Obtaining of Carbon Fibers Based Composite Materials and Study of Their Mechanical Properties

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Abstract : In this work, theoretical and experimental methods have been developed for obtaining and studying effective thermomechanical characteristics - residual stresses and deformations in panels made of nanomodified materials with an asymmetric reinforcement scheme. The study of the residual stress-strain state of structural elements made of carbon fiber reinforced plastic using the values of thermoelastic characteristics of composite monolayers identified on the basis of the developed methods made it possible to reveal the possibility of reducing the residual stress-strain state in structures with asymmetric reinforcement schemes.

Keywords: Composites, stress-strain state, strength, elastic properties.

1. Introduction

When creating nanocomposites, the key tasks are the development of efficient, reliable, and affordable production technologies for mass production, which make it possible to obtain materials with stable characteristics [1-8]. The hand lay technique, also called wet lay, is the simplest and most widely used process for producing flat reinforced composites. The process consists of laying layers of CFRP in successive layering using an epoxy matrix. Wet-laying is a molding process that combines layers of reinforced carbon fiber with epoxy to create a high-quality laminate. Before starting the installation process, you must prepare the appropriate form. This preparation consists of cleaning the table and applying a release agent to the surface. The manual laying process can be divided into four main steps: mold preparation, epoxy coating, laying and curing. Form preparation is one of the most important steps in the installation process. This process requires dry reinforcement layers and the application of a wet epoxy matrix. They are connected together - carbon fiber (reinforcing) material, impregnated with a matrix - epoxy resin.

Examples of a composite using unidirectional layers and designation of stacking are shown in Fig. 1.

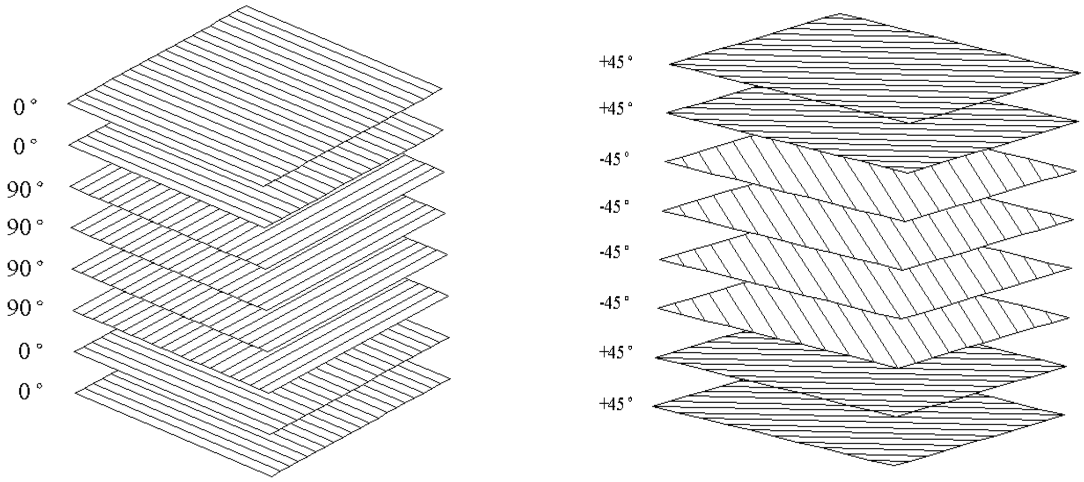

Fig. 1. Scheme of obtaining a layered composite.

Characteristics of the obtained composites

In the experiments, the properties of the matrix were determined:
Elastic modulus: 2 GPa
Tensile Strength: 20 MPa
Limiting deformations: 0,01
CTE (25-50 ºC): 36.8 10^{-6} C^{-1}
CTE (50-60 ºC): 64.72 10^{-6} C^{-1}
Density: 1,2 g/cm^3

From the reference data, we take the value of Poisson's ratio for epoxy resin: 0,2.
In the experiments, the properties of the nanomodified matrix were determined:
Elastic modulus: 2,5 GPa
Tensile Strength: 30 MPa
Limiting deformations: 0,013
CTE (25-50 ºC): 46 10^{-6} C^{-1}
CTE (50-60 ºC): 70 10^{-6} C^{-1}

2. Modeling the mechanical properties of composites

We use the model of spherical inclusions to model the properties of the filled matrix. Assuming that the reinforcing particles of fullerene soot are spheres [9-18]. We assume that the particles are absolutely solid and do not collapse (the upper estimate). Bulk content 0,6%. We use the Digimat - MF module, the averaging method of Mori - Tanaka. Strength criterion - according to the maximum principal stresses acting in the matrix.

