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ELECTRICAL CONDUCTIVITY OF ALUMINUM REINFORCED GRAPHITE ELECTRODES

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ABSTRACT

Composite, disc-like aluminum reinforced graphite electrodes were prepared, and an integrated parametric analysis has been performed to investigate the effect of some processing parameters on the electrical conductivity of the prepared samples. The presence of aluminum improved the electrical conductivity of graphite electrodes. A maximum in the electrical conductivity is always observed for samples baked at 600°C and/or for 1.5 hours baking time. The conductivity also increases with the compacting pressure. The novel idea of reinforcing graphite with metallic particulate fillers works well in improving the transport properties of graphite electrodes.

INTRODUCTION

Graphite has served as a primary material in the electrochemical industries e.g: for electrolysis anodes in which chlorine or chlorate are produced as anodic products and in the manufacture of primary cells and fuel cells [1,2]. Graphite is also utilized in cathodic protection applications for corrosion prevention of underground and under water metallic structures. Graphite anodes meet the requirements for electrolytic cell applications which include high degree of insolubility, low initial cost, availability in almost unlimited quantities, good electrical conductivity and high purity to prevent contamination of cell products. Furthermore, the development of carbon and graphite electrodes is also inseparably linked to the advancement of the electric furnace.

Graphite electrodes are relatively fragile and break easily. They are mechanically inferior to metal electrodes as they are brittle and prone to erosion and oxidation. It has been our intention to improve the mechanical properties of such electrodes by reinforcing the graphite with a metal (or a metal oxide) [3-9]. It should be kept in mind that the improvement of the mechanical properties of such systems should not be traded off for their transport and corrosion properties. They are required to exhibit good thermal shock resistance.

Very little information is published in the literature regarding the transport properties of reinforced carbon and/or graphite electrodes. Limited work has been carried out to examine the relation between the thermal conductivity and the electrical resistance of carbon electrodes [10], their strength characteristics [11] and the effect of adding metallic constituents on the performance of carbon and graphite electrodes [12,13,14].

This paper is one of a series of publications dealing with the examination of the effect of reinforcing graphite electrodes on some of their important physical, chemical and mechanical properties. We will present and analyze the effect of some of the processing parameters on the electrical conductivity of aluminum-reinforced composite graphite electrodes (ARGE).

EXPERIMENTAL

The materials utilized in this work were white graphite [300 mesh, specific gravity 2.05] and Aldrich aluminum powder [200 mesh, 99.95+%, specific gravity 2.7]. Basically all the samples were prepared within the spirit of the procedure normally adopted for the preparation of graphite electrodes [15, 16], as it will now be outlined.

Graphite and aluminum powders were weighed and mixed manually according to the required proportions. The aluminum content in the prepared electrodes varied from 5 to 40wt%. After good mixing, the mixture is poured in a carbon steel mold and compacted in a hydraulic press at different compacting pressure : namely from 2.5 to 12.5 MPa. The compacting time was kept constant at 3 minutes. The green disc-like aluminum reinforced graphite composite compacts (50 mm x 5 mm) were then subjected to different baking temperatures from 400nC to 800nC. The heating rate was set at 5nC/min and the baking time varied from 0.5 to 2.5 hours at the required baking temperature. The specimens were then allowed to cool inside the furnace at a rate of 2nC/min. To minimize oxidation and sample damage, the baking process was carried out by burying the compacts in a bed of sand (200 mesh) at a depth of 10 cm. The electrical conductivity of the Aluminum-Reinforced Graphite Electrodes was measured using a custom made Wheatson bridge as described in reference [8].

RESULTS AND DISCUSSION

The presence of the aluminum phase in the graphite matrix increased the electrical conductivity of the composite compacts. Figure 1 shows a 95% increase in the electrical conductivity of the graphite compacts as the aluminum content increases from 0% to 40%. Such a result was also observed in the work carried out previously on the thermal conductivity of ARGE [4]. Therefore, the relationship between the electrical and the thermal conductivity of graphite electrode is consistent with the work of Kalyadov et.al [10].

