The Effect of Varying Mixing and Baking Temperatures on the Quality of Pilot Scale Anodes – A Factorial Design Analysis

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Abstract

Identifying optimum anode baking and mixing temperatures are important when producing high quality anodes. The effect of varying mixing and baking temperatures were investigated in terms of the resulting anode density, specific electrical resistivity (SER), air permeability, coefficient of thermal expansion (CTE) and air and CO_2 reactivity. Six pilot scale anodes were prepared at Hydro Aluminium AS using a single source petroleum coke and < 2 mm coke fractions. A coal tar pitch was used with a Mettler softening point of 119.1 °C. The aggregate was mixed at 150 °C or 210 °C, and baked at 1150 °E, 1260 °E or 1350 °E. A 2^2 full-factorial design analysis was performed in order to determine the response of the analyzed properties to the applied mixing and baking temperature. Density, SER and air permeability were found to be highly dependent on the mixing temperature. Density and SER was also slightly affected by the baking temperatures. CTE was found independent of both the baking and mixing temperature. Air reactivity was found to be mainly dependent on the baking temperature, while CO_2 reactivity was dependent on both mixing and baking temperature. The use of the factorial design as a statistics tool is strong when investigating the effects and covariance of various production parameters.

Keywords: Carbon anodes; effect of mixing temperature; effect of baking temperature; anode performance; factorial design.

1. Introduction

Aluminum is produced according to the reaction described in Equation 1 [1].

$$2Al_2O_3 + 3C = 4Al + 3CO_2 \quad (1)$$

Carbon anodes serve as the carbon source on the left-hand side of the equation. The carbon anodes are produced from calcined petroleum coke, and coal tar pitch serve as the binder. The aluminum industry always strive to improve the production of carbon anodes in order to improve cell stability and lifetime of the anodes. As the anodes are consumed, they need to be changed every 22-28 days. Anode change is part of the routine work in a potroom, and causes temporary instability in each individual cell. Hence, good anode quality is crucial to maintain stable operation and optimize lifetime of the anodes [1]. High density, low electrical resistivity, low impurity level, low permeability and low air and CO_2 reactivity are all parameters that characterize a high quality anode. Optimization of carbon anodes rely on many different production parameters such as mixing temperature, baking temperature, coke and pitch quality, aggregate composition etc. The optimum baking and mixing temperatures are dependent on the coke and pitch qualities used [2].

The Mettler softening point of the pitch is commonly used as a standard guideline for selection of the proper mixing temperature between coke, pitch and butts. Most commonly, the mixing temperature is set approximately 50 °C above the Mettler softening point [3]. However, studies using the sessile drop technique show that an even higher temperature may be needed in order to optimize the wetting angle between the coke and the pitch, and that the wetting angle between coke and pitch is dependent on both the pitch itself and the coke substrate [4, 5]. Wilkening [2, 6] has suggested using mixing temperatures as high as 350 °C in order to improve anode density, SER and strength.

During the heating part of the baking process, the pitch binder is carbonized to pitch-coke with release of 20-40 wt% of volatiles [7]. Porosity is introduced to the anodes during the baking process due to the carbonization and the volatilization processes. This porosity is inevitable but can be reduced by good baking furnace design with good temperature control, low ΔT throughout the furnace and by using a slow heating rate [8, 9]. A target baking temperature also needs to be found, as overbaking can cause desulfurization and hence increased microporosity of the anode [9]. Jentoftsen et al. [10] suggested that underbaked anodes caused lower anodic current efficiency in the potroom.

1.1. Factorial Design as a Statistical Tool

Factorial design is a statistical tool that allows investigation of the effect of many factors simultaneously, provided that these factors are independent [11]. The 2^2 full factorial design is the simplest of its kind. The 2^2 nomenclature denotes two factors varied at two levels [12]. In the present experimental design, the two factors varied are mixing temperature and baking temperature. The two levels are a high and low value. For the mixing temperature, the high level is 210 °C and the low level is 150 °C. Baking temperature was varied on three levels (1150 °E, 1260 °E and 1350 °E, where °E denotes equivalent temperature – a measure of calcination level commonly used by Hydro to describe the baking level of an anode. More on the technique is described elsewhere [13, 14]). The statistical analysis was performed as three 2^2 full factorial designs, by treating the baking temperature in pairs, with three low and high levels i.e.: 1150 °E (underbaking) vs. 1260 °E (target baking), 1260 °E (target baking) vs. 1350 °E (overbaking) and 1150 °E (underbaking) vs. 1350 °E (overbaking). In factorial design analysis, it is common to use the term "main factor" [11] on the factors that are varied, hence mixing temperature (A) and baking temperature (B) are the two main factors. The low values are denoted -1 and the high

Factorial design helps visualize which production parameter affects the physical properties, and if any interaction between the production parameters can be seen. Factorial design can and should be used further by industry to help optimize anode production parameters; however, good planning of the experiments is crucial for experiments to be successful.

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