NUMERICAL PREDICTION OF RESIDUAL LIFE OF MULTILAYERED PCM STRUCTURE

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1. INTRODUCTION

Within the framework of this work, a unique algorithm for predicting the residual life of a multilayer flange (Fig. 1) from PCM using a structured phenomenological model is proposed. The process of damage accumulation in the flange is simulated, with a cyclic operational load.

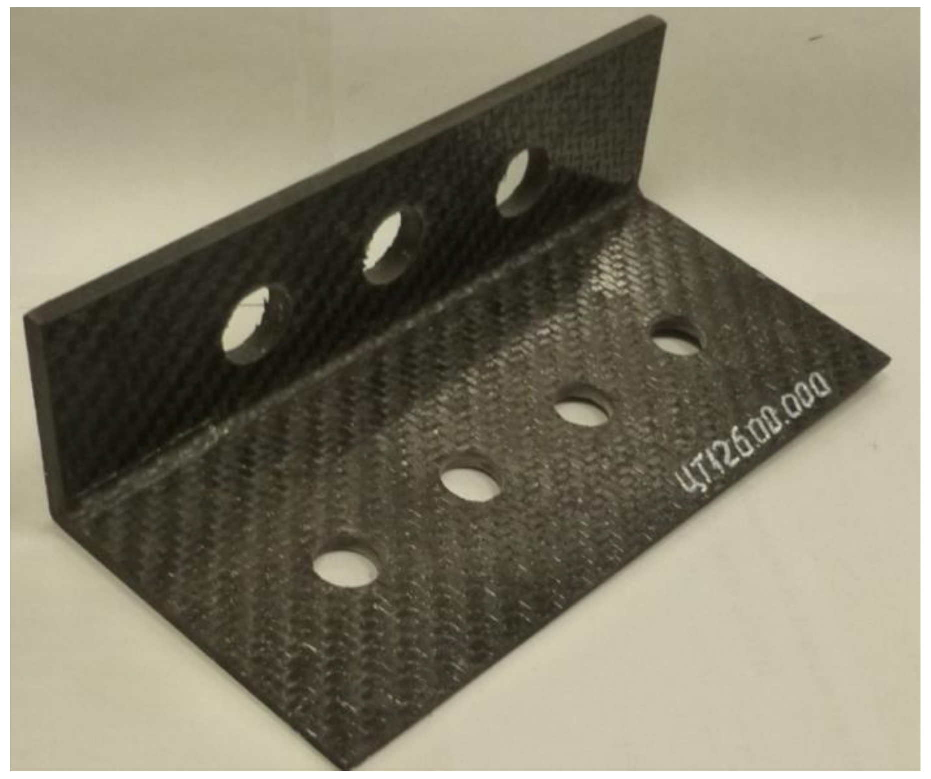

Figure 1. Specimen of composite flange

2. DESCRIPTION OF THE NUMERICAL MODEL

To model the process of damage accumulation under cyclic loading, the approach of an explicit description of the process of adhesive layers destruction of between reinforcing material layers was proposed.
Calculation of the stress strain state of the flange was carried out in an axisymmetric setting using a two-dimensional model. The following boundary conditions were used in the calculation (Fig. 2): the bolted joint area was rigidly fixed, the load (F) was applied to the end of the right free part of the flange with the maximum value in the loading cycle of 3000 N. In the calculations, it was assumed that the specified load is periodic, with sinusoidal loading cycle.