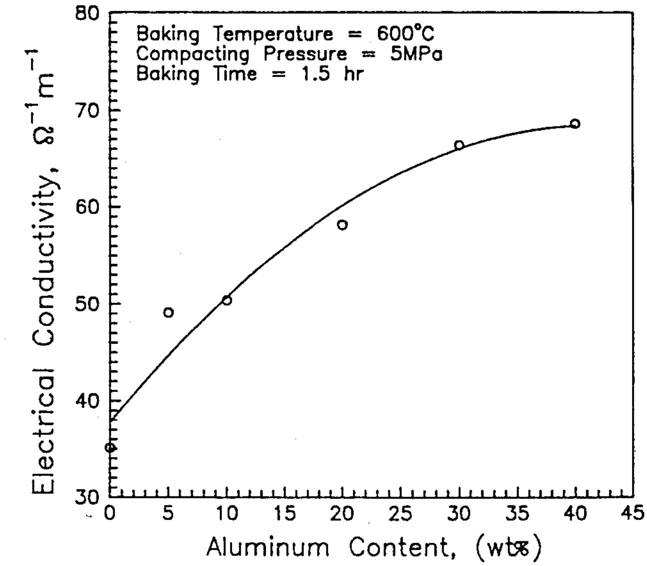

Figure 1: Effect of the aluminum content on the electrical conductivity of graphite electrodes

The effect of increasing the baking time on the electrical conductivity of ARGE is similar to that of increasing the baking temperature. In other words, one may state that baking for short periods of time at high temperatures is equivalent to baking for long periods of time at low temperatures. For instance, baking for 0.5 hour at 600nC is equivalent to baking for 1.5 hours at 400nC. Figures 2 and 3 show maxima in the electrical conductivity for sample baked for 1.5 hours and/or at 600nC baking temperature. The primary increase in the electrical conductivity with the baking time, to a maximum at 1.5 hours exhibited in Figure 2, may be attributed to the agglomeration of the aluminum particles at the given baking temperature of 600nC, which eventually

