Manufacturing of aluminum flake powder from foil scrap by dry ball milling process

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Abstract

A feasibility study for producing aluminum flake powder from aluminum foil scrap by dry ball milling under an inert argon with a few % of oxygen was carried out. It was found that the pieces of aluminum foil scrap were laminated to each other, elongated by micro-forging of the falling balls, fragmented into small pieces of foil and finally formed into flake powder, during the ball milling. A larger ball is more beneficial to the milling of aluminum foil into the flake powder due to the large impact energy during the falling of the ball. Intermediate stops during the ball milling produced a finer aluminum flake powder than non-stop milling for up to 25 h due to cooling of the vial. A larger amount of stearic acid reduces friction between the foil or the balls and vial wall, thus give less milling efficiency, 3 wt.% of stearic acid as additive being verified as the optimum content. The aluminum flake powder produced by the dry ball milling of aluminum foil scrap can be applied to fingerprint detection or to aerate light-weight concrete.

Keywords: Aluminum foil scrap; Flake powder; Ball milling

1. Introduction

Recently, great attention has been paid to environmental and economic aspects of saving material and energy through recycling. Especially, the recycling of aluminum scrap is important because the production of aluminum requires a lot of energy. A considerable amount of aluminum foil scrap occurs by slitting of aluminum foil after the rolling of aluminum. The scraped aluminum has a great possibility as raw material for changing into aluminum flake powder by mechanical grinding because of its low thickness (6–120 μm) and high purity (over 99.4%). Aluminum flake powder is widely used in fingerprint detection, aerated light-weight concrete, paint component for automobile and industrial applications, additive for ink, and explosives, because aluminum flake powder has silver color, high brightness and good adherence [1–6]. Aluminum flake powders of mean size 20–45 μm and specific surface area 3–6 m²/g are mainly used in the industry although the requirement in respect of the properties of the aluminum powder depends on the application [2]. There are various methods for the manufacturing of aluminum flake powder such as stamp milling, ball milling under dry conditions, wet ball milling, attrition milling and vibration milling [1].

In the stamp milling method, aluminum powder is milled by a hammer in an air atmosphere, moved by wind force continuously and classified into various size, but it is not used widely because of danger of explosion. The horizontal ball milling method is used widely in the making of aluminum flake powder because it is suited for mass production and provides a good uniformity of the aluminum product, although a long milling time is required as compared with attrition milling and vibration milling [1]. The dry ball milling method is carried out in a horizontal jar containing balls, powder and a process-controlling agent such as stearic acid under an inert gas atmosphere with a few % of oxygen, which atmosphere can prevent explosion. The aluminum flake powder for aerated light-weight concrete, fingerprint detection, etc., is usually produced by the dry ball milling of atomized aluminum powder. Wet ball milling is used mainly in the paste manufacturing industry for paints and inks, in which milling is performed in inorganic solvent [3,4].

A feasibility study for producing flake powder using aluminum foil scrap and the milling behavior of foil has been undertaken. The factors related to the milling process...
such as the ball size, the number of intermediate stops during the milling, the content of stearic acid and the oxygen content in the argon atmosphere are also studied. Fingerprint detection is tested to check one of the possible applications of aluminum flake powder obtained by the dry milling of aluminum foil scrap.

2. Experimental procedure

Aluminum foil scrap of thickness 6.5 μm, width 8 mm and purity 99.4 wt.% were obtained by the slitting of aluminum foil during the rolling process in Daihan Eunpakgy Industry, Korea. Strips were cut into 6 mm lengths and the cut foil are used as the initial milling material. Aluminum foil scrap of 15 g, 900 g of stainless steel balls with a diameter of 16 mm, and 3 wt.% of stearic acid as process-control agent are charged in a horizontal container of length 80 mm and inner diameter 70 mm, made of stainless steel. The content of stearic acid are varied from 1.5 to 5 wt.% in order to check the effect of the level of stearic acid. The container is filled with argon gas containing 8 vol.% oxygen which slightly reacts with the surface of the aluminum powder, prevents the explosion of the milled fine powder after exposure in air. The milling is performed for 45 h at a rotational speed of 120 rpm, which is 78% of the critical rpm [7–9].

