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Opinion
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Physical and Mechanical Properties of Epoxy Carbon Plastic During Ageing in A Moderate Climate

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Abstract

This experimental study provides an account of how storage duration (5 years, 10 years) affects both physical and mechanical properties of carbon plastic on epoxy base used in high-temperature applications. Storage duration was varied under changing temperature regimes. Accelerated climate testing showed that strengthening of the composite occurs, accompanied by a drastic difference in temperature deformation of composite samples as compared to an initial state. Anisotropy of composite material is considered.

Keywords: Carbon Plastic; Epoxy resin; Temperature Deformation; Fairing; Carbon Fibers; Thermal Deformation

Opinion

Use of composite materials reinforced with carbon fibers in missile technologies (inter-stage compartments, shells, fairings, plumage, wings, etc.) is defined by a possibility to reduce mass in increasing strength of the structure of a flying vehicle (FV). A head fairing (HF) is designed for protection from aerodynamic and thermal loads in going through dense atmospheric layers, in transporting to a launch pad and keeping FV on it as well. HF is a rotational body consisting of a front double conical part and a cylindrical part. HF consists of two identical leafs connected by mechanical locks along a longitudinal joint. As carrying fairing skins (FV) structures from a unidirectional carbon plastic based on epoxy binder are used. A distinctive peculiarity of composites based on epoxy resin is a possibility to vary physical and mechanical properties widely (filling, different physical actions). Realization of these opportunities in different carrying structures brings to decrease of mass, expansion of temperature interval of maintenance, improving characteristics related to reliability and durability [1,2]. This paper demonstrates results of experimental study of physical and chemical properties of epoxy carbon plastics vs. temperature while varying a storage term under atmospheric exposure. Matrix in a considered carbon plastic is epoxy resin – a thermo-reactive polymer with cross-sectional link, polymer chains in it are connected to each other in the solidification process and form a three-dimensional grid [3].

The filler in a carbon plastic are stripes made of carbon fibers. From the known, carbon fibers have the largest values of specific strength and rigidity. Peculiarity of operation of polymer CM at high temperatures is that in heating their physical and chemical transformations occur, with thermo-reactive matrix transforming into a sponge-like composition consisting of coke strengthened by fibers. This new material is essentially different from the original one, and transformation from one state to the other goes on continuously [4,5]. In heating up above the Debye temperature, when specific thermal capacity becomes independent on temperature, in a uniaxial stressed state for long prismatic samples there holds a thermodynamic relation [6]:

$$\alpha^2 = \frac{c_\sigma - c_\varepsilon}{TE}$$

where α coefficient of linear thermal expansion (compression), c_s, c_e specific heat capacitances at constant stress and deformation respectively; E-elasticity module. In heating, parameters a, c_s, and E are changing with rates proportional to the rates of chemical reactions, while the connection between them remains constant. We implemented an experimental study of both thermal deformation and strength of a typical carbon plastic on an epoxy base (CPE), depending on duration of action of natural factors in storage under exposure to external conditions. Testing is

made for three steps of accelerated climate testing (ACT), imitating the following durations of the component storage:

- 1st step – initial state
- 2nd step – 5 years of storage
- 3rd step – 10 years of storage under given climate conditions.

Samples of dimensions 1x10x60 mm were cut from natural covers of the head fairings.

Heating rate of samples up to the temperature of 210^{0}C in an oxidizing gaseous medium were: 10, 20, 400^{0}C/min for a 10 min exposure. Cooling of samples is unconstrained, along with a water-cooled, closed chamber [7,8]. Results of experimental study of thermal deformation of carbon plastic reinforced with carbon stripe along the base [0^0] are presented on (Figure 1), along the weft – on (Figure 2).

