Analytical and Numerical Homogenization of a Bio-Source Concrete

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Abstract

In this paper, we are interested in the analytical homogenization of the elastic properties of concrete with jute fibers of composite material (CJF). Is to characterize the behavior of the concrete reinforced with jute fibers. This behavior will be investigated by using the two-dimensional (2D) nonlinear finite element method, where Ansys commercial software is used as a modeling tool. In order to show the effect of volume fraction Vf on the fibers in concrete, they were modeled as homogeneous isotropic materials. Results obtained from homogenization numérique were close to analytical homogenization results. It was found that the usage of the jute fibers was not significantly enhanced to characterize the behavior because this jute fiber is a weak natural material. The importance of this research is that it shows the ability to use the finite element method to simulate concrete beams reinforced with jute fibers. The results of the numerical approach and the analytical results obtained show that the concrete loaded with 6% of its volume in jute fiber is the most rigid.

Key words: Bio-source concrete, ANSYS, Volume fraction, Fibre jute, Elastic behaviour.

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I. Introduction

In recent years, renewable fiber-reinforced concretes (FRC) have been increasingly used. Reinforced concrete structures are largely employed in engineering practice in a variety of situations and applications.

The identification of the macroscopic mechanical properties, or overall "effective properties," is an important aspect in the study of composites.

Homogenization is a process in which a composite material having a microscopic structure is replaced with an equivalent material having macroscopic, homogeneous properties. In this process of homogenization, the rapidly oscillating coefficients are replaced with new effective constant coefficients. The primary objective of homogenization, i.e., of the micro-macro approach, is to replace a system with periodically varying coefficients by a limiting homogeneous system that facilitates computation.

The objective of this work is to determine the influence of the volume fraction of jute fiber in the reinforcement of bio-sourced concrete (BSC). For this purpose, we have carried out simulations on the calculation code of ANSYS structures for the purpose of homogenizing the elementary volume representative of BBS. Homogenization makes it possible to estimate the macroscopic properties of a heterogeneous material (classical continuous medium), from the properties of the different phases that constitute it and from certain parameters characterizing their spatial distributions [1].

Nomenclature
CJF : concrete jute fibre
BSC : bio-sourced concrete
E^m, Concrete elastic modulus
G^m , Concrete shear modulus matrix
E^f, , Fiber elastic modulus
G^f. shear modulus fibres
E_L, Longitudinal Young's Module
E_{TL}, transversal Young's Module

II .Modeling by the finite element method

The software for calculating structures by the finite element method ANSYS was used to model the problem of mechanical behavior of a composite beam (figure 1).

