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**A Review: The Potential of Powder Metallurgy in Recycling Aluminum Chips
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Aluminium products are becoming popular and the demand is increasing because of its special properties such as excellent corrosion resistance with good strength, recyclable and low density compared to steel. Currently, two methods used to recycle aluminium chips are conventional and direct conversion methods. Recycling of aluminium chips by the direct conversion methods is relatively simple, consumed less energy and do not harm the environment. The cost of recycled materials is much lower than the cost of primary aluminium production by conventional technique. This paper reviews the recycling technologies of aluminium chips using powder metallurgy technique.

Keywords: aluminium chip, aluminium recycling, solid state recycling, conventional recycling, direct recycling, powder metallurgy

1.0 Introduction

Many researchers are expanding the existing processing methods to produce and improve the properties of materials to fulfil the material demand. Nowadays, one of the great challenges of the world is conserving energy to reduce the usage of primary natural resources by developing and improving lightweight materials [¹]. Aluminium is the most abundant metallic element and it is the third most abundant element of the earth's crust [²]. Aluminium is widely used in building, transportation, food packaging, beverage cans, cooking utensils, food additives, medicines, surgery materials, cosmetics and water purification obviously because of its unique physical and chemical properties [³].

However, a large quantity of aluminium machined chips will be produced with the increasing application of aluminium. So, to encourage the contribution of aluminium to the industry, it is necessary to develop good recycling process. The public concern of global warming has led to the production of secondary aluminium to substitute the current used of primary resources [²]. The recycling of aluminium scrap has given benefits in economic, energy,

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environmental and resource savings compared to the primary aluminium production^{[4][5][6]}. Moreover, the modern industrial societies are focusing on minimizing the primary resource usage, nature preservation by environment pollution control and prevention and sustainability^[6]. Recently, solid state recycling method of aluminium chip has been introduced without the melting process to overcome the disadvantages of conventional method.

2.0 Aluminium Recycling

Nowadays, methods chose in recycling waste material is being concerned as one of the major issues. The cost of material processing produced by conventional methods is much higher compared to recycled materials^[7]. Thus, recycling has become a well-known method used in material production, mainly in developed countries^[8]. In recent years, a technology in manufacturing materials has been developed with desired properties, including manufactured product from waste material which has been developed systematically in manufacturing materials with predetermined properties^{[9][10][11]}.

The production process of primary aluminium requires complicated processes starting with bauxite mining, purification of alumina by a Bayer process that consumes a lot of energy. This deficiency has encourage the development of secondary aluminium resources due to climate change concern and environmental benefit including energy saving, reduction of solid waste disposal and reduction of greenhouse gasses emissions. Thus, its economic and environmental benefits have made the secondary aluminium resource turn out to be even more popular issue in aluminium production area. Most reported work of aluminium recycling used pure aluminium without the specific series^[2].

2.1 Aluminium Chip Recycling

During manufacturing of products, many different types and sizes of chips are produced after the machining process^[12]. A lot of metal is lost as a result of oxidation during the recycling process, and the expenses in labour and energy as well as the cost on environmental preservation raise the general cost of such processes^{[10][13]}. However, only 5% of energy required in producing the aluminium from ore needed to recycle it^{[9][14]}. Therefore, secondary aluminium has been approved in many countries. The efficiency of the two methods can be evaluated by comparing the total cost involved and percentage of metal losses during the recycling processes. From the Figure 1, it can be seen that the conventional process produces about 52%, while the direct conversion process introduced here produces about 96% of the extruded products^[17].

Figure 1: Comparison between (a) Conventional Method and (b) Direct Conversion Method^[17].

3.0 Conventional Method

Melting process is the main basic steps in conventional aluminium recycling method. However, the conventional process can recycle less than 55% of aluminium scrap. This drawback is very significant, because the amount of recycled aluminium has been growing systematically since the sixties and its consumption at present is very high. However, aluminium scrap melting creates potential hazards. Conventional method needs high energy consumption but has low recovery efficiency due to melt loss and post melting scraps processing. In recent years increasing interest has been shown in chip recycling processes by direct conversion method without the melting process [9]. In case of aluminium chip, the remelting losses are particularly very high due to fine fraction and small cross-section. Thus, the recovering efficiency of recycling of aluminium chip by remelting is low and develops interest to recycle it by different method without the remelting process [13].

