Thermomechanical Characterization of the Carbon Anode During Baking

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Abstract

Aluminum electrolysis cell performance is highly related to the quality of carbon anodes. In this regard, anode baking is one of the most important steps in the anode manufacturing process in which green anodes undergo a pyrolysis to reach the desired properties. The understanding of the phenomena occurring during this process is essential in order to predict the final anode properties. This prediction could be achieved with the establishment of a three-dimensional thermo-chemo-mechanical baking model based on porous media. This model includes several parameters that must be identified in laboratory. This work is focused on the experimental characterization of the mechanical behavior as a function of the baking level. In order to limit the influence of raw material properties variation, laboratory scale carbon anode samples with constant recipe and homogeneous density were fabricated and used to generate the required database. The main mechanical properties measured were the Young modulus and the compressive strength. The rupture modes related to each baking level were also identified.

Keywords: Baking process, carbon anode, mechanical properties, high temperature test, rupture mode.

1. Introduction

Aluminium is commercially extracted from alumina in electrolysis cells through the Hall-Héroult process. The performance of a cell is strongly related to the carbon electrodes required to perform the electrolysis. The electrode group includes the cell lining and carbon anodes. The later ones are key elements in this process as they ensure transportation of electrical current in the cell and act as an electrochemical reducer in the aluminium production process according to the following global reaction:

$$2Al_2O_3 + 3C_{(s)} \rightarrow 4Al_{(l)} + 3CO_{2(g)}$$

Carbon anodes are typically made of calcined petroleum coke (65 wt.%), coal tar pitch (15 wt.%) and recycled butts (20 wt.%) mixed all together at around 170 °C to form the anode paste [1]. This paste is then compacted or vibrocompacted to form green anode blocks (dimensions vary according to cell technology). The anode blocks are then generally baked in pits of ring type furnace in the range of 1100 °C - 1200 °C [2].
In the baking process, the final properties of baked anode vary. This could be explained by the structure of the furnace which is composed of pits in which the green anodes are stacked on top

of each other. Thus, the positions of the anodes block are different which leads to a different baking history for each block.

The baking phase is characterized by chemical mechanisms in which the anode paste passes through different states affecting its final properties. As mentioned by D'Amours [3], these properties are mainly influenced by the chemical composition of the pitch and its phase changes. At about 100 °C, the pitch becomes soft and its viscosity decreases. Between 150 °C and 250 °C, the viscosity of the pitch increases improving the cohesion between aggregates because of the volatilization of part of its oil. Then, beyond 250 °C, the release of condensable volatiles takes place until 500 °C. By condensation and polymerization, the pitch transforms to a semi-coke at around 450 °C following by its carbonisation at more than 550 °C giving a solid material in its final microstructure. In this topic, several studies were carried out on carbonaceous materials based on the mixture coke/pitch to study the evolution of their mechanical properties at high temperature. D'Amours [3] tested the compressive strength and Young's modulus for partially and fully baked ramming paste samples. It was found that by increasing baking level from 175 °C to 400 °C, the compressive strength and the Young's modulus increase quickly until 250 °C and then stabilizes at 400 °C with a small decrease in Young's modulus beyond 700 °C. Similarly, Orangi [4] tested partially baked ramming paste samples at 200 °C and 250 °C. For tests carried out at 160 °C and 200 °C, the compressive strength increases simultaneously with the baking level. Also, the Young modulus increases from 200 °C to 350 °C and then gradually decreases. In regards to carbon anodes, Kallel et al. [5] measured its mechanical properties at baked levels ranging from room temperature up to 1200 °C and at different test temperatures. The results obtained showed that the compressive strength and the Young's modulus are characterized by low values between 120 °C and 400 °C. Furthermore, a transition was observed at 300 °C represented by a peak, but no explanation of this phase was mentioned [5]. In another study, Racine et al. [6] measured the Young's modulus of the anodes for test temperatures between 25 °C and 950 °C. They concluded that the Young's modulus remains almost stable regardless of the test temperatures.

