



SECONDARY ALUMINUM ALLOYS IN TRANSPORTATION

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Key words: *secondary aluminum alloys, transportation industry, aluminum recycling, energy efficiency, aluminum scrap, sustainable materials, industrial applications, environmental impact, material properties, future developments.*

Abstract: *Aluminum and its alloys are gaining significant attention due to their high strength-to-weight ratio, corrosion resistance, and recyclability. This study explores the use of secondary aluminum alloys in current and potential transportation applications. Secondary aluminum production involves recycling aluminum scrap, significantly reducing environmental impact and energy consumption. Research shows that recycled aluminum is 92 percent more energy-efficient than primary production, making it a sustainable alternative.*

In transportation, secondary aluminum alloys are used in automotive components, aircraft structures, and railway systems. These applications benefit from the material's lightweight nature, improving fuel efficiency and reducing greenhouse gas emissions. Additionally, the durability and cost-effectiveness of recycled aluminum make it appealing for widespread use.

This report analyzes the mechanical and physical properties of secondary aluminum alloys, comparing them with primary aluminum to highlight benefits and trade-offs. It addresses recycling challenges like contamination and alloying element losses, proposing advanced techniques to overcome these issues. Future work in this field will focus on innovative recycling technologies and optimizing alloy compositions to meet the transportation industry's evolving demands. The findings emphasize the role of secondary aluminum alloys in promoting sustainable development and advancing transportation technology.

INTRODUCTION

Aluminum and its alloys play a crucial role in modern industries due to their lightweight, strength, and corrosion resistance properties. These characteristics make aluminum a popular choice for various applications, including transportation. The demand for aluminum in the transportation industry continues to grow as manufacturers seek to improve fuel efficiency and reduce environmental impact. In addition to primary aluminum production (which is derived directly from bauxite ore), secondary aluminum (or recycled aluminum) production from recycled scrap has become increasingly important in meeting this demand [1].

Secondary aluminum production involves the recycling of aluminum scrap into usable aluminum alloys. This process significantly reduces the environmental footprint compared to primary aluminum production, which is derived from bauxite ore through energy-intensive

processes. Recycling aluminum requires only about 8% of the energy needed for primary production, making it a highly energy-efficient and sustainable alternative. The process of collecting, sorting, melting, and refining aluminum scrap not only conserves natural resources but also mitigates waste and reduces greenhouse gas emissions [2-5]. As a result, secondary aluminum production plays a vital role in the circular economy, enhancing the material's lifecycle and contributing to more sustainable industrial practices.

The purpose of this study is to explore the use of secondary aluminum alloys in transportation [3] and to examine their potential impact on the industry [6]. The objectives of the research include evaluating the performance of secondary aluminum alloys in various transportation applications, analyzing their environmental benefits compared to primary aluminum production, and assessing the economic implications of using these alloys. The scope of the study will focus on the current trends and future prospects of secondary aluminum alloys in the transportation sector, providing valuable insights for manufacturers, policymakers, and stakeholders in the industry.

PROPERTIES AND PRODUCTION PROCESS OF SECONDARY ALUMINUM ALLOYS

One of the significant advantages of secondary aluminum alloys lies in their exceptional strength-to-weight ratio, crucial for enhancing fuel efficiency and performance in transportation. Despite differences in mechanical properties compared to primary aluminum due to impurities, advanced processing aligns them closely, making secondary alloys viable for high-performance applications. These alloys also exhibit excellent corrosion resistance, crucial for transportation, and maintain satisfactory thermal and electrical conductivity, suitable for various applications.

Another primary benefit is their recyclability, significantly reducing carbon footprint and conserving resources compared to primary aluminum production. Secondary aluminum alloys contribute to environmental sustainability by generating fewer greenhouse gas emissions and reducing the need for mining and processing bauxite ore. The diverse sources of aluminum scrap ensure a steady raw material supply, supporting a circular economy and reducing reliance on primary aluminum.

Effective sorting and preparation are crucial for ensuring alloy quality, involving advanced technologies to achieve high purity levels [2]. Melting in specialized furnaces, refining to remove impurities, and adding specific alloying elements contribute to achieving desired properties. Common refining techniques include fluxing, inert gas bubbling, and filtration systems to ensure a clean melt. Alloying elements such as silicon, magnesium, copper, zinc, and manganese are added to the molten aluminum to enhance specific properties.

Overall, secondary aluminum alloys play a crucial role in transportation, offering sustainable alternatives with comparable properties to primary aluminum alloys. With meticulous control throughout the production process, secondary alloys meet the demands of various applications, supporting sustainable development in the transportation industry.

APPLICATIONS IN AUTOMOTIVE INDUSTRY

Secondary aluminum alloys are vital in the automotive industry [7,8], serving various components such as engine parts, body panels, wheels, and structural elements. They provide lightweight construction, corrosion resistance, high strength, and flexibility, thereby enhancing vehicle performance and longevity. Corrosion resistance is crucial for durability, particularly against environmental elements. Lighter vehicles made with these alloys improve fuel efficiency, thereby reducing emissions. Integrating secondary aluminum alloys enables sustainable vehicle production without compromising performance. These alloys are essential for achieving the automotive sector's sustainability and efficiency goals. Many manufacturers

produce high-quality secondary aluminum alloys for automotive use, including Alumag, Raffmetal, TRIMET, Hydro, Real Alloy, Novelis, Constellium, Rio Tinto, and Kobe Steel. Each brand offers a range of alloys tailored to meet car manufacturers' high demands for lightweight, durable, and sustainable materials.

