Minerals Engineering 46–47 (2013) 167–176

Contents lists available at SciVerse ScienceDirect

Minerals Engineering

journal homepage: www.elsevier.com/locate/mineng

The use of thermomechanical analysis to characterise Söderberg electrode paste raw materials ☆

J.P. Beukes [a,*], H. Roos [a], L. Shoko [a], P.G. van Zyl [a], H.W.J.P. Neomagus [a], C.A. Strydom [a], N.F. Dawson [b]

[a] Chemical Resource Beneficiation, North-West University, Potchefstroom Campus, Private Bag X6001, Potchefstroom 2520, South Africa
[b] Xstrata Alloys, PO Box 2131, Rustenburg 0300, South Africa

ARTICLE INFO

Article history:
Received 22 February 2013
Accepted 13 April 2013
Available online 9 May 2013

Keywords:
Thermomechanical analysis (TMA)
Continuous self-baking electrodes
Söderberg electrodes
Anthracite
Coal tar pitch
Pre-baked electrode graphite

ABSTRACT

Continuous self-baking electrodes, i.e. Söderberg electrodes, are commonly employed in the industrial operation of submerged arc furnaces to conduct electrical energy from a transformer(s) to the smelting zone inside the furnace. Söderberg electrodes are formed from Söderberg electrode paste consisting of two components, i.e. a binder that is mostly a coal tar pitch and a solid filler that can be either coke or calcined anthracite. In this paper it is demonstrated how thermomechanical analysis can be used to characterise the thermal dimensional behaviours of Söderberg electrode paste raw materials. Two case study coal tar pitches, three anthracites and a pre-baked graphite electrode sample were characterised. Results indicated that the method applied can be used to determine the baking isotherm temperature more accurately than previously. Enhanced knowledge of the baking isotherm temperature is critical to ensure safe, profitable and continues furnace operation. The results also indicated that the coal tar pitches shrunk approximately 12% if exposed to temperatures above the baking isotherm temperature up to 1300 °C, while the anthracites calcined at 1400 °C expanded 0.6–1.0% in the same temperature range. The magnitude differences in thermal dimensional behaviour and difference in motion (shrinkage *vs.* expansion) indicates the vulnerability of a Söderberg electrode baked for the first time at temperatures exceeding the baking isotherm temperature. In contrast to the calcined anthracites, the uncalcined anthracite samples shrunk 6–8% if exposed to temperatures up to 1300 °C. This stresses the importance of the efficiency of the calcination process of the anthracite prior to Söderberg electrode paste production to enhance dimensional stability of the Söderberg electrode paste. The results also indicated that the method detailed in this paper can be used by Söderberg electrode paste producers to optimise the selection of raw materials and to do quality control on calcined anthracite.

1. Introduction

In the operation of submerged arc furnaces (SAFs) electrodes conduct electrical energy from a transformer(s) to the smelting zone inside the furnace. Generally two types of electrodes systems are used in industrial smelting applications, i.e. pre-baked electrodes and continuous self-baking electrodes (Söderberg electrodes). The Söderberg electrode system is quite commonly applied since Söderberg electrodes are less expensive than pre-baked electrodes, Söderberg electrodes with larger diameters than pre-baked electrodes can be made and the Söderberg electrode system does not require furnace shutdowns to extend the electrodes (Innvær, 1992; Arnesen et al., 1979).

In Fig. 1 a simplified representation of a typical Söderberg electrode is presented. A Söderberg electrode consists of a cylindrical steel casing extending from a platform located above the furnace down into the furnace (Asphaug and Innvær, 1997; Innvær, 1992; Toromanoff and Habashi, 1989; Arnesen et al., 1979). The electrode casing serves as a mould for the electrode paste that consists of a coal tar pitch binder mixed with a solid filler such as calcined anthracite or coke (Innvær, 1992, 1989, 1983; Toromanoff and Habashi, 1989). Heat from the furnace together with electrical current passing through the casing and casing fins melt the electrode paste (Asphaug and Innvær, 1997; Ord et al., 1995; Innvær, 1992; Innvær et al., 1986; Toromanoff and Habashi, 1989). The solid electrode paste that is added to the top of the electrode casing melts and fills the entire diameter of the electrode casing when it reaches a temperature of approximately 50–100 °C (Wilkinson et al., 2001; Asphaug and Innvær, 1997; Ord et al., 1995; Innvær, 1992; Innvær and Olsen, 1980; Arnesen et al., 1979), depending on the softening temperature of the electrode paste utilised. At a temperature of approximately 400–500 °C the electrode paste is baked into a solid carbonaceous electrode (McDougall et al., 2004; Andersen et al., 2001; Asphaug and Innvær, 1997; Ord et al., 1995; Fitt and Aitchison, 1993; Innvær, 1992; Innvær et al.,

* Corresponding author. Tel.: +27 82 460 0594; fax: +27 18 299 2350.
E-mail address: paul.beukes@nwu.ac.za (J.P. Beukes).