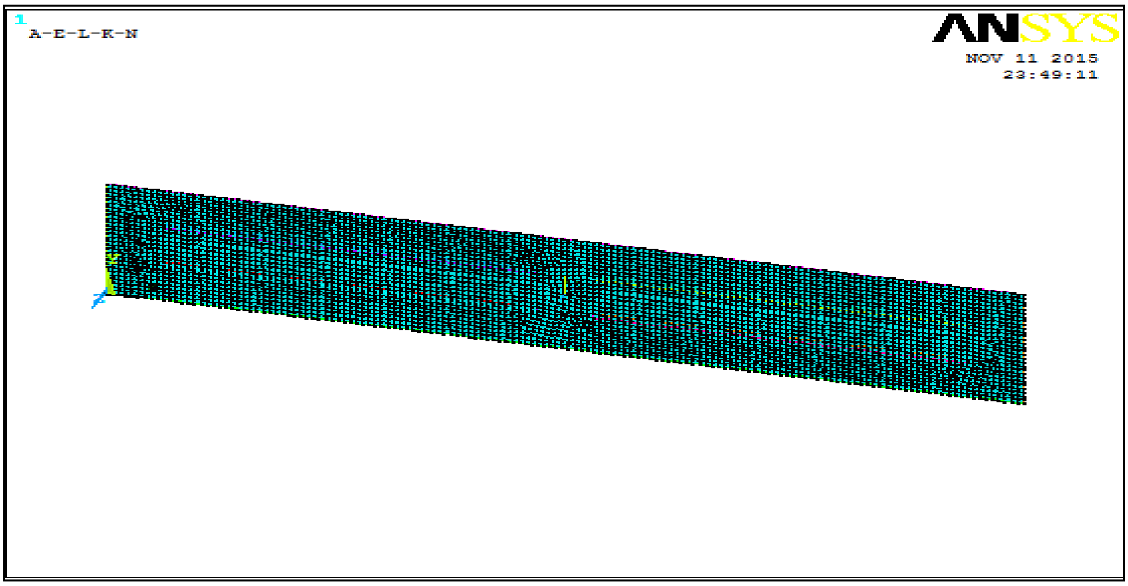


Figure 1 : composite beam By Ansys

II.1 Element types

The considered geometry is with a grid by the 2D rectangular element PLANE182. This element has four nodes and two degrees of freedom (translations direction X and Y [3] [4].

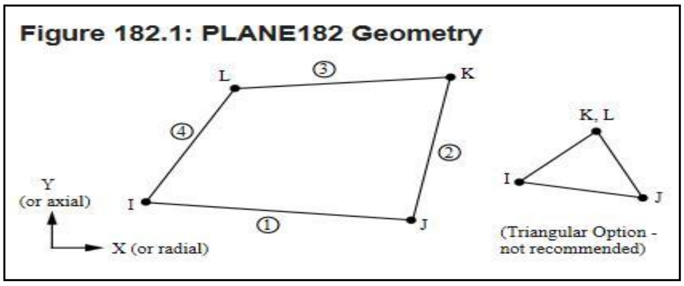


Figure 2 : Element Types of ANSYS Modelling [3]

II.2 PROPERTIES

The following table 1 groups together the main elastic characteristics used in this simulation :

Table 1 : Elastic characteristics of material utilized **[6]**

Material	Young's modulus (GPa)	Poisson's ratio	Volumic mass (g/cm3)
concrete	*45*	0.2	*2,4*
Jute fiber	26.5	0.3	1.3-1.5

III. Numerical homogenization

The mechanical behavior of a heterogeneous material requires the analysis of its microstructure and the resolution of a microscopic problem [7]. The homogenization method consists in replacing a real non-homogeneous material by a homogeneous fictitious material with equivalent macroscopic properties [8], [7], [Jam 08]. For homogenization to be possible, it is necessary to be able to define a representative elementary volume of the material. The result of homogenization, on this volume, will be the behavior of the equivalent homogeneous material [09].

The homogenization of the "concrete / fiber" composite material is carried out by the characteristics of the homogenized concrete being defined, a homogenization is carried out for the concrete with jute fibers (see Figure 3). The Young's modulus and the shear coefficient are noted, respectively: E^m, G^m, for the matrix (concrete), for the fibers (jute) E^f, G^f.

Figure 3: the steps of homogenization of the fibres concrete [11]

The preferred cell for fiber concrete is a rectangle (length Lc, width lc) comprising a coated fiber at equal distances from the outer sides of this rectangle. The fiber has a length lf and a width lf (s ee Figure
4). The dimensions of the base cell are determined as a function of the percentage by volume of the fibers [12]

