Creation and Non-Destructive Control of Electric Heating Elements of the Aircraft Icing Prevention System

Mykhail Leonidovych Kazakevych ¹, Oleksandr I. Semenets ², Volodymyr M. Kazakevych ¹, Andrei S. Kondratyuk ¹, Oleksandr O. Chirva ², Oleksyi O. Shestakov ², Grigoryi A. Kutko ²

¹State Enterprise “KOLORAN“ LV Pisarhevsky Institute of Physical Chemistry of NAS of Ukraine. 03028, pr.Nauki,31, Kyiv, Ukraine, e-mail: kazakevich.m@gmail.com
² ANTONOV COMPANY, st.Tupoleva, 1, Kyiv, Ukraine, e-mail: info@antonov.com

Abstract: One of the priority directions of searching for new materials and testing methods in aviation is the development of conductive composition and manufacturing of heating elements (HE) for the electrothermal anti-icing system of aircraft and their nondestructive control. Using of polymer materials with nanotubes, as well as graphene-based heaters, have low weight, fast and uniform heating, and efficient energy consumption. Conducted research using a scanning electron microscope (SEM) to optimize the composition of carbon fillers (graphene and carbon nanotubes) in composite materials for creating electrically conductive anti-icing elements of aircraft structures. One of the most important instrumental methods of technical diagnostics of potentially dangerous objects is remote infrared (IR) thermal imaging diagnostics based on the registration of the temperature field. The principle of thermal diagnostics is based on the comparison of the thermal fields of the reference and the monitored object. Temperature anomalies are indicators of defects, and the value of temperature signals and their behavior over time makes it possible to give quantitative estimates of the object's parameters. Namely, with the help of thermal imagers, non-destructive thermal control is carried out not only of propeller screws. panels of rockets and airplanes, but can also be offered to assess the quality of HE. They detect defects. cracks, structural changes, water infiltration sites and ice jams.

Keywords: Visual and Heat Inspection; Composites; Anti-icing System for Aircraft
CREATION AND NON-DESTRUCTIVE CONTROL OF ELECTRIC HEATING ELEMENTS OF THE AIRCRAFT ICING PREVENTION SYSTEM

Mykhail KAZAKEVICH

SE “KOLORAN” LV Pisarzhevsky Institute of Physical Chemistry of NAS of Ukraine
State Enterprise ANTONOV, Ukraine
Main Zones of protection against icing: the windshield of the crew cabin 1, wing tips 4, air intakes 5, tail fin tips 6.

- Risk optimization is one of the main problems today in all areas, especially in aviation.
Aircraft icing is a phenomenon that creates significant problems for flight safety. Because aircraft are operated in cold atmospheric conditions, they are prone to ice accumulation on various surfaces. Such ice formation can seriously affect the aerodynamic characteristics and controllability of the aircraft.

The relevance of this meteorological phenomenon is confirmed by statistical data. According to the statistics of the International Civil Aviation Organization (ICAO), since 2020, the frequency of aviation accidents is 3.2 per million flights and continues to decrease, nevertheless, annually, 7% of all air accidents occur due to icing.

An example of icing on the aircraft wing leads to a violation of the uniform flow of air and deterioration of the aerodynamic characteristics of the surfaces of the aircraft, which significantly affects flight safety.
• Compared to the current state-of-the-art systems, conductive heating elements (hereinafter HE) based on polymer materials using nanotubes, as well as heaters with graphene, are characterized by low weight, fast and uniform heating, and efficient energy consumption compared to previous metal heating systems.

• Various new carbon nanomaterials, including electrically conductive composites with carbon nanotubes and graphene, have been studied as heating elements in the literature. Nanotubes have a very high tensile strength. Instead of tearing or breaking, the CNT begins to rearrange its molecular orbitals, adapting to a new shape (becoming more elongated, compressed, or bent).

The Scheme of electrothermal • The authors have developed a multi-layer coating "ETM-
EMKAN" with an optimal content of carbon nanomaterials, which will allow to effectively implement the technology of protecting aircraft structures from icing. The multilayer coating contains a first ground layer of electrical insulating material (anti-corrosion ground) and a heat-generating layer, which contains a polymer base, a heat-conducting dielectric, a reinforcing base and carbon nanomaterials connected to the output contacts, a second ground layer of electrical insulating material and a layer of aviation paint.