Other than that, Samuel [17] and Gronotajski and Matuszak [9] also states that the conventional recycling method produces only 75-81% during the melting step because of high generation of new scrap (about 25% of new scrap produced during casting), high energy consumption (6000 kcal/kg are required for remelting scrap), high operation costs due to various operations and high pollution (mainly due to fumes and dross generated during the remelting of the scrap). With the direct conversion method, aluminium recycling can be carried out without melting phase. It is characterized by fewer steps, better efficiency of recovery and low generation of new scrap.

3.1 Direct conversion Method

Although metal recycling have many advantages, it is not exempt from environmental issue. In recent years, many efforts have been develop to produce 'Cleaner Recycling Technology' that are flexible, efficient, less energy consuming, free from use of harmful substances, minimize waste and emissions and more environmental friendly. Direct conversion methods of aluminium recycling have many benefits including cost and energy saving other than environmental protection by reducing the hazardous gas emission. Moreover, the process is simple, which required less energy and do not harm the environment [9]. A new technique was used by Fogagnolo et al. in which the aluminium chips is directly cold or hot pressed and then hot extruded. By eliminating the milling process, the technique resulting more economic recycling process [18]. Al7075 alloy chips with addition of pure Al powder was recycled through powder metallurgy route was conducted by Sherafat et al. [7]. Thus, large area of application and high demand of aluminium has made the topic of aluminium recycling becoming more and more interesting [4].

Up to 40% of material, 26-31% of energy, 16-60% of labour cost can be save by conducting the direct conversion recycling of aluminium scrap [9]. By using the conventional aluminium recycling method, several melting techniques were conducted to study the recyclability of aluminium chips and the effects of chips preparation in the aluminium dross production and recovery rate [12]. Besides, the pressure of cold press also affects the melting process. Research had been conducted using both conventional and direct conversion methods to recycle different types of aluminium chips. For example, aluminium turning chips were melted at 800°C with protective salt flux under nitrogen atmosphere. They also stated that the complicated part was to separate the selected aluminium chips into different types and sizes [15][16]. Other than that, aluminium chips were milled into powder, cold compacted and followed by extrusion at the temperature range of 500–550°C [9]. Other researchers also added the sintering process before the final extrusion [17]. Tekkaya et al. directly hot extruded the 6061 aluminium chips into blocks [20]. Using the direct conversion recycling process, Sherafat et al. mixed the 7075 aluminium chips with aluminium powder to study the effects of amount of aluminium powder and extrusion temperature on the mechanical properties of materials produced [7].

One of the processes presented in previous paper is by converting the chips into powder through ball milling. The obtained powder was then cold pressed and hot extruded, with and without ceramic particulates to produce aluminium alloys or aluminium matrix composites. Gronostajski et al., also presented a process for recycling process for recycling aluminium chips and producing metallic composite materials. In this process the chips were granulated by the means of a cutting device and then produced particles were mixed with tungsten or iron-chromium powder, the mixture was milled in a high-energy ball mill, cold pressed and hot extruded to produce composite materials [9][21].

These alternative recycling processes have in common the material transformation from chips to powder milling. Fogagnolo et al. employed a new technique in which they recycled the material directly from the chips formed by cold or hot pressing followed by hot extrusion, avoiding the milling step, which results in a more economic recycling process. This new technique can also be employed to recycle chips deriving from aluminium matrix composites machining, which is still more difficult to obtain by other techniques [18]. Sherafat et al. also fabricated two phase material between recycling Al7075 alloy chips with pure Al powder using powder metallurgy route [7]. Therefore, recycling of aluminium scrap is an interesting subject because of the broad applications of this metal and low efficiency of processes used to recycle metal scrap [4].

Only limited work has been reported on the mechanical properties and microstructure of Al 6061 and Al 7075 by using direct conversion method. In previous study, there is also limited evaluation on the addition of Al₂O₃ as reinforcement and how the particle size and the amount of reinforcement can affect the microstructure and mechanical properties of materials [22][23]. Besides, the speed of rotating ball mill and sintering temperature in powder metallurgy also can affect their properties.