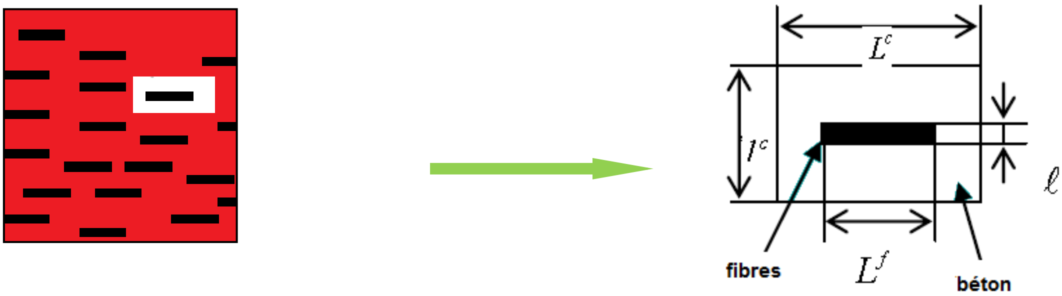
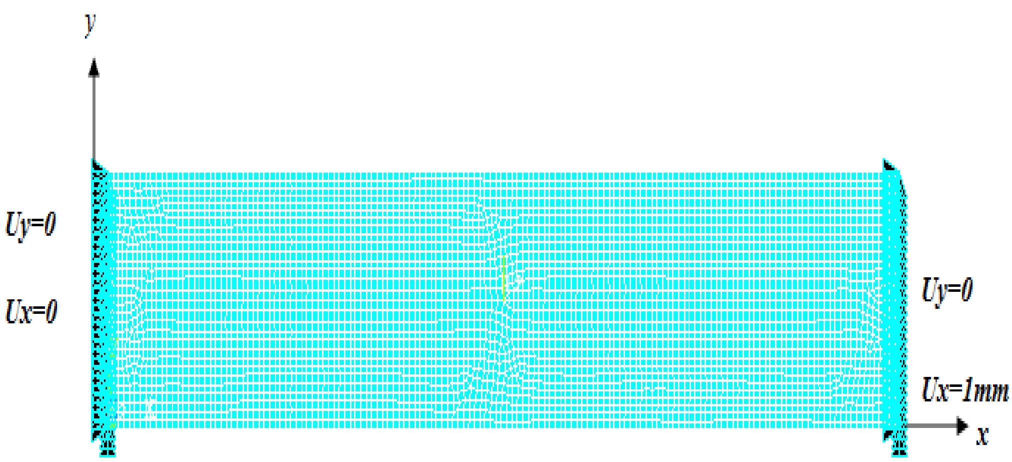


Figure 4 : cell size of concrete reinforced by fiber [12]

III.1 Boundary conditions and finite element calculation methods

To calculate the composite beam, a displacement is imposed on one side of the Volume elementary in a given direction. Symmetries are taken into account in boundary conditions.

- Simulation of a tensile stress in a direction i (i = x, y) makes it possible to determine the two elast ic modules E1, E2
- Simulation of the shear stresses according to the planes (x, y) makes it possible to determine the s hear modulus G12,
- This method based on the stress at the links from a forced displacement allows by the use of the laws of behavior to deduce the constant elastics.



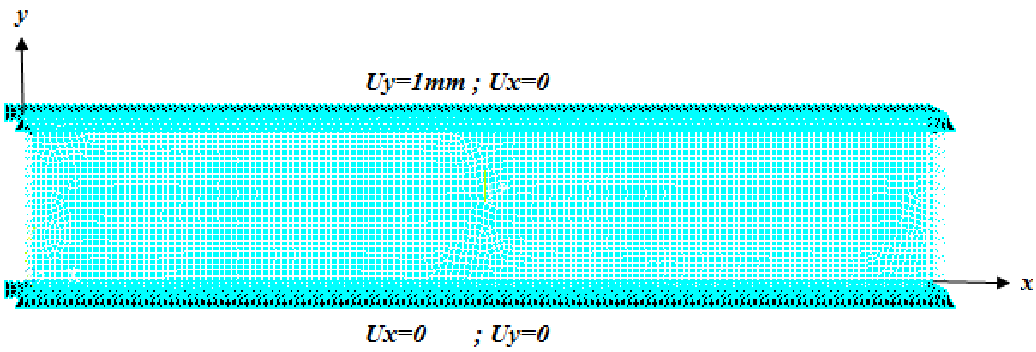


Figure 5 : Boundary conditions for in-plane traction simulation (x, y).
(a) on the x axis, (b) on the y axis.