0892-6875/$ - see front matter © 2013 The Authors. Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.mineng.2013.04.016

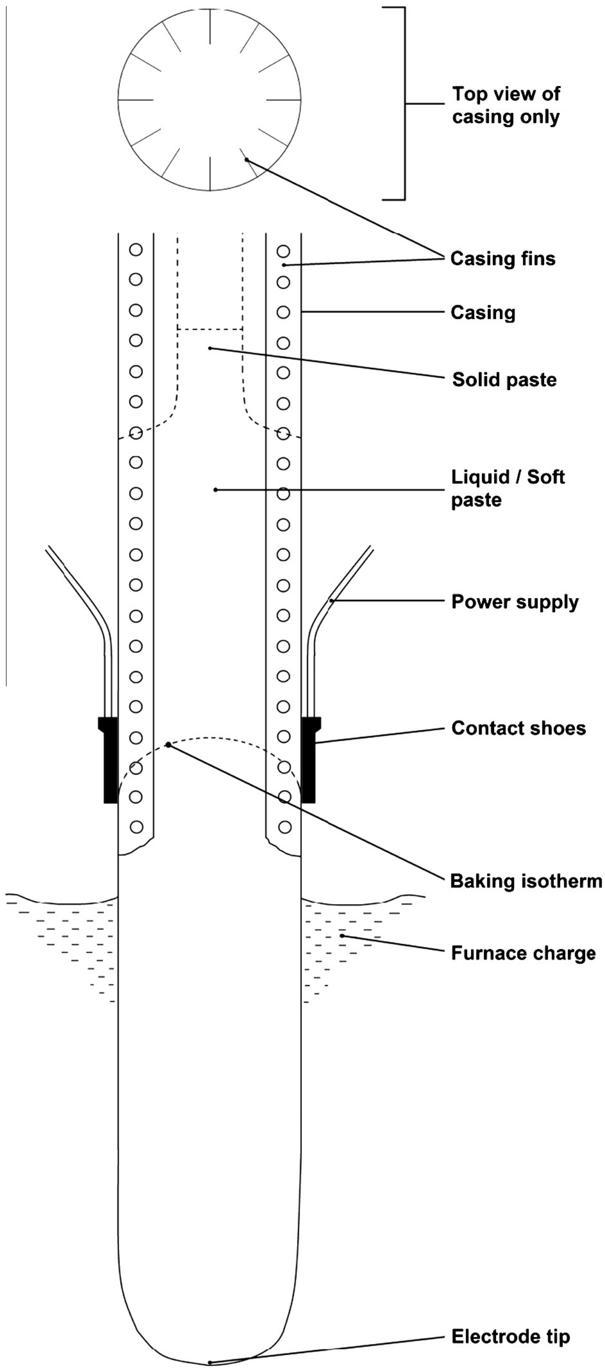

Fig. 1. Simplified representation of a Söderberg electrode, adapted from Arnesen et al. (1979). The main figure at the bottom indicates a side sectional view of the electrode, while the top image indicates the top sectional view of the casing only.

1986, 1984; Innvær and Olsen, 1980; Arnesen et al., 1979). This temperature is commonly referred to as the baking isotherm temperature. The mechanical strength and electrical conductivity of the electrode increase as the baking process progresses. During the early stages of the electrode baking process, i.e. when the electrode paste is still soft, electrical energy is conducted mainly by the steel electrode casing and the casing fins. At a temperature of 800–1000 °C, the baked carbon electrode is able to conduct the full electrical current (Asphaug and Innvær, 1997; Innvær et al., 1986).

In order to ensure safe, profitable and continues operations many aspects have to be managed in a Söderberg electrode system. These aspects are collectively referred to as electrode management. Notwithstanding the importance of electrode management, relatively little information has been published in the peer reviewed public domain on this topic during the last decade. This sometimes leads to out of date information from literature being utilised in papers. As an example, in a relatively recent paper (Meyjes et al., 2010) a model was introduced to predict some operational aspects of a Söderberg electrode. The thermal expansion data of the electrode paste utilised in this model was based on research published in McDougall et al. (2004), who in turn referred to Innvær et al. (1984) that published the thermal expansion data of a Söderberg electrode paste originating from a single producer. Internationally the raw materials utilised in Söderberg electrode paste production vary significantly, due to the availability of suitable coal tar pitches and solid filler materials. In order to stimulate research focussing on Söderberg electrode management and more specifically electrode paste production, a novel technique utilising thermomechanical analysis (TMA) was developed to determine the thermal dimensional behaviours of Söderberg electrode paste raw materials. In this paper it is demonstrated how this technique can be used to gain insight into important electrode management parameters, and in what manner this technique can be used by Söderberg electrode paste producers to improve the quality of paste produced.

2. Materials and methods

2.1. Materials

As mentioned, Söderberg electrode paste consists of two components, i.e. a binder that is mostly a coal tar pitch and a solid filler, which can be either coke or calcined anthracite (Innvær, 1992, 1989, 1983; Toromanoff and Habashi, 1989). Two coal tar pitch samples were received from the only commercial supplier of coal tar pitch used for the production of Söderberg electrode paste in South Africa. The first sample was a low softening point (LSP) coal tar pitch, while the second sample was a high softening point (HSP) coal tar pitch. Three uncalcined anthracite samples were also obtained from different anthracite mines in South Africa. These specific anthracites are calcined and used in the production of Söderberg electrode paste at one of the largest Söderberg electrode paste producers in South Africa.

Although the focus of this paper was on the raw materials utilised in Söderberg electrode paste production, i.e. coal tar pitch and calcined anthracite, a pre-baked electrode graphite sample was also obtained from the only manufacturer of pre-baked electrodes in South Africa. This facilitated the comparison of measured thermal dimensional behaviours of the Söderberg electrode paste raw materials with a completely baked graphite electrode.

None of the raw material suppliers wanted to be identified. Therefore, the coal tar pitch, anthracite and pre-baked electrode graphite samples were denoted as LSP and HSP coal tar pitch, anthracite A1, A2 and A3, and pre-baked electrode graphite, respectively.

2.2. Methods

2.2.1. Anthracite and coal tar pitch characterisation

In order to characterise the coal tar pitch and anthracite samples received, proximate analyses were conducted with SANS 5925:2007, SANS 131:2011 and SANS 50:2011 methods in order to quantify the moisture, ash and volatile contents, respectively, while the fixed carbon content was determined by difference. Ultimate analyses were also performed to determine the carbon and hydrogen contents with ASTM D5373, the nitrogen content with