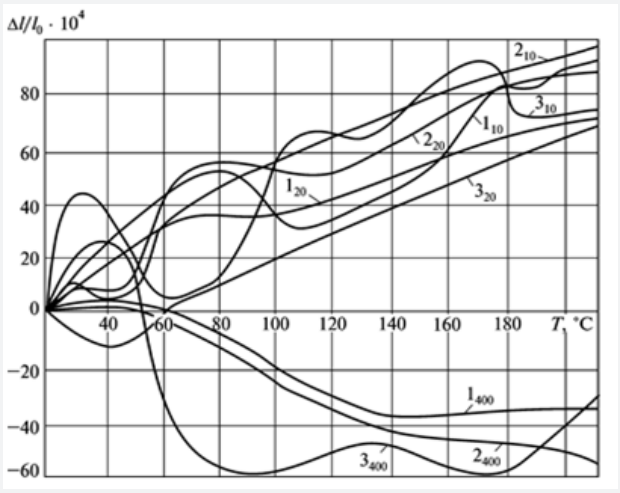

Figure 1: Dependence of the relative thermal deformation CPE in the direction of the base [00] on temperature (numbers next to the curves – numbers of steps and a heating rate).

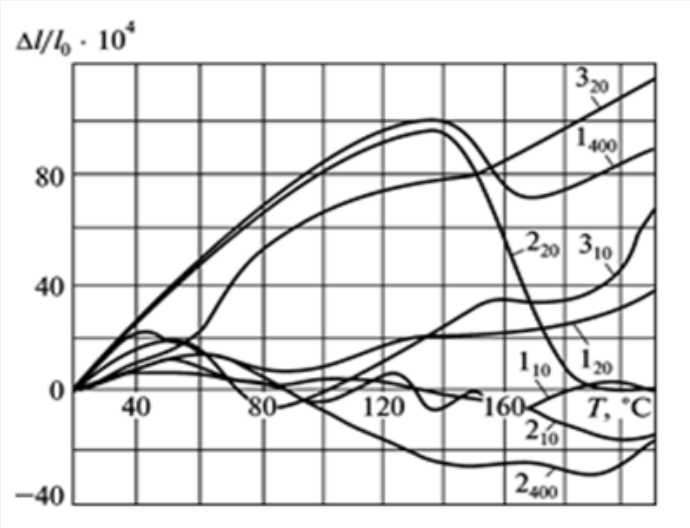

Figure 2: Dependence of the relative thermal deformation of carbon plastic in the direction of weft of the filler [900] on temperature

On all figures, in the dependencies of the relative thermal deformation on temperature some designations are accepted: numbers next to the curves – numbers of steps of climate testing and the heating rates of the samples, ^{0}C/min. Values of thermal deformation of the composite in the direction of the base in the initial state, before storage (1st step), are characterized by expansion in heating up to 210^{0}C and shrinkage in cooling, are more essential when a heating rate was lower. The curve of temperature expansion of the material at 10^{0}C/min has poly-extreme sign-changeable character with max σ_B and min $\frac{\Delta l}{l_0} = -9 \times 10^{-4}$

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. Increase of the heating rate brings to the increase of temperature expansion in heating, and to decrease of its shrinkage in cooling.

Temperature deformation of samples CPE after 5 years of storage (2nd step) is drastically different from that in the initial state. At a final in our case temperature 210^{0}C, shrinkage is found for all the heating rates of the samples in cooling down to room temperatures. Amplitude of the change of temperature expansion-shrinkage CPE along the base for the 2nd step is 43×10^{-4}. For the 3rd step (10 years of storage), the range of values of temperature expansion-shrinkage is of the order of magnitude larger than shrinkage of the 2nd step, and almost three times as large as the level of maximal values for thermal expansion for the 2nd step. Maximal and minimal values of CPE in the direction of base are presented in (Table 1), where A – amplitude values of thermal deformation obtained for each heating rate. Change of thermal deformation of carbon plastic CPE vs. temperature along the base and weft [0^0, 90^0] has typical for thermo-reactive resins poly-extreme character with a distinct dependence on the heating rate. A qualitative difference in curves $\frac{\Delta l}{l}=f(T)$ shown on (Figure 1), demonstrates the difference of adhesion interaction of the epoxy binder with the filler before and after ageing. Due to difference in sign, coefficients of linear thermal expansion (for the binder – positive, for the carbon filler – negative [9]), in increasing the temperature there are two competitive processes – expansion and shrinkage. Destruction of adhesion bonds worsens interaction of the filler with the binder, and for the aged samples, cut along the direction of reinforcement, causes shrinkage.

Table 1: Maximal and minimal values of thermal deformation of carbon plastic CPE in the direction of the base.