IV. Analytic homogenization (Mixing law)

Longitudinal Young's Module E L

The Longitudinal Young's Module Ex is determined by the longitudinal tensile test see (Figure 6)

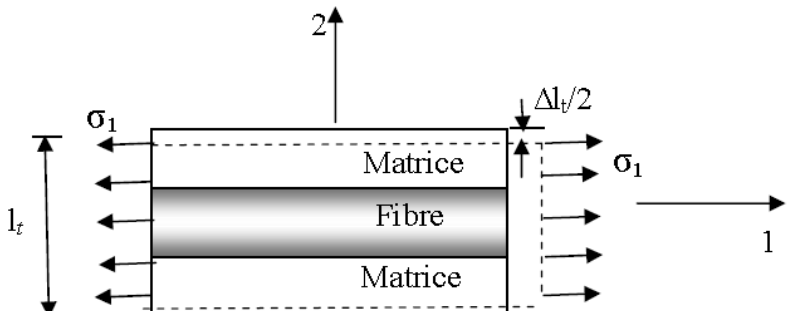


Figure 6: Simplified Scheme for Longitudinal Traction [2]

The deformation in the fiber and in the matrix requires:

$$\varepsilon_f = \varepsilon_m = \varepsilon_l \qquad 1$$

Constraints in the fiber and matrix are expressed by:

$$\sigma_f = E_f \varepsilon_l \qquad \sigma_m = E_m \varepsilon_L \qquad 2$$

The total charge applied is:

$$F_l = \sigma_f s_f + \sigma_m s_m \qquad 3$$

The average stress $\sigma_1 = \frac{E_1}{S}$ is written :

$$\sigma_l = \sigma_f v_f + \sigma_m (1 - v_f) \qquad 4$$

$$\sigma_l = E_l \, \varepsilon_l \qquad 5$$

The combination of relationships 2 and 5 was conducted to express the young longitudinal module.

$$E_L = E_f V_f + E_m (1 - V_f) \qquad 6$$

IV.I. Transversal Young's Module ET

The transversal Young's Module ET is determined by the transverse tensile test, or when the composite is loaded in the direction normal to the fibers.

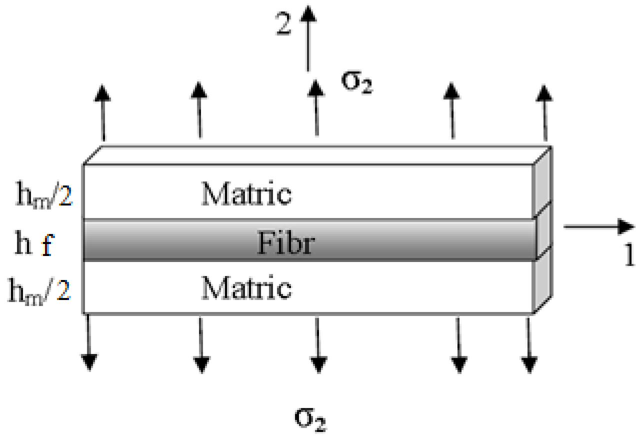


Figure 7 :Simplified transverse traction scheme [2]

The height of the layers should check:

$$v_f = \frac{h_f}{h_f + h_m} \text{ et } 1 - v_f = \frac{h_f}{h_f + h_m} \quad (7)$$

Imposing equal stress:

$$\sigma_m = \sigma_f = \sigma_2 \quad (8)$$

Deformation of the fiber and matrix in the transverse direction:

$$\varepsilon_f = \frac{\sigma_2}{E_f} \quad \varepsilon_m = \frac{\sigma_2}{E_m} \quad (9)$$

