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Squeeze Casting of Aluminum and Magnesium Alloys for Electric Vehicles

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Abstract

The rapid growth of electric vehicles (EVs) has intensified the demand for lightweight metallic components that offer high structural integrity, reliable thermal performance, and improved energy efficiency. Squeeze casting has emerged as a key manufacturing route for aluminum and magnesium alloys, combining the geometric flexibility of casting with the microstructural refinement achieved through pressure-assisted solidification. This mini critical review synthesizes current advances in squeeze casting of A356, 6xxx, and 7xxx series aluminum alloys, as well as AZ91, AM-series, and rare-earth-modified magnesium alloys. The process–microstructure–property relationships are examined with emphasis on dendrite refinement, porosity suppression, enhanced mechanical performance, and improved thermal characteristics. EV-specific applications—including motor housings, battery trays, structural subframes, and interior support systems—are discussed to highlight the complementary roles of aluminum and magnesium in achieving vehicle-level lightweighting targets. Recent developments in alloy design, hybrid manufacturing, and intelligent process optimization are also reviewed, along with the technological challenges that continue to limit large-scale industrial adoption. The review concludes by identifying future research directions focused on advanced alloy formulations, integrated computational design, sustainable recycling pathways, and adaptive squeeze-casting control strategies for next-generation EV architectures.

Keywords: Squeeze Casting, Aluminum Alloys, Magnesium Alloys, Electric Vehicles, Lightweight Materials, Microstructure, Thermal Management, Rare-Earth Alloys, Motor Housings, Battery Enclosures

1. Introduction

The rapid expansion of electric vehicles (EVs) has increased the demand for lightweight metallic components that provide improved structural, thermal, and functional performance, while supporting vehicle-level energy efficiency goals. Global EV market share has nearly doubled year-over-year in recent periods, driven by regulatory pressures, expanded model availability, and the shift from internal combustion engine (ICE) architectures to battery-electric platforms [1]. As EV production accelerates worldwide, the global electric car stock has shown a steep and sustained rise over the last decade, as illustrated in Fig. 1.

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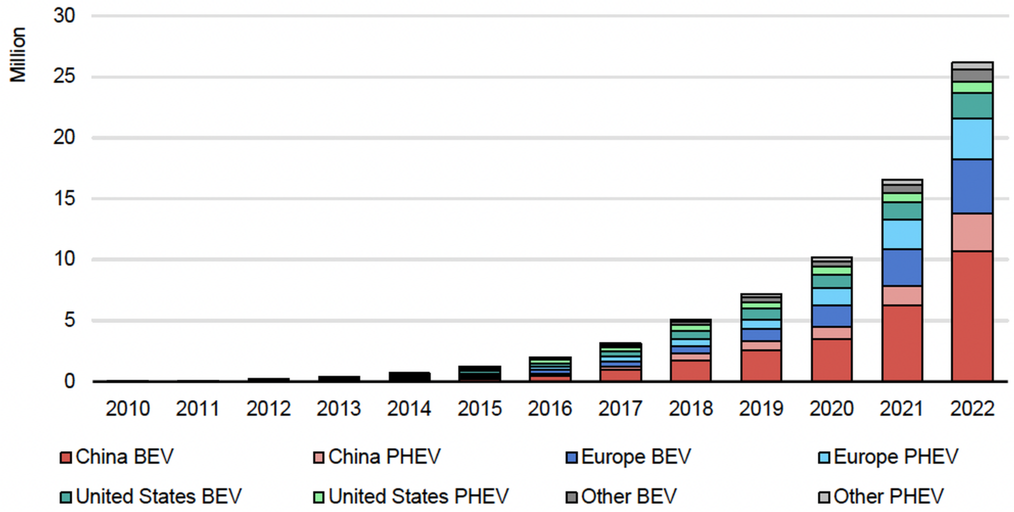

Figure 1: Global electric car stock in major regions from 2010–2022. Data source: IEA Global EV Outlook 2023.

As EVs require fewer mechanical components than ICE vehicles, the value of remaining metallic components increases, especially those associated with electric motors, battery enclosures, power electronics, and chassis subsystems. This transition has renewed interest in advanced forming processes that enable weight reduction without compromising safety or durability. Because lightweighting directly influences the long-term environmental impact of EVs, the distinction between conventional, baseline EV, and lightweight EV trajectories shown schematically in Fig. 2, highlights the importance of reducing component mass as cumulative distance travelled increases.

