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A Review on Aluminum Alloy Recycling Technique

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Abstract: Aluminum are the most often used material on a daily basis and can be frequently recycled without loss of its properties. Aluminum considers as fast-growing in the market because of its physical properties. Therefore, the demand usage of aluminum material will increase as well as the impact to the environment when producing aluminum. So, there are several techniques that currently being used by the industry to recycle the aluminum which are conventional recycling, semi-direct recycling, and direct recycling. Thus, this paper presents a review on the techniques used in recycling aluminum as well as responses analyzed in collected research paper and discuss the benefits obtained from the techniques used. Moreover, this paper is categories as a theoretical literature review. So, this paper involves 2 main step which are surveying and critically reading the existing literature and also summarizing and taking the point of the analysis in an ordered manner. Then, the historical trend can show that the conventional recycling becoming less attractive compare semi direct and direct recycling because both recycling are much more eco-friendly and less energy usage as well as low cost operation. However, more study should be done on this topic frequently so that a better review and understanding on this topic can be obtain.

Keywords: Aluminum, Conventional Recycling, Direct Recycling, Semi Direct Recycling, Recycling Techniques

1. Introduction

Aluminum is one of the most frequent metals found in the crust of the earth which this material can easily be mined on-site. Basically, aluminum material came from raw material such as Aluminum ore or also known as bauxite where it can be mine at bauxite mining area. Then it will be transferred to the factory to be process as alumina which pass through the Bayer process then the alumina will be refined through the Hall-heroult process where pure aluminum will be made. Thus, the demand of usage in aluminum material increasing around the world because of its physical properties such as light in weight, good formality, good thermal conductivity, resilience, non-corrosive, non-sparking, non-toxic, and non-combustible. therefore, this aluminum material capable to contribute to the multiple applications areas such as robotics, manufacturing, aviation industry, automotive industry, shipbuilding,

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and daily basis equipment. However, even the aluminum product become as waste product. This aluminum material can still be recycled repeatedly without any loss of its material characteristic.

1.1 Recycling

As time pass by, technology keeps developing to improve the quality of lifestyle. Where recycling method was introduced to reduce the negative impact from production of aluminum product on the environments as well as human surrounding. For example, in primary production requires a lot of energy to operate the factory and has a variety of environmental impacts which effecting in biodiversity loss, habitat loss, carbon emissions, and erosion. Therefore, recycling the waste product can reduce the primary production operation and also help to reduce the cost production which recycling method has less cost production compared to primary production. So, currently over 90 percent of aluminum is recycled, and the practice is increasing because of its beneficial such as less energy consumption, reduction in waste and less greenhouse gas emission [1].

Currently, there are several techniques that industry using to recycle the aluminum waste. But each of the techniques have different approach to recycling and also have different advantage and disadvantage during the process of recycling. Thus, the difference among the recycling techniques will be studied.

2. Literature Review

The recycling aluminum techniques is one of the ways that aluminum can be recycled after previous manufacturing, where aluminum scrap will be recycled back. And these techniques can be divided into three techniques which are conventional recycling, semi direct recycling and direct recycling.

2.1 Conventional recycling technique

In Conventional recycling, the main process for this technique is the melting process. Basically, aluminum waste will undergo melting process which the waste will be renew as the new product. Moreover, various intermediate procedures are needed for this technique such as cleaning, pre-compaction, casting, and cutting of ingot. Typically, the energy consumption for this technique is around 16 Gj/t to 19 Gj/t [2].

2.2 Semi direct recycling

In Semi Direct recycling can be divided into four techniques which is powder metallurgy technique, hot extrusion, cold extrusion, and spark plasma sintering.

Powder Metallurgy techniques involves several major processing stages. The first stages are the breakdown into tiny size particles of the original compounds where the desired material are needed to be change into powder form which can be through a various process such as atomization, grinding, and chemical reaction. Then second stage are more metals or non-metals are blended into homogenous combination where it can produce much higher strength characteristic for the desired product. And the next stage is where the mixture is entered into a molten chamber and squeezed into a compact green mass to generate a low cohesive mass such as the pressing process will compress the powder mixture into a new shape so that voids can be reduce and increase the density of the product. And lastly, sintering process will occur which this process is a heat treatment where the material will heat up just below its melting point so that it can keep the beneficial properties of the metal while fusing the material tightly together [3].

