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Review Manufacturing Process of Aluminium Scrap Casting

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Abstract. This research examines various approaches in improving the quality and efficiency of the aluminium recycling process, focusing on the effect of waste type, casting method, and process parameters on the mechanical properties of the resulting product. Several studies have shown that the type of aluminium waste, such as pistons and cans, affects the hardness of the final product, while non-conventional cooling media such as coconut milk water can produce a more homogeneous microstructure. In addition, casting methods such as centrifugal casting are superior to sand casting in producing tighter microstructure and better mechanical quality. The addition of elemental tin (Sn) to recycled aluminium has also been shown to improve hardness and wear resistance, making it more suitable for severe applications. Controlling the casting temperature and controlling porosity are also important factors in obtaining products with optimum mechanical strength. While these results are promising, further research is needed to optimise cost efficiency, environmental impact and sustainability in the aluminium recycling process.

Keywords: aluminium recycling; casting method; coconut milk water cooling; centrifugal casting, tin addition; sustainability

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1. Introduction

The use of aluminium waste in the casting process is a promising solution to address the growing problem of aluminium waste and the need for sustainable manufacturing practices. Aluminium is one of the highly recyclable materials, which can significantly reduce environmental impact and production costs when reused in casting processes. However, the application of aluminium waste in casting faces several challenges, such as maintaining material properties, managing impurities, and optimising the casting process to ensure product quality (1).

The aluminium scrap casting process has great potential in the manufacturing industry as it enables the reutilisation of materials that were previously considered as waste. Thus, this process not only helps to reduce the amount of waste generated but also provides economic benefits by lowering the cost of raw materials. Nonetheless, a major challenge in the use of aluminium scrap is the presence of impurities and unwanted alloying elements that can affect the mechanical properties and microstructure of the final product. Therefore, refinement techniques and careful control of alloy composition are required to ensure consistent product quality (2,3).

Several studies have examined the impact of alloying elements and impurities on the mechanical properties and microstructure of cast aluminium components. For example, Badia et al. (4) investigated the improvement of recycled aluminium piston quality through the addition of tin in the remelting process. In addition, a study examined the impact of adding pure aluminium to aluminium scrap on the toughness and microstructure of cast motorcycle wheels (5). Furthermore, a study investigated the effect of variations in casting temperature on the microstructure and hardness of recycled Al-Si castings produced using Styrofoam patterns (6). Innovations in recycled aluminium casting techniques continue to grow along with the increasing need for environmentally friendly and economical materials. Several new techniques have been introduced to improve the efficiency and

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quality of casting products from aluminium scrap. For example, the use of semi-solid casting technology (thixocasting) can reduce casting defects and improve the mechanical properties of the final product. In addition, more effective filtration and degassing techniques have been developed to remove impurities and gases trapped in scrap aluminium before the casting process, which contributes to the improvement of the final product quality (3,7).

The use of aluminium waste also provides benefits in terms of environmental sustainability. By recycling aluminium, the industry can reduce the energy consumption required to produce new aluminium from bauxite ore. The production process of aluminium from bauxite ore is very energy intensive, so by recycling aluminium scrap, significant energy savings and reductions in greenhouse gas emissions can be achieved. Therefore, the application of scrap aluminium casting technology not only provides economic benefits but also supports environmental conservation efforts (8).

2. Methodology

The research begins with the collection and sorting of aluminium scrap from various sources, such as beverage cans and industrial waste, using mechanical and magnetic methods to ensure high quality raw materials. The sorted scrap is then cleaned through thermal or mechanical methods to remove contaminants such as paint and plastics. Next, the aluminium is melted in a furnace at high temperatures (670°C–750°C) with precise temperature control to prevent excessive oxidation. Purification is conducted through degassing methods, using vacuum or argon gas injection to remove dissolved gases, and the addition of elements like titanium and boron to improve the microstructure and mechanical properties of the metal. The molten aluminium is then cast using die casting or sand casting methods, with controlled cooling to produce products with optimal microstructures. Finally, the products undergo quality inspection using non-destructive methods such as X-rays to ensure there are no structural defects. A process flowchart is also developed to facilitate understanding of these recycling stages.