APPLICATIONS IN AEROSPACE INDUSTRY

In the aerospace industry, secondary aluminum alloys are increasingly being used in various structural and component applications. Aircraft structures, such as fuselage frames, wings, and landing gear components, rely on the lightweight and high-strength properties of aluminum alloys. Secondary aluminum alloys are used in various landing gear parts (struts and supports, linkages and actuators) due to their high strength-to-weight ratio and durability. The ability to withstand high stress and fatigue, combined with excellent corrosion resistance, makes secondary aluminum alloys suitable for these critical applications. Components such as brackets, fittings, engine components (engine casings, cooling systems) and interior structures (seating frames, overhead bins and luggage racks, interior panels and partitions) also benefit from the use of secondary aluminum alloys due to their ease of fabrication and maintenance.

Some of the advantages of using secondary aluminum alloys in aerospace are [9]: weight reduction (fuel efficiency, increased payload, extended range); cost-effectiveness (material costs, maintenance and repair); sustainability (energy savings, resource conservation, reduced waste); performance and reliability (strength and durability, corrosion resistance, fatigue resistance).

Some specific examples of secondary aluminum alloy brands commonly used in the aerospace industry include: Alcoa 2024-T3, Kaiser Aluminum 7075-T6, Constellium HSA6, Aleris 6061-T6, Kobe Steel KBM10. These brands offer specific alloy compositions tailored to meet the stringent requirements of aerospace applications, ensuring high performance, reliability, and safety in aircraft structures and systems.

APPLICATIONS IN RAILWAY TRANSPORT AND IN RAILWAY SYSTEMS

Secondary aluminum alloys are increasingly utilized in railway transport and systems [10,11]. Below are a few examples of their many such applications.

Structural applications - in the construction of train bodies and carriages, which gives energy efficiency, increased speed, enhanced payload capacity; in various structural components of train bodies, including: frames and beams, exterior panels.

Interior Applications: Inside the train, secondary aluminum alloys are used to manufacture a range of components: seating frames, luggage racks and partition panels, interior panels. Aluminum interior panels are durable and resistant to wear and tear, making them ideal for high-traffic areas within the train. Aluminum's excellent thermal conductivity allows for efficient heat distribution, which is beneficial for maintaining comfortable temperatures within train cabins. Aluminum panels can be combined with insulation materials to enhance acoustic performance, reducing noise levels inside the train and improving passenger comfort.

Exterior Applications: in the construction of train doors and window frames due to their light weight, strength, and corrosion resistance; in roofing and flooring applications - roofing panels, flooring systems.

Secondary aluminum alloys play a vital role in enhancing the performance, durability, and sustainability of railway transport and systems. Their lightweight construction, high strength, corrosion resistance, ease of fabrication, thermal conductivity, and cost-effectiveness make them a preferred choice for a wide range of applications in the railway industry. By leveraging the unique properties of secondary aluminum alloys, railway systems can achieve improved efficiency, reduced environmental impact, and enhanced operational reliability.

The use of secondary aluminum alloys in railway applications involves various specific alloy brands and types that have been engineered to meet the demands of the industry. Here are some notable examples of secondary aluminum alloy brands and their applications in railway transport:

- Hydro CIRCAL is a series of aluminum alloys that contain at least 75% recycled post-consumer scrap. This makes it one of the most sustainable aluminum products on the market. It is used for structural components, exterior panels, and interior fittings in train carriages. Their high recycled content and excellent mechanical properties make them ideal for reducing the environmental footprint of railway vehicles while maintaining structural integrity and durability.

- Novelis Advanz™ is a range of high-strength aluminum alloys that are extensively used in automotive and transport sectors, including railways. These alloys are known for their high recycled content and superior performance characteristics. It is used in the construction of lightweight train bodies, doors, and roof panels. The high strength-to-weight ratio and excellent corrosion resistance of these alloys help improve fuel efficiency and reduce maintenance costs.

- Constellium Securalex™ is a brand of aluminum alloys specifically designed for safety-critical applications in the transport industry. These alloys are formulated with high recycled content and offer enhanced impact resistance and energy absorption capabilities, and are used in the manufacturing of crash-resistant components, such as sidewalls and structural beams in train carriages. Their ability to absorb impact energy helps enhance passenger safety in the event of a collision.

- ALCOA Endure™ - alloys that incorporate a significant amount of recycled material. These alloys are designed to offer long-term durability and resistance to harsh environmental conditions. They are used in the construction of exterior cladding, window frames, and flooring systems for trains. Their durability and corrosion resistance ensure long service life, and reduced maintenance requirements.

Other aluminum alloys, tailored for use in various transportation applications, that focus on sustainability by maximizing the use of recycled aluminum are: ReAl™ from Rusal, KSTAL™ from Kobe Steel, etc.

