A Non-Destructive Technique for the On-Line Quality Control of Green and Baked Anodes

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Abstract

Carbon anodes play an important role in the electrolytic production of aluminum. They have a significant impact on economics and environment. Carbon anodes are made of dry aggregates, composed of petroleum coke, recycled rejects, and butts, bound by coal tar pitch. Due to several factors, cracks and defects appear in anodes during the fabrication process, affecting their quality. It is thus essential to control the quality of anodes before their use in the electrolysis cell. Current practice for the quality evaluation (visual inspection, core analysis) gives limited information. As an alternative to this practice, the electrical resistivity measurement, one of the key indicators for anode quality and its homogeneity, can be used. A simple and non-destructive method has been developed for the specific electrical resistivity measurement of anodes (SERMA) for on-line control of anode quality. Various tests have been carried out at both lab scale and industrial scale. In this study, the resistivity distributions in the lab scale anodes were measured and compared with those of the tomography analysis. The method is able to detect defective anodes even before the baking process.

Keywords: Carbon anodes; quality control; non-destructive method; electrical resistivity.

1. Introduction

Carbon anodes are used in the electrolysis cell for the production of primary aluminum according to the Hall-Hérault process. These anodes are made of a dry aggregate composed of calcined petroleum coke, butts, and green and baked rejects. The dry aggregate particles are bound by coal tar pitch. The dry aggregate and the pitch are mixed and compacted in a vibro-compactor to produce green anodes. The green anodes are baked in a baking furnace. During the baking process the volatiles in pitch are removed from the carbon material. Cracks are created in the anode material due to the pressure of the volatiles [1-3]. These defects affect the final quality of the anode and increase the production cost and energy consumption. Thus, it is necessary to inspect the anodes before their introduction into the electrolysis cell.

In industry, the anode quality is usually inspected by two methods: visual inspection of the anode surface and analysis of a cylindrical sample (core) taken from the anode. The visual inspection gives only limited information since the inside of the anode cannot be examined. The analysis of core can provide significant information; however, it is a destructive technique and can be applied to a few anodes (about 1.5% of the anodes produced) during the anode production. Also, the sample is taken from a region near the top of the anode, which does not necessarily represent the entire anode [1].

There are some non-destructive methods which are used to evaluate anode quality in the laboratory but are not applied to the inspection of industrial anodes. Among these methods, the ultrasound inspection is used for the detection of defects, dimensional measurement and material characterization. However, its application is difficult on rough, irregular, heterogeneous porous materials [4]. Amrani et al. [5, 6] performed an ultrasound inspection on core samples from carbon anodes and was able to detect the cracks in these samples. However, it was not possible to apply this method to large carbon blocks because of the limited penetration of the ultrasonic waves into the material.

Eddy current testing is a method used for the detection of defects in a conducting material. The application of this technique has been published in the literature [[7], [8], [9]]. Haldemann and Fawzi [10] developed an eddy-current based system to detect flaws in carbon anodes. In their system, the eddy current was induced by a coil surrounding the carbon block. Then, by measuring the impedance of the coil, it was possible to detect the presence of cracks. The authors complemented this method with the electrical resistivity measurement using the four point method. The main drawback of this system is the limited penetration of the eddy current into large anodes, and the influence of external magnetic fields.

Audet and Parent [11] designed a system made of one emitting coil and two receiving coils connected to a sensing device. A carbon anode sample was moved in the emitting coil resulting in the modification of the electromagnetic field. Thus, a current was induced in the receiving coils. By comparing the measured signal to that obtained using a reference sample, the authors were able to estimate the electrical conductivity of the sample. This system was limited by the short penetration of the electromagnetic field into the sample. The large size of the coils also restricted the industrial implementation. Moreover, it required the calibration using a homogeneous reference anode which is difficult to do in practice. In addition, the systems developed by Haldemann and Fawzi [10], and Audet and Parent [11] give a bulk information about the sample but cannot locate the position of the defect.