3. Aluminium Scrap Casting Manufacturing Processes

The manufacturing process of aluminium scrap casting plays a crucial role in the recycling industry and the production of high-quality aluminium products. Using aluminium scrap as raw material not only reduces environmental impact but also allows for cost savings in production. This process involves a series of stages, including the following:

3.1. Aluminium Scrap Collection and Sorting

The collection and sorting of aluminium scrap is an important step in the aluminium recycling process to ensure the quality of the material used in remanufacturing. Aluminium scrap is collected from various sources, including recycled products such as beverage cans, aluminium foil, and industrial waste such as aluminium scraps from manufacturing processes. Once collected, aluminium scrap then goes through a sorting process to separate the aluminium from other unwanted materials, such as other metals, plastics, and organic materials (9,10).

This sorting process can be done mechanically or magnetically. Mechanical sorting involves the use of welding and shredding machines to separate aluminium from other materials based on size and weight differences. Magnetic sorting, on the other hand, uses magnetic devices to separate aluminium from ferromagnetic metals such as iron and steel. The combination of these two techniques allows for the collection of cleaner aluminium scrap ready for the casting process (11,12).

3.2. Raw Material Preparation

De-coating and cleaning of aluminium scrap is an important step in the aluminium recycling process to ensure the quality of the material used in remanufacturing. Aluminium scrap often has protective coatings such as paint, plastic or other organic materials that need to be removed before the aluminium can be reprocessed (13). This process is done through thermal or mechanical methods.

Thermal De-coating Process: Thermal de-coating involves heating aluminium scrap in a low-oxygen environment to remove the protective coating without oxidising the aluminium. The process also helps remove moisture and organic contaminants before the aluminium is broken down into liquid. This process not only reduces metal losses but also improves the efficiency and cleanliness of the heating process (14,15).

Mechanical De-coating Process: This process involves the use of welding and crushing machines to separate aluminium from other materials based on size and weight differences. This process is often carried out using rotational kilns or rotating kilns that heat the aluminium scrap in a stream of hot gases. This process helps to remove the protective layer and ensures the aluminium is ready for further processing (14,15).

The classification of aluminium scrap is an important process to ensure that the materials used in the recycling process are of consistent quality and conform to set standards. Aluminium scrap can be categorised based on the type and grade of aluminium contained in it. This classification helps in determining the proper value and application for each type of aluminium scrap (16).

Types of Aluminium Scrap: Aluminium scrap can be divided into several types based on its form and source. The main types include aluminium scrap generated from recycled products such as beverage cans, aluminium foil, and industrial waste such as aluminium scraps from manufacturing processes. These types can be further divided into clean aluminium scrap (without contaminants) and dirty aluminium scrap (with contaminants such as other metals, plastics, or organic matter) (17).

Aluminium Content: Classification by aluminium content is also important to ensure that the material used in the recycling process has a high enough aluminium content to produce a quality product. Aluminium scrap with high content is usually more valuable and easier to recycle than scrap with low aluminium content (11).

Classification Process: The classification process involves the use of advanced technologies such as optical sensors, beam measurement, and mechanical devices to separate and identify the type of aluminium scrap. These technologies help in ensuring that the collected aluminium scrap can be reused in manufacturing processes with high efficiency (12).

3.3. Smelting Process

The aluminium smelting process is an important step in converting aluminium scrap into a form that can be reused in production. Aluminium scrap that has been classified and cleaned is then melted in a furnace using gas or electricity. Heating is done at very high temperatures, usually between 670°C and 750°C, to ensure that the aluminium melts properly without excessive oxidation or contamination (18).

Temperature Control: Heating at the right temperature is critical in the aluminium melting process. Too low a temperature can cause the aluminium to not fully melt, while too high a temperature can cause excessive oxidation and damage to the furnace. Therefore, the melting temperature is tightly controlled using sophisticated sensors and monitoring systems to ensure optimal results (19).

