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Stress state analysis and optimization in the vicinity of the sensor of SMART-material

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Abstract

Composite materials in practical human activity are well positioned, and their range of applications is constantly expanding. Composite materials based on polymer are widely used among the different kinds of composite materials. The nomenclature of these materials is very wide and their properties are different from each other. For these reasons, the complex structure of the material and number of other factors, the traditional methods of assessing the strength and reliability of construstions from polymeric composite materials (PCM) should be complemented. In particular, by using new and effective monitoring systems. One of these modern methods of diagnostics is creation SMART-materials with embedded sensors. As a sensors the piezoelectric sensors or optical fibers are used. They can be located on the surface of the material or embedded in the polymer composite material. New methods of diagnostics products from these materials increase their competitiveness. Based on numerical modelling and experimental researches, the aim of the work is to search different ways of solving the problem, that allow to increase SMART-material reliability as well as proper registration of the strain field, using the fiber-optic sensors and piezoelectric elements. The problems of the adhesive joint geometry optimization that appear while mounting sensitive elements on the PCM surface and designing optical fiber outputs were considered in this paper. The results of adhesive joint influence on sensors indications were shown. Besides, the stress-strain state analysis that includes the singular solutions for the points, where infinite stress may occur, was carried out in the framework of this study.

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Keywords: Smart materials; fiber optic sensors; singularity; composite materials

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1. Introduction

Materials on polymer basis are widely used among composite materials. The variety of these materials and their wide application in products that require high reliability leads to the need of new approaches. Along with traditional methods new approaches will be used for evaluating the strength and reliability of structures made of polymer composite materials.

One of such approaches connected with the use of effective monitoring systems. Discussing the topic of composite materials monitoring, it is reasonable to use the term smart materials. According to the classification of smart materials that was given in [1], smart materials should include one or several of the following structures: sensing elements, actuator systems, real-time information processing systems. To implement the concept of smart structures composite materials are match to each other in the best way because during its manufacturing the suitable elements could be embedded. Primarily, systems containing sensitive elements (sensors) that allow to monitor the composite material by various parameters have been spread among the smart materials.

At the present time, the most promising design of smart materials that contains sensors is associated with the use of optical fibers and piezoelectric materials. Sensors based on the fiber optics can measure different physical and mechanical quantities, capable to withstand the strains which are comparable to the strains of the composite. They are light and affordable in manufacturing, immune to electrical interference and under severe conditions have advantages, including sensitivity, compared to other sensors.

Also fiber optic sensors can be easily integrated with other equipment for remote monitoring and allow observing composite structure during all stages of its manufacturing: design, testing, operation. One of the main tasks of using fiber optic sensors in composite materials is related to the strain measurement. Problems that encountered in the implementation of this feature are related to the strain measurement of the fiber Bragg gratings and described in the details in the review [2]. The questions of the influence of embedded fiber on the properties of polymer composite material, the issues of input-output optical fiber from the composite material, the tasks of choosing a model that linked the strain of the optical fiber at location of a fiber Bragg grating with measurement of its resonant wavelength and the problem of calibration are observed. There are a number of other problems that need to be investigated, for example, the influence of temperature, time, and complex stress.

One of the problems that appeared when sensors are embedded into a composite material is related to the optimization of the stress state nearby the sensors. In this paper, the problems of optimizing the stress state in an adhesive joint when the sensor is mounted to the material surface, optimizing the stress state in the optical fiber exit zone from the composite material, and the effect of the adhesive joint on the fiber optic sensors readings are studied.

2. Optimization of stress state in adhesive lap joints

A lap joint is the most common type of adhesive joints when mounting the sensors on the material surface. The design diagrams of such adhesive joints contain singular points. In problems of the elasticity theory, there are singular solutions, which are due to the presence of infinite stress values at individual points (lines) of the domain, known as singular points (lines). Among these points are points on the body surface where the surface smoothness condition is violated, the type of boundary conditions changes, and different materials contact, or internal points where, for example, the condition of smoothness of the contact surface of different materials is violated [3, 4]. Infinite stress values appear in an idealized model of a real object considered in the framework of the linear elasticity theory. Singular solutions usually indicate that the simulated object has clearly expressed stress concentration areas.

There are various ways to reduce the stresses in the adhesive lap joints. One of them is to change the shape of the external surface of the adhesive layer at the ends of the contact area. Fig. 1 shows two variants of adhesive lap joints: with and with no spew fillet (l_N and l_W are the lap area lengths for joints without and with a spew fillet, respectively). The design models of these joints have singular points A and B on the body surface, at which different materials are connected, and a point C, at which the smoothness of the contact surface of the two materials is violated.

In the lap joint with a direct end of the adhesive layer obtained by removing the excessive adhesive from the edges of the contact area, a nonuniform stress distribution on the contact surface and stress concentrations at the ends of the contact area are observed. Changes in the rectangular shape of the end of the adhesive layer by forming an external excessive adhesive (spew fillet) help distribute the load on a larger area and provide a more uniform stress distribution. It was shown in [5–12] that the use of spew fillets at the ends of the contact area of adhesive joints decreases the stress