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The Application Of Vibration Analysis For Determining Defects In Composite Material

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ABSTRACT

In this article the problems occurring during the operation of composite materials are discussed. A summary of information about composite materials, their application features is given. Important aspects of the diagnosis of composite materials are considered. Some methods for finding defects in composite materials are proposed. An experimental study showed no dependence of the oscillation frequency on the occurrence of defects, but clearly demonstrated its change from the location of the defect. The proposed defect control method shows the possibility of creating a system for controlling delamination in composite materials on the basis of vibration processes and to determine its main parameters.

KEYWORDS

Vibration analysis, defect, composite material, delamination, resonant frequency, acoustic method.

INTRODUCTION

Composite material refers to a material consisting of several layers combined into a single whole. But at the same time, each layer is clearly expressed and separated from another similar layer (see Figure 1). For their combination a kind of "adhesive" basis is used, which binds the layers together and affects the final properties of the material [1].

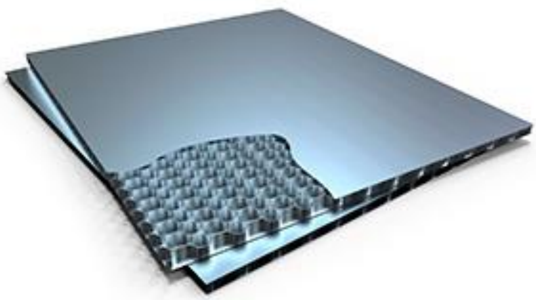


Figure 1. Composite material

Like any other structural material, composites have both advantages and disadvantages. The main advantages are:

- high strength (comparable to metals);
- low mass (in comparison with metals);
- high resistance to temperature changes and negative temperatures;
- high corrosion resistance;
- high vibration and shock resistance;
- fire resistance;
- chemical resistance.

The main disadvantages of composites:

- high hygroscopicity;

- increase in size and volume with strength increasing;
- production toxicity;
- anisotropy;
- low maintainability.

Equally important is the simplicity of giving a "beautiful" modern form. The use of composites is directly related to their advantages and disadvantages. Primarily, composites are used where high strength is required with an insignificant mass of the product: transport, aviation, shipbuilding, containers for chemical production, animal farms, etc. Promising areas of application of composites are bridge construction, trunk pipelines, medical equipment (orthopedics), etc. [2]. It is known that thermal conductivity (see Figure 2) is associated with the process of heat transfer, which is the process of transferring energy from one particle to another, located in close proximity to each other. Several components coexist in a composite material and the total thermal conductivity of composite materials is determined by the thermal conductivity of its individual elements and to a large extent depends on the materials used, the quantitative and qualitative ratio of the components, and the type of structure. The numerical value of the thermal conductivity of composites is in the range from fractions to tens of units W / mK. To determine the calculated effective thermal conductivity, various methods and formulas are used, for example, the Maxwell formula:

$$\lambda_{eff} = \lambda_{medium} \left(\frac{\lambda_{particles} + 2\lambda_{medium} - 2v_{particles}(\lambda_{medium} - \lambda_{particles})}{\lambda_{medium} + 2\lambda_{medium} + v_{particles}(\lambda_{particles} - \lambda_{particles})}\right) \quad (1)$$

The accuracy when applying formula (1) is from 20 to 40%, and for composite materials based on silicone with various fillers is higher than 20%.

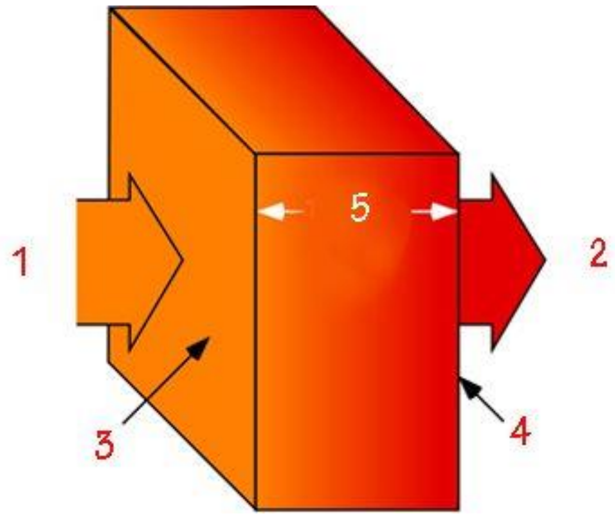


Figure 2. The effect of thermal conductivity: 1- thermal energy; 2- thermal conductivity coefficient; 3- temperature of the first surface; 4- temperature of the second surface; 5- material thickness

