Aluminum Material Recycling Efficiency Study Based on Multi-Country Comparison

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Abstract. Aluminum is one of the most abundant metals in the world and plays an important role in various industries, but the synthesis of bauxite into aluminum is accompanied by serious environmental pollution, such as electricity consumption, carbon dioxide, and toxic by-products. This paper analyzes the development of aluminum materials, specifically discusses how aluminum metal is made and recycled, and analyzes ways to add value to aluminum from the perspective of circular economics, then proposes ways to popularize the standardization of automotive parts so as to improve the efficiency of aluminum recycling in the automotive industry.

1 INTRODUCTION

Aluminum is one of the most common metals in the world and also the most widely used element. it can be seen everywhere from coke cans to aerospace technology equipment. But as we pursue more aluminum production, we must also consider environmental pollution. In addition, with the COVID-19 significantly boosting global aluminum demand, therefore we need to make a reasonable trade-off between more aluminum resources and sustainability in economic terms.

Even in modern times, many companies are gradually reducing the cost of material recycling, such as Renault, which has made a lot of efforts in the recycling industry. But from a macro perspective, human efforts are not enough. The gradual application of aluminum to different parts of the car is a very mainstream path for the future, so this will also be very closely linked to the demand for aluminum. In this paper, a very detailed study and investigation of the recycling stages of aluminum materials and the recycling of aluminum materials in automobiles is conducted, and finally it is concluded that the environmental pollution can be minimized by reducing the cost of aluminum recycling.

2 OVERVIEW OF ALUMINUM INDUSTRY DEVELOPMENT

2.1 Distribution of Aluminum Resources

Aluminum itself is not a direct natural resource, and in nature it often exists as Bauxite (aluminum oxide) because of its physical properties. It consists of hydrated aluminum oxides, hydrated aluminum silicates, iron oxides, hydrated iron oxides, titanium oxides and silicon dioxide. It contains a mixture of various minerals such as alumina trihydrate, thin alumina, hematite, acanthite, aluminum acanthite, anatase, rutile, ilmenite, kaolinite and quartz [1].

Bauxite is a remnant rock formed by weathering of various igneous, sedimentary and metamorphic rocks. These parent rocks have undergone long-term (millions of years) weathering under tropical, subtropical or very humid temperate conditions [2]. Ninety percent of the world's known bauxite resources are located in the tropics. Other deposits outside of these dimensions have also undergone long periods of intense weathering during the geological past.

2.2 Environmental Threats Posed by Aluminum Manufacturing

Due to its rich and unique physical properties, aluminum is of irreplaceable importance in various modern industries. The first is aluminum's excellent ductility, which is very useful for modern design. The second is its durability and recyclability, which has great potential for zero-energy buildings. Today's progressively higher level of development in the Asia-Pacific region, such as China and India, and the greater demand for manufacturing have led to an increasing demand for aluminum [3]. At the same time, the development of new energy vehicles represented by Tesla is also one of the important factors increasing the demand for aluminum. Automakers such as Mercedes-Benz and BMW are increasingly replacing stainless steel with aluminum, which has similar physical properties and is lighter in weight. The above factors are expected to drive the market growth. [4].

Aluminum is not a natural substance and therefore must be produced through a series of chemical reactions with bauxite. At the same time, the large consumption of

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electricity resources and the emission of a series of pollutants during the reaction process are contrary to the sustainable development goals set forth by the United Nations.

From a production perspective, the most widespread manufacturing method, the Bayer and Hall-Herot process, requires a large amount of energy to provide the electrical supply to support the chemical reactions [5]. However, the environmental pollution associated with this manufacturing method should not be underestimated: nearly two-thirds of the total amount of polluting gases emitted are the result of this process, and the remaining pollution is also a product of the use of fuel sources and natural gas. Such a large amount of energy consumption inevitably results in a significant CO2 footprint and leakage.

3 ADVANTAGES AND DISADVANTAGES OF ALUMINUM AS A RAW MATERIAL

3.1 Advantages of Aluminum Materials

Due to its excellent physical properties such as ductility, conductivity and resistance to oxidation, aluminum is one of the most important materials in most modern manufacturing industries, such as the automotive industry or construction.