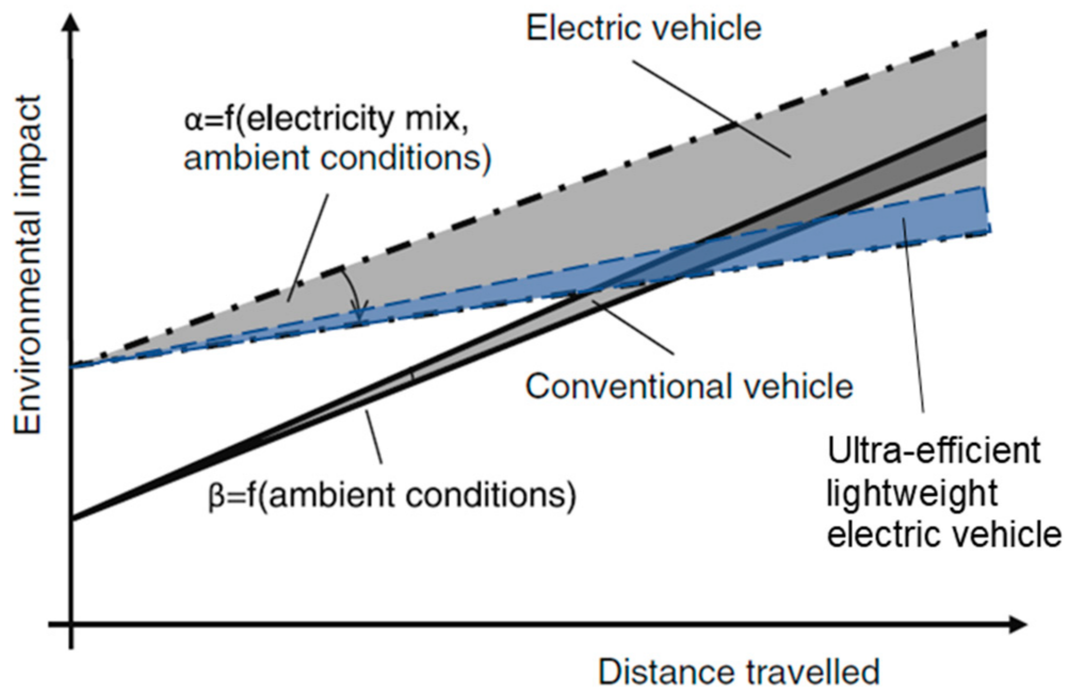

Figure 2: Environmental impact versus distance travelled for conventional vehicles, electric vehicles, and lightweight electric vehicles. Shaded regions illustrate sensitivity to energy mix and ambient conditions.

Squeeze casting has emerged as a critical near-net-shape manufacturing method for lightweight aluminum and magnesium components in EVs due to its unique combination of casting fluidity and forging-like densification. The process applies high mechanical pressure during solidification, suppressing porosity, refining microstructure, and enhancing mechanical properties [2]. Early industrial adoption demonstrated that squeeze casting can replace traditional iron and steel suspension parts; for instance, Delphi Chassis Systems successfully converted a cast-iron front knuckle to a squeeze-cast A356 aluminum design, achieving significant mass reduction while meeting stringent strength and stiffness requirements for high-volume automotive production [3].

Such applications established confidence in the process capability for safety-critical components. Recent technological progress has expanded the applicability of squeeze casting from structural chassis parts to more complex EV subsystems. For example, squeeze-cast motor housings for new-energy vehicles demonstrate improved density, refined dendritic morphology, and enhanced airtightness under optimized process parameters involving controlled pressure, pouring temperature, die temperature, and pressurization speed [4]. Similar findings are reported for 7075 aluminum alloy covers formed using a novel quantitative molten-metal feeding system, which ensures precise dosing, reduces oxide inclusions, and stabilizes flow behavior under automated control [5].

These studies highlight the significance of process-parameter optimization—such as punch velocity, mold temperature, and filling speed—to achieve consistent microstructures and high-quality castings. From a materials engineering perspective, aluminum alloys remain central to EV lightweighting due to their high specific strength, corrosion resistance, castability, and compatibility with multiple solidification pathways. Cast Al–Si and Al–Cu alloys are widely used in motor rotors, power electronics housings, and structural brackets, with squeeze casting offering improved mechanical and electrical performance compared to conventional high-pressure die casting [6]. The substitution of copper with aluminum in induction motor rotors is also facilitated by squeeze-castable alloy systems, which can deliver higher strength and acceptable electrical conductivity. Despite these advances, achieving optimal component performance requires an understanding of the complex interactions between pressure, melt temperature, die design, solidification kinetics, and alloy composition. Contemporary literature highlights that squeeze casting research is increasingly data-driven, integrating numerical simulation, orthogonal experimentation, and artificial intelligence–based optimization to guide parameter selection [2]. While these tools accelerate design, industrial adoption is still constrained by the need to tailor process windows to each alloy–geometry combination.