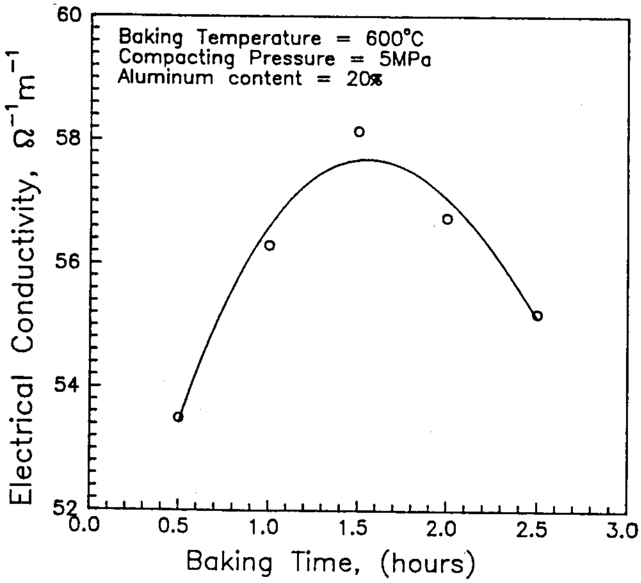

Figure 2: Plot of the electrical conductivity versus the baking time

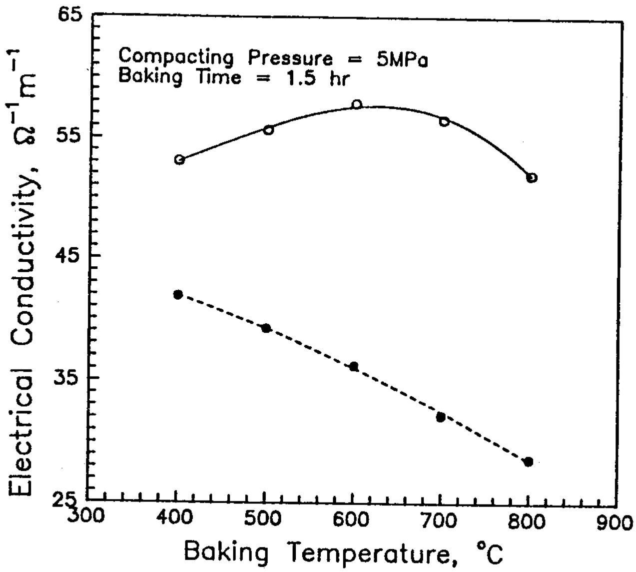

Figure 3: Variation of the electrical conductivity of graphite electrodes with the baking temperature: (——) ARGE 20wt% aluminum; (---) Plain graphite electrode

causes squeezing and elimination of any possible void spaces. Obviously, the presence of the aluminum phase improved the conductivity of the composite compacts as depicted in Figure 3. However, above 1.5 hours baking time at 600^{n}C, not only is the graphite prone to oxidation and deterioration, but also the aluminum is approaching its melting point and becomes very soft. Consequently, void spaces are created in the graphite phase and aluminum diffuses through the created pores. At temperature levels above 600^{n}C, the aluminum melts and, in addition to the oxidative effects, the diffusion of aluminum causes a disintegration of the originally agglomerated aluminum phase inside the graphite matrix, and eventually, causes the electrical conductivity of the compacts to decline as the baking temperature exceeds 600^{n}C. Figure 3, therefore, suggests that there are two simultaneous phenomena taking place: agglomeration of aluminum particles accompanied by consolidative effects as well as oxidative effects in both, the matrix and the reinforcing phases. Obviously, at baking temperature levels below 600nC (or baking times less than 1.5 hours) the former effects override, while at higher baking temperature levels (or times) the latter effects predominate. Again, such results are in agreement with those obtained for the thermal conductivity of ARGE [5].

Conceivably, the compacting pressure increased the electrical conductivity of ARGE as shown in Figure 4: a 24% increase in the conductivity is observed as the compacting pressure increases from 2.5 to 12.5 MPa. It is now believed that the effect of the compacting pressure on the transport properties of metal- (or metal oxide-) reinforced graphite electrodes is unique, since our previous work has always shown an increase in the thermal and electrical conductivities of reinforced graphite compacts [4,5,7,8] for increasing the compacting pressure. As the compacting pressure increases the inter- and intra-phase areas of contact increase, leading to the elimination of void spaces and expelling possibly entrapped air pockets. It is pertinent to point out that the rate of change of the electrical conductivity of ARGE with the compacting pressure is almost similar to that of the plain graphite electrodes, as depicted in Figure 4. Therefore, one may conclude that the compacting pressure is basically affecting the matrix (graphite) phase in the first place; the reinforcing (aluminum) phase is affected to a much lesser extent, however. In addition, Figure 5 reveals that not only the conductivity increases as the compacting pressure increases, but also the oxidative effects are delayed shifting the pattern of the change in the electrical conductivity with the baking temperature. Nevertheless, the maximum values for the electrical conductivity are yet observed to take place at 600^{n}C. Also figures 5 and 6 show that the maxima in the values of the electrical conductivity of the compacts are at 600nC regardless of the value of the compacting pressure and the aluminum content. It is pertinent to point out

