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THERMOGRAPHY OF DEFECTS IN LAMINAR COMPOSITES

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Abstract: This study analyzes the dynamics of mechanical damage and thermomechanical behavior of laminar composite materials. Complex calculations of static tensile loads are performed using thermographic analysis methodology. Post-processing of thermal data includes analysis of both calculated heat maps and thermomechanical behavior of the material.

Analysis of heat maps allows qualitative assessment of the created damage to the material at high stress levels. Thermomechanical analysis allowed quantitative assessment of damage to the laminated composite for both low and high levels of mechanical stress by defining a new thermoelastic damage variable.

Key words: Composite materials, thermographic analysis, damage assessment, thermal maps, temperature distribution.

The presence of mechanical load applied to laminated composite samples, depending on the type and direction of the applied load, may cause various types of defects, two or more of which may occur simultaneously. Such defects include: matrix cracking, interphase delamination, delamination, fiber rupture, warping (under compression) [1, 2].

The combination of these defects with changes in the applied mechanical load, changes in the state of the material and interaction with the overall structure lead to the need to use non-destructive testing methods in engineering practice. Such methods help to detect the occurrence and development of mechanical defects throughout the entire volume of the laminated composite.

Despite the existence of a sufficiently large number of experimental and analytical methods that allow reliable implementation of flaw detection of laminar composites, a non-intrusive approach is needed that could effectively and reliably detect and quantify, at the place of operation, the conditions for both the occurrence of damage and the subsequent development of damage.

The infrared thermography technique allows to fulfill this need [3]. Thermography is a non-contact method that can be easily applied in the field. The method of recording the temperature fields of the composite can be used for fast inspection of images in real time. In addition, this method is effective when examining relatively large areas of the structure.

It should be noted that most of the thermographic studies have been applied to composite materials for the detection of surface defects and for the analysis of damage or stress under dynamic loading conditions]. However, very few studies have been applied to static load tests, since composite materials are not highly dissipative under these conditions [4].

Conventional thermal data processing methods based only on thermal image analysis do not allow reliable characterization of material damage, especially for low applied loads when temperature variations are very small. The aim of this work is to analyze new descriptors of mechanical damage occurring specifically during static loading. The basic assumption of the calculation model is the absence of influence of mechanical load on the microstructure of the material. The corresponding heat conductivity equation contains a term that represents macroscopic heat sources that accumulate both due to an external power source, a thermoelastic source, and due to an internal source of dissipation.

The static mode is characterized by low temperature gradients and the velocity of displacement of convective terms. In addition, external sources are independent of time and give the equilibrium temperature of the laminar composite sample.

The analysis of the calculated thermodynamic values indicates that the thermomechanical behavior of the material can be divided into three stages. In the first stage, a linear decrease in temperature occurs, as predicted by the theory of thermoelasticity. Performing a linear regression with a high correlation coefficient allows us to compare the thermoelastic coefficient with the value of mechanical stress for the occurrence of damage. The second stage is characterized by a nonlinear, so--called soft temperature decrease.

Despite the fact that the mechanical behavior of the laminar composite sample is macroscopically linearly elastic, there is a high probability of the occurrence of a noticeable volume concentration of small microdamages.

The temperature decreases to a minimum value that corresponds to the balance between the energy spent on elastic deformation (the sample cools down) and the energy absorbed by the composite, which leads to the formation of small microdamages (the sample heats up). The third, final stage corresponds to a significant increase in the geometric dimensions of the defect inside the sample. This tendency causes the destruction of the entire sample, which is accompanied by a sharp release of a significant amount of heat.

Using the finite element calculation method, detailed heat maps were obtained that localize defects in the composite volume. The heat maps were calculated in terms of instantaneous contrast.

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