Influence of a Delamination Type Defect on the Operational Life of a Sound-Absorbing Structure with a Honeycomb Filler

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Abstract. In the framework of this research, the authors proposed an algorithm for predicting the residual life of sound-absorbing structures (SAS) from polymer composite materials (PCM) using the structural-phenomenological model. To assess the residual life of PCM structures under cyclic loading, it was proposed to use the approach of explicit description of the adhesive layer destruction process. The influence of the defect in the form of delamination on the honeycomb filler SAS operational life and stiffness was revealed. The description of the damage accumulation and destruction in the structure processes was obtained for the considered SAS under cyclic loading.

1. Introduction
Every year there is an expansion of the fields of polymer composite materials application. Composite materials are actively used in highly loaded units of aviation technology. Their use, in comparison with metal products, allows to reduce the mass, while maintaining the parameters of strength and rigidity of the structure [1-2]. To reduce the noise level that occurs during the operation of the aircraft, sound-absorbing structures (SASs) made of polymer composite materials are used. During operation, various types of dynamic loads act on the SAS, which, due to the susceptibility of polymer composite materials to the formation and accumulation of interlayer defects, can lead to fatigue failure. Therefore, the development of numerical methods for predicting the operational life and the process of composite structures destruction is an urgent task [3-6].

In the framework of this work, the effect of a defect in the form of a delamination on the operational life of a layered composite structure was researched. The object of the research was a single-layer SAS with honeycomb filler, shown in Figure 1. SAS consisted of two closed skins, between which there was a honeycomb filler. The geometric dimensions were as follows: length 200 mm, width 59.426 mm, height 16.089 mm. The casing consisted of two reinforcing layers of a woven equal strength prepreg with a reinforcement scheme [0; 0]. The honeycomb filler was made of fiberglass 1 mm thick and its height was 14.049 mm.

Figure 1. SAS with honeycomb filler.
2. Numerical model
To predict the honeycomb filler SAS operational life, the algorithm presented in [7-8] was used. The algorithm is based on the finite element method using kinetic equations with a scalar damage function. The multilayer composite structure under study is assumed in such a way that an isotropic adhesive layer is contained between the casing and the honeycomb filler. The thickness of the adhesive layer was taken equal to 10% of the thickness of the carbon fiber reinforcing layer. It was assumed that during the damage accumulation, the destruction of the structure will occur only in the adhesive layers.

Fatigue failure was modeled as a breakdown of the binder in the adhesive layers. In this way, the development of damage of the “delamination” type was simulated, which is a typical and characteristic type of these structures destruction, both under operational load and in laboratory tests [9]. The dependence of the strength of the binder on the level of cyclic loads was taken according to experimental data known in the literature [10]. A preliminary assessment of the residual life was carried out according to the weakest link criterion.

In the framework of computational experiments, a research was carried out of the effect of a defect in the form of a delamination on the honeycomb filler SAS residual life. A rectangular defect is located in the adhesive layer between the casing and the honeycomb filler (Figure 2). There is perfect contact between the casing, adhesive layer, defect and the filler. Numerical forecasting of the residual life was carried out in ANSYS Mechanical software package using the APDL program developed by the authors.

![Figure 2. The location of the defect in the SAS with honeycomb filler.](image)

The formulated problem of predicting the residual life of a SAS with a defect is solved numerically in a three-dimensional formulation. The boundary conditions were set as follows: cantilever fastening of one end of the SAS with a honeycomb filler; an alternating load is set to the opposite end, perpendicular to the honeycomb filler laying plane. The defect size was set in the form of a rectangular region with a size of 12.856x15 mm, the height was taken equal to the thickness of the adhesive layer.

As part of the computational experiments, 600 cyclic loading steps for each structure were considered. At each loading step in the numerical calculation the minimum operation life among all finite elements is determined. For the finite element with the minimal operation life, the reduction of elastic properties is performed.

According to the results of the numerical experiments, the dependences of the total number of running cycles (N<sub>Σ</sub>) on the loading step (SL) for the SASs without the defect and with the defect were obtained. Dependencies are shown in Figure 3.
An analysis of the results shows that in the first loading step, the minimum number of cycles to the first fatigue failure is $36.95 \times 10^6$. In the current research it was assumed that the minimum number of cycles before the failure determines the operational life of the structure.

The calculations for 600 loading steps that were carried out show that the dependence of the total operational life on the loading step is nonlinear. This pattern is caused by the reduction of material properties in the adhesive layers and the redistribution of the load.

We can conclude that this type of defect will slightly affect the total number of operation cycles of a honeycomb sound-absorbing structure sample.

During the cyclic loading of the SASs, the level of damage was recorded in the adhesive layers. Upon reaching the critical level of damage, the destruction of the adhesive layers was modeled through the reduction of the elastic characteristics in the damaged elements. At each loading step, a certain number of elements were destroyed. Figure 4, 5 shows the destroyed elements in the SASs with loading steps of 1, 100, 300, 600 for structures with and without the defect.
The analysis of the obtained results did not reveal (Figures 4 - 5, a - d) significant differences in the fatigue fracture of the adhesive layers of the SASs with and without the defect. The area of the destruction onset for both SASs is located directly in the zone of fixation (Figures 4, 5 a). Then there is a symmetrical distribution of the adhesive layers’ destruction area (Figures 4, 5 b).

To analyze the reduction in the structural rigidity of the SAS structures with and without the defect, the dependences of maximum displacements on the number of loading steps are shown (Figure 6).

From these graphs it can be seen that the greatest maximum displacements were observed for the structure with the defect, which is higher on average by 0.0263 mm than for the SAS without the defect. We can conclude that the presence of the defect in the form of delamination is insignificant due to a decrease in the structure rigidity during cyclic loading.

3. Conclusion
As a result of the research, the residual life was determined for the SAS with honeycomb filler. The effect of a defect in the form of delamination on the honeycomb filler SAS residual life, as well as the maximum displacements of the SAS without the defect and with the defect, were revealed. The description of the processes of damage accumulation and destruction in the profile of the considered structure under cyclic loading was obtained. The kinetic process of the SAS with a honeycomb filler destruction was simulated and described.
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