As explained above, both the ultrasound and the eddy-current testing methods are limited to thin samples because of the short penetration of the acoustic waves or the electromagnetic field into the carbon material. To overcome this limitation, the electrical resistivity measurement can be used and is an efficient and promising non-destructive testing method. This method is widely used in mining, civil engineering and composite material characterization. Matsui et al. [12] developed a system to measure the resistivity of various rock samples. They related the measured resistivity to the physical properties of the rock. Schueler et al. [13] used electrical impedance tomography to detect damages in carbon-fiber-reinforced polymers. Karhunen et al. [14] reported a 3D imaging of concrete using impedance tomography. Lataste et al. [15] developed a four-point resistivity measurement system to detect defects in concrete. There are some publications where electrical resistivity measurement has been applied to carbon anodes. Seger [16] developed a system to measure the electrical resistivity of baked anodes. In this system, the current was injected into the anode from the top through the stub holes and left the anode through a set of probes in contact with the bottom surface. The resistivity was obtained by measuring the voltage drop between the stub and the contact probes and the current flowing through each probe. Later, Chollier-Bryn et al. [17] and Léonard et al. [18] developed similar systems where they tried to reproduce the current distribution in a baked anode in the electrolysis cell. In this system, the current entered the anode through the stub holes (initially using inflatable metallic bags which were later replaced by metallic contacts) and left it from the bottom surface through a metallic brush carpet. The voltage drop was measured between a reference point on the top surface and predefined points on the side surfaces. The resistivity was calculated by comparing the voltage drop to that obtained by a numerical simulation of the current distribution in anode. The system gave an idea of the overall quality of the anode. These systems were designed only for baked anodes and cannot handle green anodes.

Figure 7 shows an image obtained from the tomography analysis of Anode 1 for a particular level between the top and the bottom surfaces. It shows a crack propagating along the length of the anode. Figures 4 (a) and (b) show the presence of defects in the region where this crack is located. Its presence and its location confirm the prediction made by the electrical resistivity measurement (see Figure 4 (a)).

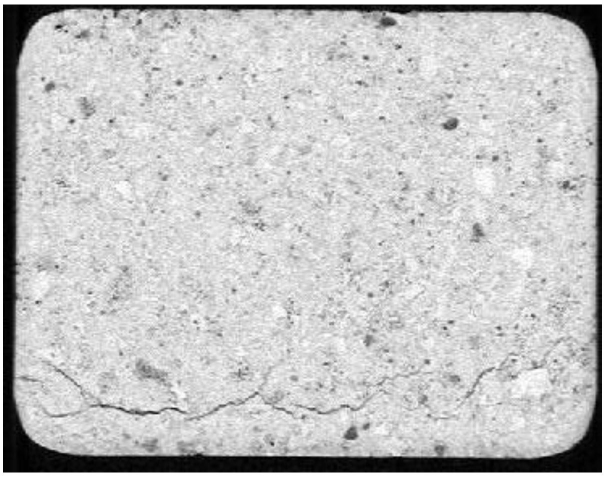

Figure 7: Visualization of a cracked region in Anode 1 by tomography.

4. Conclusions

In this work, a non-destructive testing method for the quality control of carbon anodes is presented. This method involves measuring the electrical resistivity of the anode in two directions and analyzing its distribution. Highly resistive region of the anode indicates the presence of defects/cracks in the material. The analysis of the highly resistive regions in two directions helps locate the position of defects.

A software has been developed to analyze the tomography results. The software can locate defects in a particular layer as well as cumulative defects in a particular direction.

The resistivities in green and baked laboratory anodes were measured at a number of points. The results show that there is a similarity in the distribution of resistivity before and after baking. The resistivity measurement method for baked anodes was validated by tomography analysis. The experimental results showed that the locations of high resistivity values matched with the regions containing large numbers of defects obtained by the tomographic analysis.

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