Considering the ongoing push toward mass-market EV adoption and the parallel need for lightweight, reliable, and thermally efficient components, squeeze casting provides a compelling manufacturing route for aluminum- and magnesium-based parts. This mini-critical review synthesizes recent advances in the squeeze casting of light alloys for EV applications, emphasizing process–microstructure–property relationships and identifying opportunities for innovation in component design, alloy development, and integrated simulation frameworks.

2. Fundamentals of Squeeze Casting

2.1. Process Overview

Squeeze casting is a near-net-shape manufacturing process in which molten metal is introduced into a preheated die and solidified under external pressure. The applied pressure, typically ranging from 50 to 150 MPa, suppresses solidification shrinkage, enhances heat transfer at the die–melt interface, and eliminates gas porosity by forcing dissolved gases back into solution or expelling them into the die vents [2, 4]. Unlike conventional high-pressure die casting, squeeze casting fills the cavity at comparatively slow velocities, which reduces turbulence and thereby minimizes oxide film entrapment [7]. The combination of laminar filling and pressure-assisted solidification yields a dense and fine-grained microstructure, imparting the process with characteristics similar to forging while retaining the geometric versatility of casting.

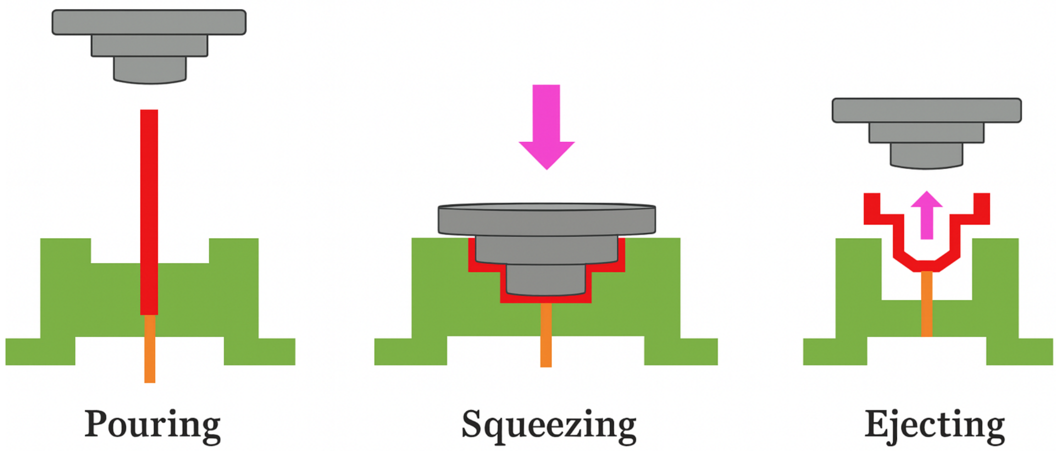

Figure 3: Schematic representation of the squeeze casting process showing the sequential stages of pouring, squeezing, and ejecting.

From a process standpoint, squeeze casting may be conducted in direct or indirect configurations. Direct squeeze casting introduces the molten metal into an open die, after which a punch applies pressure as solidification begins, resulting in a near-forged structure suitable for thick-section components [3]. Indirect squeeze casting relies on a gating system for cavity filling before applying pressure, and is particularly valuable in producing complex thin-walled parts with stringent pore-free requirements, such as motor housings and EV structural enclosures [4]. Advances in melt handling, such as quantitative feeding systems, have improved dosing accuracy, reduced oxidation, and enhanced consistency across large production batches [5]. These developments collectively expand the industrial feasibility of squeeze casting for high-integrity light-alloy components.

Thermodynamically, the applied pressure modifies the equilibrium solidification path by raising the melting point of the alloy, thereby increasing the degree of undercooling and promoting rapid nucleation. The high interfacial heat transfer coefficient under pressure (often exceeding 1000 W/m^2K) facilitates directional solidification and reduces thermal gradients that ordinarily lead to macrosegregation in conventional castings [7]. This microstructural refinement mechanism is well established for both aluminum and magnesium alloys, providing the foundation for the superior mechanical properties typically associated with squeeze-cast parts.

2.2. Relevance of Squeeze Casting for Light Alloys

Squeeze casting is particularly suitable for lightweight aluminum (Al) and magnesium (Mg) alloys because these alloys are highly sensitive to porosity, oxide inclusions, and coarse dendritic growth during conventional casting. The pressure-assisted solidification in squeeze casting effectively addresses these limitations. For Al–Si and Al–Mg alloys used in EV structures and motor housings, the process significantly reduces dendrite arm spacing and porosity, resulting in improved yield strength, fatigue resistance, and thermal conductivity [6]. Studies on A356 and 7075 alloys demonstrate that squeeze casting enhances interfacial bonding, suppresses gas porosity, and stabilizes microstructure evolution even in geometrically complex castings [5]. Magnesium alloys, although even lighter than aluminum, face challenges such as poor castability, oxidation, and susceptibility to defect formation during high-pressure die casting. Squeeze casting mitigates these issues by enabling laminar flow and providing the necessary pressure to compensate for interdendritic shrinkage. Recent reviews highlight that squeeze casting and rheo-squeeze casting are the most promising manufacturing routes for defect-free semisolid Mg components in high-volume production [8].

