Numerical Modeling of the Effects of Fiber Packing on Transverse Poisson'S Ratio ν_23 of a Unidirectional Composite Material Glass / Epoxy

Brek Samir, Meddour Belkacem, Saoudi Abdenour and Bettayab Mohammed

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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

BREK Samir*[1,2], MEDDOUR Belkacem [2], SAOUDI Abdenour [2] and BETTAYAB Mohammed[3]

[1]Laboratory (ISMA), Mechanical Engineering Department, ABBES Laghrour University, Khenchela, Algeria
[2]Mechanical Engineering Department, ABBES Laghrour University, Khenchela, Algeria
[3]Laboratory (LMANM), University 8 May 1945,Guelma, Algeria

*correspondance E-mail: brek_samir@univ-khenchela.dz
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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}.

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

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

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].

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

The coefficient η is given by:

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

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:

$$\nu_{23} = -\frac{S_{23}}{S_{22}}, \quad \nu_{23} = \frac{C_{12}^2 - C_{11}C_{23}}{C_{12}^2 - C_{11}C_{22}} \qquad (5)$$

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

Relationship of the Poisson's ratio and the engineer's moduli, (the equations used in the analytical calculation),[9]:

$$\nu_{23} = \frac{E_2}{2G_{23}} - 1 \quad (6)$$

$$K_i = \frac{E_i}{2(1-2\nu_i)(1+\nu_i)} \quad \text{avec } i = f \text{ et } m \quad (7)$$

$$G_{23} = \frac{1}{2\left(\frac{2}{E_2} - \frac{1}{2K_L} - 2\frac{\nu_{LT}^2}{E_L}\right)} \quad (8)$$

$$K_L = K_m + \frac{V_f}{\frac{1}{K_f - K_m + \frac{1}{3}(G_f - G_m)} + \frac{1-V_f}{K_m + \frac{4}{3}G_m}} \quad (9)$$

2.4 Relations of R. L. FOYE [7]

$$\nu_{23} = \nu_f V_f + \nu_m V_m \left[\frac{1+\nu_m - \nu_{LT}\left(\frac{E_m}{E_L}\right)}{1-\nu_m^2 + \nu_m \nu_{LT}\left(\frac{E_m}{E_L}\right)}\right] \quad (10)$$

3. Finite element modeling

3.1 Objective

Numerical modeling to determine the Poisson's ratio ν_{23} by finite elements is carried out using the software Cast3m, [8]. We have developed calculation programs (GIBIANE language). To study the effect of the random position of the fibers, six cases were considered, therefore six representative elementary volumes (REVs) were obtained with a fiber volume fraction of 44.3%, figure (1).

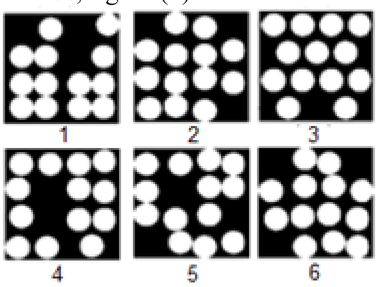

Figure 1. Models of RVEs for $V_f = 0.443$

3.2. Materials and characterizations

The composite material used in the numerical modeling corresponds to a unidirectional ply (UD) based on epoxy resin and long glass fiber (E) with a circular section. Some mechanical properties of fiberglass and epoxy resin are summarized in Table (1).

Table 1. The elastic characteristics [9]

Caractéristiques élastique	Glass E	Epoxy
Young's modulus [GPa]	73	3.45
Shear modulus G_{12} [GPa]	29.9	1.33
Poisson's ratio ν_{12}	0.22	0.30

3.3 Representative elementary volume (REV)

Square or cubic REVs are used for most numerical approximations due to the ease of solving limit value problems numerically with these geometries, for most applications the sizes of the REVs have been rather arbitrary. In this work, we considered a square REV model with side 48 µm. Figure (2) shows a typical REV. Each REV is composed of 16 cells (fiber with matrix or matrix without fiber), [3,4].

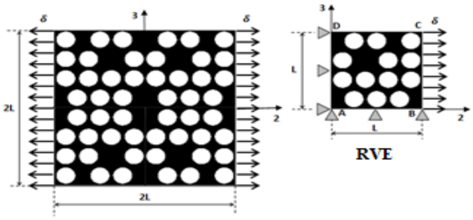

Figure 2. Cross section in plane 2-3

3.4 Mesh of the representative volume

The triangular element (Tri3) used for the realization of meshes in this study is based on a general state of 2D.

3.5 Calculation of the coefficient ν_{23} by modeling

$$\nu_{23} = -\frac{\varepsilon_3}{\varepsilon_2}, \quad \varepsilon_3 = \frac{U_3}{L_0}, \quad \varepsilon_2 = \frac{U_2}{L_0} \quad (11)$$

The axial load is modeled by a tensile displacement acting along axis 2 (U2=δ). For the boundary conditions (DA and AB two axes of symmetry),[3,4].

4. Results

The results obtained by the numerical calculation code, table 2 :

Table 2. The coefficient ν_{23} by modeling

N°	ν_{23} (Mode)	ν_{23} (Analy1) Eq(6)	ν_{23} (Analy2) Eq(10)	G_{23} MPa (Mode)	E_2 MPa (Mode)
1	0.30935	0.3011	0.3292	3775.155	9886.0
2	0.26210	0.3438	0.3292	3677.046	9281.6
3	0.43693	0.3615	0.3292	3142.567	9031.3
4	0.31713	0.3538	0.3292	3469.741	9140.2
5	0.31893	0.3481	0.3292	3495.674	9221.1
6	0.40950	0.3246	0.3292	3388.861	9553.2

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