Recovering Aluminum from Aluminum Dross in a DC Electric-Arc Rotary Furnace

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The recycling of aluminum scrap and dross yields significant economic and energy savings, as well environmental benefits. The recovery of aluminum depends on many factors. The aim of this work is to experimentally investigate aluminum recovery under different conditions. In this study, aluminum dross was processed in a direct-current electric-arc rotary furnace. The presence of crushing refractory bodies during processing was found to increase the degree of aluminum recovery by about ten percent.

INTRODUCTION

The consumption of aluminum waste has been rising continuously worldwide, which is a great stimulus for developing aluminum recycling technology.

To recover the aluminum in dross, the conventional recycling process uses salt rotary furnaces heated with a fuel or a gas burner. This treatment process produces a secondary dross containing alumina, salts, impurities, and a small amount of aluminum. Molten aluminum is tapped from the furnace and the residue is then dumped from the furnace and commonly, disposed of in a landfill. An improvement of this technology, known as the oxy-fuel process, uses a gas burner enriched with oxygen to increase the thermal efficiency.[1] Recent studies show that the most efficient means for recycling aluminum scrap has turned out to be rotary tilting furnaces, heated by plasma or electric arc, for which the use of flux is not necessary.[2,3]

Recent studies show that the most efficient means for recycling aluminum scrap has turned out to be rotary tilting furnaces, heated by plasma or electric arc.

Accordingly, there is a substantial need in the industry for an improved process for recovering free aluminum. It is particularly desirable that such a process be cost effective and ecologically safe.

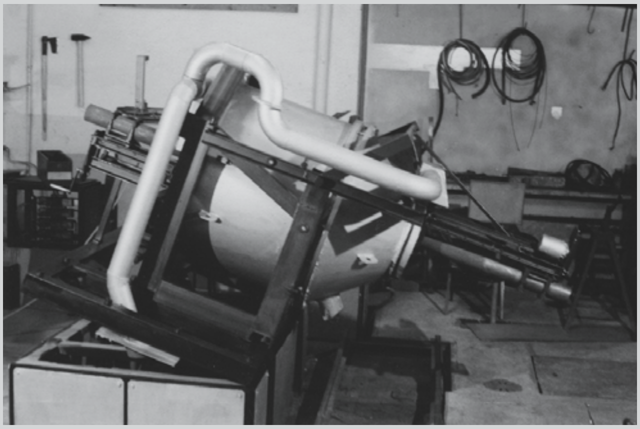

Figure 1. A DC electric arc rotary furnace.

Compact and granular aluminum dross used in the experiments was obtained by the salt-free melting of aluminum scrap. The only preliminary preparation of the compact dross was crushing it into proper size, in compliance with the size of the opening for furnace charging, and removal of fractions –1 mm. The granular dross was subjected to sieving also, to remove fractions –1 mm. In these conditions the content of the metal phase in the compact dross is 72%, and in the granular, 77%. The processing of aluminum dross was carried out in a direct-current (DC) electric-arc rotary furnace (Figure 1).

The purpose of this research is to investigate experimentally the metal recovery under different conditions and to establish the dominant factors that need to be controlled. See the sidebar for furnace details.

RECOVERING ALUMINUM FROM ALUMINUM DROSS

The pyrometallurgical processing of aluminum dross can be divided into two periods, which are carried out with different power.

Period I

In period I, 50 kg of aluminum dross is charged into the electric-arc rotary furnace (1/3 to 1/2 of the furnace size). The electric arc is ignited between the two graphite electrodes and the furnace starts rotating periodically. At the beginning of the period the furnace rotation speed is low so that the refractory is not destroyed by the strikes of the big pieces of dross as well as to minimize the formation of abrasive dust. Regulating the rotation revolutions of the furnace enables the processing of the large pieces of dross, thus eliminating much of the preliminary crushing and sieving processes. The melting is carried out with a maximum power of 50 kW (I = 250 A, U = 180–220 V) and arc length of L = 200–300 mm. The long arc provides great voltage at comparatively low power and even heating of the refractory and the charge. The variations in the furnace pressure at the expense of instability of the electricity mode are suppressed, which prevents air from being sucked from the surrounding area. Under these conditions the charge melts very quickly (Figure 2), and the average melting temperature is achieved due to the furnace rotation. This period continues until a temperature higher than the melting temperature of the aluminum—in the range of 700–750°C—is achieved. The temperature is measured every 5 minutes, and if necessary even more often.

Period II

When the desired temperature is reached, the power is decreased to maintain the constant temperature of the refractory. After some time the furnace rotation stops and the obtained aluminum is tapped into metal molds.