4.0 Al 6061 & Al 7075 Powder Metallurgy

Powder metallurgy is define as the methods or techniques used to produce metal powders by compressing the metal with or without addition of other material and heating them just below the melting temperature to solidify or strengthen the material. Basically, powder metallurgy consists of simple method starting with production of powder, powder mixing or blending with lubricants or binders, followed by compaction process into required shape and sintering process, end with optional secondary manufacturing and finishing process to produce special properties or improve the precision of powder metallurgy product. The final product is produced with sufficient strength and density suitable for its application. Figure 2 shows the simple process flow of powder metallurgy [24].

Figure 2: Simple Process Flow Chart of Powder Metallurgy.

Among many other manufacturing processes, powder metallurgy is also rank high because it can produce near net shape products with properties that are comparable with those of conventionally produced products requiring less or no secondary machining other than increasing mass production rate. A lot of components used in automobiles, aircraft, spacecraft, nuclear reactors, computer and household appliances are also produced by powder metallurgy. Powder metallurgy appear to be one of the flexible and versatile manufacturing process because of its ability to process various types of materials to produce porous products with uniform porosity, electric and magnetic materials with combination of different materials, refractory metals with high melting point which is difficult to process using conventional method, hard metals for cutting tools, frictional materials and dispersion strengthen materials such as aluminium with addition of alumina as the strengthening particles [24].

Powder metallurgy is considered a good technique for aluminium recycling. In comparison to the melting method, powder metallurgy offers the important advantages including low processing temperature compared to melting process in conventional method. Therefore, the aluminium and the reinforcement phase interaction can be prevented [25]. Powder metallurgy can improve strength and toughness at room and elevated temperature as well as provide an alloy with improved fatigue, corrosion and stress-corrosion resistance. Besides, powder metallurgy offers better control on the microstructure where better uniformity in the reinforcement distribution is possible in powder metallurgy compacts compared to casting process [26][27].

Moreover, most of 7xxx aluminium composites also primarily fabricated by powder metallurgy method due to the excellent combination of aluminium properties and the ability of powder metallurgy method to produce high performance net- or near-net-shaped parts, which can reduce or eliminate the capital and operational costs associated with intricate machining operations^{[15][28][29][34]}. The morphological and structural changes of 7075 aluminium by powder milling with nanometric alumina reinforced was investigated with different particle size and volume percentage of alumina reported the improvement in density, hardness and tensile strength of the material^[19].

5.0 Reinforcement addition

A wide variety of reinforcement such as ceramic and intermetallic particles have been reinforced into aluminium because of its unique properties such as low density, low melting point, high specific strength and thermal conductivity^{[27][30][31]}.

Ceramic reinforcement such as alumina (Al₂O₃) and silicon carbide (SiC) particles are widely used as reinforcement for aluminium alloy^{[27][30][31]}. There are two main disadvantages of ceramic reinforcement addition including high material cost and chemical reaction occur between reinforcement and matrix interfaces during materials service and processing at elevated temperature^[31]. However, Torralba J.M. et al. claim that Al₂O₃ does not react with the aluminium powder at elevated temperature and does not produce undesirable phases^[27]. So, it is more preferred to be added into aluminium powder as reinforcement.

Moreover, the addition of ceramic particles to aluminium alloy can improve the strength, hardness, wear resistance and corrosion resistance of the alloy^[25]. Thus, aluminium and its alloys have been reinforced with ceramics in order to improve properties such as wear behaviour or mechanical strength^[32].

6.0 Conclusions

Powder metallurgy is one of the most widely used methods for aluminium chip recycling due to its low processing costs added to its high versatility. Aluminium alloys offer a combination of mechanical and tribological properties and low density that makes them highly suitable for manufacturing products that can be used in several industries. The widely used particle reinforcement such as Al₂O₃ has been added to improve their physical and mechanical properties. The particle size and the amount of reinforcement can affect the microstructure and mechanical properties of materials^{[22][23]}. Besides, the speed of rotating ball mill and sintering temperature^{[26][33]} in powder metallurgy can affect their properties.

7.0 Acknowledgement

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