Hot Extrusion is one of the most used ways for producing product that are lengthy and direct metal components. These techniques can produce extensive and shear pressure in the material stock. Whereby, there are no tensile generated that allows high deformation without ripping the metal. With wear-resistance substance are placed in the cavity where the material is stored where it can endure the strong radial loads produced by the thrust of the die [4]. Basically, the entire process is performed by use of extruder and extrusion machinery particularly designed to meet the extrusion process technology. And

this technique is operated on high temperature that implies the material getting hardened above the recrystallisation temperature of the material which make the material much easier to move the material through the die of the machine.

Cold Extrusion is a method for pressing the original object such a billet at room temperature. However, the deforming object will undergo heat deformation until a few hundred degrees are reached. And the punch usually applies pressure in the stationary die to the enclosed billet, partially or completely. This technique can be divided into several main process depending on the die configuration and the material flow. So, the first process is the forward extrusion where the material will flow the direction of the punch displacement. By passing the rod through an aperture in a die, the diameter of the rood will be reduced. Then second process is reverse extrusion, where the material flow is in the reverse direction of the punch where the billet is forced to flow reversely from the annular region which located between the die and punch. Lastly the lateral extrusion where the material flow is in perpendicular of the punch displacement. The material will flow radially into the slots contained in the punch and die.

Spark Plasma Sintering is a technique that uses pressure-driven powder consolidation in which a pulsed direct electric current passes through a sample compressed in a graphite matrix [5]. This technique has several stages. The first stages are the plasma heating where electrical discharge between metal powder led to the concentrated and instantaneous heating up to several thousands of degrees Celsius. Then the second stage is Joule Heating, the pulsed DC electric current passes through the neck linking it from particle to particle. Thus, electrical heat is created and the molecules in the neck become more diffused and enhance their growth. In addition, in just few minutes the temperature quickly climbs to 2500 degree Celsius above the ambient temperature under pressures and energy pulses [6]. The last stage is plastic deformation, where the heated material will turn softened, and it exerts plastic deformation under the uniaxial force.

2.3 Direct recycling

Direct recycling is another solution for the recycling aluminum waste. This technique divided into several techniques which are high pressure torsion, screw extrusion, hot forging, and cold forging.

High pressure torsion is a new processing technique that can be used to obtain nanostructured metals. And these techniques are useful scientific tool for studying the structural and multifunctional characteristics of bulk nanostructured materials [7]. This technique has a variety of benefits, including the efficiency in which extremely high shear strain may be obtained easily, the strain rate at a particular radius can be accurately adjusted, and high strength materials can be severely deformed [8]. In this technique using powder or bulk material. Where the upper plunger is stationary, but the lower plunger will rotate torsionally at various revolutions per minutes. Resulting in full dense bulk materials with microstructures in the nanocrystalline and ultrafine grained size [9].

Screw extrusion is a manufacturing technique that involves pushing material through a die to generated semi-finished or completed product. Basically, screw extrusion has two types such as single extruder and multiscrew extruders. In single screws extruder are common with-it cheap price, simple design, robustness, and dependability. But multiscrew extrudes are even more effective at delivering uniform mixing of multiple elements [10]. Thus, this technique is entire involved with gear transmission where it causes low noise and can store large capacity. And the transmission of material in screw extruder is mainly by friction. Basically, the main part for these techniques is the screw and barrel where the screw will turn constantly which move the material through the heated barrel where the material is heated with proper temperature and blended into a homogeneous melt. So the turbulent back pressure is build up which the material will push out of the extruder.

Hot forging is a manufacturing method that involves plastically deforming metals above their recrystallization temperature, allowing the material to keep its distorted shape while the temperature dropping. Forging enhances the mechanical characteristic of the component by refining the grain structure of the applied materials which are mostly on metals [11]. The material can be deformed into a complex dimension using equipment such as sophisticated hammers and presses. Friction plays

important key role in the process when the friction forces are opposed to the spreading of the material by the surface on the die-work interface while the material in the center will freely spread.

