UDC 539.412

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Influence of working environment on strength properties of fibrous shell structures by taking into account a temperature

Degradation of mechanical properties of composite materials, typical for the aviation industry, under influence of working environment and temperature taking into account geometrical sizes and type of fiber reinforcement is studied.

Thermoset and thermoplastic composites are widely used in aviation and airspace industry [1].

During the operation, composite structures are exposed to external environment. It shows itself in contact with liquids with mineral salts (rain water), oils (hydraulic fluid AMG10 typically) and in influence of temperature fields. Temperature and fluids impair the carrying capacity of structures [2]. Frequent contact with the liquid reduces strength limit and elasticity modulus of the plastics after a certain time [3, 4]. Resulting effect may be irreversible [5] and create a damaged area in the part.

A series of studies were carried out to study the influence of fluid: determination of strength limit and elasticity modulus changing at the conditioning in liquid, determination of strength limit and elasticity modulus changing at the temperature after previous conditioning in liquid, determination of strength limit and elasticity modulus changing up to the structure thickness and reinforcement type with the previous conditioning in liquid. Typical composite materials in aviation and airspace industry [1]: epoxy fiberglass composite, epoxy carbonfiber composite and thermoplastic polypropylene fiberglass composite (Twintex), were selected as research materials. Shell cylindrical samples and flat samples for tensile tests according to ISO 527-4 were manufactured from these materials. Flat samples from Twintex were used to determine the material properties at conditioning in liquid. Shell specimens, which are dual-layer structures with a 40×1.8×350 mm polypropylene layner and an epoxy fiberglass shell 43×1.5×350 mm (6 layers of 0.25 mm) or an epoxy carbonfiber shell 41×0.5×350 mm (2 layers on 0.25 mm) wound on a layner, are used in the rest of researches. A separate version of fiberglass shell with dimensions 41.5×0.75×350 mm (3 layers on 0.25 mm), with fiber orientation $\pm 45^0$, with polypropylene layner is used separately.

Flat samples from Twintex were conditioned in seawater and hydraulic fluid AMG10 for the next time: 0, 135, 195, 333, 500, 675, and 840 hrs. At the end of each interval a portion of samples was tested on tension. The determined values of material mechanical properties changing, depending on time and presence of stitching through thickness in testing direction 90^0, are shown on Fig. 1 after the conditioning of Twintex in seawater (close to rain water with salts) and hydraulic fluid AMG10.

To account the effect, caused by external environment, the following dependences (1), (2) have been developed, which show the change of relative strength limit $\overline{\sigma_B}$ and elasticity modulus $\bar{E}$ from conditioning time *t*, temperature *T* and types of fluid and material:

$$\overline{\sigma_B} = \frac{\sigma_B'}{\sigma_{B0}} = 1 - \frac{{k_\sigma}^{-1} \cdot \frac{RT}{V_m} \cdot \frac{m_{\text{н}}(1 - e^{-kt})\cos(wt)}{m_0}}{\sigma_{B0}}; \quad (1)$$

$$\bar{E} = \frac{E'}{E_0} = 1 - \frac{{k_E}^{-1} \cdot \frac{RT}{V_m} \cdot \frac{m_{\text{н}}(1 - e^{-kt})\cos(wt)}{m_0}}{E_0}, \quad (2)$$

where k_σ, k_E – coefficients of recalculation of internal stresses, R – universal gas constant, V_m – partial molar volume of fluid in the composite, E_0 – initial elasiticity modulus, σ_{B0} – initial strength limit, $m_{\text{н}}$ – maximum mass of composite with liquid, when the saturation point is reached, m_0 – initial mass of composite before the influence of liquid, w – frequency of oscillations of sublimation process in composite with liquid, k – speed of liquid adsorption process, σ_B' – effected strength limit, E'– effected elasticity modulus. Using the dependences (1) and (2), the theoretical curves were calculated for conditioning of Twintex in fluids.

