Electrical Resistivity Measurement of Carbon Anodes Using Van Der Pauw Method

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Abstract

Electrical resistivity of carbon anodes is an important parameter in the overall efficiency of aluminium smelting process. In order to characterize their electrical resistivity, a cylindrical core is extracted from the top of the anodes. The electrical resistivity of the core samples is measured according to ISO 11713 standard. This method consists of applying a 1A current along the revolution axis of the sample, and measuring the voltage drop on its side, along the same direction. Theoretically, this technique appears to be satisfying, but cracks in the sample, either generated during the anode production, or while coring the sample may induce high variations in the measured signal. Van der Pauw method, as presented in 1958 by L.J. van der Pauw, allows measuring the electrical resistivity of any plain sample with arbitrary shape and low thickness even in the presence of cracks. In this work, measurements were performed using both standard and van der Pauw method, on both flawless and cracked samples. Results provided by van der Pauw method appeared to be more reliable and repeatable.

Keywords: Carbon anodes; aluminum smelters; electrical resistivity; van der Pauw.

1. Introduction :

Carbon anodes, used in Hall-Héroult process to produce aluminium, are characterized to control the quality of produced anodes along the process. Usually, core samples are extracted from the top of the anodes, beside the stud holes. This location may lead core samples to have some structural flaws, especially at their bottom [1,3]. Core sampling itself may also induce flaws such as cracks in the samples [4]. The characterization of anode cores is achieved using ISO11713 standard method. This standard is merely an adaptation of ASTM B193-02, used as test method for resistivity of electrical conductors materials. Though, this latter method requires a sample with no cracks or visible defects. Cracks located in the radial axis may most probably induce overestimated values on the measured electrical resistivity, which would not necessarily be representative of the electrical resistivity of the anodic block.

Van der Pauw (VdP) method [5,6] for measuring electrical resistivity of samples of various shapes was presented 60 years ago. More recently, Kasl and Hoch [7] proposed a study using VdP method on circular and cylindrical samples. This study shows that samples with a thickness smaller than their diameter gives an accurate value of electrical resistivity. In addition, contacts placed along the edge of the sample are preferred those placed on the top of the sample. Using VdP method allows working with samples much smaller than those used with ISO11713. By reducing the size of the sample, the risk of the presence of flaws reduces.

In this study, the reliability of the VdP method for electrical characterization of carbon anodes was investigated and compared with the standard method, currently used in aluminium industry. Finally, defects were intentionally introduced to the anode cores, and their electrical resistivity was measured using both methods in order to assess the sensitivity of these methods compared to the defects.

2. Materials and method:

For both methods performed at the university, the current is provided by a Laboratory DC Power Supply GW GPR-1810HD. Current and voltage are measured with an Agilent 34461A $6_{1/2}$ Digit Multimeter. In the case of the standard method, the sample was maintained between two steel plates, both placed on springs to apply the 3 MPa pressure required by the standard. Voltage drop was measured with two thin pins mounted on spring to apply the same pressure on each spots. These pins are located on a handle on which they keep the same distance apart. The description of the setting is presented schematically in figure 1. Measurement performed by our industrial partner were done using the R&D Carbon RDC 150 for Specific Electrical Resistance.

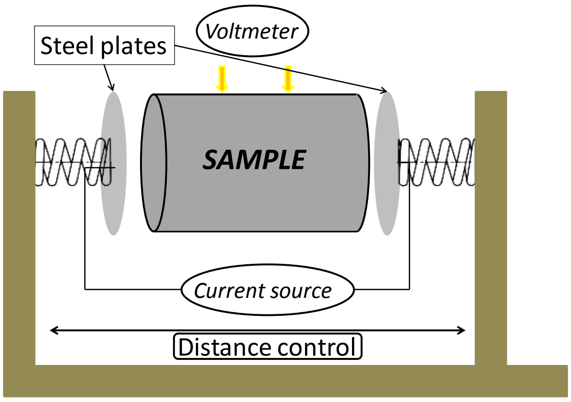

Figure 1. Schematic view of the setting used for the measurement of electrical resistivity of carbon anodes according to ISO11713 standard.

It has to be noted that a constant difference of 4.5 μΩ·m was measured between the standard method performed in the industry and at the university. The correction will be applied to each required situation, to clarify the graphs. For the Van der Pauw method, as it was decided to take advantage of the cylindrical symmetry, the sample holder was made of a self-centered chuck designed for turning machines. Current suppliers and voltage probes were made of copper bars, with a V shape facing the sample edge, to minimize the contact area, as can be seen in figure 2.a).

Method of calculation ⇒ Original conductivity (S/m) ⇓	Equation 1
18000	18587 Error: 3.26 %
20000	20665 Error: 3.33 %
22000	22542 Error: 2.46 %

Table 7. Electrical resistivity of a sample containing a crack, normal to axis of rotation, calculated using FEM method. Void volume removed from the calculation.

To ensure the validity of the statement that the void contribution has to be taken account in the case of a defect place in the plan, the same simulation was performed with a thinner crack, of negligible volume, as presented in table 7.

Method of calculation ⇒ Original conductivity (S/m) ⇓	Equation 1
18000	18189 Error: 1.05%
20000	20215 Error: 1.07%
22000	22229 Error: 1.04%

Table 8. Electrical resistivity of a sample containing thin crack of negligible volume, normal to axis of rotation, calculated using FEM method.

The results presented in the tables 3 to 8 show that, using FEM, the Van der Pauw method is adapted to the measurement of electrical resistivity of material containing structural defects.

4. Conclusion:

The results obtained experimentally shows that on industrially produced anode cores, the Van der Pauw method appears to be more accurate and less sensitive to macro and micro structural defects in the material. As the cracks in anode cores are not necessarily representative of the microstructure of the whole anode, the knowledge of electrical resistivity of the material without the effect of crack gives a better information on the electrical properties of the anode block. This method shows a good repeatability in the measurement of electrical resistivity of samples. Numerical simulation using Finite Element Method showed that this method is perfectly suitable for the measurement of electrical resistivity of samples containing defects or flaws such as macroscopic cracks, in different orientation, as presented in the last section. It has to be noted that depending the size and orientation of the defect toward the sensors, the defect may induce an error in the calculation of electrical resistivity.

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