Cold Forging is a metal forming and manufacturing process in which a bar of metal is inserted into a die and then pressed with a second closed die, which the process is done in the room temperature or below the metal's recrystallization temperature and modifies the original metal's size or shape until it takes the die's form. Moreover, these techniques can improve tensile strength and yield strength while lowering the material ductility [12]. The equipment the sued in cold forging is a vertical press either manually fed or fully automatic. So, the process begins with a chemic all lubricated bar slug forced inside a closed die under extremely high pressure. Then metal flows and take the forms of the die shape.

3. Methodology

This paper is conducted based on the interested study field where the first step is deciding the goal and scope for the research paper. Then, the second step is literature review where a comprehensive bibliographic search of books and articles are conducted. After that, the third step is development process where surveying and critically reading the existing literature and summarizing and taking the point of the analysis was conducted in this step. And lastly is the analysis process to evaluate from previous step to develop an organize literature review.

3.1 Type of data collection

The date collected from the literature review process is a secondary data collection. Where the data was extracted from the primary data and use as a reference for better understanding as well as reduce the risk of misunderstanding. Moreover, secondary data can be collected through media, articles, reports, reviews, and research done by another researcher.

4. Result and Discussion

4.1 Summary Based on table of Literature Review

Figure 1 illustrates the chart diagram analysis based on collected research paper in table of literature review. As can be observe from the chart diagram, the number of research done on melting process is 8. While in semi direct techniques consist of 4 different techniques, the highest number of research done is 25 which are the hot extrusion. Hot extrusion techniques become trend since 1996 until 2019 and data can be seen in the appendix A. this technique become trend because of its ability to improve the final product to become much better. For example, Gronostajski (2012) describe that with addition small amount of tungsten powder to the waste product able to recycle directly into the final product [13]. Other than that, Sherafat (2010) also experimented with two-phase material were fabricated by mixing with pure aluminum powder [14]. And the result improvises the recycled materiel increasing in the yield and ultimate tensile strength. Then, as for direct recycling also consist of 4 different techniques and the highest number of research done is hot forging which has total 11 amount of research that has been done since 2013 until 2020. As for the latest research done by Ahmad (2020) states that the effect of temperature and holding time with presence of particulate alumina by using hot press forging will increase the value of ultimate tensile strength [15]. Therefore, hot forging has the same characteristic as hot extrusion which this technique capable to manipulate the characteristic of the recycled materials as it can be much better product. In addition, most of the techniques are not very approachable among the researchers because of the limitation of the technique such as limited amount of supply and expensive cost for equipment and operation which are common issue among the researcher to conduct the experiment.