The milling time, the ball size (diameter 9.6 or 16 mm), the number of intermediate stops during milling for 25 h, and the content of stearic acid were varied in the dry ball milling process. Aluminum flake powder of 1 g during the milling was sampled and characterized. The mean size, the size distribution and the specific surface area of powder are measured using a particle size analyzer (Coulter LS130) and the Brunauer–Emmet–Teller (BET) method using a Micromeritics ASAP 200 system. The shape of the aluminum flake powder is also checked by optical microscopy and scanning electron microscopy (SEM).

3. Results and discussion

3.1. The feasibility of converting aluminum foil into flake powder and milling behavior of the aluminum foil

Fig. 1 shows the milling process for converting aluminum foil into the flake powder. During the milling of the cut foil (6.5 μm × 6 mm × 8 mm) using steel balls of diameter 16 mm for 5 h, the foil was micro-forged by the falling of the balls and deformed plastically into an elongated shape of width 4–5 mm and length 10–12 mm and fragmented into small pieces of foils of width 2–3 mm and length 6 mm. Most of the aluminum foil is changed into coarse flake powder by milling for up to 10 h, as seen in Fig. 1d. The variations of mean size and specific surface area of the powder with milling time are shown in Fig. 2. As the milling time was increased from 10 to 25 h, the powder size decreased continuously from 97 to 14 μm and the specific surface area increased due to the reduction of the powder size and the change of the powder shape into flake. These results show that the milled aluminum powder is not severely coagulated during the milling under dry atmosphere due to the coating of stearic acid on the surface of the aluminum powder [10–12].

Fig. 3 shows the optical microstructure of the aluminum powder with milling time. The observations show that the foil was laminated into several layers between the balls, micro-forged into elongated pieces of foil, then fragmented into laminated small pieces of foil or single pieces of foil after milling for 10 h. Fig. 3a shows large laminated powder and coarse flake powder milled for 10 h. The aluminum foil is milled into coarse laminated powder, cracked in a local area of the laminated powder, and then separated into smaller pieces of laminated powder. As shown in Fig. 3b,
coarse flake powder is changed into smaller flake powder with a single layer, or a laminated form occurs with crack nucleation and growth in the laminated flake powder after milling for 15 or 20 h. As the milling time increases up to 25 h, the powders is work hardened, and fragmented into fine flake powder, as shown in Fig. 3c.

The milling process of aluminum foil into the flake powder is shown systematically in Fig. 4, and the process is summarized as follows: (1) The foils is laminated, micro-forged by falling balls and elongated (Fig. 4b). (2) A crack occurs in the elongated foil and it is fragmented into small laminated pieces of foil or single piece of foil (Fig. 4c). (3) Coarse laminated aluminum powder is formed by the milling of the laminated small pieces of foil (Fig. 4d). (4) These small pieces of foil are fragmented by local crack nucleation and grow into fine flake powder with high aspect ratio (Fig. 4e). (5) The fine flake powder with high aspect ratio is changed into very fine flake powder by work-hardening and fragmentation (Fig. 4f).

3.2. Effects of the ball size, intermediate stops and the content of stearic acid in the dry ball milling of aluminum foil

Fig. 5 shows the variation of mean powder size with milling time in the case of using balls of different size. Observation by the naked eye showed that after milling for 5 h, the original cut aluminum foil mostly remained intact in the jar containing steel balls of 9.6 mm diameter, but severely deformed and elongated foil such as (4–5) mm × (10–12) mm was formed when using steel balls of 16 mm diameter. After milling for 15 h, the mean powder size in the case of using 16 mm diameter balls is finer than that for the 9.6 mm diameter balls, which means that the larger balls give more impact force to the aluminum foil than do the smaller ball [13–15]. The weight of a steel ball of diameter 16 mm is about five times greater than that of a 9.6 mm ball (16.9 g vs. 3.4 g) although the number of 9.6 mm balls in the jar is larger than that of 16 mm balls when the same weight of balls is charged in the vial (number of balls 253 vs. 53). The 16 mm balls have a smaller collision frequency, but give a high impact force to the foil and accelerate the fragmentation of the aluminum foil into powder.

