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Methods and key features of climatic tests of aircraft composite structures

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Abstract. This article discusses the methods and key features of conducting climate tests of aircraft products made of polymer composite. The performance characteristics of composite structures are affected by operating temperatures and moisture saturation. In the course of accelerated moisture saturation in climate chambers and subsequent tests, monitoring and forecasting of moisture content levels requires, in some cases, computational studies. Moreover, the diffusion characteristics of composites used in calculations often require experimental determination.

1 Introduction

Over the past few decades, the share of composites in aircraft structures has been steadily increasing. Composites differ significantly from classical materials in a number of characteristics and properties. In particular, the structure temperature and moisture content can significantly reduce the mechanical and strength characteristics of composite structures. For most modern carbon plastics, the increased moisture content and high temperatures lead to a reversible decrease in performance. Polymer components of composite materials (in particular, with binders based on various resins) have the ability to absorb moisture from the environment. The diffusion of moisture into the composite causes it to swell and acts on the matrix as a plasticizer or softener. Climatic strength certification tests are designed to confirm the reliability of the structure, including when exposed to the above-mentioned climatic factors. Since the tests must take into account the effects of climatic factors over the entire service life of the aircraft, the duration of such tests is calculated in years. In order to reduce this time, methods of accelerated testing of polymer composite structures are used.

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2 Climatic tests

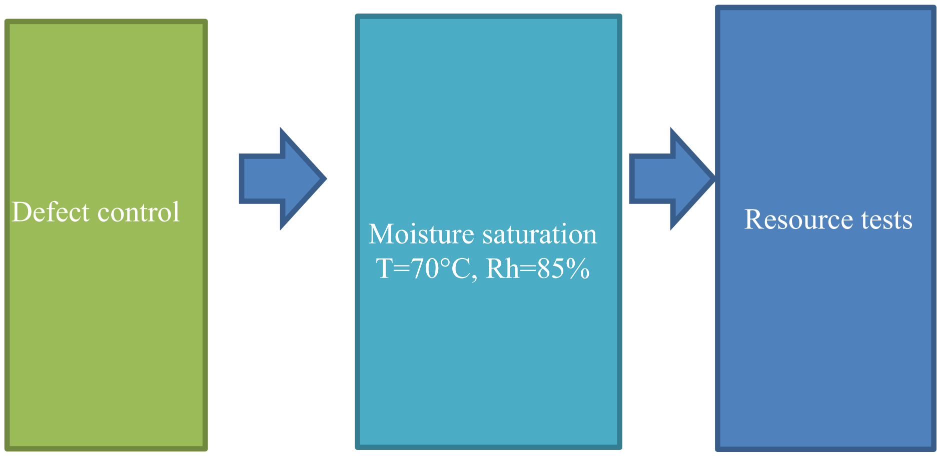

Fig. 1. Approximate view of the program of static climatic and strength tests of aggregates made of composite materials of passenger aircraft.

The temperature of static testing is determined from the operating conditions in areas with low average daily temperatures and the maximum equilibrium temperature determined from the heat balance condition when parked at the airfield during the hottest time of day.

Accelerated moisture saturation is carried out in climate chambers at a temperature of 70°C and humidity of 85%. Accelerated moisture saturation allows you to achieve a moisture level in structures that corresponds to the maximum real saturation during operation. Regular monitoring of moisture content is carried out by weighing the witness samples on analytical scales. The witness samples are kept under the same conditions as the structures during the entire period of accelerated moisture saturation. Moisture saturation is carried out until the structure reaches a state of equilibrium. The time to reach the equilibrium state depends on the diffusion properties of the material and the thickness.

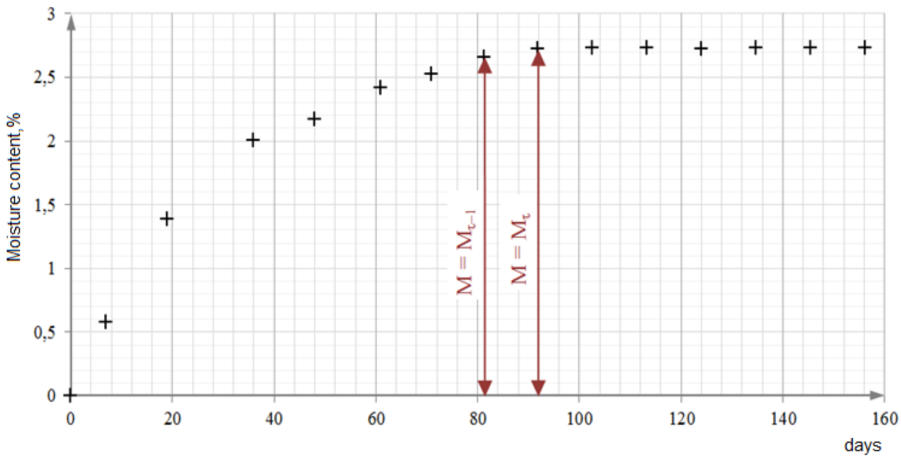

Fig. 2. Results of mass gain measurements by witness samples.

Criterion of equilibrium moisture saturation:

$$|M_\tau - M_{\tau-1}| < 0{,}01\% \quad (1)$$

To be able to predict the moisture set, the time to reach the equilibrium state, and the amount of moisture, it is necessary to determine the diffusion properties of the material, such as the diffusion coefficients and the maximum moisture capacity. The measurement of diffusion characteristics is based on the analysis of the initial section of the curve of the dependence of moisture content on the duration of saturation. At the next stage, the diffusion characteristics of the material are generalized to the entire spectrum of environmental conditions. It is assumed that the diffusion coefficient depends on the water saturation temperature according to the Arrhenius law:

$$D(T) = D_0 \exp\left(-\frac{E_a}{RT}\right) \quad (2)$$

The maximum moisture content, on the contrary, does not depend on the temperature of moisture saturation, but depends on the humidity of the air φ:

$$M_\infty = M_{max}\left(\frac{\varphi}{100\%}\right)^b \quad (3)$$

Based on the research results, the dependence of the diffusionx characteristics of the material on the parameters of the medium is derived.

