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COMPOSITE MATERIALS FOR AIRCRAFT RADIOPARENT DOMES

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A broad spectrum of materials is considered, developed and used within ONPP Tekhnologiya for manufacturing radioparent domes for different types of aircraft. Theoretical and experimental development is carried out in the enterprise, and optimum structures are determined for the walls of antenna domes made from different composite materials taking account of a set of operational effects in aircraft, providing creation of broadband radiolocation systems with improved structural strength by not less than 10%; optimum production methods and a scheme for manufacturing complexly shaped domes are provided, including those based on multilayer structures of heat-resistant radioparent composite materials.

Keywords: radioparent domes, composite material, fiberglass-reinforced plastic, inorganic binder, three-layer structure.

INTRODUCTION

Contemporary aircraft are a very complicated engineering complex. Currently in aircraft building world practice there is a steady tendency towards an increase speed and manoeuvrability, based on strong competition among manufacturers of aircraft, helicopter, and rocket technology in a world market of military and civil technology. This implies a steady increase in specifications laid down for structural radioparent elements, mainly for aircraft antenna radomes.

Taking account of the functional purpose of a radioparent dome (RPD) quite a considerable set of increasingly rigid specifications are laid down that as a rule are complicated in view of existing contradictions. For example, satisfaction of requirements for electronic properties (EP) providing a certain wall thickness over a dome shell generating line, correspondingly superimposes some limitations with respect to heatproof properties of a dome and conversely.

The existing systematic approach for developing radome structures gives rise to resolving a set problems:

– choice of shell material taking account of the required EP and dome operation conditions;

– development of methods for providing prescribed EP;

– choice of component materials for joint assembly and development of its structure;

– choice of a water-repellent coating in the case of use of a porous ceramic shell or CM;

– development of a procedure for simulating prescribed dome operating regimes during terrestrial tests.

Development of dome structures in all stages is performed considering the high requirements for level and stability of dielectric properties of radioparent materials and dome shell wall structure providing minimum distortion of an electromagnetic field in a prescribed frequency range and under all operating conditions. Considering a requirement for guaranteeing the working temperature of a medium surrounding electronic equipment in an aircraft nose section, the dome material should exhibit good heat insulation properties, the basis of which are low thermal conductivity and relative good heat capacity. Aircraft domes are subject to intense dust and rain erosion from an air basin. This may change antenna radome quality considerably due to a change in thickness, and also as a result of moisture within pores, and this worsens electronic properties. At supersonic flight speeds there thermal cycling loads that combined with the phenomena indicated above reduce unit reliability. In view of this special attention is acquired by moisture protection and anticorrosion coatings, whose physicomechanical properties should be selected sufficiently carefully by conformity of

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Fig. 1. Model of a RPD based on epoxy binder.

their dielectric properties, thermal conductivity, thermal shock resistance, and linear thermal expansion coefficient.

During aircraft flight at supersonic speeds there is intense heat erosion of a dome, as a result of which there is a change in its electronic and heat resistance properties. Therefore in designing domes it is necessary to consider this effect by appropriate selection of materials and prediction of their properties in accordance with manufacturing technology and shell structural parameters. Requirements for a dome are also based in relation to class of rocket in which a dome is used, land – air, air – air, etc. If a dome is used for protecting a radiolocation station (RLS) of a rocket of the land – air class, then during storage and operation it is subjected to cyclic action of temperature from –60 to +60°C, loaded during shipment and loading during application for its main purpose, and at the same time domes of the air – air class are additionally subjected to such action during operation on a suspender of vibrodynamic loads and cyclic change in temperature during flight and landing of a carrier, and during combined flight. The heating temperature of a rocket dome, installed on a on a prospective carrier, exceeds 250°C during combined flight.

In analyzing the whole set of requirements, laid down for contemporary rocket antenna domes and by separating their contradictory nature, it is necessary to study them individually for each specific dome during creation of its structure and manufacturing technology.

One of the main problems in creating domes is choice of materials for their development for specific dome operating conditions.

MATERIALS AND METHODS

From a whole variety of structural materials for manufacturing aircraft fiberglass-reinforced plastic should be isolated, i.e., composite materials (CM) based on inorganic orientated quartz fiber, glass, and silica fillers, used extensively within structural assemblies of aircraft and rocket engineering. For a new generation of aircraft, rockets, and engines use of fiberglass-reinforced plastic makes it possible to reduce object weight considerably, and this means to increase fuel efficiency of aircraft and increase useful load.

