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Numerical modeling of the effects of fiber packing on transverse Poisson's ratio ν_{23} of a unidirectional composite material Glass / Epoxy

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ABSTRACT

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In this study, the main objectives will be to predict the Poisson's ratio ν_{23} of a unidirectional Glass/Epoxy composite material and to study the effect of the arrangement of the fibers on the Poisson's ratio ν_{23}. We used the micromechanical approach and a Castem calculation code based on the FEM method. The results obtained from the numerical modeling were compared with those obtained by the available analytical models.

1. Introduction

Composite materials are very widely used in the manufacture of structures. However, these materials are characterized by heterogeneity and anisotropy, so they present great challenges in predicting the characteristics of the matrix/reinforcements mixture for example the determination of the modulus of elasticity E_2 [1-4] and the coefficient of Poisson ν_{23} is still of interest to researchers because of the diversity of results obtained by several approaches and both features are used to study the mechanical behavior of composites in 3D. The present study aims mainly to predict the Poisson's ratio ν_{23} of a unidirectional Glass/Epoxy composite material, and to study the effect of the arrangement of the fibers on the Poisson's ratio ν_{23}.

2. Analytical models

The analytical method uses various mathematical expressions to predict elastic constants such as modulus of elasticity, shear modulus, and Poisson's ratios. The mixture rule method, the Halpin-Tsai model and the exact solution are ones among different used methods.

2.1 Rule of mixture (ROM)

It is the simplest method to determine the elastic properties of a unidirectional composite material. The classical mixing rule useful for accurately predicting the longitudinal Young's modulus E_1, Eq(1), [5] but does not accurately predict the Poisson's ratio ν_{23}.

$$E_1 = E_{fL}.V_f + E_m.(1 - V_f) \quad (\textit{Voigt model}) \tag{1}$$

$$\nu_{12} = \nu_f.V_f + \nu_m.(1 - V_f) \quad (\textit{Voigt model}) \tag{2}$$

where, E_{fL}, E_{ft}, ν_f are fiber properties (respectively longitudinal elastic modulus, transversal elastic modulus and Poisson's ratio), E_m, ν_m are matrix properties (respectively elastic modulus and Poisson's ratio) and V_f is the fiber volume fraction.

2.2 Halpin-Tsai model (HT)

The Halpin-Tsai equation, Eq. (3), was developed as a semi-empirical model to determine the transverse Young's modulus E_2, Poisson's ratio ν_{23} and the longitudinal shear modulus G_{12} [6].

$$M_C = M_m\left(\frac{1+\xi.\eta.V_f}{1-\eta.V_f}\right) \tag{3}$$

The coefficient η is given by:

$$\eta = \frac{\left(\frac{M_f}{M_m}\right)-1}{\left(\frac{M_f}{M_m}\right)+\xi} \tag{4}$$

Mc : E_T,G_{LT} or ν_{23}. M_m: E_m,G_m or ν_m . M_f: E_f,G_f or ν_f

ξ is an empirical factor, which measures the fiber reinforcement of the composite material. In general, ξ can vary from zero to infinity. For the transverse modulus E_2 for a square network of circular fibers and V_f= 0.55, we take ξ=2 to calculate E_2 and ξ=1 to calculate the shear modulus G_{12} [6].

2.3 Relations of the Poisson's ratio ν_{23} with the coefficients of the compliance and The stiffness matrix

You can use the equations:

$$\nu_{23} = -\frac{S_{23}}{S_{22}}, \nu_{23} = \frac{C_{12}^2 - C_{11}C_{23}}{C_{12}^2 - C_{11}C_{22}} \tag{5}$$

S_{23},S_{22} : flexibility matrix coefficients
C_{11},C_{22} et C_{12} : stiffness matrix coefficients