The mobile electrode lifts upward, the furnace tilts, and the hard residue, which is a grayish powder, is discharged slowly from the rotary furnace. When the furnace is cleaned, new charge is loaded as quickly as possible in order to avoid further cooling of the furnace and to minimize energy loss.

Figure 2. The coalescence of the liquid aluminum drops.

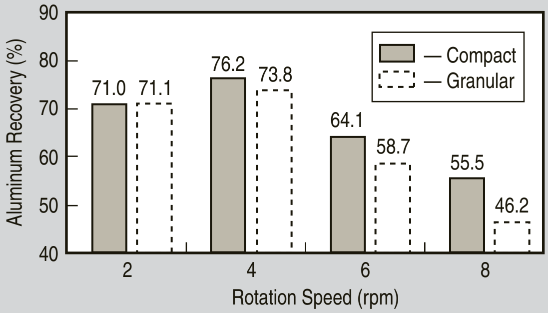

Figure 3. The impact of furnace rotation speed on the degree of aluminum recovery.

Influence of Different Factors on Aluminum Recovery

The factors that can be altered in this process to impact aluminum recovery are: rotation speed of the furnace, argon flow rate, retaining time before tapping, and tapping temperature.

Furnace Rotation Speed

In these experiments, eight melts were made under the following conditions: casting temperature, 720–730°C; retaining time before casting, 0 min.; consumption of argon, 1,000 L/h; and rotation speed, 2 rpm, 4 rpm, 6 rpm, and 8 rpm. The degree of aluminum recovery from this series is represented in Figure 3.

At a rotation speed of 2 rpm the degree of aluminum recovery does not depend on the granular-metric composition of the charge. The best results are achieved with a rotation speed of 4 rpm. By increasing the revolutions of the rotation above the optimum, the degree of the aluminum recovery decreases since part of the melt is dispersed in the slag phase and there is no possibility for the aluminum drops to agglomerate.

As a result of the furnace rotation, crushing and grinding occur when the pieces of dross bump into each other. According to the preliminary experiments, about 50% of the compact dross resulting from these operations form large fractions (–4 + 2 mm), enabling more aluminum recovery. At high rotation speeds, large amounts of fine fractions of granular dross are released with the outgoing gases, but also at these speeds liquid drops cannot agglomerate, leading to less aluminum recovery.

Consumption of Protection Gas

The second series of experiments involved four melts made under the following conditions: casting temperature, 720–730°C; retaining time before tapping, 0 min.; consumption of argon 500 L/h, 1,000 L/h, 1,500 L/h, and 2,000 L/h; and rotation speed, 4 rpm. The degree of aluminum recovery according to the argon flow rate is given in Figure 4. By increasing the consumption of argon the degree of recovery is slightly increased, as well as the melting duration.

The melting duration decreases when large amounts of argon are consumed, if the charge is laid over the hot residue of the previous melt. In this case, the oxygen that entered the furnace when the charge was added oxidized the small metal drops, thus releasing a large quantity of heat. Consumption of large amounts of argon control this process.

Such melts, where the aluminum is used as fuel, can be done without power consumption. Of course, the argon consumption is closely related with the level of hermetic seal of the furnace. The greater the hermetic seal, the less argon consumption is needed to protect the melt and the electrodes from oxidation. For the specific aggregate, argon consumption greater than 1,000 L/h is not economically justified.

Retaining Time

In the third series of experiments, three castings were made under the following conditions: casting temperature, 720–730°C; retaining time before tapping with switched-off heating, 0 min., 5 min., and 10 min.; consumption of argon, 500 L/h; and rotation speed, 4 rpm.

After reaching a pouring temperature and switching off the heat, the furnace rotation speed was increased to 6 rpm. Figure 5 shows aluminum recovery in relation to the retaining time before casting with switched-off heating.

Increased retaining time before casting with increased furnace rotation speed results in an 8% greater aluminum recovery.

Tapping Temperature

In the fourth series of experiments, three melts were made under the following conditions: casting temperature, 800°C, 760°C, and 720°C; retaining time before tapping with switched-off heating, 0 min.; consumption of argon, 500 L/h; and rotation speed, 4 rpm. The results from this series are given in Figure 6.

