Nondestructive Control of Physico-Mechanical Properties and Quality of Carbon Materials and Products Used in the Production of Aluminum

Elena Kovarskaya[1] and Igor Moskovenko[2]
1. Deputy General Director,
2. General Director
«ZVUK», Saint Petersburg, Russia
Corresponding author: info@ndtest.ru

Abstract

The report reflects the modern world level in the field of non-destructive quality control of various kinds of materials and products, primarily carbon, used in the production of aluminum and shows the possibility of using modern methods of acoustic control for quality control. The possibility and expediency of using acoustic methods, based on measuring the natural vibration frequencies of products for the evaluation of the physico-mechanical properties of carbon materials, whose quality largely determines the life expectancy of the cell and its main technical and economic indicators. The effect of porosity is shown both on the performance of carbon products and on the results of their acoustic control, which allows using rapid non-destructive testing in production conditions using modern methods and tools. The use of such a rapid method can increase the reliability of the control of manufacturing carbon products, used in the production of aluminum. It can also help to prevent the construction of cells with materials whose physical and mechanical properties are outside specifications and can contribute to an improvement of cell technical and economic performance parameters.

Keywords: Carbon materials in aluminum electrolysis cells, nondestructive testing, physico-mechanical properties of carbon materials, acoustic control methods, frequencies of natural oscillations.

1. Introduction

The quality of carbon products used in the production of aluminum largely affects both the operating period of the electrolysis cell and its main technical and economic parameters. The operability of carbon blocks is significantly affected by their porosity. Porosity of pressed and prebaked carbon products, including bottom blocks and prebaked anodes, is in a certain way related to the mechanical strength of such products: with an increase in porosity, the mechanical strength decreases (due to weakening of adhesion between particles of carbon material), while a decrease in porosity entails an increase in the mechanical strength of the block. At first sight, it seems that in case of a strong decrease in the block porosity, its increasing mechanical strength should contribute to its greater durability and operability. However, with a decrease in porosity, the internal stresses, occurring in the body of the block when it is saturated with molten salts, will begin to appear. These stresses, proportional to the capillary pressure of the penetrating salts and directed from the inside of the block, will weaken the cohesion of the carbon particles, which, in turn, will result in a significant increase in the block volume and its disintegration. To a great extent, treatment of carbon products with electrolyte depends on their porosity and, consequently, on the average size of the pore radius, which increases with increase of the total porosity of the carbon block [1]. Table 1 shows the capillary pressure of melts (for 1000 °C), calculated depending on the pore radius [2]. These data indicate that the internal stresses arising in the cathode blocks of aluminum cells with penetration of molten salts, should

Table 1. The average pore radius in the cathode blocks with different porosities and capillary pressure for sodium fluoride and cryolite-alumina melts

Porosity, %	Average pore radius, mm	Capillary pressure, Pa	
		NaF	Na_3AlF_6+12,5% Al_2O_3
12.6	0.0201	14130	1770
13.8	0.0228	12900	1560
14.8	0.0330	8500	1075
15.5	0.0398	7200	890
17.2	0.0457	6195	725

increase with a decrease of their porosity or pore radius. It should be pointed out that these data are calculated for conditions without taking into the account the effects of aluminum dissolved in the electrolyte, which further increases the capillary pressure, and consequently, increases the penetration of molten salt into the pores of the carbon material.The performance of carbon products used in the production of aluminum is, therefore, largely affected by their porosity.

2. Method essence

It is commonly known that, in order to control the physico-mechanical properties of various kinds of materials and products, which are largely affected by porosity, acoustic control methods are used, including those based on measuring natural oscillations frequencies (NOF) of products [3]. This is due to a significant difference in the conditions of propagation of acoustic oscillations in the material and the air that fills in the pores (the sound velocity C_l in carbon block is 2000–3000 m/s, while in the air it is around 300 m/s). When using NOF measuring, an indicator was introduced, a sound index (SI), being an integrated characteristic of physico-mechanical properties, which is largely determined by the porosity of the monitored products. The sound index is an interval of the reduced acoustic wave propagation velocity (velocity of propagation of longitudinal elastic oscillations in indefinitely long thin rod) in the material. The sound index is denoted by an odd integer number equal to the average value of the parameter in a particular gradation C_l, expressed in m/s and multiplied by 10^{-2}. The sound velocity is interrelated by means of a known relation (Equation 1) with important parameters characterizing the physico-mechanical properties of the material *modulus of elasticity* (Young's modulus) E and the material density ρ.

