Studying the stiffness of thin-layered compositions with delaminations

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Abstract. As part of the construction, thin-layer compositions take loads, work in contact with various environments, and work under influence of physical fields. All this can lead to delamination of the compositions and changes in their mechanical properties. The method of physical modeling of compositions with defects in the form of delaminations is considered. The stiffness properties of thin-layer compositions with local delaminations are studied by experimental-theoretical method.

1. Introduction
Imitating natural constructions, various thin-layer compositions are created to solve many technical and economic problems, providing the necessary qualities [1, 2]. During exploitation, the compositions work in contact with various media and are affected by various physical fields. All this can lead to delamination of the composition. Defects in the form of delaminations (figure 1) can change the mechanical properties of the composition. Along with the change in stiffness properties, at the boundaries of the separation from the effects of surface loads q, stress concentrations can appear (figure 2), which contribute to further separation and can lead to the destruction of the entire composition.

Figure 1. Compositions with local delaminations: (a) – two-layer; (b) – three-layer.

To assess the efficiency of thin-layer compositions with local areas of delaminations, it is necessary to have data of the change in their mechanical properties during exploitation. Studies of thin-layer compositions with local areas of delamination are relevant.
2. Methods of making compositions with defects in the form of delamination

Depending on the specifics of the technology of making the composition, it is necessary to develop methods for the formation of samples with local areas of delamination. Cases of the formation of two-layer and three-layer compositions by lamination of individual layers are considered. The structures of the samples for the compositions "polymer film + polymer film" and "polymer film + fabric + polymer film" with areas of delaminations are shown in figure 3. Instead of thin paper for artificial delamination, it is possible also to use a thin oily layer.

![Figure 3. Compound of composition before lamination.](image)

As films for lamination, polyester-based films were used (multi-layer film with a thickness of 75 microns, as a rule, three layers). A white coarse calico fabric (100% cotton, 0.18 mm thick) was taken as the fabric for the samples. The diameter of the samples is D = 100 mm. To physically simulate a local defect in the areas of delamination, we include into the structure thin paper with a small tension stiffness, which excludes the connection with the adjacent layer during lamination. Next, we prepare laminated structures, we obtain the necessary samples for further research. The type of samples of the compositions “polymer film + polymer film” with a strip of delamination with width \( h = 1.5 \text{ cm} \) and “polymer film + fabric + polymer film” with delamination in the center with a diameter \( d = 2 \text{ cm} \) are shown in figure 4.

![Figure 4. Types of the samples: (a) – strip delamination; (b) – delamination in the center.](image)

Samples with defects allow to study the effect of delaminations parameters on the changes in sample's stiffness properties. Such studies have great practical importance.

3. Research tool

An effective approach of the study of the mechanical properties of thin-layer compositions is an experimental-theoretical method [3]. The method is based on the synthesis of experimental data and theoretical ratios derived from the nonlinear theory of thin shells. From the experiment, we obtain the dependence \( \text{"pressure } p \text{ – deflection } H\). For the case of elastic deformation with an average bend, the tangential stiffness \( B \) for a polymer composition can be determined by the formula:

\[
B = 0.293pa \left( \frac{a}{H} \right)^3,
\]

where \( p \) – is a uniformly distributed pressure; \( a \) – is the radius of the working part of the membrane; \( H \) – membrane deflection in the center (height of the dome rise).
4. Tension stiffness of a fabric–polymer composition with delaminations

The following cases are considered: N1 – “film + fabric + film”, fully glued along the entire surface; N2 – “film + fabric + film”, not glued in the center with a diameter of \( d = 2 \text{ cm} \); N3 – “film + paper + fabric + paper + film”, fully not glued over the entire surface of the fabric. Film thickness 75 microns. A thin napkin was used as paper. Radius \( a = 4 \text{ cm} \).

The dependence of deflections of samples \( H \) from pressure \( p \) (for the considered cases of delamination) is presented on figure 5. By (1) calculated tensile stiffness. The dependence of the change in tension stiffness \( B_{avr} \) from the size of delamination \( d \) is shown on figure 6. As seen on figure 5 and 6, delaminations of multilayer compositions affects on their stiffness.

![Figure 5. Dependence «H – p»](image1.png)

![Figure 6. Dependence «B_{avr} – d»](image2.png)

5. Tension stiffness of polymeric composition with delaminations

The following cases are considered: R1 – “film + film”, fully glued along the entire surface; R2 – “film + film”, not glued on delamination strip with width \( h = 1.5 \text{ cm} \); R3 – “film + paper + film”, fully not glued over the entire surface of the fabric. Film thickness 125 microns. Radius \( a = 4 \text{ cm} \).

The averaged values of the deflections of samples \( H \) in the dependence from pressure \( p \) are presented for the considered cases in table 1. The tangential stiffness \( B \) calculated for (1) and the average values for the considered load range are also shown there. The dependence of the change in tension stiffness \( B_{avr} \) from the size of delamination \( h \) is shown in figure 7.

| \( p \), MPa | \( R1 \) (\( h = 0 \text{ cm} \)) | \( R2 \) (\( h = 8 \text{ cm} \)) | \( R3 \) (\( h = 1.5 \text{ cm} \)) |
|------------|------------------|-----------------|------------------|
| \( H \), mm | \( B \), kgF/cm | \( H \), mm | \( B \), kgF/cm | \( H \), mm | \( B \), kgF/cm |
| 0.02       | 2.63             | 824.6           | 4.24             | 196.8         | 3.97             | 239.7           |
| 0.03       | 3.00             | 833.3           | 4.65             | 223.8         | 4.41             | 262.3           |
| 0.04       | 3.34             | 805.2           | 4.97             | 244.4         | 4.72             | 285.3           |

\[ B_{avr} = 821.0 \]

\[ B_{avr} = 221.7 \]

\[ B_{avr} = 262.4 \]

As can be seen from table 1 and figure 7, delamination of multilayer compositions affects on their stiffness.
6. Conclusion
On the basis of an experimental-theoretical method, studies of the mechanical properties of thin-layer compositions "polymer film – fabric – polymer film" and "polymer film – polymer film" with local delamination were carried out. Delamination of compositions significantly affects on their stiffness.

References
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