When electronic equipment get exposed to vibrational loads with a wide range of frequencies, the bending, transverse, longitudinal and surface waves, which propagate through the material of the equipment can occure and excite noise-vibration in electronic elements and devices. In addition, the impact of vibration significantly develops and accelerates the destruction processes associated with the presence of delamination, cracks, etc. Even those product elements whose defects do not appear under normal conditions can turn out to be extremely sensitive to weak vibrations (spot welding, etc.). Technical materials, which seem to be homogeneous, always contain a large number of various origins defects and a wide variety of sizes. At the submicroscopic level, these are the inclusion vacancies in the almost regular structure of the material, dislocation, and pore. At the microscopic level, there is a spread in the orientation, size, and properties of the particles that make up the material. At the microscopic level, the properties of the material are different due to the large-scale heterogeneity.

Under the action of cyclically changing stresses created by vibration, the phenomenon of material fatigue is observed. Two factors have a significant effect on the fatigue strength of a material: load repetition and time factor. In ductile metals, plastic deformations do not allow local stresses to exceed the limit value of fluidity for a given metal and thereby contribute at stages close to failure to distribute the stress uniformly over each section. One of the main characteristics of the material when exposed to cyclic loads is cyclic viscosity, which is not a constant value, since it depends on the magnitude of cyclic stresses and on the increase in the number of stress cycles. These changes in the cyclic viscosity, characterized by a change in the hysteresis loop, allow us ascertaining the presence of two simultaneously occurring factors in the metal under the action of cyclic loads:

- hardening factor, which is taken as hardening and mechanical aging of the material caused by its plastic deformation;
- softening factor, for which the residual stresses in crystallites and between crystallites are taken.

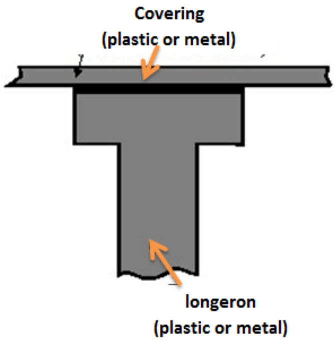
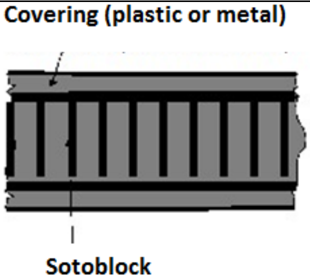
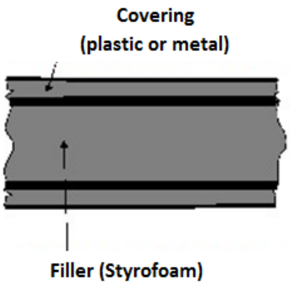
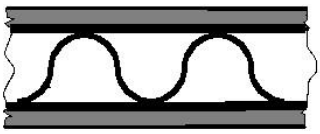
The fatigue process of a material depends on the comparative intensity of both factors, which change by the number of loading cycles and their frequency increase. The degree of the influence of loading frequency on the characteristics of the fatigue strength of the material depends on the material, the nature of the loading, the level of stress (the ratio of the maximum stress of the cycle to the elastic limit), the presence of stress concentrations, the environment, and temperature. The goal of this paper is to study possibility of use the vibration analysis method for determining defects in composite material.

MATERIALS AND METHODS

The wide use of composites has led to the emergence of problems associated with quality control in the composites manufacture and operation. The main defects of polymers are associated with a change in structure (loss of uniformity): the appearance of pores, cracks, delamination (see Table 1). The structure uniformity can be identified by one of the following methods: optical, radiation, thermal or acoustic. The easiest and most informative way is acoustic. Control methods of composite materials, such as: control of the impedance method (equipment - combined transducer, split-combined transducer), local method of free oscillations (equipment - percussion transducer), velocimetric method (equipment - acoustic flaw detector), acoustic-topographical method hav developed on basis of acoustic method.

