TECHNICAL AND ENVIRONMENTAL ASPECTS CONTINUOUS FIBER PRODUCTION

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The evolution of compositions of E-glass fiber is related to solving technological and environmental problems in production thereof and to reducing the cost of the raw material. The most common alkali-free aluminum borosilicate E-glass has the following chemical composition, wt. %: SiO_2 52–56; Al_2O_3 12–16; B_2O_3 5–10; MgO 0–5; CaO 16–25; Na_2O+K_2O 0–2; TiO_2 0–1.5; Fe_2O_3 0–0.8; F^- 0–1. Boron-containing E-glass fiber combines high mechanical strength and dielectric properties with rheological properties ensuring stable process of fiber formation in a wide range of linear density. Boron-free compositions of E-glass comprise, weight %: SiO_2 54–65; Al_2O_3 9–15; MgO 0–4; CaO 17–25; Na_2O+K_2O 0–2; F^- 0–0.5. The best known boron-free E-fiber is Advantex of Owens Corning Corp. [1–4].

The aim of this research is comprehensive assessment of technological and physical-chemical properties of boron-containing and boron-free E-glass, and production ecology of continuous fibers based on them.

Borosilicate and boron-free glass was synthesized for comparative analysis of technological properties of glass for E-glass fibers. The composition of borosilicate glass comprises, wt. %: SiO_2 53.6–58.0; Al_2O_3 14.2; B_2O_3 3.1–9.0; MgO 1.4–2.7; CaO 19.55–22.35; Na_2O+K_2O 0.5; Fe_2O_3 0.15; F^- 0.3. Colemanite 75 micron was used as boron-containing raw material. Boron-free E-glass contain, wt. %: SiO_2 60.0–61.4; Al_2O_3 12.0–13.3; MgO 2.6–2.9; CaO 22.3–22.9; TiO_2 0–0.4; Fe_2O_3 0.3; Na_2O+K_2O 0.8.

For studying glass melting processes during test glass synthesis positional heat treatment of the charge was performed at temperature range of 700–1500°C. It was established that under identical time-temperature modes of synthesis glass melting processes intensify with increase of the boron oxide content in the glass compositions. The formation of eutectic melts between borates, silicates and aluminosilicates promotes the batch melting at 1000–1100 °C and the transformation of a heterogeneous material mixture into thehomogeneous melt at 1300 °C. In the synthesis of boron-free glass, vitrification processes are completed at 1400–1500 °C.

Boron oxide in course of silicate and glass formation processes is mainly in chemically bonded state: colemanite $\rightarrow$ calcium borate $\rightarrow$ calcium borosilicate. This predetermines reduction of high-temperature volatility of boron compounds.

It was established that heat consumption for glass melting processes, all other conditions being equal, for boron-free glass is 3385.6 kJ/kg of molten glass, which is 14.3 % more than for borosilicate E-glass, heat consumption for which being 2901.45 kJ/kg of molten glass.

At studying the glass by viscometry method it was established that boron oxide content decrease in borosilicate glass composition leads to expectable viscosity increase within all the temperature range, which is particularly significant in temperature range of melting and fiber formation. While shifting from boron-containing to boron-free glass, the temperature corresponding to the production viscosity of 10^2 Pa·s changes from 1180 to 1260 °C.

Temperature range of boron-free glass crystallization is shifted towards higher temperatures: the upper crystallization temperature for Advantex boron-free glass composition is 1227 °C whereas for borosilicate glass with 9 wt.% content of boron oxide it is 1150°C. Accordingly, temperature for boron-free fiber formation must be 60–80 °C higher than that of boron-containing fiber. Increase in fiber production temperature causes increase in energy consumption at this technological stage of production, and intensifies the processes of sublimation and dissolution of platinum-iridium alloy – feeder material – in the glass melt.

For comparative assessment of E-glass according to specified parameters, roving produced by different manufacturers was tested, obtained from Advantex boron-free glass and boron-containing E-glass. The breaking load at testing boron-containing glass roving is 1270 H, of Advantex boron-free roving – 1260 H.

As evaluation criterion of chemical resistance of the fibers, tensile strength after their treatment in different media was adopted, due to its importance for composite materials. Distilled water and alkaline solution with pH 12.9 were used as aggressive media. Adjusted for coefficient of variation, the strength of boron-containing and boron-free fibers prior to testing is on the same level and equals 2400–2560 MPa.

Exposure to water and alkaline solution results in virtually the same strength reduction level for all the types of fibers.

Production ecology of melting boron-containing and boron-free E-glass in recuperative furnaces was evaluated. It was established that method of boron-free melting in recuperative furnace has the greatest impact [5].

Calculation of the coefficient (criterion) C, taking into account the volume and danger of emissions was performed to assess the environmental impact of the industries:

$$C = \sum_{i=1}^{n} \left(\frac{M_i}{TLV_{ce}} \right)^{\alpha_i},$$

where n is the amount of pollutants entering the air from stationary sources of emissions; M_i is the mass of the i-th pollutant, kg/t of glass; TLV_{ce} (Threshold Level Value continuous exposure) is the average daily maximum permissible concentration of the i-th pollutant in the air, mg/m^3; α_i is a nondimensional constant that allows to correlate the degree of impact of the i-th pollutant with the impact of the third hazard class pollutant.

It has been found that glass melting in recuperative furnace makes the greatest impact on the environment (criterion C is 414). In case of boron-containing E-glass the gas-flow rate is reduced and, accordingly, nitrogen oxide emissions are reduced at its melting stage (criterion C is 370).

As a result of comprehensive research of glass for continuous electrically insulating E-fiber it was established that boron-containing glass has technological advantages due to more intensive glass melting processes, and its production process according to environmental indicators is comparable to boron-free glass production indicators. It was established that E-fiber composition does not have impact on the specified glass roving strength indicators. Exposure to water and alkaline solution results in virtually the same strength reduction level for boron-containing and boron-free fibers.

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