Temperature and Stress Distribution on Carbon Electrodes for Silicon Metal Production Under Transient Temperature Conditions

by

Paolo D'Ambrosio and Italo Letizia

ELETTROCARBONIUM S.p.A. - 05036 Narni Scalo (Terni), Italy

Introduction

During operation of submerged-arc reduction furnaces for Silicon metal production, the electrodes are often subject to non-steady thermal conditions. These produce high mechanical stresses in the electrodes, and could impair their integrity. Furthering previous investigation, where steady-state stresses had been studied (1), the authors have now calculated the internal stress and temperature distribution for some typical cases of non-steady state conditions. The purpose of this study was to single out the most critical conditions for the electrodes, so that practical information for operation could be obtained.

Subject under investigation

For two different grades of electrodes (semi-graphite grade and anthracite grade) 1200 mm in diameter, working under steady-state conditions with an average current density of 6,5 A/cm^2, the following typical cases of non-steady state conditions were studied:

a) furnace stopping and electrode lifted out of the charge;
b) furnace stopping for a relatively long period, with electrode kept submerged, followed by furnace re-starting.

The present article deals with the study carried out for the case "a", using an anthracite grade electrode.

Physical model and method for calculation

The physical model employed was:

a) electrode column characteristics: electrodes 1200 mm in diameter; total length under the contact clamps 2900 mm; electrode portion submerged by the charge in steady-state conditions 2300 mm;
b) no joints in the electrode;
c) physical characteristics of the electrodes at room temperature as per Table I;
d) no skin effect;
e) axisymmetric distribution of temperature and stresses;
f) validity of the law of linear elasticity of material;
g) the only external force taken into account: the weight of the electrode.

Table I

Electrical Resistivity	$\Omega\,\mu m$	45
Thermal Conductivity	W/mK	12
Coeff. of Thermal Expansion	1/K	$3 \cdot 10^{-6}$
Young's Modulus	N/mm^2	$5 \cdot 10^3$

For the calculation, variations of physical characteristics with temperature as well as with the "thermal background" of material were taken into account. Their values were measured in our lab over the temperature range 20-2500°C. Variations of the current density along the radius of the electrode, caused by electrical resistivity variations, were also taken into account. The non-steady state conditions investigated were:

- electrode submerged by the charge, working in steady-state conditions up to time $t=t_0$ (i.e., for $t < t_0$);
- power-off with electrode immediately lifted out of the charge at time $t=t_0$;
- electrode staying in such conditions for the whole period $t > t_0$.

This is a physical schematization of real cases occurring in the industrial practice of furnaces for Silicon metal production. For the temperature calculations, the well-known differential equation of heat balance in non-steady state conditions (the Fourier equation) was used, with suitable boundary conditions. The mechanical stress condition was determined by solving the differential equation system formed by:

$$\left\{\begin{array}{l} \text{- equations of stress balance} \\ \text{- equations of stress-strain relationship} \\ \text{- constitutive equations of material} \end{array}\right.$$

with suitable boundary conditions.

The mathematical solution was determined by the method of "orthogonal arrangements", using a suitable computer.

Results and discussion

The computer gives temperature and stress distributions as a function of time. The results of temperature calculations show that straight after the electrode has been lifted out of the charge, the thermal gradients in the zones near the surface area of the electrode increase substantially, as compared to the steady-state conditions. The stresses caused by these temperature distributions are shown in the figure as a graph, at several significant moments of time. The figure shows the vertical section of a half-electrode (since the physical model is axisymmetric), with the lines of equal axial stress σ_z. It can be noticed that straight after the electrode has been lifted out, high tensile stresses occur in the electrode, near its surface area, with risk of fracture. Such a situation is long-lasting. Thermal gradients and stresses progressively decrease only 2-3 hours after the electrode has been lifted out. From all this, it is clear that the partial or total lifting of the electrode column out of the charge is to be avoided in industrial practice.

Conclusion

The results reported here as an example, as well as those of other cases the authors have investigated, show that the mathematical-physical model used is suitable to obtain useful information about stresses in non-steady state conditions. Up to now, the results of such studies have reflected operative electrode behaviour. The authors intend to keep on with this investigation, improving the mathematical-physical model and achieving even more reliable results.

References

1. P. D'Ambrosio, I. Letizia, "Temperature and internal stress distributions of carbon electrodes used in an electric arc furnace for the production of Silicon metal", Carbon '80, Baden-Baden, 30 June-4 July 1980.

2. L. Di Stasi, "Forni Elettrici", Editore Patron, Bologna, 1976.

3. R. Innvaer, L. Olsen, "Practical use of mathematical models for Soederberg electrodes", Proceedings, 37th Electric Arc Furnace Conference, Detroit, 1979.

4. L. Olsen, A. G. Arnesen, I. Bencze, R. Innvaer, "Temperature distribution in Soederberg electrodes", Proceedings, 7th International Congress of Electroheat, Warsaw, 1972.

5. Tu-Lung Weng, E.J. Seldin, "Calculation of steady-state temperatures in graphite electrodes in an electric arc steel furnace", Carbon 15, 1977.

AXIAL STRESS DISTRIBUTION AT DIFFERENT TIMES ON AN ANTHRACITE GRADE ELECTRODE LIFTED OUT OF THE CHARGE