Table 1. Typical structures of composites and their defects

Structures	**Simplified structure sketch**	**Possible defect**	**Instructions**
Polymer composite material (PCM) (organoplastic, fiberglass, carbon fiber)		Delamination between the plastic layers.	control from both sides
Adhesive bonding metals		Non-glue between sheets of metal.	Control from a thinner layer.
Adhesive bonding of metal and PCM or thermal insulating material		Non-glue between PCM and metal. Delamination between PCM layers.	Control from a thinner layer.
Adhesive bonding of PCM - rubber-metal		Non-glue between PCM – rubbre- metal. Delamination within PCM layers.	

Connection: covering-longeron.		Covering delamination. Delamination Covering from longeron	Control from covering side.
Connection: covering-sotoblocks.		Covering delamination. Delamination Covering from sotoblocks	
Connection: covering - filler.		Covering delamination. Delamination Covering from filler	
The adhesive construction with cell filler.		Covering delamination. Delamination Covering from filler	

Numerous experiments have shown that when the homogeneity of the composites is disturbed, the frequency of natural oscillations changes - the amplitude increases at the location of the defect. Moreover, the greater the delamination, the greater the amplitude. The experiments determined that the natural frequencies of various composite materials arising under the external acoustic influence, and determined the values of the frequencies corresponding to those or other defects. Particularly noted is the need for careful selection of the magnitude of the external acoustic effects in order to increase the accuracy of diagnosis. Available experimental data showing the dependence of the amplitude on the distance from the center of occurrence of the defect.

The temperature effect of the catalytic activity of materials is shown in figure 3.

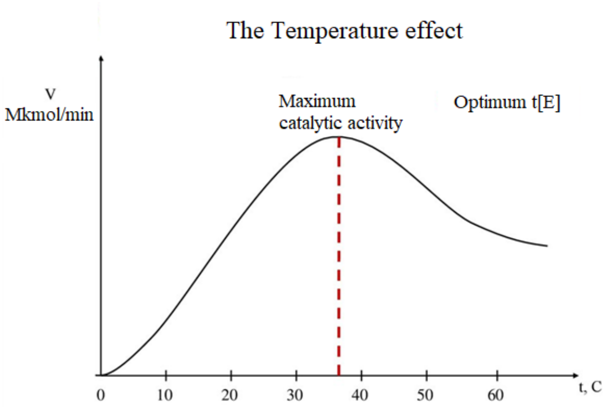


Figure 3. The temperature effect of the catalytic activity of materials

To find a defect, it is preferable to use non-destructive testing methods, which include the acoustic method as well. After finding the defect, it is necessary to determine its size, assess the progression of damage and decide on the further use of the product. Next, we will consider in detail the use of vibration approaches of defectoscopy to establish the fact of stratification of the composite structure, as well as the location and size of the defect using the analysis of individual natural frequencies and vibration modes. A distinctive feature of the considered waveforms frequencies is a significant excess of the oscillation amplitude in the area of delamination compared with other parts of the contracture.

The external driving force, required to excite these waveforms, can be provided by a system of piezoelectric elements placed on the inspected structure. The possibilities of the proposed approach are demonstrated on a numerical finite element model of a composite plate with delamination. The formulation of the problem takes into account the dissipative properties of the material, necessary for reliable simulation of the vibration processes. A strong dependence of the waveform frequencies of the delamination defect on the size of the defect and a weak dependence on location were found. This makes it possible to set the system of damage detecting to a defect of a certain size. The study showed that the proposed approach can be successfully used for the detection of delamination in composite structures.

RESULTS AND DISCUSSIONS

Let's give an example of the application of the acoustic method of defectoscopy. A composite plate of 15 layers, each of which is 0.26 mm thick (see Figure 4), is defective. Overall dimensions 300 x 300 mm. Total thickness 3.9 mm. Characteristics of the composite material:

- homogeneous elastic isotropic;
- E = 58 GPa, v = 0.3, p = 1800 kg / m3.

