Numerical Investigation of the Load Free Permanent Strain in Carbon Anode During Baking Process

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Abstract

Baking is the final step of the anode production, which plays a major role in attaining the anode properties required by industry. However, the anode baking is a costly process during which various complex phenomena take place. It is therefore important to ensure good understanding of the impact of these phenomena on the baked anode quality. Regarding the mechanical aspect, various strain mechanisms occur in the anodes during the baking and evolve with respect to the spatial distribution of temperature and its rate of change in the baking furnace. Each of these mechanisms contributes to the stress equilibrium in the carbon anode and can lead, depending on the baking conditions, to poor mechanical properties including cracks when the failure limit is exceeded. In this paper, a new approach for the modelisation of one of these mechanism, the load free permanent strain, is presented. Experimental data obtained from free dilatometric tests were mathematically described using successive temperature activated evolutions for the phase transition, devolatilization and graphitization process. While existing parameters were used for the devolatilization evolution process, an optimization procedure was used to identify the remaining parameters of the equations. Model results showed good agreements with the experimental data.

Keywords: Carbon anodes; anode baking; mechanical properties; chemical swelling; baking Index.

1. Introduction

Aluminum production plants require a constant supply of carbon anodes for the electrolysis process, which are both a carbon source for the reduction of the alumina and an electrical conductor for the electrolysis reaction. The final anode quality is one of the determining factors for the quality of aluminum produced, influencing the cell stability, metal quality, energy consumption, and environmental emissions of the process. Therefore, good quality anodes, characterized by a high chemical purity, high electrical conductivity, low air and carbon dioxide reactivity, high thermal shock resistance and high mechanical strength, should be used [1, 2].

The carbon anode paste is manufactured using petroleum coke, pitch and recycled materials (anode butts, baked and green scrap). These components are mixed together in the anode paste plant and then formed into a green anode using a press or vibrocompactor. Green anodes are then cooled and stored before the baking process, which will complete the anode production. Baking is vastly considered as the most costly step of the production process, bringing the anode to its final quality.

In recent years, the optimization of the baking process has become a subject of interest since the costs and impacts associated with its operation are fairly important. However, direct temperature and/or strain measurements are difficult due to the nature of the volatile gas present during baking as well as high temperatures. This has led researchers to develop mathematical models of the baking furnace to further understand the impact of this process on the carbon anode final quality.

2. Baking furnace modeling approach

The current baking furnace model of the carbon research group at UQAC [3] allows the computation of the temperature distribution in the anodes and in the gas while considering all the important phenomena related to fluid flow and thermal aspects encountered during baking. However, this model does not take into account the effect of baking on the mechanical state of the carbon anode, where high stresses can lead to crack initiation and propagation. Moreover, a mechanical model of the anode baking could help understand the source of stress generation during the process and enhance the final product quality. The proposed modeling approach is to weakly couple a mechanical sub-model of the anode stacking to the existing 3D thermo-fluid model using its temperature field provided at each time step, as shown in Figure 1. The mechanical sub-model is based on a user defined constitutive law to properly evaluate the stress distribution in the carbon anodes, considering the effects of the baking process on the material as well as the mechanical impact of the packing coke on the anode during the baking process.