Fiberglass-reinforced plastics are one of the main widespread composite materials combining high strength, low density, good dielectric properties, and acceptable cost. Use of different combinations of reinforcing and binder components makes it possible to create materials with a range of controllable properties, and this predetermines the considerable variety of fiberglass-reinforced plastic spheres of application. In particular, fiberglass-reinforced plastics are used extensively both within Russia and overseas for manufacturing RPD and open directly transmitting electronic complexes for aerospace, marine, and overland technology for civil and special purposes [1 – 3].

A set of contrary requirements is laid down for radioparent objects (RPO) made from fiberglass-reinforced plastics. RPO should exhibit primarily prescribed electronic properties, on which depend operating distance, accuracy, and reliability of radiolocation equipment, and means of communication. Simultaneously RPO should be quite stable and protect antennae and radiolocation equipment beneath them reliably from external action (force, climatic, etc.) over the extent of a whole operating period.

Currently epoxy, phenol, organosilicon, polyimide, and polyester binders are used most widely in manufacturing RPO (RPD), in the main GNTs RF VIAM developments [1, 4].

Binders based on epoxy resins occupy a leading place in production of objects for electronic purposes. Epoxy polymers exhibit good mechanical and dielectric properties under normal conditions and maintain them with an increased moisture content and action of other climatic factors. Today ONPP Tekhnologiya has considerable experience in the production of RPO from composite materials based on epoxy binder type ÉDT-10 (Fig. 1) for use as closed and head domes for rocket complexes (primarily antiship and marine based).

Silicate foam plastics (SF) and silicate polymer CM, consisting of cloth and hollow spherical fillers within a polymer matrix, are a promising radioparent polymer CM.

Microsphere glass textolites have a series of production advantages in the manufacture of single-layer and multilayer structures. An important advantage is the possibility of their preparation in one operation at low pressure in rigid dies or by vacuum and autoclave molding. Precise wall thickness is provided. The objects obtained with low weight exhibit good strength and stiffness indices, are reliable in operation, and provide good dielectric properties. In OAO ONPP Tekhnologiya a composition of silicate glass prepreg and technology for preparing it have been developed. The material obtained of the SSPR type exhibits low density (1.0 – 1.4 g/cm^3) combined with dielectric properties varying over a wide range (dielectric permittivity 1.5 – 3.0, dielectric loss angle (100 – 140)$\cdot 10^{-4}$).

These materials are promising for manufacturing large radioparent (multilayer) structures for land- and sea-based aircraft, since they make it possible weight, improve electronic properties, and increase operating reliability.

Phenolformaldehyde (phenol aldehyde, phenolic) resins are used for manufacturing fiberglass-reinforced plastics for electronic purposes of the FNst.kv type due to low cost and satisfactory physicomechanical properties. Fiberglass-reinforced plastic based on phenolformaldehyde binder is classified as heat resistant, exhibiting good strength properties and capacity to operate for a long time at temperatures reaching 350 – 400°C. However, for all of the increasing specifications for objects, in particular for developed RPO, operating under rapid heating conditions up to 800 – 1000°C, existing forms of heat-resistant binders are unsatisfactory.

A method has been developed in ONPP Tekhnologiya for improving heat resistance (retention of a high level of mechanical properties at elevated temperature) and structural stiffness of an object by additional impregnation with organosilicon resin followed by polymerization. The method has made it possible to increase object heat resistance made from fiberglass-reinforced plastic operating under rapid heating conditions, with retention of good strength properties and dielectric characteristics up to 1000°C (short term) [5].

Highly heat-resistant organosilicon resins are used for additional impregnation: products of the MFSS and TMFT types. The MFSS-8 (methyl phenyl spirosiloxane) product is an oligomer with molecular weight of 2200 produced in the form of an acetone solution with density of 0.91 – 0.97 g/cm^3, it does not contain functional groups, and hardens without addition other substances. The MFSS-8 product is a typical representative of polyorganosiloxanes of spirocyclic structure. The TMFT product (tetrax (methylphenylsiloxanhroxy) – titanium) is a crosswise structure polymer with a high degree of resistance to thermal and thermal oxidation destruction.

In order to retain good physicotechnical property indices and operating reliability elements of thermally loaded structures during operation it is necessary to employ CM capable of operating in the range 600 – 800°C for a long time, and short-term at 1200°C. A solution of this problem is use of inorganic binder, for example phosphate binders. Phosphate binders are aqueous solutions of phosphoric acid salts. A special place among various phosphate binders is occupied by aluminochromophosphate. Due to a high melting temperature aluminum phosphates based upon it make it possible to prepare objects for service up to an environmental temperature of about 1500°C.

In ONPP Tekhnologiya vacuum and contact molding methods are used to produce composite material KhAFSkv based on inorganic (aluminochromophosphate) binder and textured cloth filler.