In particular, Mg alloy systems such as AZ91 and AM series exhibit refined non-dendritic structures and enhanced mechanical stability under squeeze casting conditions [8]. These features are especially valuable in lightweight EV applications where low density must be balanced against strength and thermal management performance. Process innovations for light alloys further underscore the relevance of squeeze casting. Luo *et al.* emphasize that squeeze casting belongs to a new generation of "high-integrity casting processes," capable of meeting the increasingly strict safety and reliability requirements of automotive and aerospace industries [7]. High integrity is achieved not only through porosity reduction but also through compatibility with emerging alloy systems designed for structural EV applications. The process is particularly well aligned with integrated computational materials engineering (ICME) approaches that optimize solidification and predict defect formation.

In light of the increasing interest in aluminum and magnesium matrix composites for advanced functional performance, squeeze casting also offers superior wettability and particle infiltration compared to gravity casting routes. For aluminum matrix composites (AMCs), pressure-assisted infiltration promotes uniform dispersion of reinforcement and minimizes interfacial porosity [9]. Similar advantages have been documented in emerging metallic-reinforced light-alloy composites, where squeeze casting is used to control interfacial reactions and enhance mechanical and corrosion properties [10]. These capabilities extend the relevance of squeeze casting beyond monolithic alloys into next-generation EV materials and multifunctional structures.

3. Squeeze Casting of Aluminum Alloys for EV Components

3.1. Common Alloys (A356, 6xxx Series, 7xxx Series)

Aluminum alloys used in EV components must satisfy simultaneous requirements of low density, structural integrity, thermal management, and manufacturability. Among these, A356, 6xxx series, and 7xxx series alloys represent the primary families adapted for squeeze casting. A356 remains widely adopted due to its castability and consistent solidification response under pressure, which facilitates the production of porosity-free structural parts, such as knuckles, subframes, and suspension arms [3]. The 6xxx series (typically Al–Mg–Si) offers a balance of strength and thermal conductivity, and is increasingly used in EV battery tray structures and housings, where heat dissipation and structural stiffness must coexist. Meanwhile, 7xxx series alloys, especially 7075, have gained renewed focus for high-strength EV components.

The squeeze casting of 7075 using controlled quantitative feeding minimizes oxide entrainment and improves microstructural uniformity [5], making it suitable for mechanically demanding enclosures and high-load vehicle interfaces. Modified aluminum matrix composites (AMCs) produced through hybrid stir–squeeze casting processes also appear in EV applications where enhanced stiffness, wear resistance, or thermal stability is desirable. Reinforced aluminum wheels, brake components, and structural inserts have been demonstrated using such methods [11]. Although traditional MMCs are not yet mainstream in mass-produced EV architectures, their relevance is increasing for thermally stressed or tribologically critical parts.

3.2. Process–Microstructure Relationships

The effectiveness of squeeze casting for aluminum alloys is rooted in the microstructural refinement induced by applied pressure. Pressure accelerates heat extraction at the die interface and suppresses interdendritic porosity, enabling a transition from coarse dendritic morphology to a fine, uniformly distributed α-Al matrix. Investigations of direct squeeze cast motor housings for new-energy vehicles show that increased squeeze pressure significantly reduces secondary dendrite arm spacing (SDAS) and produces compacted eutectic Si, enhancing both airtightness and structural reliability [4]. Similar refinement is observed in A356 components, where pressurized solidification promotes grain refinement without requiring excessive mold superheat. In 7xxx alloys, pressure minimizes hydrogen porosity and refines η and $MgZn_2$ precipitation zones, enabling improved mechanical stability [5]. For EV-relevant AMCs, the combined action of stirring and squeeze pressure enhances uniformity of reinforcements such as Al_2O_3 or TiC. Electromagnetically assisted semisolid squeeze casting produces globular primary α-Al morphologies and minimizes particle agglomeration, which is crucial for fatigue-sensitive EV structures [12]. These microstructural changes collectively result in reduced segregation, finer grains, and improved microstructural homogeneity—key enablers for predictable component performance in EVs.