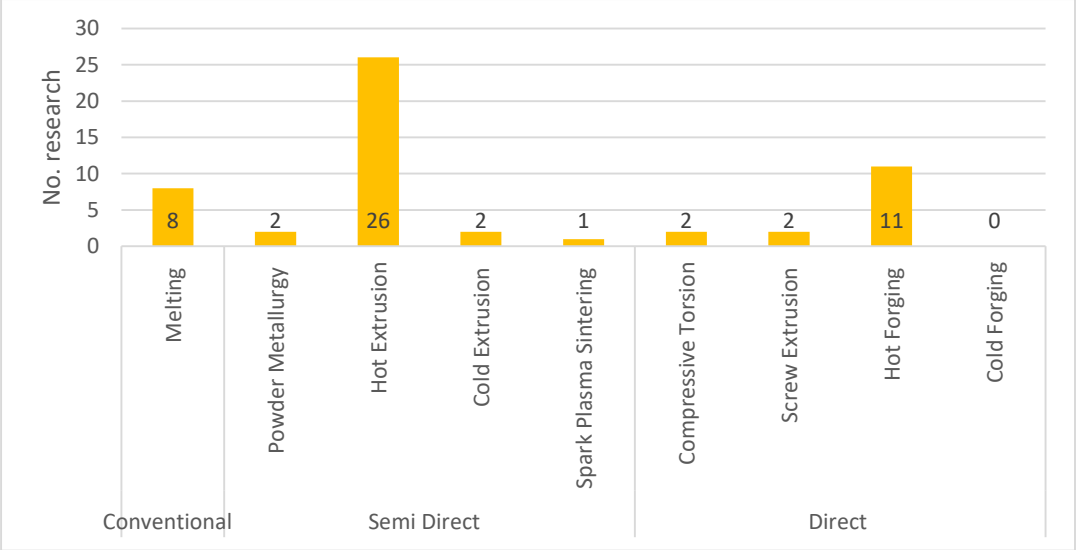

Figure 1: Chart Diagram analysis based on table of literature review

The Historical trend of the examined techniques in the literature review is demonstrated in figure 2. Early 1995, researcher begin experimenting the recycling of aluminum using the conventional techniques which based on the melting process. And this technique continually developed and many researcher has proposed new idea for the improvement in this process such as the equipment modification, new re-melting process and type of material shape. Then, starting in 1996 the semi direct recycling was started to be experimented by Gronostajski et al where he describes that aluminum chips and its alloy can directly converted by semi direct recycling technique to the finished product. And since then, the techniques have continually developed through many forms of modification such as different volume of machined chip, addition of pre-process and different shape of die which the modification can improve and enhance the characteristic of final product. After that, as for direct recycling started recently in 2011 and the first researcher done on these techniques is Wideore. After that, experimenting based direct recycling techniques has been conducted every year. And through the process of experimenting on direct recycling, there are several modifications that been conducted such as different temperature, different holding time, and addition of pre-process and material.

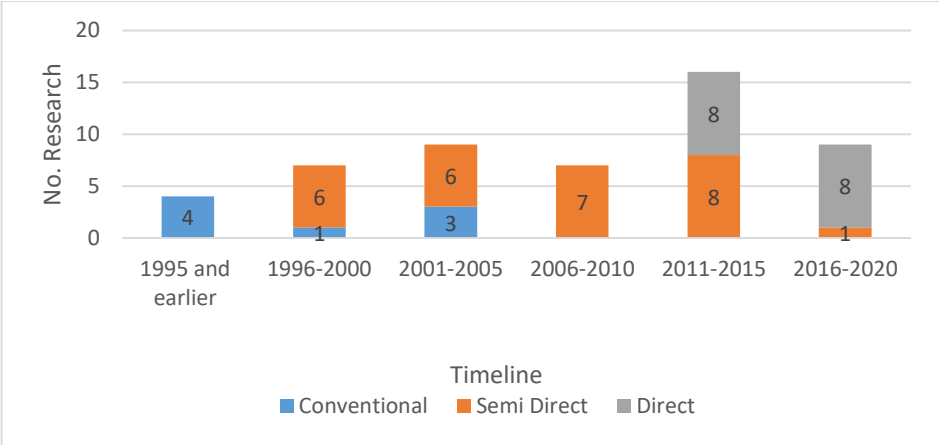

Figure 2: Historical trend of the examined techniques in the literature review

4.2 Primary Production versus Conventional Recycling Technique

Conventional recycling techniques consider as the oldest technique for recycling aluminum. But still used till this modern generation. And when comparing between primary production and conventional recycling technique. One of the differences is the energy consumption for the operation where conventional recycling only consumes 5% of the energy used in primary production. Thus, when reduction in energy consumption has the potential to lower the cost of aluminum production. Beside that, in term of greenhouse gas emission, the theoretical carbon consumption for the primary production is 333.3 kg per tonne of aluminum which equals to 1222.2 kg of carbon dioxide per tonne of aluminum. In fact, nearly 97 percent of the greenhouse gas emission emitted in primary production are saved in conventional recycling. Therefore, conventional recycling technique are more beneficial for aluminum industry compared to primary production. But the usable amount of recycled aluminum only covers between 30-40 percent of the demand of aluminum. Roughly 60-70 percent of the demand must be covered by primary production [16]. Thus, the demand for aluminum will not wait for the aluminum to be recycled as the demand keep increasing. So primary production of aluminum still on going to meet the demand as lack of scrap to be recycle.

4.3 Comparison on Conventional Recycling and Solid-State Recycling

As stated before, that the melting process is one of the primary components in the conventional aluminum recycling technique. But these techniques only capable to recycled less than 55 percent of original volume of aluminum scraps. Thus, this deficiency was not accepted by the industry as the amount of recycled has been steadily increasing due to high demand and becoming unfavorable techniques nowadays [17]. Moreover, the percentage of recovering efficiency of recycling of aluminum by remelting is low, and the energy usage during the melting process is high. As result, higher cost operation and energy consumption. And 45 percent of aluminum losses can be identified as extrusion scraps, melting losses, dross, casting scraps and extrusion butts. Researcher such as Gronostajski (1999) also states the same opinion about the conventional techniques where this process is characterized by high energy consumption which required about 6000 kCal/Kg of energy for the remelting process, higher operation cost and high level of pollution such as fumes and dross generated during the process [18].