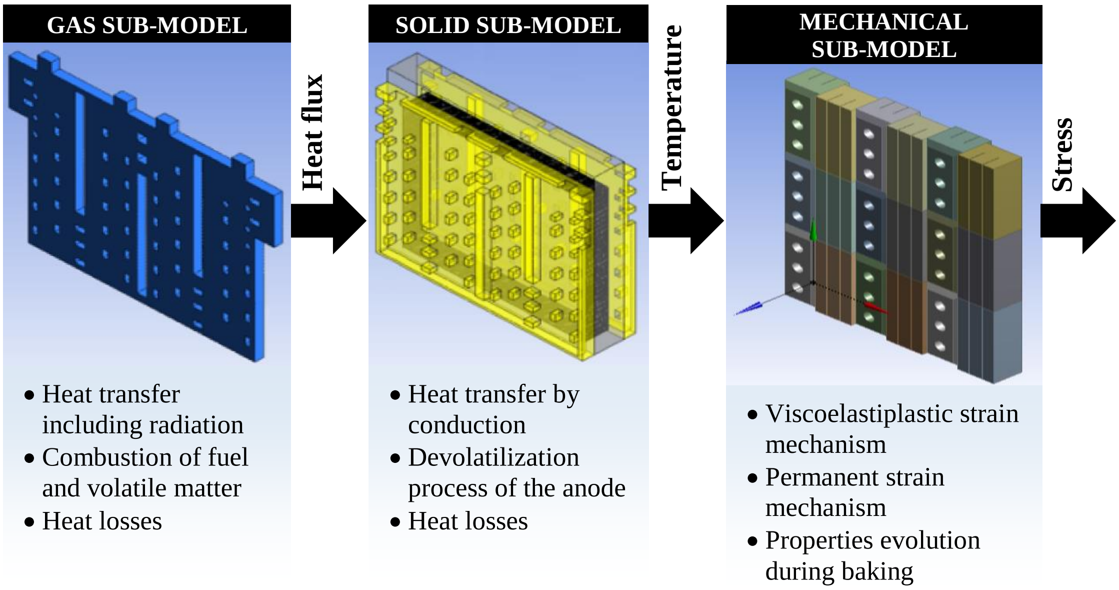

Figure 1. Characteristics and output description of the sub-models (Gas and solid sub-model images taken from [3])

6. Conclusions

In this paper, a mathematical model, developed to determine the load free permanent strain in carbon anodes based of the phenomena observed during baking, is presented. The load free permanent strain was subdivided into five strain mechanisms representing the phase transition, the release of three main volatile components and the graphitization. Existing kinetic parameters were used to represent the devolatilization of condensable gases, hydrogen and methane. The remaining parameters were successfully identified using a progressive optimization process. Numerical results are in good agreement with the experimental results, allowing the different processes responsible for the final strain to be analyzed. This model will be used in a future work to compute the mechanical stress in a carbon anode during the baking phase.

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8. References

1. T. Foosnaes and T. Naterstad, Carbon: Basics and principles, in *Introduction to aluminium electrolysis*, K. Grojtheim and H. Kvande, Editors. 1993, Aluminium-Verlag: Düsseldorf. 87-137.
2. Markus W. Meier, Cracking behaviour of anodes, 1996, *Swiss Federal Institute of Technology*, Sierre, Switzerland.
3. M. Baiteche, Développement d’un modèle transitoire en 3d du four horizontal de cuisson d’anodes en carbone, 2015, *Université du Québec à Chicoutimi*, Chicoutimi, Canada.
4. Kristine L. Hulse, Anode manufacture: Raw materials, formulation and processing parameters, 2000, *The University of Aukland*, Sierre, Switzerland.
5. Nathalie Bouchard, Pyrolyse de divers brais utilisés dans la technologie söderberg et analyse des matières volatiles, 1998, *Université du Québec à Chicoutimi*, Chicoutimi, Canada.
6. D. Kocaefe, et al., A kinetic-study of pyrolysis in pitch impregnated electrodes. *Canadian Journal of Chemical Engineering*, 1990. 68(6), 988-996.
7. Duygu Kocaefe, et al., Thermogravimetric study on devolatilization kinetics of chinalco anodes during baking. *Journal of Materials Science Research*, 2013. 2(2), 22-34.
8. Ying Lu, Effect of pitch properties on anode properties, 2016, *Université du Québec à Chicoutimi*, Chicoutimi, Canada.
9. D. Richard, et al. Development and validation of a thermo-chemo-mechanical model of the baking of ramming paste. *Light Metals*. 2005,733-738.
10. Guillaume D'Amours, Développement de lois constitutives thermomécaniques pour les matériaux à base de carbone lors du préchauffage d'une cuve d'électrolyse, 2004, *Université Laval*, Québec, Canada.
11. H. N. Murty, D. L. Biederman, and E. A. Heintz, Kinetics of graphitization. *Carbon 7*, 1969. 7(6), 667-681.