Inspection of baked carbon anodes using acoustic techniques

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Abstract

High quality baked carbon anodes contribute to optimal performance of aluminum reduction cells. However, the currently decreasing quality and increasing variability of anode raw materials (coke and pitch) make it challenging to manufacture anodes with consistent overall quality. Intercepting faulty anodes (i.e. damaged due to internal cracks and voids) before they are set in reduction cells and deteriorate their performance is therefore important. However, this is a difficult task even in modern and well instrumented anode plants because lab testing using core samples can only characterize a small proportion of the anode production due to the costly, time consuming, and destructive nature of the analytical methods, and these results are not necessarily representative of the whole anode block. Therefore, the objective of this work is to develop a rapid and non-destructive method for quality control of baked anodes, based on acoustic techniques. The acoustic response of the anodes was analyzed using a combination of signal processing and multivariate statistical methods. The sensitivity of the acoustic signals to various defects is demonstrated using a sliced anode which was submitted to CT-scan (X-ray) to visualize the internal structure.

1. Introduction

The currently decreasing quality and increasing variability of anode raw materials (coke and pitch) make it challenging to manufacture anodes with consistent overall quality. Intercepting faulty anodes before they are set in reduction cells and deteriorate their performance (i.e. energy consumption and efficiency) requires testing all or the majority of manufactured anodes. However, even in modern and well instrumented anode manufacturing plants, the traditional lab inspection strategy based on core sampling can at best evaluate the properties of about 1% of the manufactured anodes due to the costly, time consuming, and destructive nature of the analytical methods. In addition, core sample properties are typically available after the anode was set in the reduction cells due to the long lab delays. For economical and logistics reasons, it is generally not possible to improve the rate of anode testing by increasing the lab work load. Furthermore, the properties obtained from core samples are not necessarily representative of the whole anode block as reported by Sinclair and Sadler [1-2], who provide a complete list of issues related with the use of core samples for quality control and decision making. Indeed, anode blocks are heterogeneous materials that may contain different types of internal defects (i.e. coke particles not penetrated by pitch, regions of high/low pitch concentration, pores and cracks) which can lead to anisotropic distribution of properties within the block. The current strategy may completely miss these defects if the core is not sampled where the defects are located. Hence, the mechanical properties, electrical resistivity obtained from core samples may only reflect localized properties. Therefore, rapid and non-destructive techniques to inspect anode blocks should be investigated in order to provide a better picture of the block quality in a timely fashion. This would allow anode sorting strategies to be put in place and feedback corrective adjustments to be implemented on paste plant and baking furnace operation parameters.

Acoustic emission (AE) methods have been widely used as a non-destructive technique in the inspection of composite materials, such as concrete and refractories [3-5]. However, applications of AE for testing complex porous materials naturally containing pores and cracks, such as baked carbon anodes, are not as common as for denser materials such as parts made of metal alloys or highly graphitized carbon materials, which are expected to be free of internal voids. The main issue with anodes is to separate defects affecting their performance in the reduction cells from the internal porosity which is always present when both types of voids attenuate the acoustic waves propagating through the materials. The only publicly available reports on the application of acoustic methods on carbon electrodes appears to be those of Allaire [6] and Allaire et al. [7] using the SonicByte™ system [8]. Their work mainly focused on measuring the elastic properties of refractory and carbonaceous materials as a mean of detecting defects. Although, this technique may help identify faulty anodes, it only provides an estimate of the overall material properties. Inspecting the anode block at different positions should provide more information about the distribution of pores and cracks within the volume, and provide a clearer diagnostic. This is essential for taking appropriate corrective actions on the anode manufacturing plant operation.

The objective of this work is to investigate the use of acoustic emission techniques for volumetric inspection of baked carbon anode blocks. It focuses on detection and identification of two types of internal voids, namely pores and cracks, using the attenuated acoustic signal propagating through the material. To prove the concept, a baked anode was sliced along its length and analyzed by CT-scan (X-ray) to reveal its internal structure [9]. Acoustic excitation waves at different frequencies were sent through the materials and the attenuated signals were measured at different positions from a certain number of slices. Several features were computed from the AE signals and collected in a data matrix which was then analyzed using Principal Component Analysis (PCA) [10]. The clustering patterns obtained in the PCA score space suggest that the proposed approach is sensitive to the concentration of pores and the size of cracks, and that both types of voids can be distinguished. The results were validated qualitatively using CT-scan images.

The paper is organized as follows. The experimental details about the acoustic emission set-up as well as the baked anode sample are presented first. The methods used for processing and analyzing the acoustic signals is described after which the results obtained with the proposed approach are discussed. Eventually, some conclusions are drawn.

2. Experimental

2.1. Acoustic emission system

An overview of the AE signal measurement system is shown in Figure 1. Signal conditioning was performed by pre-amplifiers. The conditioning signal (with a gain of 40 dB) was fed to the main data-acquisition board in which the AE waveforms and parameters were stored.

signal were then collected from several slices divided into corridors along the anode height. A vector of temporal attenuation features were calculated from each anode samples and then Principal component analysis (PCA) was applied to the attenuation feature matrix. The results have shown that the AE signal features are sensitive to the presence of cracks within the anode samples (measured by overall signal attenuation) and to the density of pores distributed throughout the block. The CT-scan images of the samples served as a reference for qualitative validation of the observations made from the AE signal features. The proposed approach appears very promising for full scale anode inspection. Future work should concentrate on validating the robustness of this method on several real anodes in plant to pave the way for the online control.

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7. References

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