Estimation of durability fabric composite material considering changes of temperature condition

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Abstract. The fabric composite material is considered. For its representative cell the 3D finite-element model is developed. Researches of conformity to law of influence of overfall of temperature are considered on durability of fabric composite material.

1. Introduction
At projection of elements of designs and composites structures problems of assessment of their rigidity, strength and a durability taking into account a material destruction under the influence of operational factors – power influences, heat drops and also severe atmospheres and various physical fields belong to the major.

In works [1, 2] options of defining ratios of process of deformation and a photodestruction of sheet composite are offered and the task about a durability of a representative element of this material is considered (actually for material with curved reinforcing layers and transversal rectilinear fibers). Here the three-dimensional model of a cell of a composite on the basis of fabric is considered. It contains the larger number of design characteristics and expands a range of the varied parameters in the analysis of their influence on a durability of fabric composite material (FCM).

2. Structure of fabric composite material
Let's consider the sheet and fabric composite representing fabric from high-tenacity synthetic yarns and a sheet polymeric covering. The last serves usually for protection of the reinforcing basis against influence of atmospheric factors and giving of air tightness to material. The regularity of structure of FCM allows to distinguish one its cell formed by two next vapors of threads (longitudinal and transversal to the filament) (fig. 1). We approximate geometry of threads cosinusoids, and their sections – ellipses.
Let's bring, following [1], structures of defining ratios. As a result of external not power aggressive impacts, in particular, of uv-radiation, there are phase changes and changes of mechanical characteristics of a polymeric matrix of FCM which we will call a material destruction (from influence of ultraviolet – its photodestruction). At the same time there is a diffusion of a destruction in thickness of material on some layer of height of \( h \) (this process goes from the surface subject to radiation). In this regard we use scalar parameter \( W \) – photodestruction parameter. It is considered that it is proportional to radiation intensity \( \gamma \). For it as a defining ratio the evolutionary equation of a look is accepted:

\[
dW/dt = U(\sigma, \omega, W, h)
\]

(1)

Here \( \omega \) - some state variable of material.

Accepting for simplicity that the surface of radiation represents the plane, deep into of material we will describe process of penetration of a photodestruction the equation similar to a ratio (1):

\[
dh/dt = R(\sigma, \omega, W, h)
\]

Let's enter as a state variable the parameter of damage \( \omega \) [2] which describes accumulation in material of defects like microcracks, micropores. For it the defining ratio differentially is also used

\[
d\omega/dt = \Omega(\sigma, \omega, W)
\]

The material durability condition in [1] was offered to be described the look equation:

\[
f(\sigma, \varepsilon, \omega, W, g) = 1.
\]

Here \( g \) – the structural parameters including, in particular, ultimate strength.

Further we will give the simplified ratios for the growing old fabric composite material [1].

The kinetic equation is relative it was accepted in the following form:

\[
d\omega/dt = B(\sigma/\sigma_0)^k \frac{1}{(1-\omega)^\chi} \left[1 + \left(\frac{W}{u}\right)^\eta\right]
\]

Here \( \sigma_i \) – intensity of tension, and constants \( B, k, q, \chi, u, \sigma_0 \) it is necessary to receive from experiments.

The parameter \( W \) characterizing photodestruction level was approximated on area of the considered cell by some function with coefficients for which ratios of type (1) were accepted. Parameter – \( W(\chi) \) photodestruction level on the surface subjected to radiation was for this purpose injected, and the distribution law of degree of a photodestruction on depth in calculations for simplicity was considered as the linear:
\[
W = W_0(1 - \frac{a_i - z}{h}) , \quad z \geq (a_i - h) \\
W = 0 , \quad z < (a_i - h)
\]

Relatively \( h \) and parameter \( W_0 \) the evolutionary equations in a look were used:

\[
\dot{W}_0 = \gamma \gamma_w \frac{(1 + \frac{\sigma_{t_0}}{\sigma_{t_0}})^m}{(1 + \frac{W_0}{W_i})^n} , \quad m, n > 0 , \quad \dot{h} = \frac{\gamma_h \gamma_h [\frac{(a_i)}{\gamma_h} + 1] W_0^b}{[1 + \frac{h_h}{h_0}]^a[1 + \frac{W_0}{W_2}]^n},
\]

Here \( \gamma \) – intensity of uv-radiation, \( W_i, W_z, n, m, \gamma_w, \sigma_{t_0}, \sigma_h, \gamma_h, h_0, \mu, p, \eta, b \) – the constants defined from experiments, \( \sigma_{t_0} \) – intensity of tension on a surface \( z = a \).