Transverse elongation

$$\Delta l_2 = \varepsilon_f h_f + \varepsilon_m h_m \quad (10)$$

The transverse deformation:

$$\varepsilon_2 = \frac{\Delta l_2}{h_f + h_m} = \varepsilon_f \frac{h_f}{h_f + h_m} + \varepsilon_m \frac{h_f}{h_f + h_m} \quad (11)$$

$$\varepsilon_2 = \varepsilon_f v_f + \varepsilon_m (1 - v_f) \quad (12)$$

This deformation is related to the stress imposed on the cell by the transverse module

$$\sigma_2 = E_T \varepsilon_2 \quad (13)$$

The expression of the transversal young modulus is:

$$\frac{1}{E_T} = \frac{V_f}{E_f} + \frac{1 - V_f}{E_f} \quad (14)$$

$$E_T = E_m \left[1 \Big/ 1 + \left[\frac{E_m}{E_f} - 1 \right] V_f \right] \quad (15)$$

IV.2. Longitudinal shear module G_L

The longitudinal shear module is determined by the schematic longitudinal shear test in Figure 8.

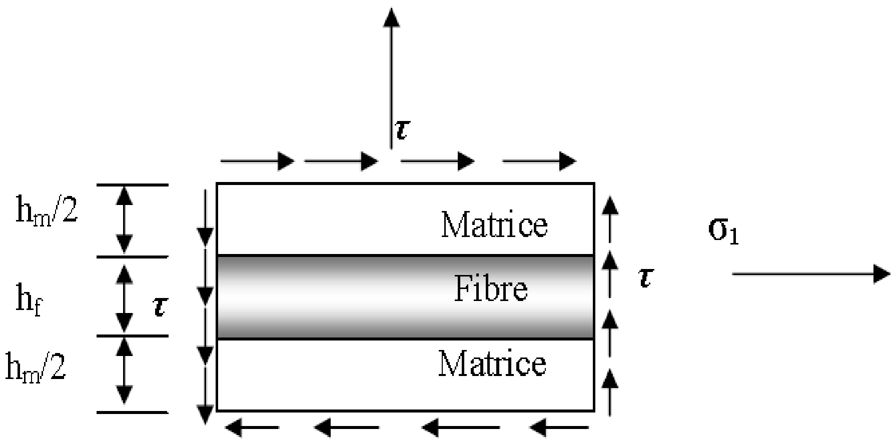


Figure 8: simplified diagram of the longitudinal shear test [1]

The shear deformations of the fiber and the matrix:

$$\gamma_f \frac{\tau}{G_f} \qquad et \qquad \gamma_m \frac{\tau}{G_m} \qquad 16$$

The deformations induced in the fiber and in the matrix:

$$\delta_f = h_f \gamma_f \qquad \delta_m = h_m \gamma_m \qquad 17$$

Total deformation:

$$\delta = \delta_f + \delta_m = \gamma_f h_f + \gamma_m h_m \qquad 18$$

The shear angle of the cell

$$\delta = \frac{\delta}{h_f + h_m} = \gamma_f v_f + \gamma_m (1 - v_f) \qquad 19$$

This angle is linked to the shear stress by the longitudinal shear module G $_{LT}$:

$$\gamma = \frac{\tau}{G_{LT}} \qquad 20$$

The expression of the longitudinal shear modulus

$$\frac{1}{G_{LT}} = \frac{v_f}{G_f} + \frac{1 - v_f}{G_m} \qquad 21$$

$$G_{lT} = G_m \left[{}^{1}\Big/ (1 - V_f) + \frac{G}{G_{ft}} V_f \right] \qquad 22$$

V. Analysis of Results

Table 2 groups the results obtained by numerical simulations and compares them with the analytical values obtained by the mixture law formulas.

The graphs in Figures 8 and 9, 10 present the assessment of the mechanical behavior of the composite beam for the bio-source concrete material (BSC) as a function of the density fraction of fibers Vf, the elastic characteristics intended in Table 1.

In the analytical homogenisation (mixing law) the evaluation is practically linear as long as the young module of the matrix is superior to the Young module of the fiber uses, On the other hand, the numerical homogenisation has another curve which shows that the maximum value of young module in the X and Y direction is obtained in the concrete reinforced with jute fiber their density fraction is $V_f = 6$ %.

