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Aluminum Circular Economy in the Bicycle Industry

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Abstract

From a traditional perspective, Bicycles are considered low-carbon emission transportation tools for commuting and traveling. This study analyzes aluminum recycling pathways within the bicycle manufacturing process to illustrate the bicycle circular economy model for the industry stakeholders to better understand the roadmap for improving from manufacturing to recycling. The goal is to promote the bicycle industry's sustainable development by achieving economic benefits and environmental protection. A comprehensive analysis of the entire lifecycle of the bicycle manufacturing process including production, usage, and recycling, was conducted for future application and manufacturing improvement. This research identifies existing technical barriers, policy limitations and restrictions, and issues related to market acceptance. In response to these challenges, a framework is proposed to draw a roadmap for the industry to make informed decisions on circular-economy-centered practices. This approach encourages companies to improve carbon emission efficiency to contribute to the long-term sustainability of the bicycle industry.

JEL classification numbers: L11, M10.
Keywords: Carbon Emission Efficiency, Circular Economy, Aluminum Recycling, Sustainability.

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1. Introduction

With the growing emphasis on carbon reduction policies in major bicycle markets, the circular economy has emerged as one of the most effective methods for achieving carbon reduction in the bicycle industry. It is well-known that bicycle manufacturing involves extensive use of aluminum extrusions, which are processed through various metalworking techniques to produce components before being assembled into bicycles.

During the production process, manufacturers can efficiently sort different types of aluminum alloy waste during operations such as lathing, milling, grinding, and sawing. This enables continuous recycling of aluminum alloys within a closed system, achieving zero waste in production and significantly reducing the carbon footprint of bicycle products. This approach maximizes the carbon efficiency of aluminum usage. Additionally, this production and consumption model reduces reliance on natural resources, ensuring that the economic development and consumption within the bicycle industry do not negatively impact the natural ecosystem.

This study explores how the bicycle industry can achieve the dual goals of environmental sustainability and economic benefits through the circular economy model, including reviewing the current state of the bicycle industry in terms of material selection, design innovation, manufacturing processes, and recycling of end-of-life bicycles, and analyzing the challenges faced in implementing the circular economy. Furthermore, this paper reveals, through case studies, the experiences and lessons learned from successful circular economy strategies and proposes responsive strategies. These strategies not only enhance resource utilization efficiency within the industry but also strengthen pollution control and promote green economic growth. In a world increasingly focused on climate change and the finite nature of resource extraction, building a sustainable circular economy model for the bicycle industry is not just an environmental responsibility but also an economic necessity. The findings of this study will provide practical recommendations and references for policymakers, industry leaders, and academic researchers, contributing to the sustainable transformation of the bicycle industry.

2. Literature Review

2.1 Circular Economy

The concept of the circular economy can be traced back to Boulding's (1966) work, where he likened Earth, with its limited resources, to a spaceship traveling through space. Within the framework of a "closed economy" with finite resources, it is imperative to consider how resources can be reused as much as possible, while also avoiding the generation of waste and pollution.

2.2 Application of Aluminum Alloys

Aluminum alloys are currently the most widely used materials in bicycles due to numerous advantages. These include being lightweight, having excellent short-term hardness and rigidity, and being easy to shape according to mechanical principles while maintaining strength. Additionally, aluminum alloys do not rust and can reduce weight through tube drawing techniques. However, it has drawbacks, such as a lack of elasticity, which can lead to metal fatigue. Despite the material's hardness, the rigidity can make the bicycle frame less able to absorb road vibrations, reducing overall comfort (Chuang et al., 2007).

2.3 Challenges and Obstacles in the Circular Economy

The recycling and reuse of aluminum shavings, a byproduct of the bicycle manufacturing process, represent one of the significant challenges in establishing a circular economy within the industry. Aluminum is widely used in bicycle frames, rims, and other structural components due to its lightweight and high-strength properties. However, manufacturing of the parts generates a large amount of aluminum shavings. Effectively recycling and reusing metal shavings to minimize waste and promote sustainable development is an urgent issue for the bicycle industry.

The first challenge in recycling aluminum shavings is the collection and classification. The shavings generated during bicycle production are often mixed with cutting oils, dust, and other metal shavings, reducing the purity of the aluminum and complicating the recycling process. Cleaning and sorting the shavings on-site is necessary to improve recycling efficiency and aluminum purity. However, this requires additional investment in labor and equipment, which can be a significant burden for small bicycle manufacturers.

