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THE CALCULATION METHOD OF SMALL-SIZED COMPOSITE ENCLOSURES IN CAD/CAE SYSTEMS

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S u m m a r y. This article is about the possibility of calculating of the small enclosures made of composite materials in CAD/CAE systems. The initial data for calculating consists of the fiber and matrix elastic constants and the fiber volume content in the composite. The stress-strain state has been obtained. The enclosure was loaded with the internal pressure.
K e y w o r d s: composite, heterogeneous model, homogeneous model, physico-mechanical properties, stress tensor, transversally isotropic body.

INTRODUCTION

New materials gain large scales in a world where science and technology develop rapidly. They are used in various fields. It concerns space and aircraft. Composite materials can be attributed to this. They are more durable to the traditional construction materials and alloys. Thus, there is a need for analysis of structures and their components made of composite materials in the CAD / CAE systems [3-10, 19-21].

Most of strength calculations use homogeneous (isotropic) materials. Their properties are independent of their spatial position in a coordinate system. The another approach is required for calculating of the CM [14-17].

The purpose of the article is to develop a calculation methods of small enclosures made of composite materials (CM). This can be performed with the help of a modern CAD / CAE systems (particularly in the software package ANSYS).

OBJECTS AND PROBLEMS

The heterogeneous model is one of the major models made of composite materials, which are used for durability and design analysis of structures [1, 2].

The heterogeneous composite model is based on the notion of isotropic material as the reinforcing fibers with their idealized interaction fig. 1. They can be ordered or randomly placed in the isotropic matrix. The fibers are usually parallel to each other.

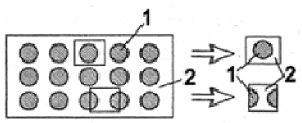

Fig. 1. The heterogeneous composite model: 1 - fiber, 2 - matrix

Thus, the physical and mechanical properties of the matrix and the fibers and their volume fraction in the CM are needed to know for the calculation of monolayer element of the unidirectional CM.

The elastic constants of the matrix and fibers are generally initially known while the manufacturing of the products made from CM. Their volume content in the CM is also known. It is necessary to move from the elastic constants of the composite elements to the composite constants for calculating the CM in CAD / CAE systems [11-13, 18].

The elastic constants are calculated by a certain law for the unidirectional composite. It depends on the direction of fibers. Relatively speaking, the direction along fiber is for1, and across the fiber is for 2. The along-the-fibers elastic modulus is calculated by the formula [1]:

$$E_1 = E_B \cdot \Theta + E_M \cdot (1-\Theta), \quad (1)$$

where: E_B– elastic modulus of the fibers;

Θ– fiber volume content;

E_M– elastic modulus of the matrix.

The across-the-fibers elastic modulus is calculated by the formula:

$$E_2 = \frac{E_B \cdot E_M \left[E_B \cdot \Theta + E_M \cdot (1-\Theta)\right]}{\left[E_B \cdot \Theta + E_M \cdot (1-\Theta)\right] \cdot \left[E_M \cdot \Theta + E_B \cdot (1-\Theta)\right] - \Theta \cdot (1-\Theta) \cdot \left(E_B \cdot \mu_M - E_M \cdot \mu_B\right)^2}. \quad (2)$$

The along-the-fibers Poisson's ratio of the composite is calculated by the formula:

$$\mu_{12} = \mu_B \cdot \Theta + \mu_M \cdot (1-\Theta), \quad (3)$$

where: μ_B – Poisson's ratio of the fiber;

μ_M – Poisson's ratio of the matrix.

The across-the-fibers Poisson's ratio of the composite is calculated by the formula:

$$\mu_{21} = \frac{E_B \cdot E_M \cdot \left[\mu_B \cdot \Theta + \mu_M \cdot (1-\Theta)\right]}{\left[E_B \cdot \Theta + E_M \cdot (1-\Theta)\right] \cdot \left[E_M \cdot \Theta + E_B \cdot (1-\Theta)\right] - \Theta \cdot (1-\Theta) \cdot \left(E_B \cdot \mu_M - E_M \cdot \mu_B\right)^2}. \quad (4)$$

The shear modulus in the plane of isotropy depends on the elastic modulus and Poisson's ratio. It is found by the formula [1-5]:

$$G_{ij} = \frac{E_i}{2 \cdot (1+\mu_{ij})}, \quad (5)$$

where: E_i– i-direction elastic modulus;

μ_{ij} – j-direction Poisson's ratios while loading in the direction of " i ".