So the numerical model gave different results than the analytical model, Based on the results obtained, we note that the elasticity modules EX and EY and the shear module G_{xy} decrease if we exceed the density fraction of jute fiber $V_f = 6\%$ in the matrix.

Numerical versus Analytic Homogenization Results

The following table summarizes the results obtained from the numerical homogenization and homogenization analytic of the beams:

Table 2 ; The Effects of jute Fibers Additions of the **elastic properties**

	homogenization analytic (mixing law)			**numerical homogenization (Ansys)**		
V_f %	G_{xy} (Gpa)	E_y(Gpa)	E_xGpa)	G_{xy}(Gpa)	E_y(Gpa)	E_x (Gpa)
0	18,75	45	63,75	18,76678	45,55698	63,514
1	18,593882	45,454546	64,0484271	18,622361	46,94998	64,30955
2	18,440341	45,918367	64,3587087	18,534672	46,699992	64,683086
3	18,289316	46,391753	64,6810689	18,396844	47,214983	64,695
4	18,140745	46,875	65,0157448	18,222203	47,347127	65,119595
5	17,994568	47,368421	65,3629888	18,117957	47,724957	65,426026
6	17,850728	47,87234	65,7230679	18,0021	47,894945	65,722159
7	17,709169	48,387097	66,0962655	17,86665	46,566076	66,093
8	17,569837	48,913044	66,4828808	17,75555	46,445761	66,041824

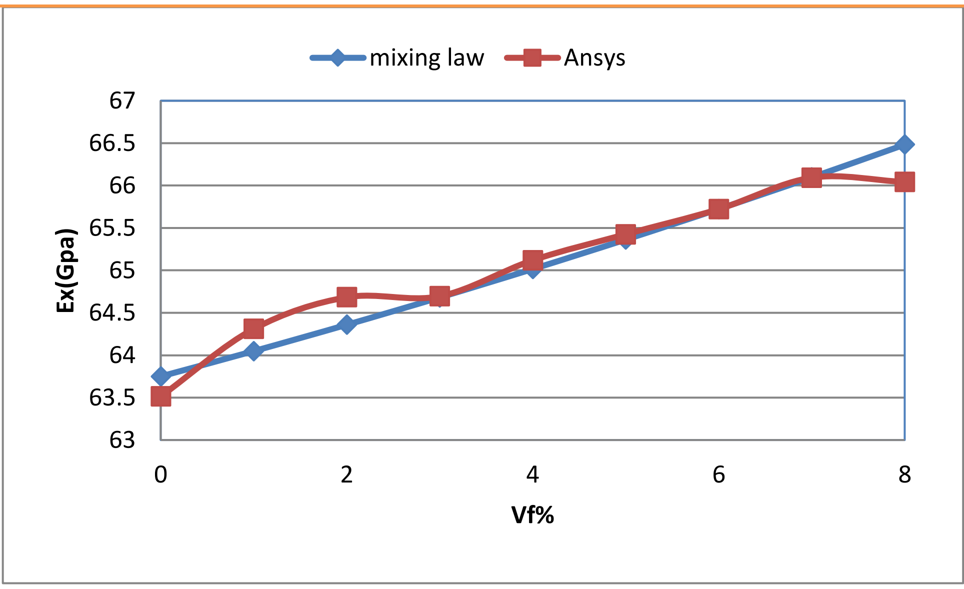


Figure 9: the evolution of the Young's Module (X) as a function of the volume fraction of the jute fiber