The plate has a square delamination between 6 and 7 layers of size L_d with boundaries S_1 and S_2. The center of the plate and the center of the defect are the same.

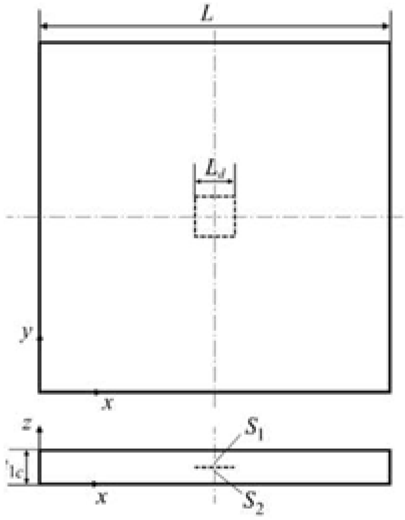


Figure 4. Defective Plate

ANSYS software was used for modeling. Fig. 5 shows a cross section of a plate model with delamination with bending vibrations. The plate's own oscillations obey the harmonious law.

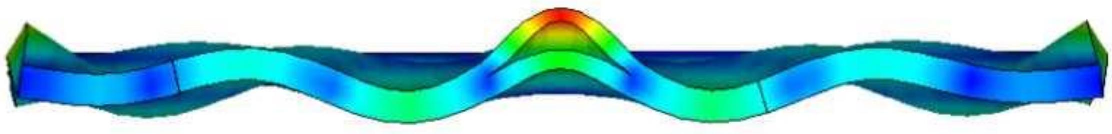


Figure 5. Cross-sectional view of a numerical model of a plate with delamination under bending vibrations.

The frequency of oscillations of the defect is inversely proportional to its size. Since it is desirable to detect the defect at the initial stage of appearance, the generated frequency should be large. In our example, this is 107 kHz. An external source is already required to generate such a frequency. According to fig. 6 when the center of the defect coincides with the center of the plate under study, the acoustic waves diverge uniformly from the center in all directions. At the same time, in the center the amplitude of oscillations is maximum. When defects are located in other places, the vibration propagates not so symmetrically

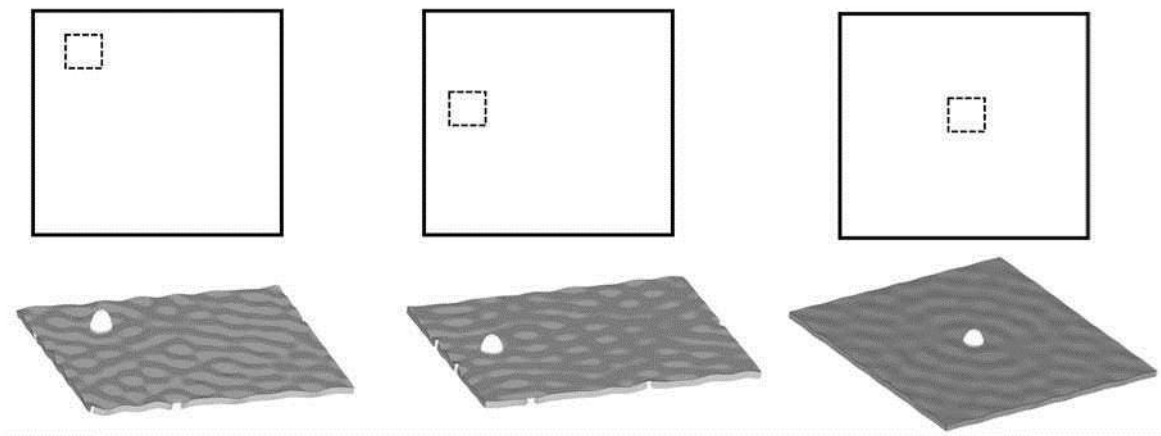


Figure 6. Own vibration shapes at different layering locations on the plate

The distortion of the natural oscillations is primarily due to the change in the stiffness of the composite at the point of occurrence of the defect. To compare the "defective" amplitude with the "reference" one, you must first determine the latter. For this purpose, an experimental setup was assembled, the scheme of which is shown in Fig. 7. Plate 2 had many degrees of freedom due to its single point suspension. Speaker 2 generated sound waves with a frequency of 1 kHz. A Polytec PDV100 laser vibrometer with a sampling frequency of 48 kHz worked as a recorder.