These experiments found that the greater the tapping temperature, the higher the degree of aluminum recovery achieved. The higher tapping temperature predetermines the higher temperature of the secondary aluminum dross,

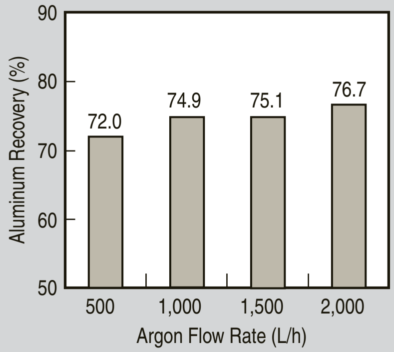

Figure 4. The impact of argon flow rate on the degree of aluminum recovery.

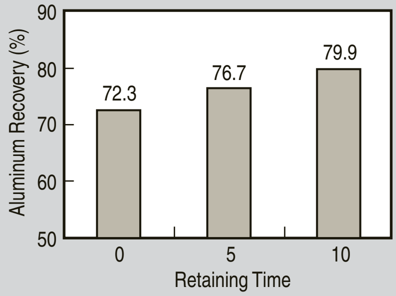

Figure 5. The impact of retaining time on the degree of aluminum recovery.

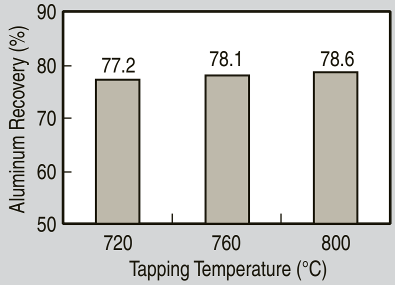

Figure 6. The impact of tapping temperature on the degree of aluminum recovery.

DIRECT-CURRENT ELECTRIC ARC ROTARY FURNACE

Pilot Direct-Current Electric-Arc Rotary Furnace

A unique pilot direct-current (DC) electric-arc rotary furnace with a capacity of 150 kg has been designed and constructed for the recycling of low-quality scrap and aluminum dross. The construction of the furnace shell (Figure 1) consists of two elements—a cylinder with a diameter of 1,000 mm and an axially positioned frustum of a cone—mounted one above the other by means of flanges and bolts. At the two ends of the cylindrical part welded rings lie on the four supporting rollers to rotate the furnace. The bottom of the cylinder is closed by a ring where the furnace is opened to feed the electrode-cathode. The electrode-anode is passed through the conical part of the shell. The refractory of the furnace shell consists of two layers: a thermo-insulating layer of perlite (50 mm) and a working layer of high alumina castable refractory (50 mm). The openings on the bottom of the cylinder and on the conical parts are closed with doors, which are thermo-insulated by refractory wadding, and through the openings of which appear graphite electrodes. These doors are fixed on the support mechanisms that move the electrodes.

The support mechanisms for electrode movement, the supporting rollers of the furnace, and the hydraulic and electrical equipment are fixed on the main support frame of the furnace. The furnace is rotated by a hydraulic motor capable of rotating it at speeds up as high as 25 rpm. The axial movement of the graphite electrodes is carried out in the following way: the cathode (static mounted electrode) is moved manually by means of motion screw and floating nut; the positive electrode (anode), which can be taken out of the working space of the furnace, is moved axially by means of an analogous system (motion screw, floating nut) operated by an electro-motor.

The mechanisms for operating the two motors are installed on the mobile and immobile frame. The mobile frame is turned with the help of hydraulic cylinder at 90° toward the furnace axis (Figure A), thus allowing free access to the working space of the furnace. The construction allows one of the electrodes (the anode), apart from moving axially (parallel to the furnace axis), to move 90° outside the working space. A construction peculiarity of this furnace is that the axially positioned graphite electrodes are placed 100 mm away from the rotation axis of the furnace. This allows the furnace to be fed only once with a greater quantity of charge for recycling. The design prevents its falling on the electrodes at high rotation speed. It also allows the charge to be cut into greater pieces, which results in lower costs for preliminary preparation of the charge.

The displacement of the electrodes leads to an improvement in the radiant heat exchange in the working space of the furnace. The gas feeding to achieve the desired atmosphere in the furnace space is carried out through a hollow graphite electrode (cathode). In this way, besides achieving the desired working atmosphere, the burning of the voltage arc is stabilized.

The furnace has a special tap hole for liquid aluminum pouring, thus making unnecessary any additional measures to keep the secondary dross in the furnace when pouring out the metal.

The furnace ventilation system is indirect (only gases released from the furnace are absorbed), which creates conditions for maintaining a protective atmosphere in the working space with a comparatively low consumption of inert gas.