The criterion of destruction was accepted, following Rabotnov Yu.N. works, in the simplified look:

\( \omega = 1, \quad t = t_{crit} \),

where \( t_{crit} \) – time at which there occurs destruction. We will call this time for short a durability or critical time. In the second option he registers in a look \((\sigma_{T_0} \) - ultimate strength of the unimpaired material):

\( \sigma_i = \sigma_{T_0} (1 - \omega), \quad t = t' \)

Let’s conduct qualitative researches of regularity of influence of temperature drop on a longevity of fabric composite material. The law of change of temperature of \( T \) is adopted in the form presented in fig. 2.

In this case for assessment of a longevity we use the principle of the linear toting of damage according to which destruction happens when performing a condition

\[
\sum \Delta t_i h'_i = 1 \quad (2)
\]

In fig. 2. \( \Delta t \) - it is a step on time. For example, defined as three months of spring, summer, fall and winter, temperature drop in a year happens four times. According to it is possible to write down a condition (2) in a look

\[
N_{years} \cdot \left( \frac{\Delta t}{t_{spring}} + \frac{\Delta t}{t_{summer}} + \frac{\Delta t}{t_{autumn}} + \frac{\Delta t}{t_{winter}} \right) = 1 \quad (3)
\]

Here \( N_{years} \) - required number of years which defines a longevity of the considered type of a composite at this or that temperature drop \( \Delta T \).

The mechanical characteristics entering creep ratios will depend on temperature effect of \( T \). The function \( f_1 \) defining the law of change of mechanical characteristics of creep from temperature was accepted in a look

\[
f_1 = \left[ f_0 \cdot \left( Arctg \left( \frac{T - T_{average} + \frac{tg \left[ \frac{1}{f_0 - 1} \frac{\pi}{2} \right]}{\theta_1} \cdot \theta_1 + \frac{\pi}{2} \right)}{\frac{\pi}{2}} \right)^2 \right]^{t_1}
\]

(4)
where \( f_0, \theta_1 \) - the experimental parameters which define the nature of change of mechanical characteristics depending on temperature. The function \( f_2 \) defining the law of change of an elastic modulus from temperature was accepted in a look:

\[
f_2 = \left\{ f_0, -\arctan \left( \frac{T - T_{\text{average}}}{\theta_2} \right) + \frac{\pi}{2} \right\}^2
\]

Here parameters \( f_0, \theta_2 \) - parameters which define the nature of change of an elastic modulus depending on temperature effect.

In fig. 3, the picture of change of an \( f_2 \) and function \( f_1 \) to \( T \) is shown from, it agrees [3].

![Fig. 3](image)

Fig. 3. The functions defining the nature of change of mechanical characteristics from temperature

We apply an eight-nodal isoparametric space finite element to sampling of area. Further we will give the main ratios in a vector form.

For the analysis of tensely strained state we use the principle of the virtual work in increments

\[
\int \int \int \Delta \sigma \cdot T \Delta \varepsilon \cdot dV = \int \int \int P \cdot T \Delta \mu \cdot dS
\]

The complete deformation consists of the elastic deformation, a creep strain and deformation arising from damage existence. In a vector form it can be written down in a look:

\[
\Delta \hat{\varepsilon} = \Delta \varepsilon^c + \Delta \varepsilon^e + \Delta \varepsilon^\omega
\]

Where \( \Delta \hat{\varepsilon} \), \( \Delta \varepsilon^c \) - vectors of increments of the complete and resilient part of deformation, \( \Delta \varepsilon^e \) - a creep strain increment vector, \( \Delta \varepsilon^\omega \) - a vector of an increment of the deformation arising from damage existence.