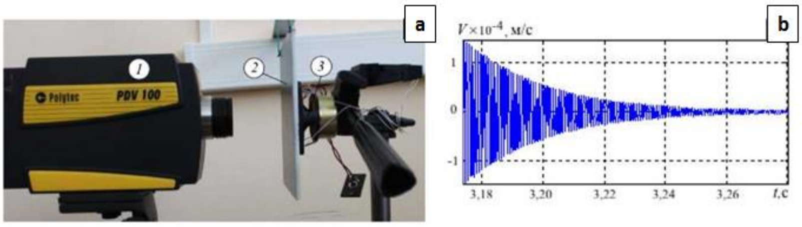


Figure 7. Experimental installation: 1 - vibrometer; 2 - plate; 3 - speaker; on the right is the view of the normal velocity component at the measured point of the plate at attenuation stage.

As a result, the dependences of the oscillation amplitude on the point of occurrence of the defect were determined (see Figure 8).

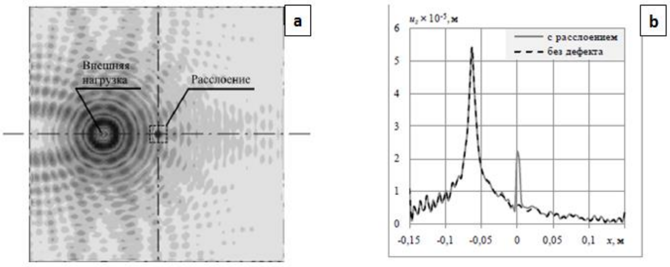


Fig. 8. The field of displacements in a plate with delamination with forced steady-state oscillations at the resonant frequency of the defect (a) and the distribution of the amplitude of displacements along a line passing through the center of the defect (b). Further studies revealed the dependence of the displacement amplitude on the geometric location of the center of oscillation (see Fig. 9). In fig. 10 and 11 show the effect of the distance from the center of the defect on the amplitude of the oscillations.

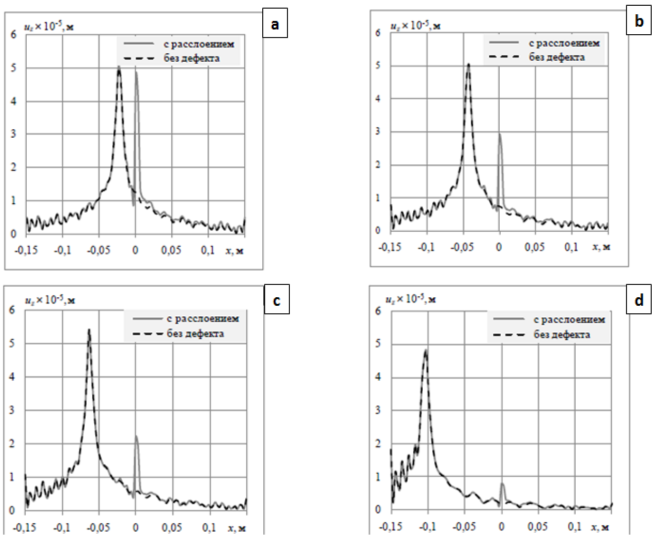


Figure 9. The distribution along the line passing through the center of the delamination, the amplitudes of displacements for different relative to the geometric center of the plate the positions of the point of application of an external periodic effect, mm: 23 (a); 43 (b); 63 (c); 103 (d)