Other than that, Solid state recycling techniques is introduce which involve both semi direct and direct recycling. These techniques are much more compact, reliable, more energy saving, free of hazardous chemicals, reduction in waste and pollution, and more environmentally sustainable. Where these techniques capable to recycle 95.2 percent of original volume of aluminum scraps completely turn into recycled product. So, in term of recovering efficiency of recycling aluminum for solid state technique are higher than conventional as well as for the level of pollution where solid state techniques are much lower than conventional recycling where Gronostajski (1997) shows that the products recycled through solid-state technique results to a material characterized by a low porosity and relative density greater than 95 percent and does not have harmful effect to the environment [19]. However, by using these techniques repeatedly. It may possibly have the same or perhaps stronger mechanical properties as the original ingot of aluminum specimen such as Lajis (2013) states that highest value of ultimate tensile strength can be achieved for the recycled product at maximum temperature through the solid-state technique [20].

4.4 Comparison on Conventional Recycling, Semi Direct Recycling, and Direct Recycling

So, in conventional recycling techniques most of the research paper discuss about the improvement that has been conducted by the researcher for example, Dispinar and Campbell (2004) investigate the quality of aluminum alloys at every stage of production [21]. Geertruyden (2005) using consolidated material improve the metal recovery as much as 20 percent [22]. And Macintosh (1983) investigate the different type of furnace [23].

Then, as stated before, hot extrusion was considered as the most favourable process in semi direct recycling. So, most of the research paper are based on hot extrusion process. So, comparing with

conventional recycling, this technique uses less energy, tends to produce fewer aluminum losses, and has a shorter cycle time. These techniques also can be used to make semi-finished or finished product. Moreover, semi direct techniques also can increase further for the strength of the product by adding reinforcement phase such as adding pure aluminum powder with aluminum chips and consolidating the mixture which conducted by Sherafat (2010) and the result shows that with small amount of pure aluminum powder, the strength of the material increasing [14]. Other than that, semi direct also can produce different shape of recycled product such as researcher Chiba (2015) which conducted recycling material in the form of equilateral C-channel where it can be used for specific purposes.

Besides that, aluminum alloys also can be recycled using directly recycling techniques, which is reasonably easy process that uses little energy, produce little waste, and has low environmental impact where it is same as semi direct recycling technique. Basically, Direct recycling is based on Hot forging which it has most reviewed research paper. So in term of difference between other techniques, this techniques removes two pre-process step that were previously used in conventional and semi direct recycling such as cold-compact and pre-heating which make this technique much simple to conduct. Other than that, most of the hot forging process conducted based on the effect on temperature and holding time. For example, Ahmad (2020) Stated that the temperature was the major influence on all reaction and followed by holding time. Where the result shows that high value of ultimate tensile strength, elongation of failure and microhardness were achieved [15]. Thus, it only requires to manipulating the temperature and holding time for this process, and the recycled product can be recycled and achieved better characteristic and much more simples process compare to other techniques.

5. Conclusion and recommendations

In conclusion, countless research has been conducted by other researcher to investigate the practical aspect of aluminum recycling techniques such as conventional recycling, semi direct recycling, and direct recycling. Each of these techniques has different uniqueness to produce recycled product. As stated before, Semi direct and direct recycling technique are much better compare with conventional recycling techniques in term of recovery efficiency of recycling aluminum, energy consumption, and cost production. Beside that, in conventional recycling also has high capital for the equipment and unavoidable condition such as the bifilms. Other then that, in semi direct become trending among the research due to the various improvements that can be made where it can reduce significant amount of aluminum losses. Lastly, direct recycling become trending recently due to it simple improvement and working step where it can reduce working progress and to product a better characteristic of the recycled product. As for recommendation, more study should be done on other techniques such as powder metallurgy, cold extrusion, spark plasma sintering, compressive torsion, screw extrusion and cold forging frequently by using aluminum material so that a better review can be obtain and understanding on this topic which can make better comparison based on the process.

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