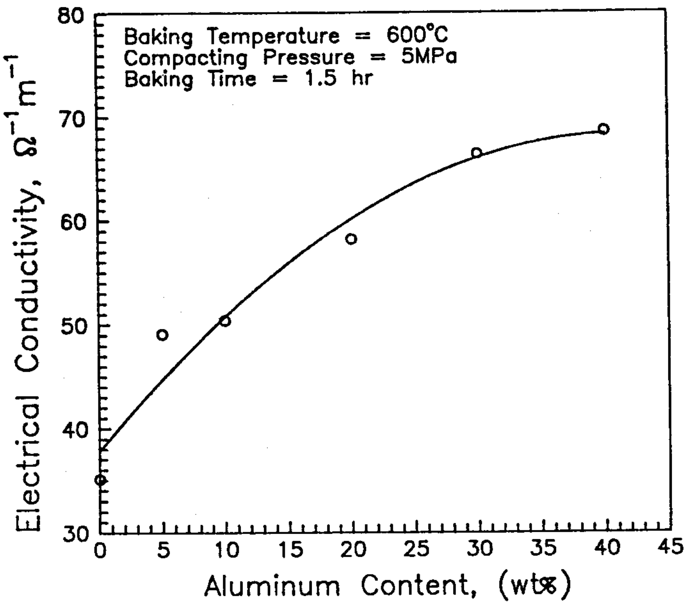

Figure 4: **Variation of the electrical conductivity of graphite electrodes with the compacting pressure: (——) ARGE 20wt% aluminum; (---) Plain graphite electrode**

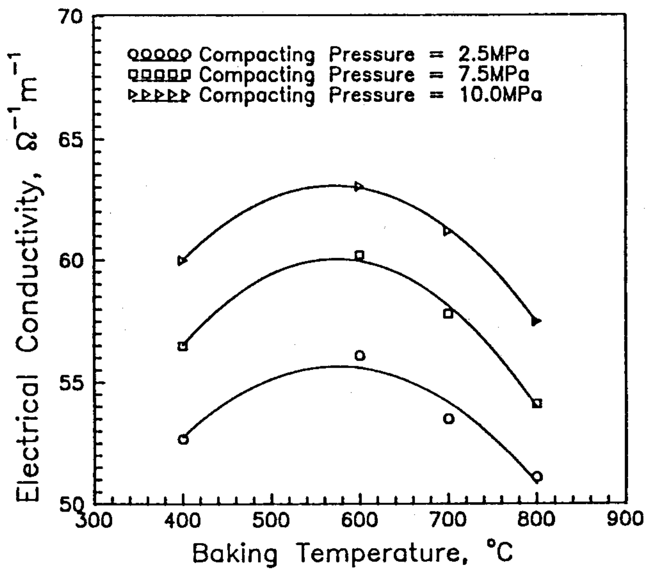

Figure 5: **Plot of the electrical conductivity versus the baking temperature for ARGE at different compacting pressures. (Baking time = 2 hours, aluminum content = 20wt%)**

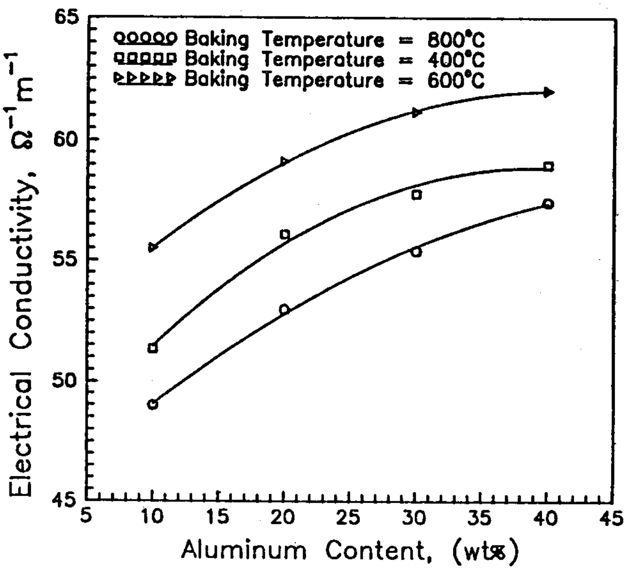

Figure 6: Variation of the electrical conductivity of ARGE with the aluminum content at various baking temperatures. (Compacting pressure = 5 MPa, baking time = 1 hour)

that a typical behavior was also recorded for the variation of the thermal conductivity of ARGE with the simultaneous change of the baking temperature and the compacting pressure [5].

