New Insights toward the Characterization of the Carbon Paste Forming Process

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Abstract

Anode vibrocompaction plays a crucial role in defining the average density and the density gradients of the prebaked anodes. During this process, several parameters such as the frequency, the amplitude, the duration and the dead weight should be controlled. In order to improve this process, the physical mechanisms that govern the anode densification during the vibrocompaction should be understood. The aim of this work is to investigate experimentally how cyclic loading and loading rate affect the densification of a carbon paste. For this purpose, series of quasi-static cyclic and monotone dynamic compaction tests were carried out. The experimental results revealed that decreasing the amplitude of the cyclic load leads to a decrease of the stress needed to reach the target density and a decrease of the reversible component of the total deformation at the corresponding density. The results also showed that the strain rate has no effect on the compaction behavior of the carbon paste in the quasi-static regime. However, in the dynamic regime, increasing the strain rate decreases the compressibility of the carbon paste. Finally, the results obtained shall pave the way for a better understanding of the cyclic loading and the strain rate effects on the rearrangement of particles and the buildup of air pressure in the carbon paste during the forming process.

Keywords: Carbon paste, cyclic compaction tests, strain rate, air pressure, particles rearrangement.

1. Introduction

Aluminum is produced through the Hall-Héroult process where the alumina (Al_2O_3) dissolved in a bath of cyolite is reduced by a prebaked carbon anode. Carbon anodes are consumed gradually during the electrolysis process and are replaced periodically (every 25-30 days). The anode performance affects the overall energy efficiency of the electrolysis process [1]. The anode manufacturing process includes several steps that affect anode quality. First, the raw materials (calcined coke, coal tar pitch, and anode butts) are mixed at a temperature around 170 °C to form anode paste [2] . The paste is then generally formed through a vibrocompaction process at 150 °C. The resulting green anode blocks are baked in a furnace in the temperature range of 1100 °C to 1200 °C [3]. Finally, the anodes are attached to a rod with cast iron before being placed in the electrolysis cell.

The vibrocompaction process significantly affects the quality of the prebaked anodes. A poor compaction can lead to [4]:

1. High permeability, which increases the air and CO_2 reactivity of the anodes in the reduction cell;
2. High electrical resistivity (due to high porosity and fine cracks) that leads to an increase in electrical consumption and the greenhouse gas emissions [5];
3. Critical cracks in the anode that may lead to anode failure.

In order to improve the vibrocompaction process, the behavior of the green anode paste (GAP) at high temperature and under cyclic loading should be understood. Few studies have been published on the rheological behavior of the GAP [6] . The behavior of the GAP depends on the temperature of the sample and its composition [7]. Thibodeau et al. [8] performed quasi-static cyclic tests on the GAP at 150 °C in a flexible mold. The authors showed that the curvature in the strain response changes when the stress in the actual cycle reaches the maximum stress of the previous cycle. Beyond this stress, the GAP showed a softening behavior. They related this softening behavior to the breakage of aggregates that was captured by an acoustic recording system. In the same study, creep tests have been performed on the GAP. The strain response during creep stages showed a time-dependent behavior. They concluded that under static and monotonous loading, the GAP densification is dominated by the aggregates rearrangement until the solid skeleton is formed. After this point, the additional permanent deformation is resulted from the aggregates breakage. Yet, the comparison between the monotone and the cyclic compaction as well as the investigation of the cyclic amplitude effect on the densification process is not done in this work. Azari et al. [9] performed uniaxial compaction test on the GAP with different pitch/coke ratio and two quasi-static strain rates. It has been shown that the strain rate has little effect on the GAP densification. However, the effect of the dynamic strain rate on the GAP densification is not considered in this work.

To the author's knowledge, these are the only works that studied the behavior of the GAP during the compaction. There is thus a lack of information on the rheological behavior of the GAP subjected to dynamic and cyclic loadings. In this study, the behavior of an alternative carbon paste (ACP) under cyclic and high strain rate loadings is investigated experimentally. The results are analyzed in order to understand the physical mechanisms of carbon paste densification: Two hypothesis are presented.

2. Materials and Methodology

2.1. Experimental Set-Up

The experimental set-up is presented in Figure 15. A DARTEC hydraulic press is used to carry out all the compaction tests. The maximum load capacity of this press is 250 kN. The height of the sample is measured using a displacement transducer (LVDT). A thin-walled mold was fabricated for the ACP testing. The geometrical and mechanical properties of the mold are summarized in Table 10.

Table 10. Geometrical and mechanical properties of the mold.

Inner Diameter (mm)	Wall Thickness (mm)	Height (mm)	Young's Modulus (GPa)	Poisson Ratio
254	0.356	140	220	0.31

The diameter/height ratio is chosen greater than one to minimize the mold/paste friction effect on the overall compaction behavior. The mold was instrumented with four pairs of axial and radial strain gauges equally spaced on the circumference of the mold at a height of 40 mm. The strain

2- Increasing the maximum amplitude of cycles increases the stress needed to reach a target density as well as the elastic deformation of the paste at a given density.
3- The strain rate of monotone compaction has no effect on the compressibility of the carbon paste in the quasi-static regime. However, increasing the strain rate in the dynamic regime decreases the compressibility of the carbon paste.

Two hypotheses were presented to explain these results. They highlight the air pressure built-up in the pores and the rearrangement of aggregates as the main driving phenomenon for the paste vibrocompaction. Further tests will be carried out to validate these hypotheses.

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