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Purification Processes Involved in Aluminium Recycling: A Review

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***Abstract*: Aluminium taken directly from the earth is called primary aluminium. Due to the continuous extraction of primary aluminium, the aluminium content present in the earth's crust may get exhausted within a few decades. So, the focus is shifted over recycling of the used aluminium which is called as secondary aluminium. The secondary has several advantages over the primary aluminium. The former has a very less energy consumption and environmental friendly when compared to the latter. The major issue with the primary and secondary aluminium is the impurities present in it. The main aim of this paper is to give an overview about the various techniques involved to remove the impurities present in aluminium.**

***Keywords*: aluminium purification, impurity removal, structural modification and degassing**

1. Introduction

Aluminium is a white silvery metal which is about 8% on the earth's surface is preferred in many applications due to its unique properties. It is generally present in oxide forms like bauxite and kaolinite. The metal is extracted from the earth by means of Bayer's process and Hall Heroult's process. Due to its well-known properties like high strength to weight ratio, ductility, corrosion resistance, electrical and thermal conductivity, aluminium is used for variety of applications like construction works, automobiles, aerospace applications etc.,. Generally, aluminium is classified into two categories as cast alloys and wrought alloys. The cast alloys are produced through different types of casting techniques like sand casting, die casting and pressure casting. Whereas, wrought alloys produced by casting the molten metal into ingots and followed by subsequent hot working and cold working processes to turn them into rods and plates.

2. Techniques involved in removing impurities

In aluminium, the commercial purity aluminium has a maximum purity of 99.95% which can be rarely used for any applications. So,it is necessary to add other elements as alloying content in order to change the mechanical properties as per our requirements. The major alloying elements are copper, manganese, silicon, magnesium and zinc. Other than these elements, the rest can be considered as impurities. Iron is the most pervasive impurity that is present even when extracted from the bauxite ore. Iron has a deleterious effect over the properties of aluminium. There are various processes involved in purifying the aluminium melt. They are

3. Iron removal through structural modification

Zhang [1] says that the presence of iron in the aluminium alloys above 0.05wt% is not acceptable mainly in aerospace applications. So, iron must be removed from aluminium. The removal of iron from aluminium is more complex as the iron content in it decreases. Now, our aim changes towards nullifying the effect of iron using various alloying elements like manganese, cobalt, strontium and beryllium. Among these alloying elements, Zhang [1] considers that manganese is much more effective. These alloying elements tend to change the microstructure of the alloy which is the main reason for the mechanical properties. Iron has a very low solid solubility in aluminium and it forms secondary phases in aluminium. Among the various phases formed, β-AlFeSi has a high effect over the properties as it has a needle-like, platelet structure which tend to act as stress raisers and increases the brittle properties of the material. The addition of these alloying elements tend to change the needle like microstructure to Chinese script like microstructure.

A. Effect of manganese

Even though the addition of manganese has a deleterious effect over the mechanical properties of aluminium, it is mostly used in neutralizing the iron content present in the Al-Si cast alloys. Manganese seems to be effective due to its atomic size and the crystal structure similar to that of the Fe atom. The effect of the iron is reduced as the manganese addition converts the brittle platelet structure to compact morphologies like globular, polyhedral or Chinese structure. This helped Zhang [1] to find that the tensile strength restored.

After the addition of manganese in the Al-Si alloys, the β-Al_5FeSi phase is found to be reduced and a more of α-$Al_{15}(Fe,Mn)_3Si_2$ is found in the aluminium. The morphology of this phase varies based on the cooling rate and the concentration of Mn and Si. More Chinese script structure is observed when the iron and the manganese content are about0.87wt% and 0.35wt% respectively with a higher cooling rate. The amount of manganese required to neutralize the iron content is not a well-established as it varies depending on many factors like the cooling rate, initial Fe-Si content and heat treatment. If the Fe content exceeds reaches beyond 0.45wt%, a 1:2 weight ratio of Fe and Mn is advisable. In Al-Cu alloys, Mn helps to suppress the platelet Cu_2FeAl_7 and helps to recover the ductility but a loss of yield strength occurs.

B. Effect of cobalt

As similar to manganese, cobalt can also be used to remove the effect of iron. Since, Fe and Co has a similar atomic size, cobalt can also be used to precipitate the Fe rich phases. But it is less effective and a comparatively large addition is required than manganese. Jianwei Gao [1] Co/Fe about 0.5-1 is suggested as an appropriate ratio to change the platelet structure into globular shapes.