CONCLUSIONS

The following conclusions may be drawn from the analysis presented:

- The presence of aluminum increases the electrical conductivity of the graphite compacts.

- A maximum value for the electrical conductivity is manifested for compacts baked at 600nC and/or for 1.5 hours.

- The baking time and temperature exhibit similar effects on the electrical conductivity of ARGE: baking at high temperatures for short periods of time is equivalent to baking at low temperatures for prolonged periods of time.

- The maxima in the values of the electrical conductivity of ARGE occur at 600°C baking temperature and/or 1.5 hours baking time, regardless of the aluminum content and the compacting pressure.

- The graphite matrix is much more sensitive to the compacting pressure when compared to the aluminum reinforcement.

- The changes in the electrical and the thermal conductivities of ARGE with the processing parameters are rather intimately related and of a basically similar trend.

REFERENCES

1. **Gupta, N.K., 1971,** Carbon Electrodes for use in Electrochemical Investigations, Rev. Sci.Instrum., 42, 1368-74.

2. **Manoharan, N.A., Goodenough, J.B.,** and **Hamnet, A.J., 1987,** Fuel Cell Electrode for Oxidizing Methanol, Appl. Electrochem., 17, 413-16.

3. **Zahran, R.R., 1989,** Specific Conductivity of Copper-Reinforced Carbon Electrodes, Alx. Eng. J., 28, 215-18.

4. **Zahran, R.R., 1990,** Thermal Conductivity of Copper-Reinforced Carbon Electrodes, Mater. Lett., 10, 3, 93-98.

5. **Zahran, R.R., 1990,** Thermal Conductivity of Aluminum-Reinforced Graphite Electrodes, Mater. Lett., 10, 4&5, 187-190.

6. **Zaraa, M.A.,** and **Zahran, R.R., 1991,** Corrosion Behavior of Alumina-Reinforced Carbon Electrodes in Hydrochloric Acid Solutions, Alx. Eng. J., 30, 1, 1-4.

7. **Zaraa, M.A.,** and **Zahran, R.R., 1991,** Electrical Conductivity of Alumina-Reinforced Carbon Electrodes, Alx. Eng. J., 30, 1,5-8.

8. **Zahran, R.R., 1991,** Electrical Conductivity of Nickel-Reinforced Graphite Electrodes, Mater. Lett., 10, 9&10, 461-464.

9. **Zahran, R.R., 1991,** Corrosion Behavior of Copper-Reinforced Carbon Electrodes in Dilute Hydrochloric Acid Solutions, J. Mater. Sci., 26, 5693-5697.

10. **Kalyadov, E.B., Varypaev, E.S.,** and **Kovdrashenkova, M.F., 1985,** Investigation of the Interrelation of the Thermal Conductivity and Electrical Resistivity of Carbon Electrodes, Solid Fuel Chem., 19, 5, 132-38.

11. **Krasheninnikov, M.G., Rusakov, S.L., Borisov, V.M., Savanin, V.P.,** and **Belkin, A.S., 1986,** Strength and Electric Resistance of Electrodes based on Iron Oxides, Steel USSR, 16, 3,132-34.

12. **Klotz, H., 1971,** Production of Graphite-Metal and Graphite-Metal Compound Composites, Ger. Offen., 2, 0204,185, 9-14.

13. **Bonnemay, M., Bronoel, G., 1971,** Properties of Porous Electrodes and Possibilities for their use in Future Generators, Trans. Soc. Advan. Electrochem. Sci. Technol., 6, 2, 63-71.

14. **Nakajima, T., Kawasguchi, M., 1985,** Preparation and Properties of the Graphite Intercalation Compound, $C_xF(MF_n)_y$, New Mater. New Process., 3, 278-79.

15. **Keyser, C.A., 1959,** Basic Engineering Metallurgy, Edward Arnold.

16. **The Electric Arc Furnace, 1981,** Private Communications with Committee on Technology, International Iron and Steel Institute, Brussels.