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Chemistry in Aviation Materials Science

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All-Russian Scientific Research Institute of Aviation Materials, State Research Center of the Russian Federation (VIAM), the leading institute in materials science within the aviation industry and a major scientific center of Russia, is engaged in development of nonmetallic materials based on a wide variety of classes, types, and sorts of chemical products. During many years of research works more than 2000 brands of materials have been created for aerospace engineering purposes, and they form a material basis for the construction of the Russian aircrafts and engines. The role of the chemical industry in development of aviation materials is essential. Creation of many advanced materials for aviation and rocket engineering is based on great chemical discoveries. At the same time, the development of the chemical industry itself was driven by the need for new types of machinery and weaponry. Improvement and intellectualization of aviation and rocket products required the development of such branches as microelectronics, laser technology, and means of communication, which in turn made it a priority task to develop chemistry and a new promising scientific field: materials science.

Upon the initiative of A.T. Tumanov, VIAM Director, and under the guidance of D.P. Novikov, Deputy Chairman of the Military-Industrial Commission, a meeting was held in Kremlin with the participation of V.A. Kargin and K.A. Andrianov, members of the Academy of Sciences. The meeting resulted in approval of the concept of establishment of the corresponding industrial branch. The decision of the Military-Industrial Commission in December 1968 and the resolution of the USSR Council of Ministers in June 1970 provided the organizational and economic basis for the solution of this problem, which became a matter of state importance. VIAM was selected as the chief institute responsible for the solution of the problem and Tumanov was appointed the head of the research works. More than 50 organizations and enterprises from various industrial sectors were involved in the performance of the works. Thus, a new scientific field, development of polymer composites on various bases and for different purposes, appeared. Further development of this branch gave an impetus to creation of new polymer matrices, including epoxy, phenol, organoelemental, polyimidic, polyester, and many others, as well as reinforcing materials. In order to ensure the production of these new types of fillers the following steps were made: boron fiber production was established at Dzerzhinskii pilot plant (in Gor'kii oblast), carbon fiber production was started at Moscow and Chelyabinsk electrode plants and at "Khimvolokno" Balakovo production association, and production of whiskers of SiC, Al_2O_3, and other high-melting compounds at Redkino pilot plant.

The successful achievements were associated with the industrial policy of the state and the implementation of large-scale projects, where Chief design engineers and chief researchers played critical roles. A good example demonstrating the significance of chemistry and the chemical industry in development of complicated aerospace equipment is the Buran reusable orbiter, which consists of 90% composites. When design bureaus set this challenging task, it demanded of the institutes of the USSR Academy of Sciences and the sectoral institutes (VIAM, GNIIKHTEOS: State Research Institute for Chemistry and Technology of Organoelemental Compounds etc.) to develop special research programs and to create a wide range of new high-strength, high-modulus, and heat-resistant fibers, binding and functional materials. It was a difficult task to develop compounds that ensure reliable adhesion of quartz heat-protection tiles to the case of the launch vehicle and the orbiter. As a result of these works, joint efforts of the researchers, designers, and engineers involved in the project made it possible to create materials that still remain unmatched.

For many years the greatest scientists of the Soviet Union, including such members of the Academy of Sciences as K.A. Andrianov, G.K. Boreskov, N.S. Eni-

kolopov, V.A. Kabanov, V.A. Kargin, N.A. Plate, N.N. Semenov, and many others, lead special-topic research works in chemistry. L.A. Kostandov, S.V. Golubkov, and Yu.A. Polivanov were among the leaders of the chemical complex who made a significant contribution into its formation and development.

During the period of the economic crisis there was a drastic reduction in the domestic market of chemical products. In competition with foreign companies Russian producers of hi-tech chemical materials (raw materials for carbon-fiber fillers, synthetic oligomers and polymers, and engineering polymers) turned out to be extremely vulnerable. Intensification of activities of foreign companies on the Russian market meant that in such market segments as, for example, production of synthetic fibers, paints, and lacquers, the domestic production output either went down or rose only negligibly. During the last decade the Russian defense industry has not provided the required demand for a number of products of low-tonnage chemistry.