Combustion Method: In the aluminium smelting process, gaseous fuels such as propane or methane are used to heat the furnace. These fuels provide consistent heat and can be fine-tuned to achieve the desired temperature. Another alternative is the use of electricity through electrodes to generate the required heat. This method is more environmentally friendly and is often used in modern smelters (20). Gas Filtration and Control Process: During the smelting process, gases generated from fuel combustion or chemical reactions with aluminium must be properly controlled to prevent contamination. These gases are directed through a filtration system to remove small particles that can damage the quality of the aluminium produced (21).

3.4. Purification and Microstructure Modification

a) Degassing

Degassing is an important process in aluminium processing to remove prohibited gases such as hydrogen trapped in molten aluminium. These gases can cause pores and weaknesses in the final product, so it is important to remove them before the aluminium is crushed and further processed (19).

Vacuum Method: The degassing process using the vacuum method involves reducing the pressure within the molten aluminium furnace. This increase in vacuum allows restricted gases, including hydrogen, to expand and be released from the aluminium. This method is effective in producing aluminium with very low hydrogen content, but requires expensive equipment and higher operational costs (22).

Argon Injection Method: This method involves injecting argon gas or another unreacted gas (inert gas) into molten aluminium through a device such as a carbon rotor or pore. These gases form bubbles that carry hydrogen and other contaminants to the surface of the molten aluminium, where they are released. This method is more efficient and is often used in industry as it can reduce the regasification effect after the process (19).

b) Grain refinement

Grain refinement is a process that aims to reduce the grain size in the metal microstructure, which ultimately improves the mechanical properties and surface quality of the metal. Elements such as titanium (Ti) and boron (B) are often used as grain thinning agents due to their ability to accelerate the formation of heterogeneous nucleation and reduce grain size (23).

Grain Dilution Process: When diluent elements like Ti and B are added to molten aluminium, they help in the formation of heterogeneous nucleation, which is the process of formation of crystalline nuclei on the surface of diluent particles. This heterogeneous nucleation enables the formation of smaller, uniform grains during the freezing process. This process is very important as smaller grains result in better mechanical properties, such as higher strength and hardness, as well as smoother surfaces (23).

Benefits of Grain Thinners: Grain thinners not only improve the mechanical properties of metals, but also help in reducing structural weaknesses caused by large grain size. In addition, grain thinners can improve the surface quality of the final product, reduce the presence of pores, and increase resistance to cracking (24).

3.5. Printing

a. Liquid aluminium

Liquid aluminium is poured into moulds using either die casting (high or low pressure) or sand casting methods, depending on the application and production volume. The process of casting liquid aluminium into moulds is a critical step in the production of high-quality aluminium (19). There are two main methods used: die casting (high and low pressure) and sand casting. The selection of the method depends on the specific application and the desired production volume.

Die Casting (High and Low Pressure): Die casting is a process in which molten aluminium is heated in a furnace and then pressed into a metal mould at high speed and high pressure. This process enables the formation of parts with high dimensional accuracy and smooth surfaces. There are two types of die casting: high pressure die casting (HPDC) and low pressure die casting (LPDC). HPDC uses extremely high pressure (up to 1,200 bar) to quickly feed molten aluminium into the mould, making it suitable for mass production and components with thin wall thickness1. LPDC, on the other hand, uses lower pressure and is slower, but provides better mechanical strength and allows for more complex geometries (25).

Sand Casting: Sand casting is a traditional method that uses sand-based moulds to insert molten aluminium. The process involves making a mould from sand that is filled with heated liquid aluminium2. Once the aluminium has melted and hardened, the sand mould is opened to remove the moulded component. Sand casting is more flexible and can be used for the production of larger and complex parts, but usually results in less smooth surfaces and lower dimensional accuracy compared to die casting (26).

b. Cooling

Cooling is a very important process in the formation of solidified metals with optimal density. After aluminium or other metals have been melted and pressed into a mould, cooling is performed to transform the metal from a liquid state to a solid state. This cooling process must be done carefully to ensure that the microstructure of the formed metal has optimal mechanical properties (23).

Cooling Process: Liquid metal cooling involves a carefully controlled decrease in temperature. In the early stages, the liquid metal will begin to solidify on the surface of the mould, forming a stable grain structure. This process is known as grain thinning. Subsequently, the grain cores will grow and meet each other, forming grain boundaries that are important for the mechanical properties of the metal (27).