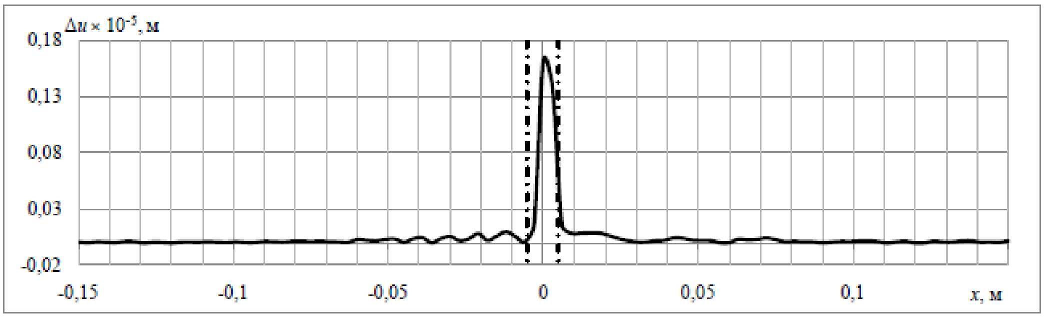


Figure 10. Graph of the difference of the displacement component U_z in a plate with a delamination and in a defect-free plate

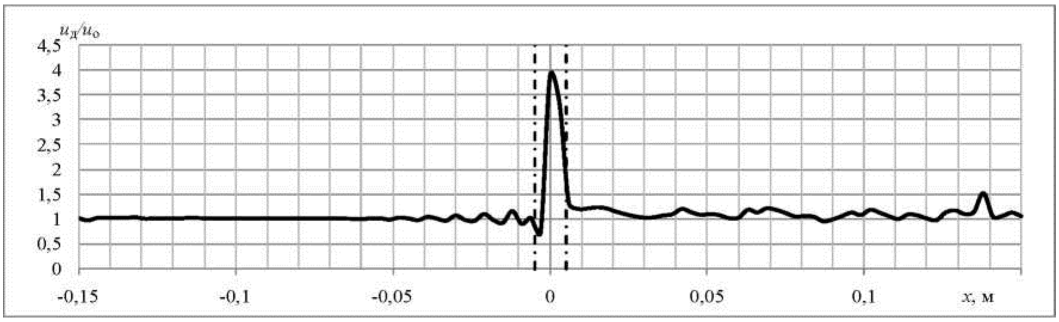


Figure 11. Graph of the ratio of the component displacements U_z in a plate with delamination to the corresponding component in a defect-free plate

The experiment showed that the ratio of the amplitudes, and the difference decreases as the loading point moves away from the defect (see Figure 12)

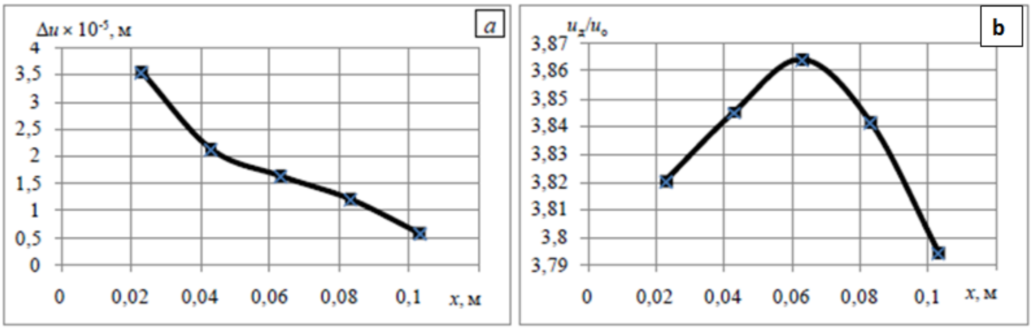


Figure 12. Change of the difference (a) and the ratio of displacements (b) in the defective and defect-free plates depending on the distance of the point of application of an external periodic effect from the center of the defect

Thus, the relationship between the amplitude of oscillations and the point of location of the defect in the composite material is obvious.

CONCLUSION

It can be seen from the above materials that the frequency and form of acoustic oscillations depends not only on the material (composite), its shape and size, but also on the defects arising in it, the main of which is the separation of layers. An experimental study showed no dependence of the oscillation frequency on the occurrence of defects, but clearly demonstrated its change from the location of the defect. The proposed defect control method allows one to substantiate the possibility of creating a system for controlling delamination in composite materials on the basis of vibration processes and to determine its main parameters.

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