3.3. Resulting Mechanical and Thermal Properties

The refined microstructures produced by squeeze casting result in superior mechanical properties compared to gravity or high-pressure die casting. For Al–Si alloys such as A356 and A12Si, improvements in yield strength and ultimate tensile strength are strongly correlated with squeeze pressure and die temperature optimization; strengths exceeding 300 MPa have been reported under optimal conditions [13]. Enhanced fatigue life is attributed to the significant reduction in shrinkage cavities and oxide inclusions. Similarly, 7075 squeeze castings exhibit higher tensile strength and stable fracture behavior due to refined intermetallic phases and minimized porosity [5]. Thermal conductivity, critical in EV battery trays and motor housings, benefits from the high density and reduced defect content of squeeze-cast aluminum. Dense A356 housings fabricated under controlled pressure demonstrate improved thermal pathways that support motor cooling requirements [4]. In reinforced AMCs, the addition of ceramic particulates enhances stiffness and wear resistance while maintaining an acceptable thermal response, making them suitable for brake components and structural inserts subjected to cyclic thermal loading.

3.4. EV Applications

Squeeze-cast aluminum alloys are increasingly deployed in EV structures due to their lightweight nature, high integrity, and adaptability to complex geometries. A356 and similar Al–Si alloys are used in subframes, steering knuckles, and suspension components, where weight reduction directly contributes to extended driving range. Early industrial demonstrations, such as the squeeze-cast aluminum knuckle replacing a cast-iron design, underscore the enduring significance of the process in vehicle lightweighting [3]. In EV-specific systems, squeeze-cast aluminum motor housings exhibit excellent airtightness and dimensional stability, supporting both electromagnetic and thermal performance [4]. Battery trays and structural enclosures benefit from the porosity-free nature of 6xxx-series squeeze castings, ensuring reliable thermal conduction and crash performance. Reinforced aluminum composites produced through hybrid squeeze casting routes are well-suited for tribological components, such as brake rotors, where enhanced wear resistance improves durability.

3.5. Recent Advancements

Recent research emphasizes alloy modification, heat treatment optimization, and hybrid process innovations to expand the applicability of squeeze-cast aluminum to EV architectures. Recycled aluminum and Al–Fe alloys, refined through ultrasonic melt processing, demonstrate improved microstructure and mechanical performance suitable for sustainable EV manufacturing [14]. The integration of electromagnetic stirring before squeeze casting enhances the uniformity of semisolid slurry and produces nanocomposite structures with refined primary α-Al particles [12]. Such modifications contribute to improved wear resistance and stability under cyclic loading. Heat treatments tailored to squeeze-cast microstructures, such as T6 aging for A356 and 7xxx alloys, enhance precipitation strengthening, enabling their use in increasingly load-bearing EV components. Furthermore, hybrid stir–squeeze casting of aluminum MMCs has progressed toward optimized reinforcement dispersion and reduced porosity through Taguchi-based parameter optimization [11].

As a result, the castings exhibit improved microstructural quality. These enhancements position the materials as promising candidates for next-generation EV thermal and structural subsystems. Collectively, these advancements underscore the expanding role of squeeze-cast aluminum alloys in high-performance EV components, driven by improvements in microstructural control, sustainability, and process integration.

4. Squeeze Casting of Magnesium Alloys for EV Components

4.1. Common Alloys (AZ91, AM Series, Rare-Earth-Modified Alloys)

Magnesium alloys have become increasingly relevant in electric vehicle (EV) lightweighting strategies due to their exceptionally low density, high specific stiffness, and inherent vibration-damping capability [15]. Among these, AZ91 and AM60/AM50 represent the most widely used commercial grades owing to their balanced castability, corrosion resistance, and manufacturability. AZ91, with its relatively high Aluminum content, offers a good balance of strength and fluidity, making it suitable for structural housings and brackets. AM-series alloys, which contain lower Al but higher Mn content, offer improved ductility and enhanced crash energy absorption, making them advantageous in EV safety-critical structures. Recent developments in rare-earth-modified Mg alloys have addressed traditional limitations related to creep resistance and thermal stability. Alloys incorporating neodymium (Nd), yttrium (Y), and gadolinium (Gd) exhibit improved high-temperature stability, refined grain structures, and enhanced aging responses through the formation of thermally stable intermetallic phases [16]. These alloys are increasingly investigated for EV applications such as motor mounts, electronic module housings, and regions exposed to elevated thermal loads. Magnesium-based composites—including those reinforced with SiC, Al_2O_3, or carbon-based reinforcements—further extend the usable envelope of Mg alloys, providing improved strength and wear resistance when processed under squeeze casting conditions [17]. Although not yet widely deployed in large-scale EV production, these composites are gaining interest for thermally stressed or tribologically demanding components.

