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High-Temperature Glass-Fiber-Reinforced Plastics for Aeronautical Products

I. I. Sokolov, V. A. Nikiforov, and R. R. Mukhametov

All-Russian Scientific Research Institute of Aviation Materials, ul. Radio 17, Moscow, 105005 Russia

e-mail: admin@viam.ru

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Abstract—The main types of both widely used and promising glass-fiber-reinforced plastics based on temperature-resistant binders that are efficient in a temperature range of 160–400°C are considered. Basic mechanical and dielectric properties of the developed glass-fiber-reinforced plastics are presented.

Keywords: glass-fiber-reinforced plastics, polymer binders, materials based on epoxy, organosilicon, and polyimide binders, glass reinforcing fillers

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To date, glass-fiber-reinforced plastics occupy a leading place in terms of volume of applications in various branches of industry, including aircraft construction, among polymer composite materials based on various reinforcing fillers. It is due to valuable set of strength, dielectric, thermal insulation, and physicochemical properties of glass-fiber-reinforced plastics, relatively low cost, processability, and low power consumption for processing [1–4].

Currently, glass-fiber-reinforced plastics based on fillers of various textile forms, nonwoven structures, and discrete fibers made of glasses with various chemical compositions—aluminoborosilicate, magnesia, silica, quartz, etc.—have been developed. Epoxy, phenolformaldehyde, cyanoether, polyimide, organosilicon, and other polymer composition were used as binders [5–6].

Glass-fiber-reinforced plastics based on epoxy binders have gained wide use at preparation of various elements of aircraft constructions (sound-absorbing panels of engines, aircraft control elements, nacelle elements, radiotransparent antenna radomes, spars of helicopter rotors, etc.) operating at relatively low operating temperatures not exceeding 160°C due to a complex of good technological and physicomechanical properties. The use of glass-fiber-reinforced plastics created on the basis of cyanoether binders with a high level of operating characteristics, including under the action of high temperatures and high humidity, is the main interest.

To create heat-resistant composite materials operating up to a temperature of 250°C, *bis*-maleimide binders processed using modern technologies are widely used abroad. In the short term, the development of technological bismaleimide binders having improved moisture resistance (bismaleimides of II generation) and high strength properties and able to be processed by nonautoclave technologies (RTM, VaRTM, RFI, etc.) is planned at the All-Russian Scientific Research Institute of Aviation Materials (VIAM) [7–10].

Heat-resistant glass-fiber-reinforced plastics based on organosilicon and polyimide binders long running at temperatures of 300—350°C and short running at temperatures up to 800°C, which have found wide use in aircraft and aerospace equipment, have been developed.

The widespread use of glass-fiber-reinforced plastics based on organosilicon binders is due to the high thermal-oxidative stability, good dielectric properties, and fire safety thereof. Among the disadvantages of this class of materials are relatively low hardness, especially interlayer hardness, and high processing temperatures (250°C and higher). Table 1 shows the properties of glass-fiber-reinforced plastics based on organosilicon binders.

When producing high-temperature products based on organosilicon binders, the methods of direct compression and pressure impregnation in rigid dies making it possible to manage without additional mechanical treatment and providing high stability of geometrical dimensions and material properties are used.

Long duration and power consumption of manufacturing process constituting hundreds of hours for large products, as well as high porosity of the resulting material, are substantial drawbacks of solution-type binders (SK-9FA, SK-9KhK, and SK-101). To overcome these disadvantages, K-9-70 binder, which is a solution of organosilicon resin in liquid oligomer

Table 1. Properties of glass-fiber-reinforced plastics based on organosilicon binders

Properties	SK-9FA	SK-9KhK	SK-101	SK-9-70K	VPS-52
Tensile strength, MPa	380	270	140	350	350
Compressive strength, MPa	115	100	80	350	150
Flexural strength, MPa	200	200	135	275	320
Young's modulus under tension, GPa	26	24.7	14.6	27	14
Dielectric permittivity ε at 10^6 Hz	4.66	3.53	3.70	3.13	3.01
Dielectric loss tangent $\tan\delta$ at 10^6 Hz	0.0026	0.0047	0.015	0.0046	0.008

Table 2. Properties of glass-fiber-reinforced plastics based on polyimide binders

Properties	STP-97s	STP-97K	STP-1TsM	STM-F
Tensile strength, MPa	500	490	650	475
Compressive strength, MPa	350	400	–	640
Flexural strength, MPa	640	400	900	700
Young's modulus under tension, GPa	34.2	30	–	33
Dielectric permittivity ε at 10^6 Hz	4.71	4.57	4.1	4.54
Dielectric loss tangent $\tan\delta$ at 10^6 Hz	0.012	0.0081	0.01	0.006

(SK9-70K glass-fiber-reinforced plastic), was developed. To improve the stability of the glass-fiber-reinforced plastic characteristics, a modification of organosilicon binder with thermostabilizing additive was performed. The products are produced by pressure impregnation (VPS-52 glass-fiber-reinforced plastic). In the course of the work, organosilicon resin and oligomer were produced on the basis of FGUP GNIIKhTEOS was organized; previously, organosilicon resins were not produced in Russia.