If the initial volumetric content of inclusions is set to 0.6%, the model predicts that the properties of the matrix will not change, since there are too few inclusions. The effect of the interfacial layer must be taken into account. For this, we will carry out a calculation with the setting of the effective volumetric content (volumetric content of the filler + volumetric content of the interfacial layer, under the assumption that their properties are equal). Let us select the effective volumetric content that allows us to describe the obtained experimental data in relation to the elastic modulus and ultimate strength.

If we select according to ultimate strength, then the effective volumetric content of inclusions should be 50%, and the modulus of the composite should be 6 GPa according to the calculation. If we select by modulus, then the effective volumetric content of inclusions should be 11%, and the ultimate strength of the composite according to the calculation should be 23 MPa.

To describe the experiment, we can assume that the effective volumetric content of inclusions is 11% (we obtain the coincidence of the calculation and experiment in modulus), and the strength of the matrix increases when a filler is added up to 30 MPa (we obtain a coincidence of the calculation and experiment in strength).

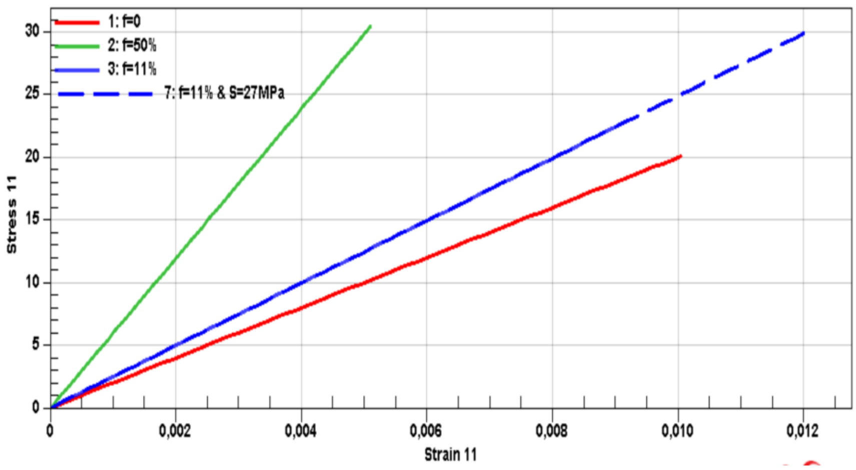

Fig. 2. Diagram of σ – ε samples with different volumetric content of inclusions (in "DIGIMAT-MF"), (green-50%, blue-11%, red-0%).

For the found volumetric content of inclusions, by selection, we determine what the volumetric content of inclusions should be, so that the calculation and the experiment on measuring the CTE of the composite coincide. For 11%, we find that the CTE of the filler (and the surrounding interfacial layer) should be 85 10^{-6} C^{-1}. The obtained high value of the CTE of the filler and the experimentally established phenomenon of an increase in the CTE of composites with a nanomodified matrix may be associated with a change in the structure of the polymer matrix or may be a consequence of the ongoing chemical reactions between the filler and the matrix [19-32].

The initial data for modeling the process of degradation of the mechanical properties of the test samples are the characteristics of the monolayer. In the test, we use fiber grade NTA 40 and matrix grade EDT 10, the properties of which are given in tables 2 and 3.

Table 2. Properties of NTA 40 fiber.

Characteristics	Unit	Value
E_1	*MPa*	257000
E_2	*MPa*	24000
G_{12}	*MPa*	16000
μ_{21}	----	0,279
μ_{23}	----	0,49
$\alpha \cdot 10^{-6}$	$^oC^{-1}$	-0,1
ρ	$г/см^2$	1,7
σ_b	*MPa*	1200

Table 3. Properties of EDT 10 matrix.