4.2. Process–Microstructure Relationships

The squeeze casting of magnesium alloys involves the application of pressure during solidification, which significantly improves heat transfer and promotes finer grain formation compared with gravity or high-pressure die casting. This refinement is attributed to accelerated solidification and suppression of shrinkage porosity, resulting in denser and more uniform microstructures. Studies examining squeeze-cast AM60 and AZ91 alloys show reductions in dendrite arm spacing and grain size with increasing applied pressure, leading to consistent improvements in strength and elongation [15]. Pressure also enhances melt feeding into interdendritic regions, mitigating the formation of microporosity that commonly limits fatigue performance in conventional castings. Rare-earth-modified Mg alloys exhibit particularly strong microstructural benefits when subjected to squeeze casting. The applied pressure stabilizes the formation of fine, plate-like, or blocky intermetallics, thereby improving high-temperature strength and reducing texture intensity. Furthermore, squeeze casting of Mg matrix composites promotes uniform distribution of reinforcements; for example, Ni–P–Co–coated SiC particles in AZ-series alloys exhibit significantly improved interfacial bonding and reduced particle clustering due to pressure-assisted infiltration [18]. Pressure also suppresses the formation of casting defects caused by poor wettability in Mg melts, thereby enhancing load transfer between matrix and reinforcement. In advanced processing variants, such as semisolid or slurry-based squeeze casting, electromagnetic stirring has been demonstrated to reduce dendritic morphology further and promote equiaxed grain structures. These refined microstructural states directly support the fatigue and creep requirements of EV structural applications [12].

4.3. Mechanical and Functional Properties

Squeeze-cast magnesium alloys demonstrate mechanical properties superior to those produced by conventional casting, owing to the densification and microstructural refinement induced by pressure. AZ91 and AM60 components produced under optimized squeeze pressures exhibit significantly higher yield and ultimate tensile strengths than those made by gravity casting, with ductility improvements frequently exceeding 30–50% [15]. The reduction in porosity and improved uniformity make these materials suitable for fatigue-sensitive EV components, including brackets, housings, and NVH-critical interfaces. Creep resistance, a key requirement for EV components operating near motors or in battery enclosures, is markedly enhanced in rare-earth-modified Mg alloys. The stabilization of thermally resistant intermetallic phases—such as $Mg_{12}Nd$, $Mg_{14}Y_2Si$, and Gd-containing precipitates—prevents grain boundary sliding and improves high-temperature dimensional stability [16]. These characteristics are essential in preventing distortion and maintaining bolt preload in structural assemblies subjected to cyclic thermal loading. Functional properties such as damping capacity, electromagnetic shielding effectiveness, and thermal conductivity further enhance the suitability of squeeze-cast Mg alloys for EVs. Mg alloys possess inherently high damping, and refined microstructures, achieved through squeeze casting, increase their energy-dissipation capability. This feature benefits EV cabin NVH performance. Composite Mg materials containing ceramic reinforcements show further increases in stiffness and wear resistance, which is beneficial for brake components or parts exposed to repetitive mechanical loading [17].

4.4. EV-Specific Applications

The deployment of squeeze-cast magnesium alloys in EVs has expanded as automotive manufacturers pursue mass reduction, improved driving range, and enhanced component functionality. Common EV applications include instrument panel supports, seat frames, motor mounts, inverter housings, and cross-car beams—components where magnesium's low density provides significant system-level advantages [15]. AM-series alloys, with their superior ductility and crash absorption characteristics, are used in structural reinforcements and interior safety systems. Meanwhile, AZ91 alloys are utilized in housings and brackets that require dimensional stability and moderate thermal performance. Rare-earth-modified Mg alloys have been investigated for high-temperature EV environments, particularly near motors and power electronics. Their improved creep resistance and stability make them suitable candidates for motor housings, gearbox covers, and power-control module supports. Squeeze casting is particularly advantageous for these components due to its ability to produce defect-free, thin-walled geometries. Historical studies conducted by Argonne National Laboratory highlight magnesium's potential for use in automotive structures, noting its favorable strength-to-weight ratio and potential for large-scale adoption when appropriate forming technologies are employed. While Mg-based composites are not yet mainstream in EV mass production, they show promise for brake components, suspension interfaces, and thermally stressed parts, where wear resistance and dimensional stability are critical [18].