The variation of the mean powder size with the cooling of the jar by intermediate stop during the milling of aluminum foil for 25 h was checked. The powder milled continuously for 25 h shows 62 μm mean size, but the powder which was milled with three intermediate stops (10, 15, 20 h, respectively) during milling for 25 h has a mean size of 14 μm, as
shown in Fig. 6. This result indicates that the falling of the balls and collisions between the balls and the aluminum powder cause increase of the temperature in the vial during the ball milling due to the plastic deformation of the aluminum powder and friction between balls, thus the aluminum powder will have a more ductile behavior. Cooling the vial by intermediate stops will decrease the temperature of the vial, and gives less ductile behavior to the aluminum powder, which are then easily work-hardened and fragmented to fine powder.

Fig. 7 shows the mean powder size with stearic acid content during milling for up to 45 h. With 5 wt.% stearic acid after 10 h milling, most of the foil has retained its original shape without changing its size. It means that too-large amount of stearic acid on the aluminum foil decreases the friction coefficient between the foil and ball, and enables their sliding over each other, with less plastic deformation in the initial milling process. All of the foil was changed into aluminum powder, even in the vial with 5 wt.% stearic acid, after milling for 15 h. The aluminum powder milled with 1.5 wt.% stearic acid for 15 h has a larger mean particle size than that of aluminum powder with 3–5 wt.% stearic acid. The result shows that coalescence of the powder is prevented by the stearic acid on the powder and the amount of solid solution of carbon in the powder increases with the addition of stearic acid during the milling, and causes hardening and diminishing of the powder size [10–12]. However, the aluminum powder with 5 wt.% stearic acid has larger size than that for 3 wt.% stearic acid due to the lubrication effect between the powder or balls and the wall of the vial. The effect of the oxygen content in the argon atmosphere during the dry milling on the mean powder size was also checked. The powder produced by milling for 25 h under an Ar and Ar+8% O₂ atmosphere have mean sizes of 60 and 62 μm, respectively and no difference in powder size distribution. This result indicates that the oxygen in the Ar atmosphere during the dry milling has no effect on the mean powder size and only prevents firing caused by the large surface area of the flake powder.

3.3. Application of aluminum flake powder manufactured from foil scrap under the dry milling process

The dry ball milled powder from atomized powder is used mainly in aerated light-weight concrete, fingerprint detection and fireworks [1]. One of the applications of aluminum flake powder manufactured by the dry ball milling of aluminum foil was checked in this study. Fig. 8 shows fingerprint detection patterns after the spraying and brushing of aluminum powder with different sizes on finger-printed...
glass. Aluminum flake powder that has a mean size of 14 μm and a specific surface area of 13.9 m²/g gives very poor fingerprint detection pattern as fine powder has less adhesion on the fingerprint line, and so is eliminated easily by brushing. However, aluminum flake powder with a mean size of 27 μm and a specific surface area of 13.06 m²/g gives a good fingerprint detection pattern. The aluminum flake powder obtained by the ball milling of aluminum foil, which has a mean size range of 14–97 μm and a specific surface area of 13.9–1.98 m²/g, is also applicable to aerated lightweight concrete.

4. Conclusions

Aluminum flake powder can be produced using aluminum foil scrap in the dry ball milling process. During the ball milling the foil is laminated, micro-forged, cracked continuously, and then finally formed into a flake shape powder. The size and shape of the flake powder produced depend on the ball milling conditions such as the ball size, the number of intermediate stops, and the amount of stearic acid. Recycled aluminum powder can be used in fingerprint detection or in aerated lightweight concrete.

References