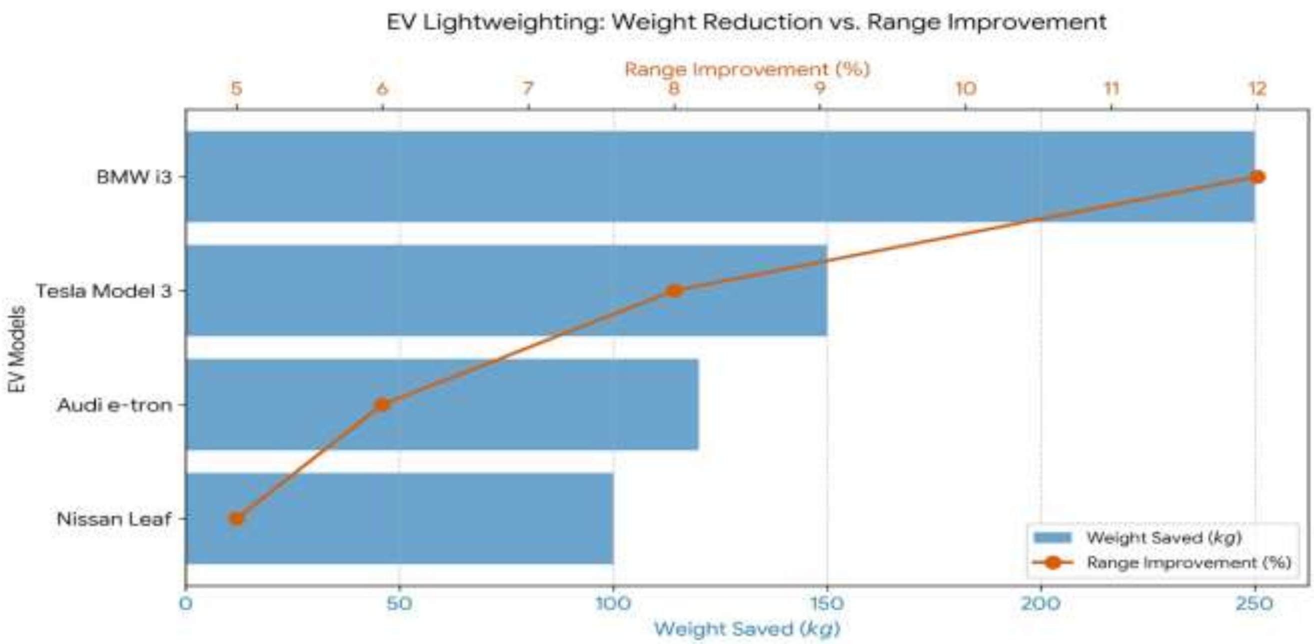
Aluminum expands roughly twice as much as steel per degree Celsius (23 vs 12 □m/m/°C). In bonded assemblies, this creates shear stress in joints through heating and cooling cycles. Managed through flexible adhesive systems and optimized fastener spacing.



7.4 Weight Reduction Summary Across EV Models

EV Model	Primary Strategy	Weight Saved (est.)	Range Benefit
Tesla Model S	All-aluminum body	~200–250 kg	~15–20%
BMW i3	CFRP + Aluminum hybrid	~250–300 kg	~20–25%
Audi e-tron GT	Multi-material optimized	~150–200 kg	~10–15%
Porsche Taycan	Multi-material + CFRP options	~100–150 kg	~8–12%
Rivian R1T	Aluminum panels + HSS frame	~100 kg	~6–8%

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open access journal
Impact Factor: 8.3 www.ijesh.com ISSN: 2250 3552



8. CONCLUSION

8.1 Summary of Findings

This report has systematically evaluated the four principal lightweight material families — AHSS, aluminum alloys, magnesium alloys, and polymer composites — for application in electric vehicle construction. The findings confirm that no single material is universally optimal. A multi-material design strategy, which assigns each material to the location where it performs best, delivers the greatest combined benefit in terms of weight reduction, safety, cost, and sustainability. AHSS remains the backbone of EV crash safety structures due to its exceptional energy absorption and cost-effectiveness. Aluminum alloys have emerged as the dominant light weighting choice, offering proven weight savings of 40–50% with good corrosion resistance and recyclability. Magnesium alloys show significant potential but are constrained by high cost and processing challenges. Polymer composites — especially CFRP — offer the greatest mass reduction potential but are currently economically viable only in premium segments. The central engineering finding is clear: a 10% reduction in vehicle mass leads to approximately 6–10% improvement in energy efficiency, enabling either a longer driving range or a smaller, cheaper battery — both critical to accelerating EV adoption globally.

8.2 Future Outlook

Short-term (2025–2030):

Wider use of third-generation AHSS exceeding 1,800 MPa tensile strength Rapid growth of large-format aluminum die castings — Tesla's 'Giga-casting' approach replaces dozens of stamped parts with a single aluminum casting, dramatically reducing assembly complexity and cost Development of aluminum-CFRP hybrid panels for mid-range EVs

Medium-term (2030–2040):
CFRP production costs expected to fall below $15/kg for recycled carbon fiber through automation Magnesium alloy room-temperature forming is under active development Standardized multi-material recycling protocols will emerge across global automotive supply chains Integration of bio-based composite materials for interior components

Long-term (2040+):
Fully recyclable thermoplastic CFRP enabling closed-loop carbon fiber recovery Smart structural materials with embedded sensors for real-time structural health monitoring Topology-optimized, additively manufactured (3D printed) components in aluminum and titanium for custom low-volume EV platforms.

REFERENCES

1. Davies, G. (2012). Materials for Automobile Bodies. Butterworth-Heinemann.
2. Mallick, P.K. (2010). Materials, Design and Manufacturing for Lightweight Vehicles. Woodhead Publishing.
3. Kulekci, M.K. (2008). Magnesium alloys in automotive industry. Int. Journal of Advanced Manufacturing Technology.
4. Lutsey, N. (2010). Automobile mass-reduction technology. UC Davis Report.
5. Modaresi, R. et al. (2014). Carbon benefits of material substitution. Environmental Science & Technology.
6. Fuchs, E.R.H. et al. (2008). Materials selection in automobile body. Composites Science and Technology.
7. WorldAutoSteel (2019). AHSS Application Guidelines.
8. Das, S. (2011). Life cycle assessment of CFRP. Int. Journal of Life Cycle Assessment.
9. Rocky Mountain Institute (2019). Economics of Electric Vehicles.
10. European Aluminium Association (2020). Aluminium in Cars.
11. International Aluminum Institute (2024). EV material trends report.
12. Schmitt, J. et al. (2025). Secondary weight saving in EVs.
13. ASM International. Material Properties Database.
14. MatWeb. Online Materials Information Resource.
15. Tesla Inc. (2023). EV structural design white paper.
16. BMW Group (2022). CFRP applications in EVs.
17. Audi AG (2023). Multi-material EV architecture report.
18. Springer Materials (2023). Engineering material data handbook.

19. Elsevier (2022). Materials Science and Engineering Journal.
20. IEEE Xplore (2023). EV lightweighting research papers.
21. European Commission (ELV Directive). End-of-life vehicle regulations.
22. U.S. FMVSS Standards. Vehicle safety regulations.
23. IIHS (2023). Crash safety guidelines.
24. CANMET Materials (2021). Lightweight metals for transport.
25. Journal of Cleaner Production (2022). Sustainability in EV materials.