$$C_l = \sqrt{E/\rho}. \quad (1)$$

In turn, the sound velocity in carbon products is associated with the correlation dependence with its strength, structural, and other physico-mechanical properties and electrophysical characteristics. In particular, a close correlation was established between the ultrasonic velocity and strength, porosity, bulk density, and specific electrical resistivity of carbon products [4]. It should be noted that the Young's modulus, which largely determines the sound velocity, is by itself a very important parameter affecting the deformation of blocks under static and dynamic loads to which the blocks are exposed in the process of their operation. A number of companies include this parameter as one of the main indicators characterizing physico-mechanical properties of carbon blocks [1].

At present time, the following principles of picking carbon products used in the production of aluminum are generally used in the aluminum industry. Specific electrical resistivity (SER) and mechanical compressive strength are chosen as the basic parameters for picking carbon products. The above indicators are assessed based on the results of measurements made on samples (cores) selected from the prebaked blanks, as well as based on the results of measurements of SER of cathode and anode blocks [4]. Based on SER gradation and mechanical strength, the

In case of the development of regulatory documentation similar to the above-mentioned GOST R 52710-2007 [8] with the code name "Carbon products: Acoustic method for determining physico-mechanical properties and sound indices based on the sound velocity", the established optimal values of sound characteristics can be included in the specifications for carbon products, which are shipped to the enterprises producing aluminum, for assembly and overhaul of electrolysers. Such requirements may be further included in contracts for the supply of products.

5. Conclusion

In conclusion, it's worth noting that use of acoustic nondestructive control, based on NOF measuring, makes it possible to carry out quick, reliable and repeatable assessment of physico-mechanical properties of real products in process, which should contribute to the most efficient use of the tested products, as well as better mutual understanding between manufacturers and consumers of carbon products used in aluminum production.

6. References

1. A.F. Grebyonkin, V.A. Kryukovskiy, and I.B. Moskovenko, Research of physico-mechanical properties of carbon blocks of various manufacturers by means of an acoustic method. *The solution of environmental problems in aluminum production: Collection of scientific papers the Russian National Aluminium-Magnesium Institute VAMI*, Leningrad: VAMI, 1990, 62-72.
2. A.I. Belyaev, E.A. Zhemchuzhina, L.A. Firsanova Physical chemistry of molten salts. - *Moscow: Metallurgizdat,* 1957, 259 p.
3. E.Z. Kovarskaya and I.B. Moskovenko, Use of natural oscillation frequencies for nondestructive control of physico-mechanical properties of materials and articles. *NDT World.* 2012. № 4 (58), 5 - 8.
4. A.F. Grebyonkin at al., Nondestructive control methods for evaluation of quality of large-size carbon products. *Increase in efficiency and reliability of operation of aluminum electrolyzers: Collection of scientific papers the Russian National Aluminium-Magnesium Institute VAMI*, Leningrad: VAMI, 1988, 26-31.
5. A.F. Grebjonkin at al., Zerstörungsfreie akustische Materialprüfung an Kohlenstoffanoden, *Aluminium-66*. Jahrgang. -1990, (9), 854-857.
6. I.B. Moskovenko, E.Z. Kovarskaya, and M.S. Shadrina Nondestructive control of physico-mechanical properties and quality of graphitized carbon products (article) *Journal of Siberian Federal University. Engineering & Technologies*, 2018, 11(4), 443-452.
7. M.V. Boubaker et al. Non-Destructive Testing of Baked Anodes Based on Modal Analysis and Principal Component Analysis *Light Metals 2017, The Minerals, Metals & Materials Series*, DOI 10.1007/978-3-319-51541-0_154
8. GOST R 52710 – 2007 "Abrasive tool. Acoustic method of determination of hardness and sound index of reduced acoustic wave velocity"