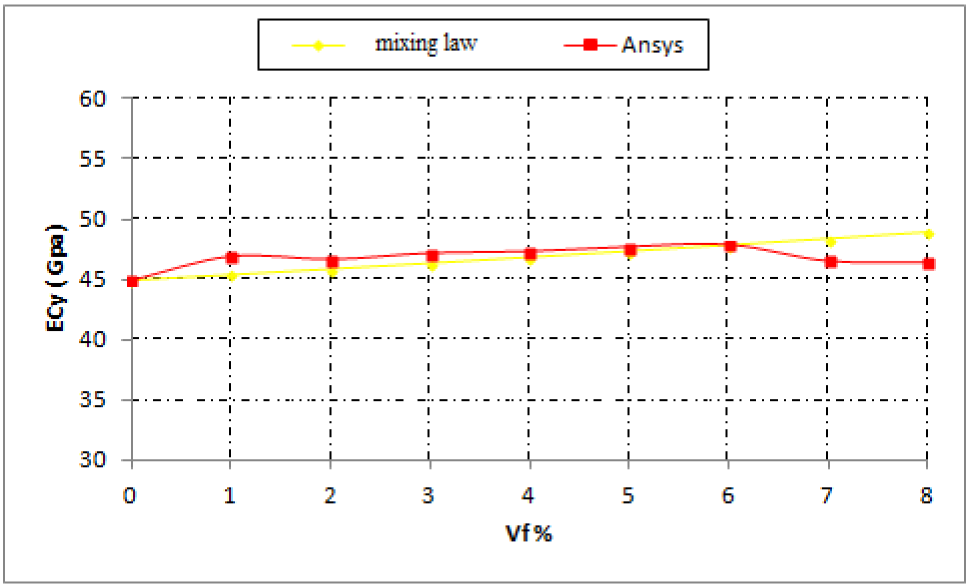


Figure 10: the evolution of the Young's Module (Y) as a function of the volume fraction of the jute fiber

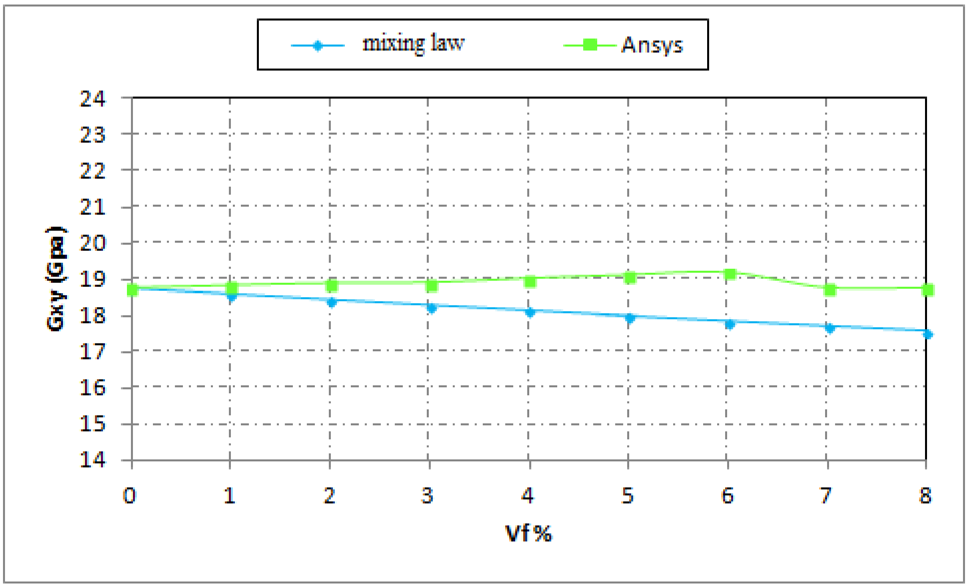


Figure 11: the evolution of the shear modulus as a function of the volume fraction of the jute fiber

VI. Conclusions:

The work carried out in this publication, the main objective of which is the numerical modeling of the elastic behavior of the concrete bio-sources, For this, we use the analytical and numerical homogenization methods.

This simulation indicates that the addition of fibers to concrete has a significant influence on the increase in elastic behavior of organic concrete (sources).

The study shows that the maximum values of the elastic behavior of bio-source concrete (concrete + jute) above are found in the density fraction vf = 6% fiber. Both theories were used to determine the elastic behavior of bio-source concrete and the influence of the fiber density fraction on orthotropic beams, using the analytical homogenization method of the mixing law theory, because their results are practically similar to those given by the numerical homogenization method based on finite elements (ANSYS).

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