4.5. Current Research Trends

Recent research has highlighted advancements in alloy design, processing science, and integrated computational approaches to optimize the squeeze casting of magnesium alloys. AI-driven optimization and machine-learning models have been increasingly applied to predict process parameters, alloy composition effects, and defect formation mechanisms [16]. Data-driven methods complement traditional empirical and simulation-based techniques, enabling more precise control of solidification conditions and microstructure evolution. Sustainable magnesium production and recycling are gaining prominence due to cost reductions in primary magnesium and the need for environmentally responsible materials in EV platforms. Large-scale castings, including integrated structural components, have been demonstrated using advanced squeeze casting methods, indicating readiness for expanded automotive adoption [15]. Investigations into Mg-based composites continue to refine reinforcement dispersion and improve interfacial characteristics, with emphasis on tribological performance and thermal stability for EV thermal systems [17]. Overall, ongoing research is converging toward high-performance structural magnesium alloys that maintain mechanical integrity, thermal stability, and durability under EV operating conditions. Squeeze casting remains a central processing route due to its unmatched ability to produce dense, defect-free, and microstructurally refined magnesium components.

5. Comparative Assessment: Aluminum vs. Magnesium in EVs

The increasing demand for lightweight structures in electric vehicles (EVs) has accelerated the use of both aluminum and magnesium alloys in high-integrity components. Although both metals provide considerable mass reduction relative to steel, their selection depends on a combination of mechanical requirements, thermal management needs, manufacturability, and cost. Squeeze casting serves as a unifying processing method that enhances the performance of both alloy families; yet, the resulting property–performance profiles differ significantly. Aluminum alloys offer a broader usable property range and superior absolute strength compared with magnesium alloys, particularly for heat-treatable grades such as A356 and 7xxx-series compositions [5]. Their relatively high thermal conductivity enables efficient heat dissipation, which is essential in battery trays, inverter housings, and motor housings. The refined microstructures achieved through squeeze casting result in low porosity and predictable fatigue behavior, supporting application in crash-relevant structural parts and high-load suspension components [3]. Aluminum also exhibits better corrosion resistance and more mature coating technologies, reducing long-term durability concerns in EV architectures exposed to environmental cycling. Magnesium alloys, while possessing lower absolute strength, deliver the highest specific strength among commonly used structural metals [15]. Their extremely low density (1.74 g/cm^3) enables substantial mass reduction in large-volume EV structural and interior systems.

Squeeze casting mitigates inherent castability challenges by improving melt feeding and reducing porosity, allowing Mg alloys such as AZ91 and AM60 to achieve mechanical performance levels sufficient for interior structural supports, seat frames, instrument panel beams, and power-electronics housings. Magnesium's superior vibration damping contributes to improved NVH performance in EV cabins, while rare-earth-modified alloys exhibit enhanced creep resistance for thermally stressed regions such as motor mounts and gearbox housings [16]. Thermal performance represents a key divergence between the two material families. Aluminum's higher thermal conductivity makes it more suitable for battery enclosures and heat-intensive powertrain assemblies, whereas magnesium's lower conductivity limits its use in components requiring high heat flux dissipation. Conversely, magnesium's lower heat capacity can accelerate the warm-up or cool-down of interior vehicle systems, offering potential advantages in applications where thermal mass should be minimized. In terms of manufacturability, aluminum alloys remain more robust against casting defects and offer greater alloy design flexibility.

Magnesium's susceptibility to oxidation and its generally narrower solidification range necessitate greater control during melt handling; however, squeeze casting significantly reduces these limitations by enabling laminar filling and pressurized solidification. Emerging manufacturing approaches, including electromagnetic stirring and reinforced Mg composites, have further expanded the usable property space for magnesium in EV environments [17]. Both materials benefit from recent advances in data-driven optimization of squeeze casting parameters, which improve microstructure predictability and mechanical performance [2].

From an application standpoint, aluminum dominates in thermal-management components and high-load structural subsystems, whereas magnesium is preferred for interior structures, housings, brackets, and components where maximum mass reduction is prioritized. The balance between strength, thermal requirements, manufacturability, and cost drives material selection. As demonstrated in historical weight analyses and feasibility evaluations conducted by Argonne National Laboratory, significant opportunities exist for expanding magnesium use in automotive structures, provided that processing technologies continue to improve. Overall, aluminum and magnesium serve complementary roles in EV lightweighting. Aluminum provides superior strength, thermal conductivity, and corrosion resistance, while magnesium offers unmatched mass reduction and NVH advantages. Squeeze casting enhances the viability of both material systems by producing dense, defect-free structures with refined microstructures. Future EV architectures are likely to incorporate optimized multi-material strategies in which aluminum and magnesium components are co-designed to meet structural, thermal, and functional requirements holistically.