During the production of high-temperature glass-fiber-reinforced plastics polyimide binders are widely used [11–12]. They are inflammable, have high thermal stability and resistance to corrosion, and provide a high level of preservation of physicomechanical properties of the materials based on them at temperatures up to 300°C. STP-97s, STP-1TsM, and STM-F polyimide glass-fiber-reinforced plastics provide a high operational lifetime at elevated temperatures (2000 h at 300°C and 300 h at 350°C). The disadvantages of the materials based on polyimide binders include a high temperature of their processing (300—350°C) and increased porosity of glass-fiber-reinforced plastics).

To improve technological properties and decrease the porosity of polyimide glass-fiber-reinforced plastics without a substantial decrease in mechanical strength and thermal resistance, a glass-fiber-reinforced plastic of STP-97K brand with a processing temperature of 170°C was developed. Table 2 shows the properties of glass-fiber-reinforced plastics based on polyimide binders.

IP-5 heterocyclic carborane-containing powdered binder is a promising binder for the production of heat-resistant glass-fiber-reinforced plastics. VPS-36 glass-fiber-reinforced plastic meant for thermally loaded aeronautical products that incorporate wide chord working and stator blades and other structural elements of GTD fans. The glass-fiber-reinforced plastic has a rather high operational lifetime at elevated temperatures: 500 h at 370°C and 50 h at 400°C. The properties of VPS-36 glass-fiber-reinforced plastic are as follows.

Properties	VPS-36
Tensile strength, MPa	610
Compressive strength, MPa	398
Flexural strength, MPa	603
Young's modulus during tension, GPa	37

Currently, studies dealing with the development of glass-fiber-reinforced plastics for working temperatures of 300—350°C on the basis of VSN-31 phthalonitrile binder are planned at VIAM. The class transition temperature of cured phthalonitriles is in the area of 450°C; they are noncombustible materials and have high strength properties, low water absorption, and practically unlimited viability. Melts of phthalonitriles have low viscosity, which makes it possible to use

RTM and RFI nonautoclave processing technologies during the production of products from PKM.

REFERENCES

1. E. N. Kablov, "Aerospace materials science," Vse Mater., Entsikl. Sprav., No. 3, 2–14 (2008).
2. E. N. Kablov, "Chemistry in aviation materials science," Russ. J. Gen. Chem. **81** (5), 967–969 (2011).
3. E. N. Kablov, "Materials and chemical technologies for aircraft engineering," Herald Russ. Acad. Sci. **82** (3), 158–167 (2012).
4. E. N. Kablov, "Innovations of VIAM as part of implementing the Strategic Directions of Development of Materials and Technologies of Their Processing for the Period up to 2030," Aviats. Mater. Tekhnol., No. 1, 3–33 (2015).
5. I. F. Davydova and N. S. Kavun, "Glass-reinforced plastics in aviation and rocketry constructions," Steklo Keram., No. 4, 1–7 (2012).
6. I. I. Sokolov and A. E. Raskutin, "Carbon- and glass-fiber reinforced plastics of a new generation," Tr. VIAM, No. 4 (2013). http://www.viam-works.ru.
7. R. R. Mukhametov, K. R. Akhmadieva, L. V. Chursova, and D. I. Kogan, "New polymeric binders for advanced methods of manufacture of structural fiber PCM," Aviats. Mater. Tekhnol., No. 2, 38–42 (2011).
8. R. R. Mukhametov, K. R. Akhmadieva, M. A. Kim, and A. N. Babin, "Melt binders for advanced methods of manufacturing new-generation PCMs," Aviats. Mater. Tekhnol., No. S, 260–265 (2012).
9. A. N. Babin, "Binders for polymeric composite materials of a new generation," Tr. VIAM, No. 4 (2013). http://www.viam-works.ru.
10. V. G. Zheleznyak, L. V. Chursova, M. M. Grigor'ev, and E. I. Kosarina, "Investigation of increasing the impact resistance of polyisocyanurate with a modifier based on linear heat-resistant polymers," Aviats. Mater. Tekhnol., No. 2, 26–28 (2013).
11. I. F. Davydova, E. N. Kablov, and N. S. Kavun, "Heat-resistant non-flammable polyimide fiberglass for aircraft and rocketry engineering," Vse Mater., Entsikl. Sprav., No. 9, 2–11 (2009).
12. I. F. Davydova and N. S. Kavun, "Heat-resistant sealed fiberglass," Vse Mater., Entsikl. Sprav., No. 11, 18–20 (2011).

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