APPLICATIONS IN MARITIME INDUSTRY AND PUBLIC TRANSIT

The use of secondary aluminum alloys in maritime and public transit sectors [3,12] is on the rise due to their lightweight, durable, and sustainable properties. These alloys offer excellent corrosion resistance, making them suitable for shipbuilding, ferry construction, and various transit components. In maritime applications, they contribute to improved fuel efficiency and maneuverability. Similarly, in public transit, they lead to weight savings, increased passenger capacity, and reduced emissions. Specific applications include ship hulls, ferry components, railcar bodies, transit buses, and light rail systems. Overall, secondary aluminum alloys represent a compelling solution for performance optimization and environmental sustainability in both industries. Some specific examples of secondary aluminum alloy brands commonly used in these industries include: Hydro CIRCAL®, Novelis evercycle™, Constellium HSA6™, Alcoa EcoLum™, Aleris SECURE™. These brands offer specific alloy compositions tailored to meet the stringent requirements of the maritime industry and public transit sector, providing lightweight, durable, and environmentally friendly solutions for shipbuilding, marine equipment, and transit vehicle construction.

ENVIRONMENTAL AND ECONOMIC IMPACT

Secondary aluminum alloys offer significant energy savings compared to primary aluminum production, requiring only 5% of the energy. This is due to the elimination of energy-intensive processes like bauxite extraction.

Using secondary alloys leads to cost savings in production and maintenance, benefiting manufacturers, consumers, and the economy [4,6].

These alloys contribute to sustainable development by conserving resources, reducing greenhouse gas emissions, and promoting environmental stewardship in transportation.

CHALLENGES AND SOLUTIONS IN RECYCLING

Recycling aluminum scrap for secondary alloys faces contamination challenges from various sources, degrading alloy quality. Techniques like pre-treatment, sorting, and fluxing help minimize contamination during melting. However, recycling may lead to loss of alloying elements, affecting properties. Controlled melting atmospheres and precise alloying additions [8] minimize losses. Innovations like electromagnetic separation and laser sorting enhance recycling efficiency. Future directions include automated sorting, sustainable processing, and digital technology integration for optimization.

FUTURE DEVELOPMENTS

Research in secondary aluminum alloys aims to enhance mechanical properties, develop cost-effective grades, and improve corrosion resistance. Material science advancements like nanotechnology and AI offer potential for superior properties. Additive manufacturing allows intricate part production with minimal waste.

Emerging recycling technologies include advanced sorting and energy-efficient melting processes. Blockchain integration ensures sustainable sourcing, impacting transportation by improving alloy quality and reducing costs.

Growing demand for secondary alloys in electric vehicles benefits from weight reduction. Circular economy practices drive recycling, conserving resources. Market expansion is projected with technology advancements and supportive regulations, establishing secondary alloys in transportation.

CONCLUSION

This study emphasizes the benefits of secondary aluminum alloys in transportation, including their environmental advantages and desirable mechanical properties. Advancements in alloy composition and recycling technologies are crucial for enhancing their effectiveness. These alloys contribute to sustainable transportation by improving fuel efficiency and supporting cleaner energy sources through recycling, which aligns with sustainability goals and lowers material costs. Embracing secondary aluminum alloys is essential for a greener and more efficient future in transportation.

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ВТОРИЧНИ АЛУМИНИЕВИ СПЛАВИ В ТРАНСПОРТА

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Ключови думи: вторични алуминиеви сплави, транспортна индустрия, рециклиране на алуминий, енергийна ефективност, алуминиев скрап, устойчиви материали, индустриални приложения, въздействие върху околната среда, свойства на материалите, бъдещи разработки.

Резюме: Алуминият (Al) и сплавите му привличат голямо внимание поради високото съотношение здравина-тегло, корозионна устойчивост и възможност за рециклиране. Статията разглежда настоящите и потенциални приложения на вторични Al сплави в транспорта. Вторичното производство на Al включва рециклирането на Al скрап, което значително намалява въздействието върху околната среда и енергопотреблението. Изследванията показват, че рециклираният Al е 92 процента по-енергийно ефективен от първичното производство, което го прави устойчив алтернативен материал.

В транспорта вторичните Al сплави се използват в автомобилни компоненти, самолетни структури и железопътни системи. Лекотата на материала подобрява горивната ефективност и намалява емисиите на парникови газове. Издръжливостта и икономичността на рециклирания Al го правят привлекателен за широко приложение.

Докладът анализира механичните и физичните свойства на вторичните Al сплави, като ги сравнява с тези на първичния Al, за да подчертае предимствата и потенциалните недостатъци. Разглеждат се предизвикателствата, свързани с процесите на рециклиране, като замърсяване и загуби на легиращи елементи, и се предлагат усъвършенствани техники за преодоляването им. Бъдещите разработки ще се фокусират върху иновативни технологии за рециклиране и оптимизиране на състава на сплавите, за да отговорят на изискванията на транспортната индустрия. Подчертава се важната роля на вторичните сплави за устойчиво развитие и напредък на технологиите в транспорта.