6. Technological Challenges and Future Research Directions

Despite the significant progress achieved in squeeze casting of light alloys for electric vehicle (EV) applications, several technological challenges continue to limit widespread industrial deployment. These challenges arise from the inherent complexity of pressure-assisted solidification, alloy-specific behaviors, and increasingly stringent EV performance requirements. Concurrently, emerging trends in digital manufacturing, alloy design, and hybrid processing present opportunities for advancing the next generation of high-performance aluminum and magnesium components. A primary technological challenge is the precise control of process parameters such as pressure, punch velocity, die temperature, and melt handling conditions. These parameters interact nonlinearly and influence solidification kinetics, feeding behavior, porosity formation, and interfacial heat transfer [2]. Although empirical optimization and orthogonal studies have yielded valuable insights, achieving consistent performance across complex geometries remains difficult. Defect prevention requires better understanding of localized cooling rates, dynamic pressure distribution, and the evolution of microstructural heterogeneities. The problem is compounded in magnesium alloys, where oxidation sensitivity, narrow solidification ranges, and the presence of volatile intermetallics demand stricter process control.

Another challenge lies in alloy development tailored specifically for squeeze casting. Commercial aluminum and magnesium alloys were originally formulated for gravity or die casting, and thus may not fully exploit the advantages of pressure-assisted solidification. For aluminum alloys, balancing fluidity, thermal stability, and precipitation response remains a key objective, particularly for EV battery trays and motor housings requiring both high thermal conductivity and mechanical strength [6]. Magnesium alloys face even greater constraints; while rare-earth-modified compositions offer improved high-temperature performance, their cost and supply-chain limitations hinder large-scale adoption [15]. There is a critical need for new compositions that simultaneously enhance castability, creep resistance, and corrosion resistance while remaining economically viable. Thermal management presents additional research challenges. As EV motors and power electronics generate increasing heat densities, the requirements for dimensional stability, airtightness, and thermal fatigue resistance intensify. Aluminum alloys benefit from inherently higher thermal conductivity, but the introduction of reinforcements or secondary phases may compromise heat flow if not carefully controlled [5]. Conversely, magnesium alloys provide superior mass reduction but require innovative solutions to overcome their lower thermal conductivity and susceptibility to localized overheating [16]. Hybrid material approaches, such as metal–matrix composites and multi-layered structures, show promise but require further study to ensure compatibility with squeeze casting and EV safety standards.

Manufacturability and scalability also remain key concerns. Large, thin-walled EV structures pose a challenge to the ability of squeeze casting to maintain uniform pressure and prevent misruns or incomplete feeding. Traditional die-design methodologies are often inadequate for predicting flow behavior under coupled thermal–mechanical loading. Integrating real-time sensing, adaptive pressurization, and in-situ monitoring of solidification could bridge this gap. Research in intelligent manufacturing and machine learning has begun to influence parameter prediction, defect detection, and performance forecasting [2, 16]. As these data-driven approaches mature, they are expected to transform squeeze casting from an empirically driven process into a model-informed, closed-loop manufacturing system.

Future research should also address sustainability and resource efficiency. With the rising demand for EVs, the need for low-carbon materials and recycling-friendly processes is becoming increasingly urgent. Aluminum recycling has reached industrial maturity; however, the influence of accumulated impurities on the squeeze-cast microstructure and durability requires further extensive study. Emerging strategies such as melt refinement, ultrasonic treatment, and impurity-neutralizing alloy additions show potential

7. Conclusion

Squeeze casting has emerged as a pivotal manufacturing route for producing high-integrity aluminum and magnesium components in electric vehicles (EVs). By combining the geometric versatility of casting with pressure-assisted densification, the process delivers refined microstructures, minimized porosity, and improved mechanical and functional performance compared with conventional casting methods. These advantages are particularly relevant as EV architectures demand lightweight structures, enhanced thermal management, and reliable performance under cyclic mechanical and thermal loading. Aluminum alloys, including A356, 6xxx, and 7xxx series compositions, benefit from superior thermal conductivity, robust fatigue resistance, and well-established processing routes. Their applicability spans battery trays, motor housings, subframes, and crash-relevant structural systems. Magnesium alloys, particularly AZ91, AM-series, and rare-earth-modified grades, offer unmatched mass reduction and high specific stiffness, making them suitable for interior structural components, brackets, supports, and thermally moderate housings. Rare-earth additions and composite reinforcements further extend magnesium's performance envelope, enabling improved creep resistance, damping capacity, and elevated-temperature stability when processed through squeeze casting. Despite these strengths, challenges remain in alloy design, process control, defect prediction, and large-scale manufacturability. Both alloy systems require refined compositions optimized specifically for pressure-assisted solidification, along with improved die design methodologies to accommodate complex geometries and thin-walled EV structures. Advanced process modeling, real-time monitoring, and data-driven optimization are poised to address these

Declaration of Competing Interests

The authors declare no known competing financial interests or personal relationships that could have influenced the work reported in this review.

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Author Contributions

A. Ragav: Conceptualization, Data Analysis, Writing – Original Draft; **Pavan Hiremath**: Supervision; Validation, Investigation, Writing – Review and Editing.

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