• The dependence of heating of carbon nanotube composites depending on the heat flux density and current power was analyzed. Optimum indicators have been identified. The surface temperature of the graphene film can be easily controlled by changing the power consumption. The
proposed strategy can be a significant progress in the implementation of energy-saving structures in the field of air transport.
SEM of carbon nanotubes deposited from a dispersion in ethyl acetate on a metal substrate at different scales

- In figure shows typical SEM image of carbon nanotubes deposited from a dispersion in ethyl acetate on a metal substrate.

- On the image you can see a continuous layer formed by entangled nanotubes. In the image on the scale of hundreds of micrometers, a discontinuous structure with large aggregates that form a grid with cavities up to hundreds of microns in size is observed. This effect is explained by the aggregation of nanotubes due to the interaction of functional groups on their surface.
TEM of carbon nanotubes deposited from a dispersion in ethyl acetate on a metal substrate at different scales.

- Also, the morphology of the obtained material was investigated by transmission electron microscopy (TEM). Analysis of microphotographs...
made it possible to establish that CNTs are sufficiently distributed in the polymer matrix evenly, forming a continuous conductive network that provides highfunctional characteristics of this material.
Thermogram of the heating element with the content of carbon nanotubes:

- To determine the value of the specific heat flux, an electric voltage of 115V was applied to the contacts of the sample. Use the Flir TG267 thermal imager to control the temperature on the surface of the sample. After the surface temperature reached constant values, the amount of electric power consumed was determined with a Keweisi KWSAC300 multimeter. The value of the specific heat flow is calculated by dividing the value of the electric power (90.6 W) by the surface area of the sample, which is covered by "ETM EMKAN" and is equal to 74 mm x 12 mm x 6 = 5.31 x 10^{-3} m². The specific heat value for this sample is 1.7 W/cm². The electrical resistance of the
experimental sample, which underwent thermal tests, is 145 Ω.

**Thermal imager indicators**

- This composite of carbon nanotubes "ETM EMKAN" is a modern and profitable replacement of anti-icing systems known to us: it reduces the mass of avia construction, is more economical, transparent for RF diagnostics, easy to use and maintain.
- The obtained results of testing the experimental sample also allow monitoring compliance with the quality requirements.
- **The non-destructive methods of control** of constructions from composite materials have special features. The purpose of non-destructive testing methods is to determine and measure deviations from the norm of material properties, to identify its hidden defects without destroying the sample or the product as a whole. Thus, the thermal control and visual methods are main.
The improvement of surface methods of non-destructive control of structures (PT, MPI, SEM and thermal) involves the use of a scientific complex approach that takes into account the properties of the controlled surfaces and means of flaw detection. The synthesis of environmentally safe penetrants and new materials, including the use of nanoparticles, dramatically expands the effectiveness and scope of testing methods.

So, for example, the use of transition metal compounds allows to fundamentally change the technology of searching for surface microdefects with the help of variable electromagnetic fields and to detect damage to magnetic and non-magnetic materials. The application of combined capillaryfield methods makes it possible to study the topology of microdefects and analyze hidden damage to structures in aviation.

A vivid example of non-traditional approaches to the development of surface flaw detection methods is the use of magnetic fluids with nanoparticles for magnetic powder flaw detection and new physicochemical phenomena such as the complex ultrasonic capillary effect developed by the authors earlier.
Conclusions

Conductive composite films must be extremely strong with good adhesion to the heated surface, such a film must be light and cheap, with physical characteristics that allow it to cover large curved surfaces.

The principle of thermal diagnostics uses a comparison of the thermal fields of the reference and the monitored object. Temperature anomalies are indicators of defects, and the value of temperature signals and their behavior over time makes it possible to give quantitative estimates of the object's parameters. That is why, with the help of thermal imaging devices, the main part of non-destructive quality control of HE is carried out. It allows you to detect such defects as density, cracks, structural changes, places of water infiltration and ice jams.

The mentioned new strategies based on nanostructured forms of carbon appear to be very promising for providing effective properties to anti-icing systems. The developed technology provides an anti-icing system for aircraft, which can be an integral part of aeronavigation panels, and therefore the structure of the aircraft.

Thus, the construction of heating elements, their optimized composition and methods of nondestructive testing are proposed in the work.
Thank YOU for attention

The report describes the results of investigations, conducted in the test laboratory of SE “KOLORAN” IPC named by L. V. Pisarzhevskiy NAS of Ukraine and in SE "ANTONOV".

kazakevich.m@gmail.com
Tel. WhatsApp, Viber +38 050 386 43 11