Characteristics	Unit	Value
E	*MPa*	2900
μ	----	0,2

The problem of determining the properties of a monolayer based on the properties of the NTA 40 fiber and the EDT 10 matrix is solved using the DIGIMAT program. "DIGIMAT" is designed for fast and highly accurate prediction of the nonlinear behavior of multicomponent materials, such as plastics, polymers, carbon and fiberglass, nanomaterials, etc., for accurate assessment of the local and global behavior of multicomponent structures using the finite element method, for preparing storage and confidential exchange of material models, for easy and highly efficient design of honeycomb sandwich panels. Also "DIGIMAT" presents to the user a number of interfaces for finite element software systems of computer engineering ("ANSYS", "LS DYNA", "SIMULIA / Abaqus", etc.), intended for computer modeling and research of problems of mechanics of a deformable solid body, mechanics of structures and software systems for finite element modeling of plastic molding processes ("MOLDEX3D", "MOLDFLOW", etc.).

Fig. 3 shows theσ–ε, diagrams obtained as a result of finite element analysis in conjunction with "DIGIMAT". Two analyzes were given: a unidirectional sample and a sample with longitudinal transverse packing. These diagrams exactly matched the diagrams obtained when testing these two types of samples.

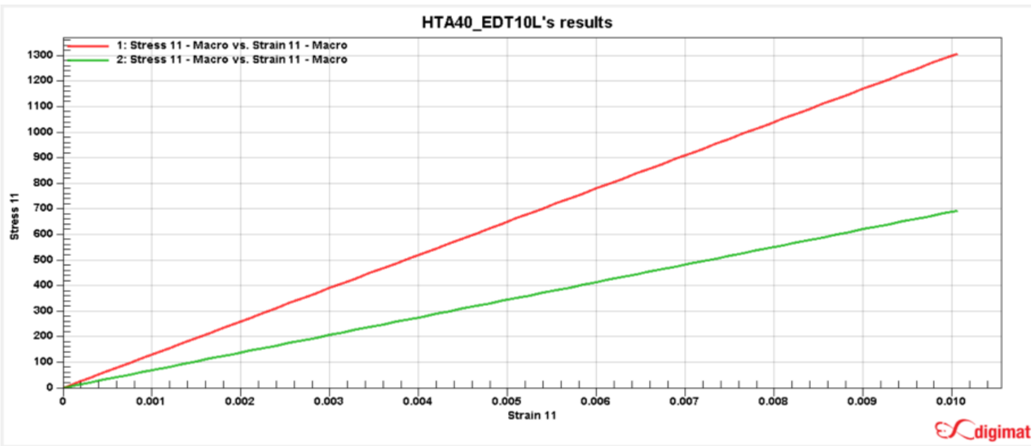

Fig. 3. Diagram of σ–ε for unidirectional specimen and specimen with packing in «DIGIMAT MF».

Based on the results of modeling properties, we obtain a matrix of package stiffnesses, which are presented in table 4.

Table 4. Found stiffness matrix from Digimat.

C11=13 3980	C12=59 93.5	C13=59 93.5	-	-	-
C21=59 93.5	C22=11 153	C23=67 23.9	-	-	-

C31=5993.5	C32=6723.9	C33=11153	-	-	-
-	-	-	C44=2658	-	-
-	-	-	-	C55=2214.7	-
-	-	-	-	-	C66=2658

Find the average modulus by the formula:

$$E_{11} = C_{11} - \frac{2C_{12}^2}{C_{22} + C_{23}} = 133979$$

The obtained value of the average Young's modulus of the packet differs from the test. It is known that when using test data for a unidirectional material in the calculation of the properties of a layered package, errors can occur, therefore, it is usually necessary to use data on the stiffness of several versions of packages with different layering of layers. If using the values of the modules, then it is not possible to describe the test data. In this work, for the properties of a monolayer, we will use an overestimated value of the transverse modulus equal to 28 *GPa*, which is higher than the experimental data obtained for unidirectional samples (6,5 *GPa*). In this case, it is possible to reliably describe the obtained experimental data on Young's modulus of composite samples with symmetric packing.

3. Conclusions

The conducted studies allowed to investigate residual deformations in panels with an asymmetric reinforcement scheme based on the obtained analytical solution, as well as numerical modeling. Comparison of the results of analytical and numerical solutions with the obtained experimental data confirms the reliability and validity of the developed mathematical models and research methods for effective thermomechanical characteristics and residual stress-strain state of panels made of layered nanomodified materials.

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