The shear modulus in the any plane perpendicular to the plane of isotropy is taken as the average of the shear modulus is calculated on the basis of equality of shear deformation and shear modulus calculated on the basis of equality of shear stresses is found by the formula [1]:

$$G_{12} = \frac{G_{12}^{Д} + G_{12}^{Н}}{2}, \quad (6)$$

where: $G_{12}^{Д}$ – shear modulus of equality of shear deformation;

G_{12}^{H}– shear modulus of equality of shear stresses;

$$G_{12}^{Д} = G_B \cdot \Theta + G_M \cdot (1-\Theta), \quad (7)$$

$$G_{12}^{Н} = \frac{G_B \cdot G_M}{G_M \cdot \Theta + G_B \cdot (1-\Theta)}, \quad (8)$$

where: G_B– shear modulus of the the fiber;

G_M– shear modulus of the the matrix.

In turn, shear moduli of fiber and matrix can be calculated by the formula:

$$G_B = \frac{E_B}{2 \cdot (1+\mu_B)}, \quad (9)$$

$$G_M = \frac{E_M}{2 \cdot (1+\mu_M)}. \quad (10)$$

Thus, we know the elastic moduli and Poisson's ratios of the fiber and the matrix, as well as the fiber volume content in the CM. Now we can calculate the the elastic constants of the whole layer.

Poisson's ratio can have 3 different values when the transversely isotropic body is loaded. It depends on the loading direction relative to the axis of symmetry. The axis of symmetry in this case is the axis Z, and the plane of isotropy is the XY plane. The loading deformations are shown in fig. 2.

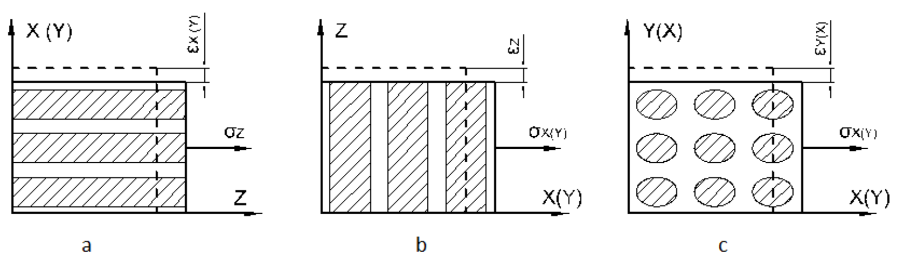

Fig. 2. Deformation of the layer at the normal stress: a - lateral deflection at the longitudinal loading; b - longitudinal deflection at the lateral loading; c - deflection at the lateral loading

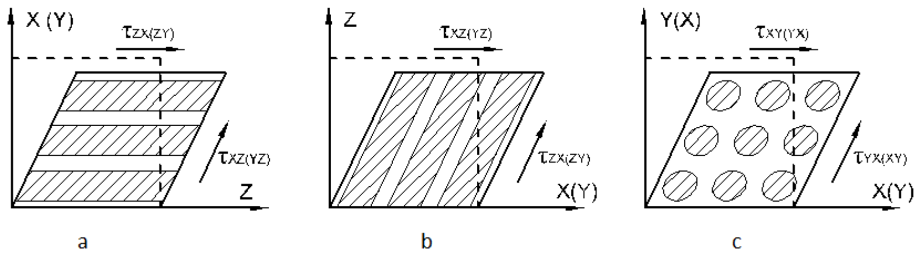

Fig. 3. Deformation of the layer for the tangential stresses: a, b - shear strain in the plane perpendicular to the plane of isotropy; c - shear strain in the plane of isotropy

Let's accept conditionally the Poisson's ratio in the plane of isotropy as "0". The shear modulus G_{xy} in this case is found by the formula (5).

Initial data of elastic constants CM components are summarized in table 1.

Table 1. The elastic constants of the CM components

Physical quantity	Designation	Value
Elastic modulus of the fibers, MPa	$E_{в}$	90000
Poisson's ratio of the fiber	$\mu_{в}$	0,28
shear modulus of the the fiber, MPa	$G_{в}$	35156
Elastic modulus of the matrix, MPa	$E_{м}$	4000
Poisson's ratio of the matrix	$\mu_{м}$	0,3
shear modulus of the the matrix, MPa	$G_{м}$	1538
fiber volume content	Θ	0,6

The data were obtained after the calculations. Table of elastic constants defined in the CAD/CAE systems is made. Tables 2 and 3 are constructed for the longitudinal and circular layer.