Effect of Cooling: The speed and method of cooling greatly affect the microstructure properties of metals. Rapid cooling can produce small, uniform grains, which increases the strength and hardness of the metal. However, cooling too fast can lead to the presence of pores and structural weaknesses.

Conversely, cooling too slowly can produce large and non-uniform grains, which can reduce the mechanical properties of the metal (28).

3.6. Casting Quality Inspection

Quality Inspection Aluminium castings are inspected using nondestructive methods, such as X-rays, to detect porosity or other structural defects. The quality inspection of aluminium castings using non-destructive methods (NDT) such as X-rays is essential to detect porosity or other structural defects. These methods allow internal inspection of components without damaging them, thus maintaining the integrity and durability of the final product (29).

Working Principle of X-rays: X-rays are electromagnetic waves with very short wavelengths and strong penetrating power. When X-rays pass through an aluminium casting, changes in density, thickness, and material composition result in variations in X-ray absorption and penetration1. Porosity, as a defect, describes areas of lower density or missing material, creating contrast in the X-ray image relative to the surrounding material (29). Advantages of X-ray Examination:

X-ray inspection enables the detection of internal defects without the need to cut or damage the aluminium casting, thus preserving its integrity for further use or additional processing. Modern X-ray technology can detect defects down to the micrometer level, ensuring that even the smallest pores can be identified, meeting stringent safety and quality standards in industries such as automotive, aerospace and electronics (23).

Inspection Process: In the preparation stage, the aluminium casting to be inspected is stably placed on the X-ray platform to ensure image clarity. The X-ray system provides real-time images, enabling immediate feedback and quick adjustments in the production process, reducing the increase in scrap rates by ensuring only defect-free components move forward (23-30).

Much research has been conducted on aluminium recycling to improve both the quality and efficiency of the process. One study showed that the type of aluminium waste, such as pistons and cans, significantly influences the hardness of castings made using a crucible furnace. This finding highlights the potential of using different types of aluminium waste to produce products with mechanical properties suited for specific applications (1).

Another study explored the impact of non-conventional cooling media, specifically coconut milk water, in the aluminium recycling process. The results demonstrated that coconut milk water produced a more uniform microstructure and improved the hardness of the recycled aluminium compared to using plain water. This discovery introduces a novel approach to enhance the quality of recycled products through innovative cooling methods (2).

Meanwhile, a comparison between two casting methods, sand casting and centrifugal casting, showed that centrifugal casting resulted in a denser microstructure and better mechanical properties than sand casting. This indicates that centrifugal casting is superior for certain applications (3).

In another study, researchers investigated the addition of tin (Sn) to improve the mechanical properties of recycled aluminium. The results revealed significant improvements in both hardness and wear resistance, making the material more suitable for demanding applications. This highlights the potential of modifying chemical composition to enhance the quality of recycled materials (4).

Research also indicated that variations in casting temperature in the Al-Si casting process impact the microstructure and hardness of the castings. An optimal casting temperature leads to a finer microstructure and higher hardness, making it a crucial parameter in aluminium recycling (6). Additionally, the importance of controlling melt loss and porosity in the recycling process was emphasized, as these factors affect the mechanical strength and efficiency of the final product (7).

Overall, these studies contribute significantly to understanding and optimizing the aluminium recycling process. However, to further enhance the process, more focus is needed on aspects such as environmental impact, cost efficiency, and the adoption of green technologies.

4. Conclusion

Research on aluminium recycling has explored various methods to improve both the quality and efficiency of the process. Key factors such as the type of waste used, casting methods, material composition, and process parameters all play a significant role. Studies have highlighted the importance of cooling media and waste type in affecting the hardness and microstructure of recycled aluminium. Additionally, methods like centrifugal casting and the addition of tin (Sn) have been shown to enhance the mechanical properties of the product. Other research has emphasized the need for controlling temperature and porosity to improve the mechanical strength of the material. However, further studies are needed to assess the cost, energy efficiency, and sustainability of these recycling methods.

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