Each phase for simplicity was considered as isotropic, the law of an elasticity was adopted by the linear:

\[
\sigma = D \varepsilon^e
\]

The creep strain and deformation, in charge of accumulation in a body of microdamages, generally, depend on many parameters of process:

\[
\Delta \hat{\varepsilon} = f_1 \sigma, W, \varepsilon^c, \omega, T, \quad \Delta \hat{\varepsilon}^\omega = f_2 \sigma, W, \varepsilon^\omega, \omega, T,
\]

where \( \sigma \) - intensity of tension, \( T \) - temperature. As the experimental determination of these dependences – very much the difficult task, some simplifying assumptions were accepted. First, on Kachanov's hypothesis was considered that accumulation of microdamages does not influence process of creep. Secondly, temperature was considered to equal some average annual size. The ratio for creep strain speed according to the theory of a current was accepted in a look:
\[ \{\Delta \xi\} = C(\sigma_i)[D^{-1}][\sigma], \quad C(\sigma_i) = (s_0 + s_1 \xi), \]

where \( \sigma_i \)-intensity of tension, \([D^{-1}]\) – a matrix, inverse to a matrix of elastic constants for a three-dimensional strained state, \( s_0 , s_1 , \xi \) – mechanical characteristics.

For the speed of the deformation arising from damage existence the similar ratio was used:
\[ \Delta \xi = z[D^{-1}] \sigma \xi \]

here \( \omega \) – damage parameter, \( k \), \( z \) – mechanical characteristics.

3. Numerical experiments
The structural and imitating model of a representative element of sheet and fabric composite allows to make numerical experiments in the wide range of variation of geometrical and mechanical characteristics of fabric composite material.

Geometrical parameters (see fig. 1) were set in millimeters and accepted the following values: \( a=0.2, d_{nit}=0.4, c_z=0.4, c_y=0.2, c_x=0.2, a_x=1, a_y=1, a_z=1 \). The following resilient characteristics were used. Elastic module \( E_{ocn} = 50\text{MPa}, \quad E_{mat} = 1\text{MPa}, \quad E_{umoc} = 50\text{MPa} \); Poisson's ratios: \( \nu_{ocn} = \nu_{mat} = \nu_{umoc} = 0.4 \). Temperature was accepted \( T = -20^\circ C, 0, 20^\circ C \).

At the left-hand end face movements across, and were fixed in the left-hand foot - movements down. At the right end face on an axis x movements were set, at forward and back end faces movement was accepted equal to zero.

Results of numerical experiments allowed to reveal regularities of change of a longevity \( t^* \) from temperature drop \( \Delta T \). In particular in fig. 4. results of a numerical experiment which showed that at increase in preliminary deformation the durability falls are given. Regularities of change of a durability depending on change of temperature are received. If change of temperature leads to little changes of resilient characteristics and parameters of creep, then the longevity \( t^* \) falls at increase \( \Delta T \).

![Durability](image)

Fig. 4. Dependence of a durability on deformation of a cell of FCM

It is also visible that at increase in preliminary deformation influence of temperature drop amplifies. For example, if deformation is equal to 1%, the durability falls for 22% if deformation makes 5%, the longevity falls up to 33% if deformation makes 7%, the durability falls for 49%.

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References

[1] Kayumov R A, Suleymanov A M and Muhamedova I Z 2005 Modeling the behavior of film-tissue material under the influence of factors *Mechanics of composite materials and constructions* 11 519–530

[2] Kayumov R A, Kupriyanov V N, Muhamedova I Z, Suleymanov A M and Shakirova A M 2007 Deformation of the representative cell film-fabric composite at finite transitions *Mechanics of composite materials and constructions* 13 165–173

[3] Kayumov R A, Muhamedova I Z, Suleymanov A M and Tazyukov B F 2016 *IOP Conference Series: Materials Science and Engineering* 158 010250

[4] Kayumov R A, Suleymanov A M, Muhamedova I Z, Mangusheva A R and Shakirova A M 2015 *The methods of evaluation of strength and durability of film and fabric composite materials* (Kazan: Kazan State University of Architecture and Engineering Press) 160