First, it is less dense or lighter than traditional materials, such as steel, which brings significant benefits. The low density of aluminum makes it possible to obtain a significant weight reduction in a body made of it [6]. Therefore, for the same fuel consumption, because the weight reduction represents an aluminum car can travel more distance using the same fuel consumption, enhancing the efficiency per unit of fuel and thus reducing the need for that fuel. In addition, the lighter body also allows aluminum vehicles to carry more cargo, making them more efficient as tools in their own right.

More importantly, the lighter body provides a better handling feel while ensuring safety: Ford is actually a very mature aluminum car company, having introduced a very large number of aluminum-clad trucks a few years ago, and it has been tested that when aluminum is used as the body, it actually provides more protective strength and can improve fuel efficiency by about 29%. And, because of the low density of the aluminum material, the central mass of the car will be better inclined to the front section of the car, providing a better driving experience for the driver. Even though the car itself loses some of its grip due to the material, the car can change direction or brake better at the same time, providing more maneuverability to withstand emergencies.

The second is the durability of the aluminum material. Compared with traditional materials, aluminum materials because of its physical structure can better resist the problem of oxidation, so when the car using aluminum shell, can provide better overall durability, reduce the frequency of car maintenance, and even provide a layer of fire protection layer to protect the body.

3.2 Disadvantages of Aluminum Materials

However, the disadvantages of aluminum compared to ordinary steel are also obvious. The most fatal is that aluminum is not as strong as steel because of its low density, therefore, using aluminum as a frame, the car will face safety problems, even though it has been suggested that aluminum can better transmit the energy generated by a collision, but it determines the safety characteristics a car has due to the lack of physical absolute properties (of course Ford makes cars with aluminum as a harder aluminum alloy).

Secondly, it is not economically efficient. For one, aluminum is much more expensive than steel, especially since the current demand for aluminum in various industries, especially construction, has increased dramatically in response to the outbreak. For example, the 2014 F-150 has a suggested retail price of about $25,000. Meanwhile, the 2015 F-150 with an aluminum body starts at $26,615[7].

At the same time, aluminum has a higher coefficient of thermal expansion compared to other metals. This leads to increased difficulty in the maintenance of aluminum products, for example, when welding operations on aluminum products, it must be extremely difficult to avoid the expansion of aluminum, so it is more difficult to maintain aluminum cars, resulting in aluminum cars will be much more expensive in terms of maintenance costs. Ultimately, these economic inconveniences are reflected in higher retail prices and subsequent repair and maintenance costs that are approximately twice as high compared to traditional steel [8].

4 CIRCULATION OF ALUMINUM MATERIALS

4.1 Reasons Why Aluminum Can Be Recycled

Recycled aluminum is a very promising industry, because the physical properties of aluminum itself lead to a higher recycling rate compared to other materials. And as a material in great demand, recycling it can reduce a very large amount of environmental pollution, every 1t of recycled aluminum can reduce the emission of carbon dioxide 0.8t, reduce the emission of sulfur oxides 0.06t, save 10.5t of water, reduce the amount of solid materials 11t, reduce the amount of waste liquid and slag disposal 1.9t, avoid stripping the surface soil and stone 0.6t, avoid quarrying vein stone 6[9].1t, in the Under the same production conditions, the investment for the production of recycled aluminum is only one tenth of that for the production of virgin aluminum. With such remarkable recycling efficiency, more advanced recycling technology can even bring a stronger competitive advantage to the economy.

The recycling efficiency of aluminum has a direct and positive relationship with the development of the country. For example, in countries such as the United States, Japan or Germany, regardless of their own aluminum imports or production, their recycled

aluminum reaches at least 30 percent. In contrast, in China or other relatively backward countries, the aluminum recycling industry is not so mature, and in China it only reaches 20 percent; this continued over-reliance on traditional electrolytic methods is already behind the mainstream trend [10].

4.2 Aluminum Circulation Method

The significance of aluminum recycling is to enhance the already more value of aluminum material by increasing its service life. As shown in Figure 1, from relatively low efficiency to maximum efficiency, we can classify aluminum recycling methods as Recycle, Refurbish, Reuse, and Maintain [11].