In this work, laboratory scale carbon anode with fixed recipe and homogenous apparent density were fabricated. Mechnical tests were carried out at different test temperatures and baking levels. Results obtained will be part of an experimental database that will allow to feed a numerical baking model based on porous media. This model will serve to predict the final anode properties and comparing the numerical simulations results with those experimental ones.

2. Materials and Method

2.1. Samples

The raw materials used in this work were provided by Deschambault aluminium smelting plant (Alcoa, Canada). The anode recipe used consists of calcined coke (83.8 wt.%) and coal tar pitch (16.2 wt.%). The choice to make laboratory scale carbon anodes instead of industrial anodes is made for the use of a controlled recipe (Table 1) limited to petroleum coke, coal tar pitch and free of recycled butts to eliminate the effect of their variations on the mechanical properties of the anode. Also, the large coke aggregates (> 8 mesh) had not been used in the recipe to avoid the scale effect due to the ratio size of aggregates/sample size. And finally to make samples with a homogeneous apparent density.

The coke was preheated at 178 °C for at least 4 hours, followed by the addition of the pitch with an additional preheating of 30 minutes. Then, these materials were mixed at the same temperature for 10 minutes to obtain the anode paste. Finally, the anode paste was compacted at 168 °C by the mechanical proctor (Figure 1) [7]. The green anode samples had an approximate diameter and length of respectively 100 mm and 250 mm. The green apparent density was in the

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6. References

1. M.W. Meier, *Cracking behavior of anodes*, Sierre, Switzerland: R&D Carbon Ltd., 1996.
2. Jean-Claude Fischer and Raymond Perruchoud, *Prebaked Anodes for Aluminium Electrolysis*, 2014.
3. Guillaume D'Amours, Développement de lois constitutives thermomécaniques pour les matériaux à base de carbone lors du préchauffage d'une cuve d'électrolyse, Thèse de doctorat, Université Laval, 2004, Québec, Canada.
4. Sakineh Orangi, Time-dependant behavior of ramming paste used in Hall-Héroult cell: Characterization and constitutive law, PhD thesis, Laval University, 2016, Québec, Canada.
5. Waleed Kallel et al., Evolution of mechanical properties of carbon anodes during baking, *ICSOBA Conference*, Québec, Canada, 2 – 6 October 2016.
6. Dany Racine et al., Innovative procedure for the characterization of thermo-mechanical properties of carbon base materials using the Gleeble ® 3800 system, *Characterization of Minerals, Metals, and Materials*, *TMS* 2015, 57-64.
7. Bowen Chen et al., Improved compaction method for the production of large scale anode paste samples for thermomechanical characterization, *Light Metals* 2018, 1387-1396.
8. An American National Standard, *ASTM C39/C39M – 16*, Standard test method for compressive strength of cylindrical concrete specimens, 2016, 1-7.
9. François Chevarin et al., Active pore sizes during the CO_2 gasification of carbon anode at 960 °C, Fuel 178 (2016) 93–102.
10. An American National Standard, *ASTM C469/C469M – 14*, Standard test method for static modulus of elasticity and Poisson's ratio of concrete in compression, 2014, 1-5.
11. Yasmine Chamam, Effet des paramètres de cuisson sur la qualité des anodes, Mémoire de Maîtrise en ingénierie, Université du Québec à Chicoutimi, November 2016, Chicoutimi, Canada.
12. Juraj Chmelar, Size reduction and specification of granular petrol coke with respect to chemical and physical properties, PhD thesis, Norwegian University of Science and Technology, 1992.
13. François Tremblay and André Charette, Cinétique de dégagement des matières volatiles lors de la pyrolyse d'électrodes de carbone industrielles". *The Canadian Journal Of Chemical Engineering*, Vol.66, February, 1988, 86-96.