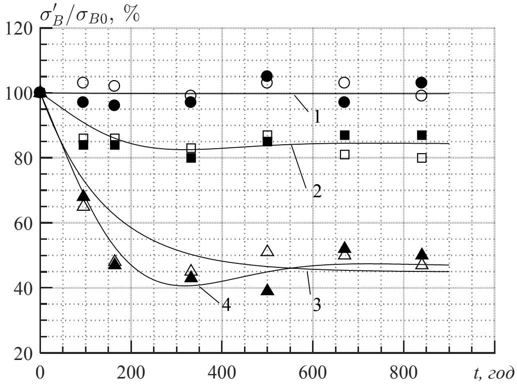

Fig.1. Dependence of relative strength limit of Twintex from time after conditioning in seawater and hydraulic fluid AMG10:
○, 1 – experimental points and calculated curve for test direction 90^0 at conditioning in hydraulic fluid AMG10; □, 2 – experimental points and calculated curve for test direction 45^0 at conditioning in hydraulic fluid AMG10; Δ, 3 – experimental points and calculated curve for test direction 0^0 at conditioning in hydraulic fluid AMG10;
●, 1 – experimental points and calculated curve for test direction 90^0 at conditioning in seawater; ■, 2 – experimental points and calculated curve for test direction 45^0 at conditioning in seawater; ▲, 4 – experimental points and calculated curve for test direction 0^0 at conditioning in seawater

The liquid gets inside to composite by adsorption. Its amount increases according to logarithmic law on time until the saturation point is reached with a certain speed, which depends on types of liquid and composite. The fluid in composite causes a swelling pressure π (3), which causes a decrease in mechanical properties of composite, but does not cause damage due to results of this research:

$$\pi = \frac{RT}{V_m}\frac{m_{\text{н}}}{m_0} \ . \tag{3}$$

To determine a joint effect of liquid and temperature on material, a study was carried out on shell structures with a polypropylene layner. Two types of shells were investigated: epoxy fiberglass with polypropylene layner and epoxy carbon fiber with polypropylene layner. The shells were conditioned in seawater for 310 hours and then tested under internal pressure at 273:373K. The results of study were normalized in relation to the initial material mechanical properties and are presented in Fig.2. The theoretical curve for the given study was calculated (Fig. 2) using the dependences (1) and (2).

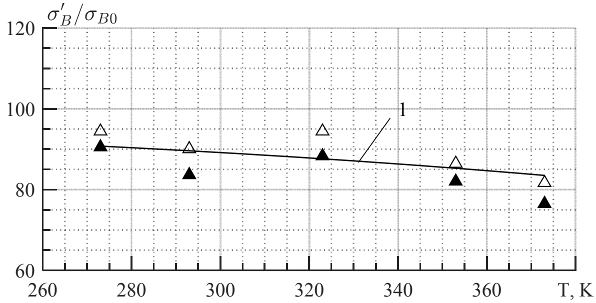

Fig.2. Dependence of relative strength limit of shells from epoxy glassfiber composite and epoxy carbonfiber composite with a layners from the temperature after conditioning in seawater for 310 hours:
Δ – experimental points for shell from epoxy fiberglass composite with layner;
▲ – experimental points for shell from epoxy carbonfiber composite with layner;
1 – calculated curve for shells from epoxy fiberglass composite and epoxy carbonfiber composite with layners

Figure 2 shows that sea water has a slight effect on mechanical properties of epoxy fiberglass and carbonfiber composites: strength limit changes at room temperature on 10% and elasticity modulus is practically unchanged. Temperature does not have a great effect on material properties in considered temperature range: within 5-10%.

Structures differ from each other by many parameters: geometric sizes, type of reinforcement, types of construction of power circuits, means of surface protection and many others. Polypropylene layner in the shells, used in this research, performs the function of protecting of composite from an effect of environment under high pressure. Let us to determine an influence of other design parameters such as an effect of geometric sizes and type of reinforcement. Let's start from influence of geometrical sizes, on the example of shell thickness, on mechanical properties of composite at conditioning in working environment, namely in seawater. Therefore, 5 samples with thickness 0.5, 0.75, 1, 1.25, 1.5 mm (2-6 layers respectively) from epoxy fiberglass composite with polypropylene layner was conditioned in seawater for 310 hours. After this, the samples were tested under internal pressure to fracture

The values of strength limit and elasticity modulus for different shell thickness are given in Table 1. Also an error of given values (Table 1) relative to the initial (before conditioning in liquid) is calculated. It can be seen from Table 1, that elasticity modulus and strength limit do not depend from thickness of shell and geometrical dimensions, when they are been conditioned in liquid.