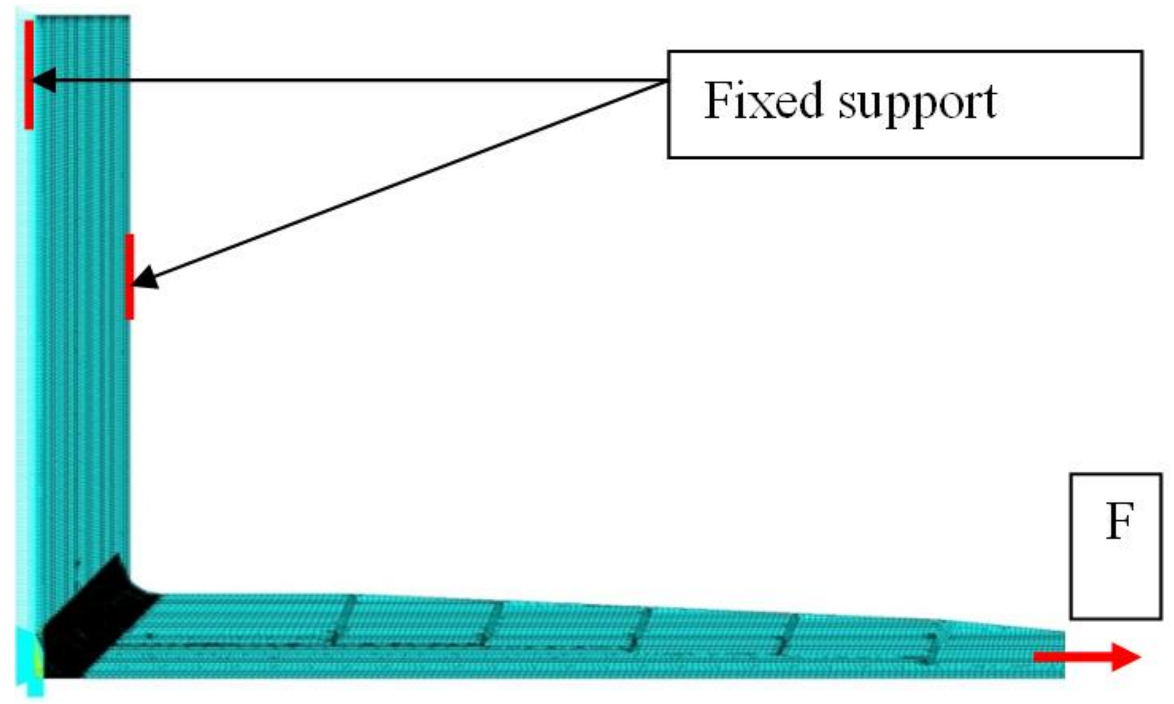

Figure 2. - Geometric model of composite flange and loading

3. DESCRIPTION OF THE ALGORITHM FOR PREDICTING THE RESIDUAL LIFE OF A MULTILAYER STRUCTURE

Kinetic equation of damage accumulation, which determines the value , in accordance with the linear rule of summation of damages:

$$\psi(N, \sigma_{mn}) = \sum_{k=1}^{N} \frac{1}{N_b\left(\sigma_i^{(k)}\right)}. \qquad (1)$$

The loading is assumed to be cyclic, symmetric with an amplitude corresponding to the maximum static load modulo. Parameter of the number of cycles before failure () is determined from a two-link fatigue strength curve for an epoxy binder by the following equations:

$$\begin{aligned} &\lg[N_b(\sigma_i)] = -0{,}0684\sigma_i + 9{,}18 \qquad \sigma_i < 42MPa, \\ &\lg[N_b(\sigma_i)] = -2{,}1029\sigma_i + 94{,}63 \qquad 42MPa < \sigma_i < 45MPa. \end{aligned} \qquad (2)$$

For each layer in each finite element, we obtain nonlinear equation for . After the decision, which determined the number of cycles before the destruction of each element . Minimum value for all finite elements is the number of cycles before the first act of fatigue failure in the construction . After this, it is assumed that the corresponding element is destroyed and the elastic moduli are reduced in it.
The remaining elements, while receiving damage, which are calculated by the formula corresponding to the kinetic equation (1)

$$\psi_j^1 = \frac{N_{b\Sigma}^1}{N_{bj}^1}. \qquad (3)$$

For the former amplitude of external load, a new stress-strain state of the structure with one damaged element q is calculated. Next, determine the number of cycles before each element is destroyed at operating stresses . Destruction in this case will occur in the element where the damage taking into account the value already accumulated at the previous step will be equal to 1:

$$\psi_j^{\Sigma} + \psi_j^2 = 1. \qquad (4)$$

The damage at the current (second) step is determined by the formula:

$$\psi_j^2 = \frac{N_{b\Sigma}^{2\partial on}}{N_{bj}^2}, \qquad (5)$$

where: - additional number of operating cycles in the second step. The total number of cycles of operating time is calculated by formula:

$$N_{\Sigma}^2 = \min_j\left(N_j^{2\partial on}\right) + N_{\Sigma}^1 \qquad (6)$$

The elastic modulus tensor for the destroyed element is reduced, and for the remaining unresolved elements, the accumulated damage is calculated:

$$\psi_j^{\Sigma} = \psi_j^1 + \frac{\min_j(N_j^{2\partial on})}{N_{bj}^2}. \qquad (7)$$

The next step starts with calculating the design stress strain state with two damaged items. Calculations were carried out in the ANSYS software package with an integrated software module.