Experiments have shown that material based on silica or quartz cloths and inorganic binder (phosphate, aluminochromophosphate) have a high strength level, improved impact strength, low linear thermal expansion coefficient, exhibit stable thermophysical properties at high temperature, and retain dielectric properties under elevated temperature conditions.

In various branches of industry, particularly in the aircraft industry, shipbuilding, rocket construction, an civil building, there is extensive use of structures with a filler (integral structures). They exhibit as a rule good stiffness parameters, specific strength, vibration resistance, good heat and sound insulation properties, and special properties (radioparency of structures made from dielectric materials). Supporting layers, secured by a filler, absorb high compressive stresses, sometimes exceeding a material elastic limit.

Depending on operating conditions of thermally loaded structures it is promising to manufacture them from thermally stable composite material (reinforced plastics), for example based on epoxy, polyimide, organosilicon, and inorganic binders. In view of a specific field of application as a reinforcing filler it is necessary to use quartz glass cloth, since materials based upon it are most radioparent and heat resistant.

In the course of work within ONPP Tekhnologiya several different forms of multilayer structures have been developed. The first version of a multilayer structure is a test specimen, whose facing was made from composite material, and a central layer of fiberglass-reinforced plastic type SSP (honeycomb filler base on electric insulating cloth and bakelite lacquer). The second version of structures was a model whose facing was made from composite material, and a central layer of heat insulation material based on silica, alumina, or basalt fibers grades ATM or VR-300.

RESULTS AND METHODS

As already noted, the operating heat resistance of phenol and pheloformaldehyde (for example, type FN-A) resins is not very good, although they have a marked advantage over other thermosetting binders, i.e., high coke residue, 50 – 60%. This provides application of phenol resins and composite materials based upon them in objects for important ablation resistance, primarily in objects for rocket purposes. A challenging area for improving CM operating properties is modification (impregnation) of pheloformaldehyde fiberglass-reinforced plastics with organosilicon oligomers (MFSS-8, TMFT). It is possible to increase values of such physicotechnical properties as moisture resistance, impact strength, and heat resistance. ONPP Tekhnologiya has made quite significant progress in this field.

A dependence is presented in Fig. 2 for ultimate strength in bending on temperature for fiberglass-reinforced plastic FNst.kv without treatment, and also impregnated with MFSS-8 followed by heat treatment.

A production operation of additional impregnation with oligomer MFSS-8 was implemented in developing a number of objects within the scope of test structural work, and this made it possible to raise heat resistance (retention of struc-

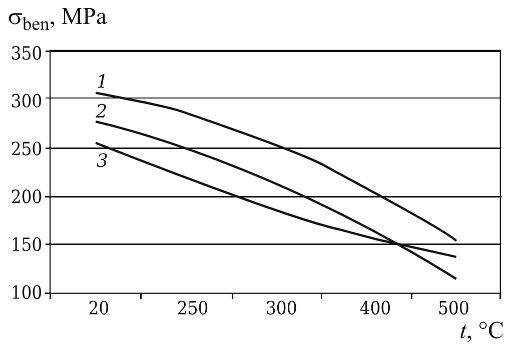

Fig. 2. Dependence of ultimate strength in bending σ_{ben} of FNst.kv glass-reinforced plastic (*1*) and FNst.kv glass-reinforced plastic impregnated with MFSS-8 product followed by heat treatment at 250 (*2*) and 320°C (*3*) on temperature *t*.

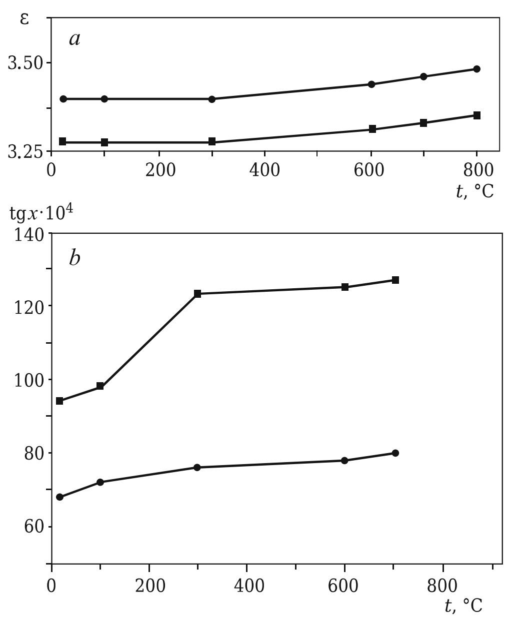

Fig. 3. Change in dielectric permittivity ε (*a*) and dielectric loss tangent $tgx \times 10^4$ (*b*) for materials grades KhAFSkv-1 (■) and KhAFSkv-2 (●) under action of temperature *t*.

tural stiffness at elevated temperature) of objects up to engineering specifications.