Additionally, the large volume and low density of aluminum shavings pose challenges for transportation and storage. Traditional transportation methods may require considerable space and incur extra costs. Therefore, implementing effective compression techniques to reduce volume or improve the efficiency of transportation systems is crucial for lowering transportation costs (Sami Al-Alimi et al., 2024).

3. Methodology

In the context of the bicycle industry, aluminum is used extensively throughout the manufacturing process. The production begins with the refinement of alumina into aluminum ingots, which are then sent to a furnace for casting into aluminum billets. These billets are subsequently transferred to extrusion plants, where they are shaped into various cross-sections, depending on the product's requirements. For example, square tubes (with square cross-sections) and round tubes (with circular cross-sections) are commonly utilized in bicycle frames.

The extruded aluminum then undergoes additional metalworking processes such as lathing, milling, grinding, and sawing, to further refine the components. On average, aluminum waste generated during these processes ranges from 15% to 30%, with the exact figure depending on several factors, including the machining techniques employed, equipment precision, and operational methods. Techniques such as cutting, drilling, and grinding can have differing impacts on waste generation. However, by implementing advanced machining technologies and high-precision equipment, manufacturers can significantly reduce waste rates.

Manufacturing Strategies: Adopting efficient recycling techniques can mitigate waste during the aluminum machining process, maximizing resource utilization and minimizing environmental impact.

Waste Management and Recycling: Effective waste management and recycling systems are crucial in reducing material waste and fostering sustainable development (Sami Al-Alimi et al., 2024).

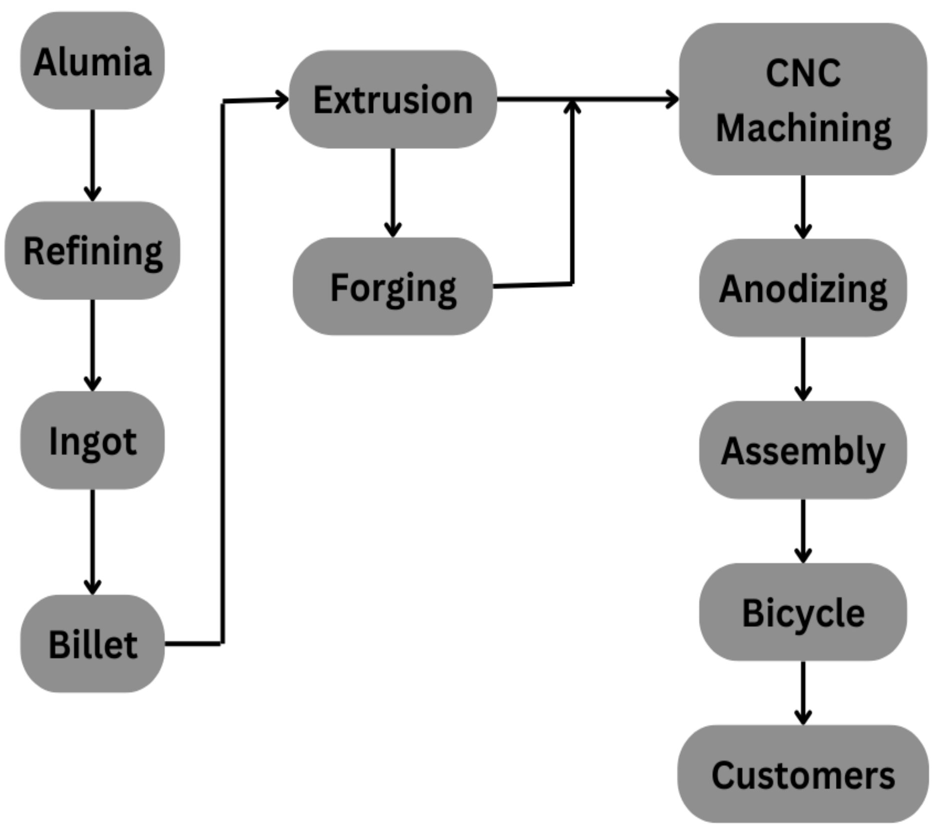

Figure 1: Aluminum-to-Bicycle Production Process Flow

Hypothesis 1: Implementation of Circular Economy Recycling of Scrap Materials

Research Hypothesis: Implementing a circular economy can reduce material costs and environmental impacts for bicycle manufacturing companies.

Variables:

Independent Variable: The extent of scrap material recycling.

Dependent Variables: Material costs and environmental impacts, with environmental impact measured by carbon footprint (CO_2e emissions).