David G. Robertson [1] concludes that the deleterious effect of iron can be partially reduced by varying the cooling rates, solution treatments and by the addition of manganese, cobalt and strontium as alloying elements.

4. Electroslag refining

The most popular strategy in iron removal methods is precipitation and separation of iron from aluminium melt. A well-established technique for producing steels and other high performance alloys is electroslag refining. In electroslag refining process, a consumable electrode is immersed in a molten slag pool and a high current is supplied through the resistive slag layer and the electrode. Due to the effect of the supplied current, the consumable electrode starts melting and falls as droplets into the molten slag pool. The metal droplets react with the molten slag and refining of the aluminium takes place.

Chen chong [2] says that consumable electrode used is commercial purity aluminium with iron content upto 0.48 mass%. The consumable electrode was cast from a 2.7kg of aluminium into 800*ϕ40mm rod. The slag used in this process is combination of chloride-fluoride containing KCl, NaCl and Na3AlF6 in the proportion of 47:30:23 mass% respectively. Addition of AlP is suggested in order to remove the iron impurities present in it. The high current supplied is about 60kVA which is single phase AC current. This method can help to remove the iron content by 18%. The electroslag refining process requires a high power and only a small amount of aluminium can be purified by this process. Chen Chong [3] expresses an alternate with a varying addition of Na_3AlF_6, the iron content decreases with increasing concentration of the salt. He says that the optimal addition of Na2B4O7 and the remelting time are 9% and 30 minutes respectively.

5. Degassing of aluminium alloys

The major factor affecting the quality of aluminium alloys are the melting condition, temperature variations and the humidity present in the atmosphere. Hydrogen is the gas which needs focus in aluminium recycling as the solubility drops in liquid aluminium just above the melting temperature. The water vapour or moisture in the atmosphere is the main source are hydrogen in liquid aluminium. The liquid aluminium reacts with the moisture content to form alumina and hydrogen. The hydrogen produced gets dissolved in the liquid aluminium and alumina is deposited at the surface. When the liquid aluminium tends to solidify, the solubility of gaseous hydrogen gets produced. Therefore, aluminium alloys will release the insoluble hydrogen which results in porosity defects throughout the solidified metal in order to the hydrogen present in the aluminium melt degassing is to be done. During remelting, it was found that the porosity is reduced by dramatic reduction of the hydrogen content says Lei Zhao [6]. The various degassing techniques are degassing using salt fluxes, rotary degassers and ultrasonic degassing.

A. Degassing using salt flux

Generally, fluxing is done to remove the impurities, alkaline earth metals and dissolve hydrogen present in the aluminium alloys as they severely affect the mechanical properties of the materials. NaCl-KCl, KCl with addition of other fluorides, chlorides and carbonates. The salt fluxes must fuse with the aluminium oxide at lower temperature and increase the viscosity of the slags which tends to remove the impurities by means of chemical reaction or physical separation. So, that a salt flux with very low melting point is preferred for this process. The metal yield is mainly dependent on the chemical composition and the amount of salt used in the flux. The KCl present in the NaCl-KCl flux can alters the efficiency of the degassing process says P. E. Tsakiridis [7]. Since, KCl is an expensive salt its addition can be reduced. A minor reduction of KCl doesn't affect the metal loss but reduces the emission. But greater reduction in KCl increases the melting point of slag and thereby affecting the metal recovery. So, an optimum use of KCl will be economically efficient and environmental friendly. In case of high magnesium alloy, magnesium chloride can be used as flux. As magnesium chloride is hygroscopic, it reduces the risk of moisture absorption which suppresses the formation of hydrogen gas in the liquid aluminium.

B. Degassing using rotary impeller

In order to remove the hydrogen gas and solid impurities present in the aluminium melt, rotary degassing is widely used in the industries. An impeller is designed in such a way that in can withstand high temperature which is to be placed inside the melt. A gas is purged into the molten alloy through the holes which is located at the bottom of the impeller. The purged gas forms bubbles which rises through the melt. The bubbles which tends to move upwards carry the hydrogen gas and solid impurity and forms sludge. The high speed rotation of the impeller shears the gas bubbles and produces a widely dispersed pattern within the melt. The hydrogen is collected by the purged gas bubbles due to the lower partial pressure of hydrogen when compared to the surrounding melt. Hydrogen diffuses into the bubbles, which rise to the top surface and expelled into the atmosphere. The initial hydrogen content, holding vessel size, purged gas flow rate, mixing capability of the rotor are the factors which has the severe effect over the efficiency of the rotary degasser.