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4. ANALYSIS OF THE RESULTS

Based on the results of the numerical calculation, a description was of the processes of damage accumulation and destruction of the structure under consideration under cyclic loading was obtained. In this case, the estimation of the number of cycles before fracture from the dependence of the fatigue strength limit for all finite elements of the adhesive layers showed that at the loading level under consideration the minimum value of the operating time before failure for the flange is N=2,819·10^8cycles.
An analysis of the kinetics of fracture revealed that the destruction of the flange begins in the region of attachment Figure 3 (a). When working 5,34·108 cycles of loading at a flange without a defect, there is a through delamination between the first and second layer in the region of fastening. Figure 3 (b). The total area of destruction was 1%. Calculations have shown that from the moment of the appearance of the first destruction to the appearance of a through delamination, the flange can withstand 2,53·108 additional loading cycles.
When there is a through delamination, a significant decrease in rigidity is observed in the flange. A critical drop in stiffness (approximately more than 15%) for a flange without a defect is observed at the 200 loading step. The value of the stiffness drop was about 17.65%, with the total number of operating cycles 534,649·10^6 (table 1).

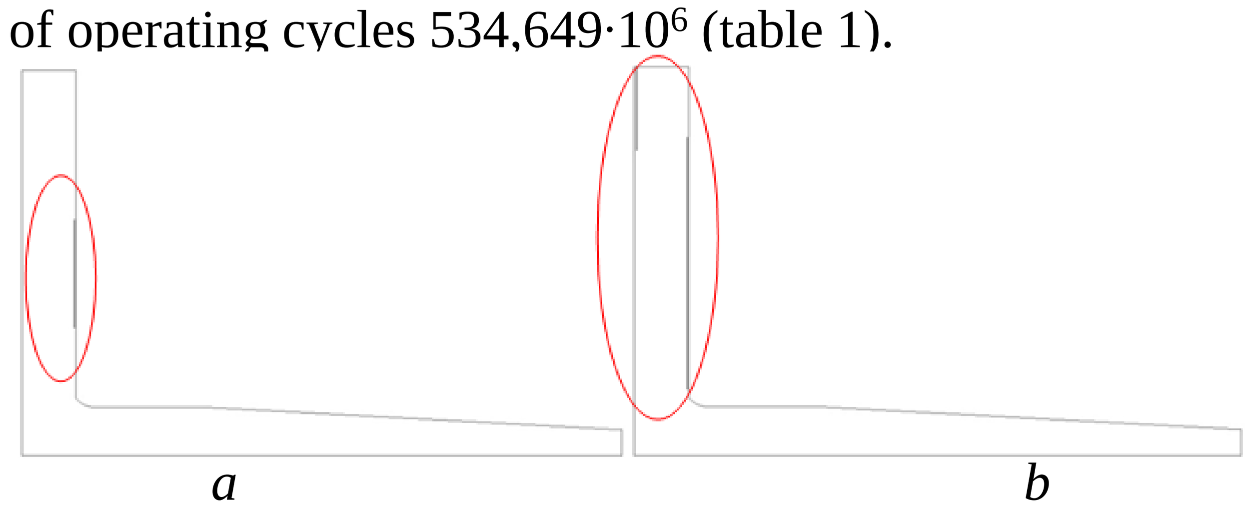

Figure 3. Areas of destruction of the flange on (a) 50 step of loading, at N= 517,621·10^6 (б) step 150 of loading, at N= 534,643·10^6

TABLE 1. Maximum movements and drop in flange stiffness

Loading step	Number of loading cycles, 10^6 *N*	Maximum displacement, mm	Stiffness drop, %
1	281,989	0,204	0
100	531,701	0,218	6,86
200	534,649	0,240	17,65
300	534,667	0,271	31,86
400	534,691	0,373	70,1

Thus, the developed algorithm and the program allow to determine the allowable value of the stiffness drop in structures made of PCM in modeling the processes of accumulation of damage and destruction under cyclic loading.