By now Russia has terminated the production of some types of polymers (polyimides and polycarbonates), special-purpose rubbers, adhesives, sealants etc. Production of carbon fibers is also under the threat of closing, although these fibers are necessary for fabrication of structural heat- and erosion-resistant composites used in modern aviation, rocket and space engineering, and the nuclear industry. More than half of low-tonnage production plants are in a critical situation, including producers of special-purpose fibers, heat-resistant organic glasses, thermoresistant organosilicon and organoelemental oligomers, fillers and pigments, special chemical additives etc. However, it is not possible to ensure defense security and economic independence of the country without development of the domestic chemical production, as there is no alternative to these chemicals in many military products.

In recent years in the engineering industry (aviation, shipbuilding, and machine-tool industry) there has been an increase in demand for items made of structural polymer materials, special coatings, insulating and noise-absorbing materials, and many others, which significantly facilitate the production technology in the corresponding industrial branches, improve the quality of the manufactured products, and in many cases are irreplaceable.

In order to find a comprehensive solution on how to provide the manufacturers of the existing types of aviation equipment and weaponry with the required materials and to create new materials for future types of aviation equipment and weaponry, a draft Federal target program on "Development, Restoration, and Organization of Production of Strategic, Scarce, and Import-Replacing Materials and Low-Tonnage Chemicals for Armament, Military and Special-Purpose Equipment for the Period 2009–2011 and until 2015" was developed by order of the President and the Government. This program is aimed at restoration of production of lost products and materials with unique properties, development and implementation of innovative "breakthrough" projects and technological processes for manufacturing of competitive products on the basis of economically effective, environmentally sound, and resource-saving technologies.

During the entire life of VIAM its research activities have been carried out in close cooperation with the institutes of the Russian Academy of Sciences, higher educational institutions, leading sectoral institutes and enterprises of the chemical industry.

The laboratory of polymer binders established by K.A. Andrianov, member of the Academy of Sciences, performs research works on synthesis and targeted chemical modification of polymer products for functional materials, fiberglass, carbon fiber reinforced plastic, and organic plastic, including self-adaptive (intellectual) composites, capable of targeted improvement of their parameters in extreme cases.

Special research works on creation of nanostructural materials have resulted in development of carbon fiber reinforced plastic characterized by mechanical characteristics improved by 10–15%, heat resistance, by 15–30%, and thermal-oxidative resistance, by 20–50°C, as well as crack resistance, fatigue and stress-rupture strength, water, oil, fuel, and fungus resistance. The Institute has developed the first nanostructural composite that can be used as a lightning-resistant coating for structures made of carbon fiber reinforced plastic. This coating remains almost intact when exposed to currents that emerge when the aircraft is hit by a lightning. As shown by research works, the most promising technology for obtainment of nanostructural polymer composites is injection of nanoparticles with grafted functional groups into the binding material, their distribution in the binder, and fixation based on chemical reactions between the binder functional groups and those grafted to the nanoparticles, which is nanostructural design.

Apart from polymer construction materials the Institute carries out works on creation of a wide range of functional materials, without which it is impossible to develop future models of aviation, rocket, and space equipment. These materials include coatings, adhesives, sealants, heat-shielding, heat-resistant, and special-purpose ceramic materials.

For many years VIAM has been acting as a link between the leading construction bureaus, which specify tasks on development of new materials for aviation and special-purpose equipment models, and the Institutes of the Russian Academy of Sciences, higher educational institutions, leading sectoral institutes, and manufacturers of finished products. As the leading enterprise in the industrial branch, VIAM determines the scientific and technical status and the main courses of development for modern materials science.

Today the world is at the threshold of the sixth technological wave, characterized by the development and application of nanotechnologies, micromechanics, photonics, quantum technology, and thermonuclear energy. Achievements in these scientific fields should lead to the creation of artificial intelligence and a quantum computer, without which it is impossible to reach an absolutely new level in basic and applied research. Under these conditions the future of aerospace engineering and the increase in its competitive ability on the global market are connected with the development of advanced materials based on various classes of chemical compounds, oligomers, and polymers subject to nanomodification, as well as the creation of new hi-tech and energy-saving technologies of their production with the use of quantum computers in the course of development. In many respects the successful creation of the materials of the future depends on the performance of joint works by the Institutes of the Russian Academy of Sciences, higher educational institutions, and enterprises of the industrial branch in the field of synthesis and both obtainment of new chemical compounds and improvement of the wide range of materials with unique properties developed by VIAM over the years.