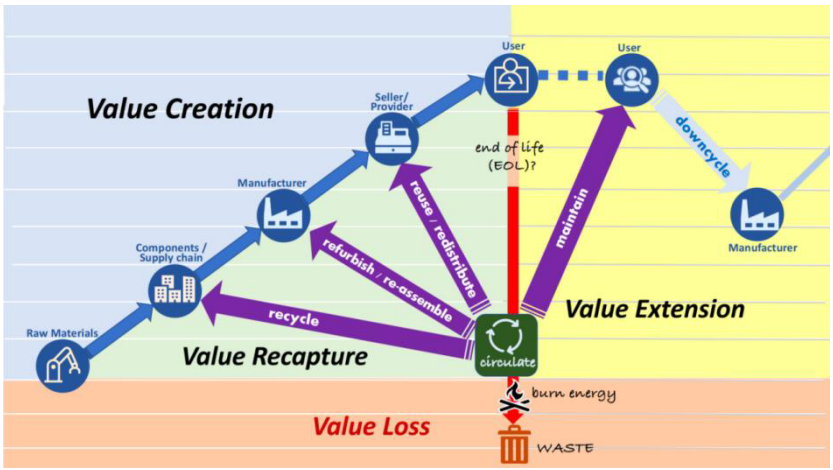

Figure 1. Recycle Loop of the Aluminum in the Automobile Filed (resource: NYU Stern Professor Rlyon Bob)

Recycle stands for the most direct recycling of used aluminum, such as the direct recycling of damaged car shells into aluminum as described in the previous section, and even though it is the most inefficient method, it provides the easiest and most direct way to recycle aluminum. With a wide variety of metal parts that make up a large portion of the total mass of a vehicle, parts such as aluminum rims, axles, handles and other scrap metal from end-of-life vehicles can be sold to scrap metal companies who will melt them down for reuse.

The significance of aluminum recycling is to increase its total value by extending its life. As shown in Figure 1, the direct recycling of raw materials increases the value of aluminum to a certain extent, but the recycling method above it has a much better efficiency. In a progressive order up to the red line, Refurbish, Reuse until Maintenance maximizes the total value of aluminum in a single pass. At the right end of the End of Life line is the Volume Extension, which recirculates aluminum that cannot be maintained, for example by downgrading it to the Refurbish part to make it valuable again.

Re-Furbish is a more advanced approach than Recycle by refurbishing used aluminum products from the original manufacturer's perspective, thereby increasing their total lifespan. For example, relative to the automotive industry, when an engine is severely damaged, highly skilled machinists can use state-of-the-art technology to rebuild it into a completely safe, cost-effective and warranty-backed engine. The old engine is disassembled, all of its surfaces and components are machined and cleaned, and the engine is reassembled using new critical internal parts. Remanufactured engines use 80-85% less energy and reduce chemical waste, raw material use and labor compared to manufacturing a new engine.

Reuse refers to the reuse or resale of used aluminum products from a retailer's perspective, thereby adding value. From the perspective of the automotive industry, the most typical example is the used car market. Professional used market sellers or car manufacturers themselves will offer buyers a more economical means of providing a used product with the same official validity through official repairs, maintenance and production. Even so, the different cultures in different countries have led to different degrees of efficiency in the cycle. The used car market in the United States and Japan is more mature than other countries, and has a larger volume of transactions, with high used car sales and a well-established market code that gives buyers confidence in the price, quality and service of the car.

Maintain means to extend the life of aluminum products from the user's point of view, and private repair, maintenance and inspection of aluminum products (cars) can be very effective in increasing the average life of cars. Similar to the "Kit Car" culture, when parts of a car are found to be damaged, the life of each body can be significantly extended by repairing the damaged parts, such as replacing a motor that has lost its durability or replacing individual parts in the case of electric vehicles.

4.3 Aluminum Recycling Efficiency

Because each country has different degrees of efficiency (development) differences in the materials cycle, the efficiency of aluminum recycling varies from country to country.

As shown in Figure 2, the world's major developed countries have formed a set of relatively mature recycling production lines for scrap aluminum alloys, and the annual output of recycled aluminum is more than half of the total aluminum production, basically

remaining at about 70%, and the output of recycled aluminum in Japan is more than 99% of the total aluminum [12].