Step number	Value	$\frac{\Delta l}{l_0}\cdot 10^4$ under heating rate of (°C/min)		
		10	20	400
1	Max	14	40	90
	Min	–12	0	0
	A_1	26	40	90
2	Max	24	85	13
	Min	–19	0	–28
	A_2	43	85	41
3	Max	70	110	—
	Min	–17	0	—
	A_3	87	110	—

Maximal values of thermal deformation CPE along the weft [90^0] for a heating rate $V_h = 10^0C/min$ is large compared to those for the base of the order of magnitude, for $V_h = 20^0C/min$ – five times as large, for $V_h = 400^0C/min$ – practically do not change. Extreme values of thermal deformation of carbon plastic CPE in the direction of the weft are shown in (Table 2). Changes of both physical and mechanical properties of CPE vs. duration of its storage are shown on (Figure 3). Curves 1-3 show change of amplitude values of a thermal deformation in the range 20-210-20^{0}C. For studied heating rates, there is an increase of values of an amplitude of thermal deformation after five years of storage (2nd step). Curves 4-6 show the change in mechanical characteristics of CPE – destructive stress σ_B and elasticity module E in stretching under normal temperatures. From graphs the smallest value of σ_b and E in stretching are characteristic for the 1st step of the component storage (1 year), then follows strengthening of UPE (5 years). Data for the 3rd step of storage (10 years) are compatible, within the error spread, with those for the second step CPE [10].

A performed multi-factor study of physical and mechanical properties of carbon plastic on epoxy base, used as a carrying surface of head fairings depending on storage duration in changing temperature regimes, considering anisotropy of the composite, showed:

i. amplitude values of thermal deformation in the temperature range 20 – 210 -20^{0}C are increasing on five years and are decreasing to an initial state after 10 years of FV storage.

ii. decrease in heating rate of a carbon plastic (from 400 down to 10^{0}C/min) brings to a multiple increase of anisotropy of its thermal deformation [72].

iii. change of elastic properties of epoxy carbon plastic in ageing is due to, mainly, to joint processes of solidification (stitching) and destruction of the binder.

iv. sorption of water in the epoxy binder increases processes of solidification, due to this shrinkage is minimal for carbon plastic after 10-year storage as destruction processes slow down.

v. we established that after 5 and 10 years of storage (2nd and 3rd steps of Accelerated Climate Testing) occurs strengthening of the composite: destructive stress σ_B and elasticity module E in stretching under normal temperature increase both in the direction of the base and in the direction of weft.

with an increase in temperature up to 160^{0}C, the strength limit of the carbon plastic in stretching, in the direction of samples cuts of 0 and 90° is decreasing about 1.7x – 2.0x, while the elasticity module is practically unchanged.

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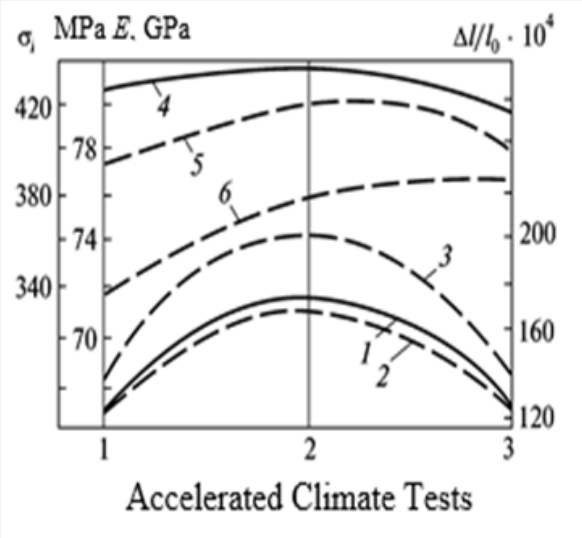

Figure 3: Change of physical and mechanical characteristics of CPE in increase of duration of storage (continuous curves – direction of the base, dashed – direction of weft).

Table 2: Maximal and minimal values of thermal deformation of carbon plastic CPE in the direction of weft.

Step number	Value	under heating rate of (°C/min)		
		10	20	400
1	Max	93	71	4
	Min	0	0	–40
	A_1	93	71	44
2	Max	95	89	2
	Min	0	0	–52
	A_2	95	89	54
3	Max	93	68	28
	Min	0	10	–60
	A_3	93	78	88

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