When conducting testsк, the water content control is determined by the technical task. A decrease in the moisture content is observed when the units are removed from the climate chamber for monitoring and loading and is associated with a relatively low humidity of the surrounding air. Composite power structures are characterized by developed flat areas. Based on the fact that the diffusion coefficient in the sheet plane is an order of magnitude lower than the value in the transverse direction, it makes it possible to reduce the complex problem of calculating spatial moisture transfer in a structure to calculations of moisture saturation in individual flat elements. In this case, to predict the moisture distribution in the structure, we apply the second method for the one-dimensional case:

$$\frac{\partial c}{\partial t} = D\frac{\partial^2 c}{\partial z^2} \quad (4)$$

The one-dimensional law applies separately for each structural element with a regular thickness. The average moisture content in the volume of the structure is determined taking into account the weight fractions of various elements. To perform numerical calculations, it is necessary to have the parameters of the environment in which the units were located from the moment of manufacture or from the moment of a known moisture distribution. Environmental parameters include the temperature and humidity of the surrounding air, as well as the temperature of structures, if it is different from the ambient temperature.

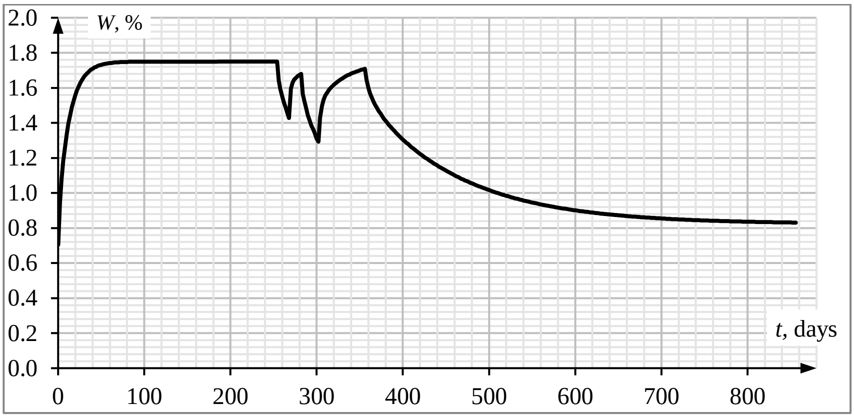

Fig. 3. An example of calculating the moisture content curve in the process of climatic strength tests of the unit.

Individual humidity and temperature sensors are used to determine the parameters of the environment surrounding the unit.

Relatively recently, tests have been conducted to saturate PCM products with aviation fuel. Products are placed in a tank filled with aviation kerosene.

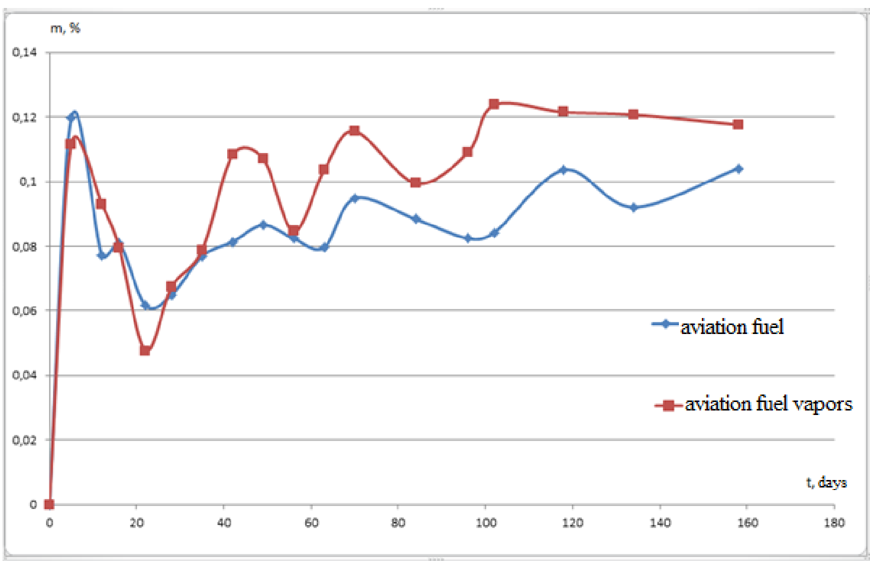

Fig. 4. Graph of mass gain by witness samples under kerosene saturation.

A special feature of kerosene saturation is a sharp weight gain in the first few days, followed by a drop in the following days. Further, the mass gain is described by Fick's law. Currently, the authors of the article are working on modifying the Fick equation to describe the entire fuel saturation process. It should be noted that the maximum weight gain when saturated with kerosene is several times less than when accelerated moisture saturation of similar products.

3 Conclusion

When conducting climate tests, it is necessary and necessary to determine the diffusion

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properties of the material and the ability to track the amount of moisture in the products during the test process. The methods presented in the article allow us to successfully solve these problems. It should also be noted that, with some modifications, they are also applicable to aviation fuel saturation tests. Further development of the ideas described in the article should include:

- addition and expansion of analytical calculation capabilities for saturation processes
- research of aviation fuel saturation issues.

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