In China, for example, the proportion of recycled aluminum production in other countries is less than 20%, which is far behind the global average. That is because the recycled aluminum industry in relatively low-developed countries started relatively late, initially formed in the late 1970s, the recycled aluminum enterprises are relatively scattered, not formed on a large scale, smelting technology and equipment is relatively backward, pretreatment sorting stage mostly rely on manual operation, smelting equipment to reflect the furnace, and no supporting auxiliary systems such as heat storage and dust removal, resulting in serious metal burn loss in the smelting process[13]. The smelting process results in serious metal burning loss, high content of impurities and inclusions, and ineffective treatment of wastewater, waste gas and slag generated from the smelting process, which cannot achieve the effect of efficient recycling of resources.

Country	Japan	Europe and America	Worldwide average	China
Proportion	>99%	70%	30%	<20%

Figure 2. Aluminum Recycling Rate in different Regions [14]

5 ALUMINUM CYCLE IN THE AUTOMOTIVE INDUSTRY

5.1 Aluminum Recycling Application in The *Automotive Industry*

The aluminum cycle passes through a very large number of processes between collection and re-use as recycled aluminum, and the prevailing approach is to reduce the cost consumption between each economic cycle (Circularity). Renault, a pioneer in automotive recycling, has been very successful in this regard. Their proposed 4-RE target is a microcosm for the entire modern automotive cycle market.

The 4Rs stand for RE-trofit, RE- energy, RE-cycle and RE-start. RE-trofit refers to the gradual design of ordinary cars into low-carbon models, and the possibility of using 3D printing technology to better design rare parts. RE-Cycle refers to better use of resources to increase the efficiency of the cycle. Finally, Re-Start refers to the improvement of technology to bring about a more efficient cycle. Renault is a very forward-looking leader in the field of RE-Cycle, having spent a very large amount of capital on optimizing the reduction of the cycle distance of aluminum materials. By expanding the efficiency between each step, the overall reduction of wasted energy is achieved.

5.2 The Help of Automotive Parts Standardization for The Cycle

The standardization of automotive components is a huge topic. Automotive components in general can be divided into two categories: simple components and complex components. Simple components refer to common parts, for example, the automotive industry has about 3000 discrete components, such as pins or rollers; on the other hand, complex designs, mainly engines, where the investment and technology is owned by a specific automotive company.

For simple parts, the benefits of standardization are obvious. Under the assumption that parts are standardized, fixed costs for economies such as machine design, or factory set-up can be omitted, and thus the market can be more easily managed. a typical example of standardization is Hartford, an aluminum parts manufacturing company with a very large number of patents and applications in the manufacture of standardized parts. Under standardized conditions, the same component can be installed in multiple vehicles as long as the space and mounting points are the same. With the support of this technology, the whole process of vehicle cycling can be made much easier.

In the three dimensions of Refurbish, Reuse and Maintain, for example, the existence of standardized parts symbolizes a complete increase in cycle efficiency to another dimension. From the point of view of businesses and the used car market, repairing cars becomes easier and cheaper, as the need for Skilled Workers and special machines can be greatly reduced. And in terms of individual car users, more concise repairs allow more groups to participate in individual car repairs, increasing the value of the overall cycle in terms of volume. Even in the case of Direct Recycle, standardization of parts ensures that the chemical composition of each part is the same, resulting in significant cost and efficiency savings in the sorting and selection process.

6 CONCLUSION

In this paper, we analyze the life cycle of aluminum, from the extraction of the raw mineral bauxite to the aluminum material, to the finished aluminum and finally to the recycling of aluminum. In the different stages of recycling, we find several stages that are the main ways to increase the overall volume of aluminum, they are reuse, refurbishment and maintenance. At the same time, considering how to maximize the profitability of each stage and minimize carbon leakage, in an extremely competitive environment for aluminum resources, the

original aluminum production methods have caused serious damage to the natural environment, including toxic gases, aluminum waste and damage to the local economy, these emergencies emphasize the importance of aluminum recycling, which is the goal explored in this paper.

Also in analyzing the four stages of automotive recycling it was found that automotive standardization is the key to improving automotive recycling. Standardization makes it easy to refurbish and repair cars, and from the perspective of an automotive plant, when they receive a used aluminum product, the plant can more easily sort through the different parts of the car and recycle them in less time.

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