Table 1. Strength limit and elasticity modulus of shell from epoxy fiberglass composite of different thickness with layner

Shell thickness d, mm	0,5	0.75	1	1.25	1.5
Elasticity modulus E, GPa / Error, %	25,4/8	23,8/1	22,6/4	25,1/6	25,1/6
Strength limit σ_B, MPa / Error, %	281/12	290/15	259/3	221/12	226/10

Influence of reinforcement type simultaneously with influence of liquid was considered in a case of internal pressure loading of shell from epoxy fiberglass composite with polypropylene layner reinforced with 3 layers of fiberglass with direction $\pm 45^0$. The first of two shells was conditioned in seawater for 310 hours (shell 1), the second was not conditioned (shell 2). Both shells were tested under internal pressure. The calculated values for conditioned in liquid shell are obtained using the dependences (1) and (2). The results of experiment and calculation are summarized in Table 2.

Table 2. Mechanical properties of shells from epoxy fiberglass composite with layner and reinforcement $\pm 45^0$

	Initial experimental data (shell 2)	Experimental data after conditioning in seawater for 310 hrs. (shell 1)	Calculated data after conditioning in seawater for 310 hrs.	Error, %
Shear strength limit τ_B, MPa	85,71	70,11	58,99	15,9
Shear modulus G, GPa	6,25	4,88	5,41	10,9

According to the results in Table 2, it can be seen that formulas (1-2) describe the change in mechanical properties of shell with reinforcement $\pm 45^0$ well enough. This indicates the absence of influence of reinforcement type on the change of material mechanical properties by taking into account a conditioning in fluid in case of absence of stitching through thickness. Therefore, the approach described by the dependencies (1-2) can be used in cases with combined composite reinforcement. In general, thickness of shell, its geometrical dimensions and direction of reinforcement (in case of absence of stitching through thickness) have no effect on changing of material mechanical properties at the joint action of liquid and temperature.

Conclusions

1. Degradation of mechanical properties is proportional to amount of liquid in composite and respectively to internal stresses caused by liquid. There is a significant impact of stitching through thickness to strength, but there is no effect on elasticity modulus: the stitching along testing direction reduces the effect of liquid, while the stitching across testing direction does not produce any effect.
2. Liquid has a slight effect on mechanical properties of epoxy fiberglass and carbonfiber composites: strength limit changes at room temperature on 10% and elasticity modulus is practically unchanged. Temperature does not have a great effect on material properties in considered temperature range: within 5-10%.
3. Thickness of shell, its geometrical dimensions and direction of reinforcement (in case of absence of stitching through thickness) have no effect on changing of material mechanical properties at the joint action of liquid and temperature.

References

1. G Marsh Airbus takes on Boeing with reinforced plastic A350 XWB // Reinforced Plastics. — Dec. 2007. — p. 26-27.
2. F. I. Babenko et al. Mechanics of composite materials and structures // Strength and crack resistance of dispersed-reinforced thermoplastics at cold climate, Volume 1. — M., 2014. — p. 4-10.
3. Chi-Hung Shen, S. Springer George Effects of moisture and temperature on the tensile strength of composite materials // Journal of Composite Materials. — №11., Issue 1. — 1977. — p. 2-16.
4. G.N. Toiskin Comparative tests of mechanical properties degradation of two composite materials under conditions of high humidity and temperature // Vestnik Samara State Aerospace University. — No. 5, Issue 36. — 2012. — p. 282-287.
5. M. K. Antoon, J. L. Koenig Irreversible effects of moisture on the epoxy matrix in glass-reinforced composites // Journal of polymer science: Part B. — No.19., Issue 2. — 1981. — p. 197-212.