C. Ultrasonic degassing

Degassing of liquid metals was widely done using ultrasound in the 1970s which was overcame by rotary degassers in the upcoming years. But due to the efficiency and environmental friendly nature again ultrasonic degassing is preferred. This method is used to produce cavities in the molten liquid. In the sound field, during alternating compression and rarefaction, the cavity is likely to turn up into a bubble filled with hydrogen. Acoustic streaming and secondary convection flows distribute the hydrogen filled bubbles in the liquid melt. The creation of bubbles by cavitation from the dissolved gases instead of introduced gases makes the ultrasonic degassing as an efficient technique. This technique consist of a sonotrode made of Ti concentrator and Nb tip tune to a frequency of about a 17.5 kHz. The preheated sonotrode is dipped in the liquid melt to a depth of 10mm to which a power supply of 4 kW. Ultrasonic treatment was applied to the molten metal for specific period and followed by periods without ultrasonic activity. Tzanakis [10] says that the cavitation intensity has a major effect over the degassing process using ultrasound and the intensity is mainly dependent on the distance of the sonotrode from the source rather than melt temperature or the power supplied to the melt. The cavitation intensity can be found by using a high temperature cavitometer made of titanium. Another study of D. G. Eskin [11] suggests that using a plate sonotrode, one can achieve a degassing efficiency of 50%.

6. Electromagnetic Degassing

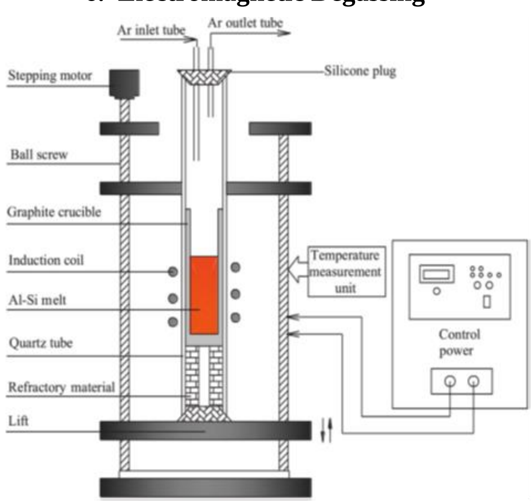

Fig. 1. Electromagnetic degassing setup

Yongsheng Ren [15] proposes electromagnetic directional solidification as a new aluminium degassing technique. In this process, they use Al-12.6%Si casting alloy which is kept in a graphite crucible placed in a 60kW induction furnace. The molten samples at 800^{0}C were pulled down by means of a controlled pulling system. In order to prevent the oxidation of the melt, argon gas is passed through the quartz tube. Due to natural cooling accompanied by the pulling, solidification takes place from the bottom to top. The solubility of the hydrogen gas present in the melt varies with the temperature. The higher temperature region has a better solubility so that bubbles travel from the lower temperature zone to higher temperature zone. Thus, porosity due to the hydrogen can be avoided at the bottom and middle of the ingot but the top is affected which can be removed through cutting off operation.

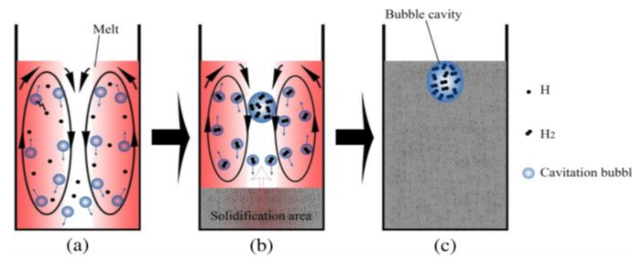

Fig. 2. Schematic representation of degassing process

7. Conclusion

During the aluminium recycling processes, it is very important to remove the impurities like iron content and dissolved hydrogen. We have discussed about the widely used techniques to remove those impurities. From this discussion

a) Iron removal through structural modification by adding manganese can be preferred over electroslag refining, as the latter incorporates more time and power consumption. But, the former involves normal melting with the addition of alloying elements alone and a large quantity of aluminium can be purified.
b) Among the various degassing techniques, ultrasonic degassing technique has a better degassing efficiency of 50% for low quantity of aluminium melt. Electromagnetic degassing can also be done but it requires a costlier setup for the process.

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