The DC power supply is 150 kVA, operating in stabilizing electricity mode. A special control panel allows control of the motion and provides the working parameters of the fur-

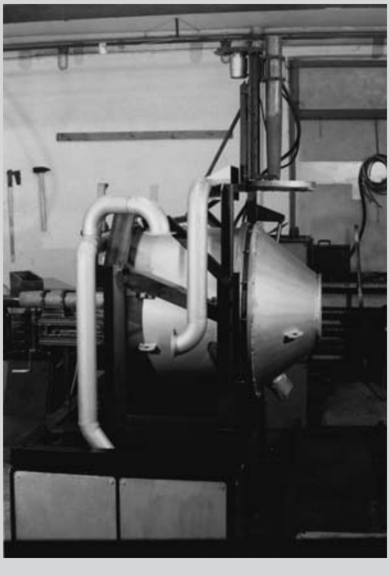

Figure A. A DC electric arc rotary furnace with a displaced 90° electrode.

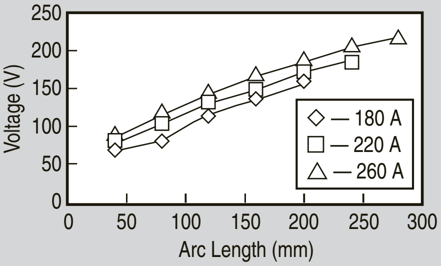

Figure B. The V-A characteristic of the argon electric arc, burning between two graphite electrodes.

nace. The temperature is measured by a thermocouple mounted in the furnace refractory. The V-A characteristics of the electric arc, burning between the two graphite electrodes of the rotary electric arc, are defined in Figure B. The V-A characteristics are slightly rising, which is typical of transferred plasma arc. The greater the arc length, the greater its resistance, and respectively, the greater the voltage. Provided that the arc is short (80–100 mm), a clear anode spot is formed. When the electrodes are cold, by increasing the arc length the anode spot continuously changes its position and the arc burns in an unstable way. When the electrodes are hot, even in the absence of a clearly marked anode spot (diffusion mode) the arc burns in a stable way.

Another way to influence the voltage of the electric arc is to change the consumption of the gas. When gas consumption increases, the voltage of the arc increases due to the cooling effect of the gas stream.

Industrial DC Electric-Arc Rotary Furnace

Because a high recovery rate of metal aluminum from aluminum dross (92%) was realized in this furnace, an industrial DC electric arc furnace was constructed. A project on the “Creation, development and marketing of innovative technology for non-flux processing of aluminum waste” was approved by the E.U. PHARE program, “Research and Development Grant Scheme.” For the purpose of this project an electric rotary furnace was designed and constructed to produce aluminum alloys and to process aluminum dross.

The furnace (Figure C) has a capacity of 1,000 kg of liquid aluminum. The installed power is 300 kVA, operating in a mode of electricity stability, supplying a voltage of 3 × 380 V. The maximum operating electricity is 1,200 A and the maximum operating voltage is 250 V.

As shown in the figure, the furnace shell (1) consists of three elements—a small cone, a big cone, and a cylinder—which are made of steel plates of 15 mm thickness. Annular rails are welded on the cones to rotate the furnace. The above-mentioned elements are covered with a thermo-insulating layer 100 mm thick, above which the working refractory layer of 150 mm thickness is laid. The furnace is rotated by a 3 kW motor-reducer through a roller chain transmission.

The bearing construction (2) consists of a frame, legs, and supports. The legs and the supports are bolted to the foundation, and the frame is mounted on top of them, with a joint connecting it to the legs. This kind of mounting allows the furnace to be tilted to 40°, by means of hydraulic cylinders that are mounted in the supports, when taking out the non-metal product after the metal casting. The front electrode holder (3) is mounted on holder (4), which consists of a shoulder joint suspended on the support column. This construction allows the holder to be turned 180° and provides free access to the working space of the furnace. The front electrode holder moves in an axial direction. The maximum motion of the electrode is 1,180 mm, which allows ignition and maintains the length of the electric arc to provide optimum electricity.

The rear electrode holder (5) moves in the axial direction of the second electrode. The maximum motion of the electrode is 1,880 mm. The electrodes are operated electro-mechanically.

The exit flue (6) is mounted on the front part of the frame and removes the released gases to the purifying system. The construction is designed so that in case the furnace is tilted, the exit flue remains connected to the ventilation system, which does not allow dust in the workshop when pouring the metal and cleaning the furnace.

The short furnace chain is realized by hydro-electrical connections that transfer the power from the power supply system to the electrode holder, and transfer the water that cools them.