Relationship: It is hypothesized that the implementation of circular economy practices in scrap material recycling is positively correlated with reductions in material costs and environmental impacts.

Hypothesis 2: Absence of Circular Economy Implementation

Research Hypothesis: Companies that do not implement circular economy practices will face higher resource costs and increased environmental liabilities.

Variables:

Independent Variable: Presence or absence of circular economy measures.

Dependent Variables: Resource costs and environmental liabilities, with environmental liability measured by carbon fees.

Relationship: The absence of circular economy measures is hypothesized to increase resource costs and heightened environmental liabilities.

Hypothesis 3: Continuation of High-Carbon Emission, Low-Cost Production Without Adopting Carbon Tax Markets

Research Hypothesis: Companies that continue to produce high-carbon-emission products will face long-term challenges such as reduced market size and decreased competitiveness.

Variables:

Independent Variable: Production volume of high-carbon-emission products.

Dependent Variables: Market size and competitiveness, measured by market share and profit margins.

Relationship: It is hypothesized that the production of high-carbon-emission products is negatively correlated with market size and competitiveness.

Hypothesis 4: Internalization of Carbon Costs and Adoption of Low-Carbon Strategies

Research Hypothesis: By internalizing carbon costs, bicycle companies will gain long-term advantages in cost efficiency and market reputation.

Variables:

Independent Variable: The extent of carbon cost internalization.

Dependent Variables: Cost efficiency and market reputation, with carbon cost efficiency measured by the percentage reduction in expenses and market reputation measured by customer satisfaction and brand recognition.

Relationship: It is hypothesized that internalizing carbon costs positively correlates with improvements in cost-effectiveness and market reputation.

4. Supporting Evidence

The European Green Deal (2024) has highlighted the carbon reduction requirements for aluminum products entering Europe, including facilitating bicycle use to achieve the goals of carbon neutralization. These carbon reduction requirements for aluminum products have gradually become a consensus in the European market. Furthermore, the European Union has established the Carbon Border Adjustment Mechanism (CBAM) to prevent carbon leakage. This mechanism imposes carbon emission requirements on imported products, including aluminum products, requiring importers to report and pay for the carbon emission costs associated with the products. Since aluminum production involves high energy consumption, aluminum products imported from other regions into the EU must comply with carbon reduction requirements.

Accordingly, the evidence robustly supports Hypotheses 1 and 4. The European Green Deal (2024) and the implementation of the Carbon Border Adjustment Mechanism (CBAM) provide strong regulatory frameworks that incentivize carbon reduction and resource efficiency in industries reliant on aluminum. The emphasis on carbon reduction requirements for aluminum products, including bicycles, aligns with the goals of both Hypotheses 1 and 4. Specifically, the circular economy practices in scrap material recycling (Hypothesis 1) are directly supported by the EU’s commitment to minimizing waste and promoting resource reuse. Likewise, the internalization of carbon costs and adoption of low-carbon strategies (Hypothesis 4) are validated by the CBAM, which holds companies accountable for their carbon emissions, encouraging long-term advantages in cost efficiency and market reputation for those who comply.

5. Analysis and Discussion

Empirical evidence from the industry reveals that aluminum is widely used due to its numerous advantages. Aluminum is recyclable without compromising its quality, reusable, and abundantly available from bauxite ore. It is also one of the most efficient and cost-effective materials. However, aluminum production is associated with high carbon emissions.

The critical challenge for the industry is to reduce aluminum's carbon footprint while retaining all its benefits, ensuring that aluminum continues to be recycled within the bicycle industry without being downgraded for use in products that do not require high strength. The concept of "carbon efficiency" is crucial here, referring to the efficiency with which energy is utilized in production processes.

Whether fossil fuels or electricity are used, greenhouse gas emissions are inevitably produced during energy consumption (Pan, 2024).

6. Conclusion and Suggestions

Proper classification and meticulous collection of aluminum shavings at the point of generation are crucial for establishing a circular economy in the bicycle industry. The recycling and reuse of aluminum waste is not only a technical and managerial challenge but also involves industry-wide collaboration, policy support, and social awareness of green transitions. Addressing these challenges requires a multi-faceted approach, with coordinated efforts to overcome current difficulties.

In the future, closer cooperation between governments and businesses will be necessary, with policies guiding and companies implementing these practices to drive innovation in recycling technologies. Furthermore, industry standardization is vital. The joint creation and enforcement of industry standards can promote the advancement and widespread adoption of aluminum recycling technologies.

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