Table 2. The elastic constants of the longitudinal layer

Physical quantity	Designation	Rated value	Value
Modulus of elasticity, MPa	E_x	E_2	10138
	E_y		10138
	E_z	E_1	55600
Poisson's Ratio	μ_{xy}	–	0
	μ_{yz}	μ_{21}	0,053
	μ_{xz}		0,053
Shear modulus, MPa	G_{xy}	G_{xy}	5069
	G_{yz}	G_{12}	12659
	G_{xz}		12659

Table 3. The elastic constants of the circular layer

Physical quantity	Designation	Rated value	Value
Modulus of elasticity, MPa	E_x	E_2	10138
	E_y	E_1	55600
	E_z	E_2	10138
Poisson's Ratio	μ_{xy}	μ_{21}	0,053
	μ_{yz}	μ_{12}	0,288
	μ_{xz}	–	0
Shear modulus, MPa	G_{xy}	G_{12}	12659
	G_{yz}		12659
	G_{xz}	G_{xy}	5069

Test calculation is performed on the "balloon" product. The balloon is calculated in the CAD / CAE system using the finite element method.

The balloon was loaded by the internal pressure P = 10 MPa with a given elastic constants of the longitudinal layer (table 2) and a given elastic constants of the circular layer (table 3). The quantity of the deformation has been increased in 100 times for clarity. Results of calculation of the balloon with the longitudinal layer are shown in fig. 4 and with the circular layer are shown in fig. 5. Tension evaluation is MPa.

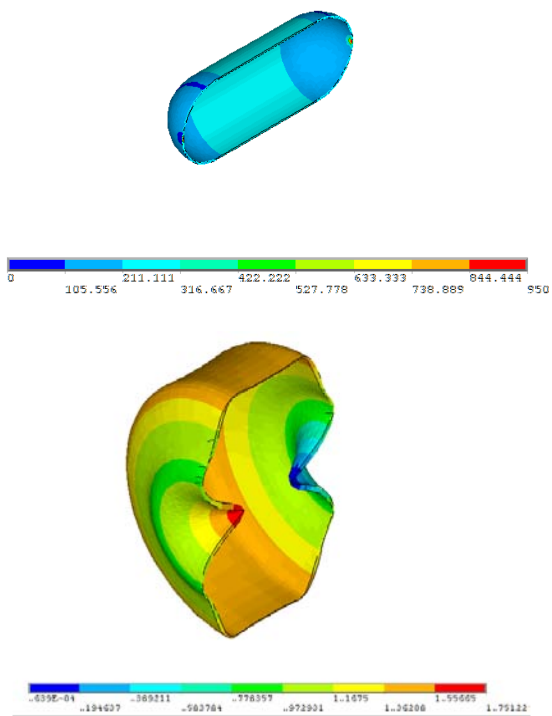

Fig. 4. Equivalent stresses in the longitudinal layer of the balloon

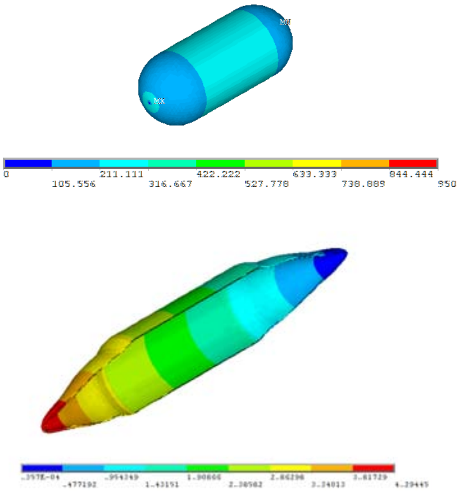

Fig. 5. Equivalent stresses in the circular layer of the balloon

CONCLUSIONS

The test calculation was performed on the "balloon" product. The calculation has shown that the method of calculation of construction elements made of composite materials in the CAD/CAE systems is suitable for modeling of the force aircraft elements. This is applicable for pipes, SPRM body, transport and launch container (TLC) based on the polymer composite.

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МЕТОДИКА РАСЧЕТА МАЛОГАБАРИТНЫХ КОРПУСОВ ИЗ КОМПОЗИЦИОННЫХ МАТЕРИАЛОВ В CAD/CAE СИСТЕМАХ

Игорь Малков, Геннадий Сыровой,
Игорь Непран, Сергей Кашкаров

Аннотация. В статье рассмотренна возможность расчета элементов конструкции из композитных материалов в CAD/CAE системах, исходными данными для расчета которых являются упругие константы волокна и матрицы, а так же объемное содержание волокна в композите. Полученно напряженно-деформированное состояние простых элементов, нагруженных внутренним давлением и сжимающей силой.

Ключевые слова: композит, гетерогенная модель, физико-механические свойства, тензор напряжений, трансверсально-изотропное тело.