CB03 - A New Prototype for Acousto-Ultrasound Analysis of Carbon Anodes

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Abstract

A new acousto-ultrasonic (AU) system was developed for non-destructive assessment of damages within pre-baked carbon anodes manufactured for the Hall-Héroult process. It improves over the technique used in past research made in the group by collecting information in a more representative manner, and receiving the same signal simultaneously in multiple positions. Therefore, AU measurements are more robust and redundant, decreasing the probability for a false evaluation. Moreover, the system can analyze full-scale anodes rapidly and in a more standardized way, reducing variation caused by human manipulation of probes and increasing the system's capacity. The AU system described in this paper is mounted on a forklift. A proof-of-concept is presented where the system is used to collect measurements on a small population of anodes in all stages of fabrication (green, baked, slotted, and rodded). The AU response of the anodes is analyzed with the aid of latent variable modelling. Results are compared between anode types and confronted with expected properties of each type of anode. Additionally, an assessment of repeatability of the results is also shown.

Keywords: Pre-baked carbon anodes, non-destructive testing, acousto-ultrasonics, latent variable modelling, repeatability.

1. Introduction

For every kg of aluminum produced by the Hall-Héroult process (H-H), 4 kg of bauxite, 0.4-0.5 kg of carbon, 13-15kWh of energy and some other additives are consumed [1]. Approximately 1% of all the greenhouse gases (GHG) emitted by metal production in the world come either as direct emissions or embodied emissions from aluminum production [2], and one of the key components in this process is the pre-baked carbon anode, the carbon source for the H-H process. Anode quality can affect smelter performance to the point of increasing GHG emission by more than 60% in addition to a 100$/t Al cost increase [3]. Quality parameters for anodes are not a new subject, nor a static one. What is considered good has changed with time both in terms of anode properties and their ranges [4–8]. An important issue throughout the industry is to manufacture consistent quality anodes [9].

A major part of the anode's mass is calcined petroleum coke (CPC), ranging from 63 %-70 % [10], which has been subject to a major quality change in the last two decades. The concentration of contaminants has steadily increased while its properties also are becoming more variable as a consequence of the new oil market dynamics [11–13]. Back several years when CPC supply was more stable, standard chemical and physical characterizations of anode properties in the lab based on core samples were more than sufficient to assess anode quality. However, in actual conditions, the typical 4-6 weeks delay before lab results are available does not allow for timely monitoring of anode quality. Moreover, core sampling rates are typically under 2% of the weekly anode production. The core sample themselves consists of only approximately 0.3% of the volume of a 1-ton anode, from which a set of 15 properties are measured and assumed representative of the anode volume. This procedure for assessing anode quality has been criticized as excessively complex [14] and potentially unnecessary. Additionally, because of the positioning of such samples and their small volumetric fraction of the whole anode body, physical defects that exist in different internal anode sections, such as cracks, are not necessarily detected, even though those are detrimental to the anode quality.

Non-destructive testing (NDT) could be a solution to these problems in the modern anode quality control system. Since the 1970s, researchers have been aware of how positive would be the capacity of analyzing full-sized anodes without destroying them and having a smaller delay to obtain the results necessary for making a decision. It would significantly increase the fraction of analyzed anodes and deliver a much faster response time to smelter operations, increasing the potential of a more profitable aluminum smelter. Multiple sensing principles can be used to create an applicable NDT.

Electrical resistivity is the oldest technology when referring to NDT applied to carbon anodes. In the 1970s an instrument for measuring baked anode resistivity was developed [15, 16]. It was made with an array of 40 current and 9 voltage probes on the bottom of the anode to measure both current and voltage simultaneously while mimicking the current pathway during full-scale operation. Although the method measures a repetitive average value, it is not capable of sizing, positioning or differentiating existing defects on an anode precisely because it only gives this average value that represents the anode as a whole.

Focused on the idea of reproducing the current distribution of an anode in service, the MIREA device was developed [17–20]. It has since then been extensively tested in more than 10 000 baked anodes. Instead of probes applied on the bottom of the anode, a current is passed through from the stub holes to a carpet at the anode's bottom while voltage drop is measured at different heights on the anode sides. Although it has not shown the capacity of differentiating the types of defects, one could argue that it is roughly capable of detecting its position through a higher resistivity measurement in a specific zone of the anode volume. Overall, the method shows that it can measure the electrical resistivity of an anode with a good representativity of the whole anode body, but differentiating the types of defects is not claimed.

Aforementioned resistivity techniques were all focused on baked anodes, which is not the case with the SERMA device [21–28]. Green anodes cannot suffer high currents passing, for those may affect the distribution of pitch due to heating. For that, the system was adapted to run at low currents. It consists in pairs of metal plates to which a matrix of voltage and current probes are assembled to measure the electrical current distribution through the anode volume. The pairs of plates are contacted on opposite sides of the anode and a controlled current is passed through. This is done both from top to bottom and from the anodes' sides, and the combination of both information is used to identify the position where defects may exist. However, this method may cause ambiguities on the positioning of those defects if multiple exist, and because the electric current passes through the least resistance pathway, one cannot be sure of the exact path where the currents have passed, complicating the positioning even more.

Another device focused on the green anode [29] is a combination of multiple four-points probes (4PP) [30]. This device combines 4 probes located in different positions on the anode's long side and 1 on the shorter side to measure the specific electrical resistivity. The data extracted from more than 120 000 anodes using this device was used as the input to build a system to predict baked anode sticking issues when unloading from baking furnaces [31]. One of the main issues with the system is contacting. This is true of most electrical resistivity-based NDTs, and it was one of the motivators to the development of contactless technologies.

Using metals coils, Haldemann & Fawzi [32, 33] designed an equipment that would generate eddy currents inside the anode when using an alternating magnetic field. As a consequence, the plant to control its process in a much faster response time. For any of those, full automation of the system will be required.

6. References

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