POROUS CARBON-CARBON COMPOSITES FOR FUEL CELLS

A. A. Tarasenko,* A. A. Lysenko,* и V. A. Lysenko**

Technology for fabricating porous current-conducting gas-diffusion supports for fuel element electrodes made of carbon-carbon composites with the structure of fabrics, knits, and nonwovens was developed. The process scheme for manufacturing gas-diffusion electrodes for fuel cells was examined. The properties of the gas-diffusion supports manufactured with the technology of the St. Petersburg State University of Technology and Design and supports from E-TEK (USA) were investigated and compared.

Due to the clear trend of the last 10-15 years toward saving energy and raw material resources, alternative, environmentally clean energy sources have been actively sought. Modern units and equipment that utilize energy from wind, water, the sun, space, geothermal energy, etc., are being developed and introduced.

Fuel cells are an effective energy source and it is no accident that hundreds of millions of dollars are allocated each year for developing programs to create them in the USA, Europe, Japan, and Korea. A national energy strategy was adopted in the USA in 1996; it was based on advances in the area of hydrogen energetics and in particular, in creating a new generation of fuel cells. In 2003, a similar program was also created in Russia (http://www.bigpi.biysk.ru/enciel/articles/-12/1001223A.htm).

Fuel cells are chemical sources of current. They directly convert the energy of fuel into electricity, by-passing low-efficiency combustion processes that take place with large losses. Fuel cells are based on two porous electrodes separated by a solid or liquid electrolyte (Fig. 1). The fuel and oxidant are fed into cavities adjacent to the electrodes; oxidation and reduction reactions take place on the electrolyte—electrode interface and a potential difference is formed on the cathode and anode:

$$\frac{1}{2} \text{O}_2 + 2\text{H}^+ + 2e^- \rightarrow \text{H}_2\text{O}.$$

When the external circuit is closed, an electrical current that performs useful work appears in it. A developed electrode surface area (up to hundreds of m²/g), rational organization of adsorption and ionization of the molecules of the reacting substances, discharge of electrons and reaction products, and high purity of the reagents are required for effective operation of fuel cells.

A design feature of such electrodes is their porosity — this prevents “flooding” of the battery. Porous metals, porous graphite, and porous carbon fibre materials can be the basic materials for manufacturing the porous electrodes used in fuel cells.

Gas-diffusion electrodes (GDE) made of carbon fibre materials such as paper, nonwovens, or fabrics open up special prospects in developing technologies for electrochemical current sources. They are light, highly porous, chemically stable, and can be manufactured by simpler technology [1, 2]. The process chain for manufacturing gas-diffusion electrodes is shown in Fig. 2.

The initial polymer textile material (a), such as fabrics and nonwovens, paper made of viscose, polyacrylonitrile, phenol, and other fibres, undergoes deep heat treatment — carbonization and graphitization (b). The heat treatment temperature can reach 2200-2500°C. At such temperatures, the initial polymer fibre material is converted into conducting material. The carbon fibre materials can be manufactured in the form of fabrics, paper, and nonwovens (c).

The carbon fibre material is then impregnated with a binder to obtain a dense, thin, sheet prepreg (d, e). The prepreg undergoes deep heat treatment, which converts the polymer binder into a carbon matrix and produces a carbon-carbon composite material in this way (f). The heat treatment temperature can be 2200-2500°C. The porous thin conducting composites obtained (g) are supports (GDS) for production of gas-diffusion electrodes.

For manufacturing the gas-diffusion electrode, the GDS undergoes hydrophobization (h). The porous hydrophobized carbon-carbon composite material can easily introduce oxygen and hydrogen (fuel) into the reaction zone and take out reaction

*St. Petersburg State University of Technology and Design; **Physical-Mechanical Center CJSC, St. Petersburg. Translated from Khimicheskie Volokna, No. 2, pp. 55-58, March—April, 2007.
products — water (i). A layer of catalytically active carbon black or catalytically active nanotubes (j) is then applied on the hydrophobized support.

In creating GDE, all elements of the composite and processes must be monitored in each stage. The initial polymeric materials must have a highly organized structure, and high-temperature treatment must give the fibre material high conductivity and porosity. From an economic point of view, it is very important to show what the yield of carbon fibres and carbon fibre will be after deep heat treatment. The GDS manufacturing technology should ensure high (70-80%) porosity and acceptable mechanical characteristics [3, 4].

We selected specially prepared nonwoven and knitted fabrics made of cellulose-based fibres as the precursors for GDS. The knitted and nonwoven materials were carbonized and graphitized, impregnated with resin, and again successively carbonized and