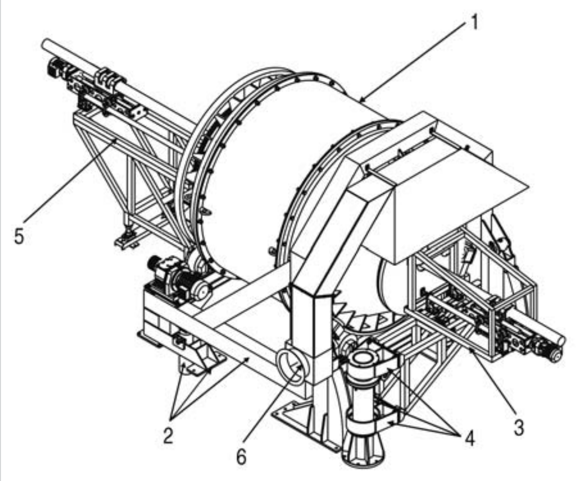

Figure C. A DC electric-arc rotary furnace with a capacity of 1 t of aluminum. 1 – shell, 2 – support construction, 3,5 – electrode holder, 4 – holder, 6 – exit flue.

in which there is fine dispersed liquid aluminum. This determines the burning of the secondary dross at the moment of its removal from the furnace. The process takes place in atmosphere (Figure 7).

According to the experiments, the optimum parameters for metal aluminum recovery from the aluminum dross in an electric-arc rotary furnace are as follows: casting temperature, 720°C; retaining time before casting with switched-off heating, 10 min.; consumption of argon, 500 L/h; and rotation speed, 4 rpm.

As a result of the experiments 900 kg of aluminum dross were processed yielding 466 kg of aluminum. The achieved maximum degree of recovery is 80%, which is considerably lower than the

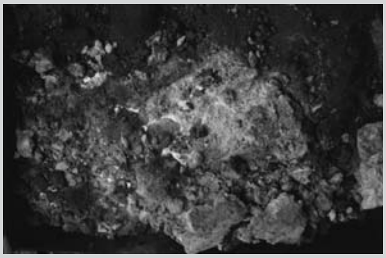

Figure 7. The burning of aluminum.

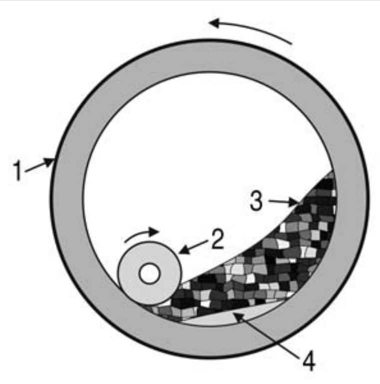

Figure 8. A scheme for aluminum dross processing with crushing bodies. 1 – rotary furnace, 2 – crushing body, 3 – aluminum dross, 4 – liquid aluminum.

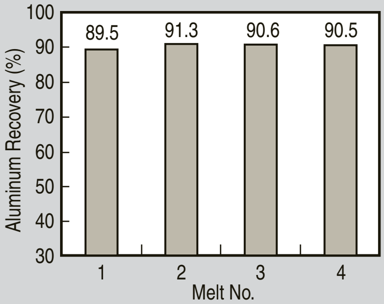

Figure 9. The impact of the presence of crushing bodies on the degree of aluminum recovery.

values for aluminum processing cited by the leading companies.[4–6] It is very likely that the high results are due to flux use or additional means that have been concealed because of the commercial character of the process.

The problem with the aluminum dross melting and aluminum scrap with low density, in general, is the well-formed and oxidized surface, which impedes the agglomeration of aluminum drops even if there is aluminum bath. In these experiments, when the furnace rotates the destruction of the oxygen layer during particle crushing is not complete.

Presence of Crushing Bodies

For crushing purposes, refractory bodies were used with dimensions of 200 mm × 293 mm and a weight of 15.6 kg. These products were chosen based on their accessibility and on the fact that they are resistant to the aggressive action of the aluminum melt. The experiments for aluminum recovery from aluminum dross were performed with the optimum technological parameters and the presence of crushing bodies, as shown in Figure 8.

The results from the experiments are given in Figure 9. The presence of crushing bodies during the processing of the aluminum dross in the rotary furnace increases the degree of aluminum recovery by about 10%. These experiments prove that for the maximum aluminum recovery from dross it is necessary to use additional resources, in this case crushing bodies, which not only destroy the oxygen layer but add fireclay to the liquid bath. This technique favors the assimilation of the finely dispersed particles of metal aluminum in the melt. Better results are expected if the configuration of the crushing bodies is changed to ellipsoid or if their size is changed, but such experiments have not been carried out.

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