Results of studies have shown good operating reliability in the elevated temperature zone for a new composite material KhAFSkv developed in ONPP Tekhnologiya. It has been shown by experiments that composite material based on silica or high strength quartz cloths and inorganic binder (phosphate aluminochromophosphate) have a high strength level, increased impact resistance, low linear thermal expansion coefficient, exhibit stable thermophysical properties at elevated temperature, and retain dielectric properties under elevated temperature conditions.

Heat resistance of the specimens obtained exceeded 1200°C (test method GOST 9.715). The change in dielectric

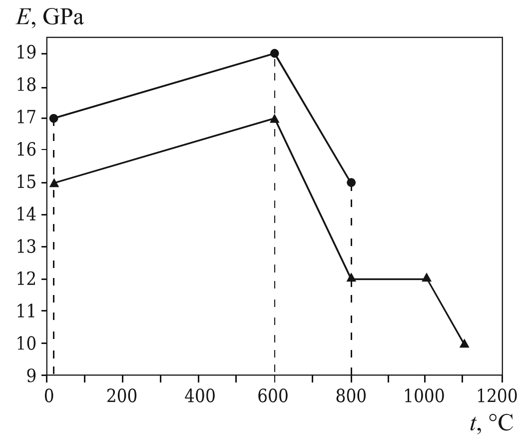

Fig. 4. Change in static elasticity modulus *E* in bending for material grades KhAFSkv-1 (▲) and KhAFSkv-2 (●) under action of temperature *t*.

parameters in the range 20 – 800°C does not exceed 5% with a frequency of ~10^{10} Hz (Fig. 3).

After additional impregnation with MFSS-8 material KhAFSkv-2 demonstrated better mechanical properties in the range 20 – 800°C compared with KhAFSkv-1 material (Fig. 4), and this makes it possible to use it in structures for prolonged operation under high loading and elevated temperature conditions.

Studies of CM mechanical properties were carried out according to GOST 4561 and GOST 4648 in IR and LMF-50 type units, and elasticity modulus was calculated according to GOST 9550. CM dielectric properties were studied by the composite resonator procedure PM 596.1549–2002 developed in ONPP Tekhnologiya.

The multilayer composite materials developed make it possible to use a unique possibility, i.e., to vary dielectric permittivity of a central layer from 1.5 to 3.5 (frequency 10^{10} Hz) depending on structural purpose. CM have satisfactory strength properties in the elevated temperature range. The multilayer materials obtained also exhibit significantly lower average density than similar single-layer material, which makes it possible to reduce structure weight as a whole to a considerable extent. In addition, the material exhibits excellent thermophysical properties, which make it possible to use it in heat insulating elements of structures. In the course of tests, approaching object operating conditions, it was possible to reduce the temperature acting on a functional element within an aircraft structure by up to 100°C with an environmental temperature at a frontal surface of about 1200°C. A model of similar heatproof screen is presented in Fig. 5.

Composite material KhAFSkv may be used in thermally loaded objects and structures of for electronic purposes, operating at temperature from -60 to +800°C for a long time, and up to 1200°C for a short time in aviation, space, and other fields of special engineering.

Fig. 5. Model of three-layer heat-shield screen made from inorganic glass-reinforced plastic.

CONCLUSION

Currently within Russia and overseas industrial production is being assimilated for a broad range of heat-resistant composite materials.

Use of new structural functional composite materials in aircraft assemblies instead of metals makes it possible not only to reduce the overall weight of a structure by 30 – 35%, but also improve considerably operating reliability compared with material based on epoxy binders. It is promising to use heat-resistant thermosetting binders and materials based on them for manufacturing friction assemblies, requiring lubricants, and as high-temperature heat insulation of critically important aerospace technology elements.

Of no less value are developments of polymer materials for structural purposes, including for shipbuilding. In the field of application at high temperature of thermosetting binders there are power supply systems for underwater and surface vessels, marine power installations, and drilling platforms, with increased reliability of improved operating life, creation of new equipment, and ship fireproof structures for reducing the risk of occurrence of unexpected situations.

In ONPP Tekhnologiya theoretical and experimental work has been carried and optimum structures have been determined for the walls of antenna radomes made of CM taking account of a set of operating properties in an aircraft, providing creation of broadband radiolocation systems with structural strength improved by not less than 10%; choice of optimum production method and manufacturing has been made for complex shaped aircraft radomes, including those based on integral multilayer structures of radioparent CM, providing a reduction in scatter of the main physico-mechanical and dielectric properties of material by not less than 10%.

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