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Estimation of the elastic characteristics of mortars reinforced with short Borassus aethiopum mart fibers

Abelim Passoli[1-2], Tiambo Abbas Datchossa[1], Emmanuel Olodo[1], and Douti Lare[3]

[1]Laboratory of Applied Energetics and Mechanics (LAEM), Polytechnic School of Abomey-Calavi,
University of Abomey-Calavi, Benin

[2]National Institute for Scientific Research of the University of Lomé (NISR-UL), University of Lomé, Togo

[3]Laboratory of Research in Engineering Sciences (LRES), Polytechnic School of Lomé, University of Lomé,
01BP1515 Lomé 01 Togo

ABSTRACT: No sustainable development can be achieved or have any real meaning if it does not promote the use of local materials. In the northern regions of West Africa, one of the potentials to be developed for the benefit of construction is the use of Borassus aethiopum mart fibers (BAMF). The aim of this work is to estimate the elastic characteristics of mortars reinforced with Borassus aethiopum mart fibers to encourage the use of this material.

To achieve this, we formulated a cement mortar, in accordance with the requirements of standard EN 196-1, reinforced with 10% Borassus aethiopum mart fibers, in volume fraction. The reference mortar is denoted M0, while the mortar reinforced with BAMF is denoted MB. The characteristics were estimated using the homogenization formula (HF) and the Hashin-Shtrikman upper and lower bounds. The characteristics of the mortar and the Borassus aethiopum mart fibers were determined before they were considered in the composite material characterization model.

The results of the study show that the Hashin-Shtrikman bounds have acceptable values for limiting the range of validity of the elastic characteristics of the material. The homogenization formula proposes an increased value for the elastic characteristics of composite materials, although it still gives an idea. The Hashin-Shtrikman HS^+ upper bound gives the most acceptable value for Young's modulus of elasticity, which is 22.11GPa for a Poisson's ratio of 0.15.

KEYWORDS: Mortar, Borassus aethiopum mart short fibers, elastic characteristics, homogenization.

1 INTRODUCTION

Development is the desire of every people, every nation, every country. Development means development in all areas of human life, starting with housing. In fact, housing is one of the most captivating parameters when it comes to the level of affluence of a people or an individual.

However, it's impossible to raise the standard of housing without revolutionizing building materials and mastering them. The current trend is not only towards large-scale production, but also the use of sustainable materials [1], [2]. As a result, builders in recent decades have been greatly encouraged to focus on materials based on plant biomass. This is justified by the great interest shown by the scientific community in this type of material [3], [4], [5], although it should be pointed out that the valorization of plant biomass is a waste management alternative [6].

However, most of the biomass plant-based materials deal with the possibility of using these reinforcements in polymer matrix [7]. Only a few propose their use in cementitious matrix materials [8], [9]. Even fewer studies focus on the use of Borassus aethiopum mart fibers as reinforcement in cementitious matrices.

The aim of the present work is to propose an estimate of the elastic characteristics of mortars reinforced with Borassus aethiopum mart fibers, to encourage their use as construction materials.

2 Materials And Method

2.1 Materials

The material covered by this study is mainly mortar reinforced with Borassus aethiopum mart fibers.

2.2 Method

2.2.1 Formulation Of Mortars Reinforced With Borassus Aethiopum Mart Fibers

The Borassus aethiopum mart fibers-based mortar (MR), whose elastic characteristics are assessed, is obtained by replacing 3% of the volume fraction of M0 mortar with Borassus aethiopum mart fibers. The reference mortar (M0) is formulated in accordance with EN 196-1.

2.2.2 Principle Of Homogenization

Homogenization aims to provide a means of estimating the characteristics of a heterogeneous material by considering the characteristics of the various constituents. The constituents can be summarized as the matrix and the reinforcements. To simplify the calculations, which could prove very complex, the following assumptions are made:

- inclusions and matrix are linearly elastic and isotropic.
- inclusions are axisymmetric: their shapes and sizes are identical and are characterized by their aspect ratio r=L/D, where L is the length of the inclusions and D is their diameter.
- inclusion-matrix adhesion is perfect at the interface and remains so throughout deformation.

2.2.3 Material Components

The study material consists of cement mortar and roast tree fibers. The cementitious mortar acts as a matrix, while the Borassus aethipum mart fibers act as reinforcements.

2.2.4 Methods For Estimating The Elastic Characteristics Of Borassus Aethipum Mart Fibers-Reinforced Cementitious Mortar

- Homogenization formula

The young’s modulus is given by:

$$E = V_m E_m + V_i E_i \qquad (1\text{-}1)$$

The Poisson’s ratio is given by:

$$\nu = V_m \nu_m + V_i \nu_i \qquad (1\text{-}2)$$

- Hashin-Shtrikman Bounds

Hashin and Shtrikman [10], [11] use the solution of Eshelby’s problem by considering an equivalent homogeneous material surrounding the inclusions by the various composite constituents (reference material). If the reference material is the most “rigid” of the constituents, the estimate gives an upper bound (HS$^+$). But when the reference material is the least rigid of the constituents, we obtain the lower bound (HS$^-$) [12]. The Hashin and Strikman (HS) bounds can be written as:

$$C^{HS^-} \le C_{hom}^{HS} \le C^{HS^+} \qquad (1\text{-}3)$$

Lower bound of Hashin-Shtrikman (HS$^-$)

$$C^{HS^-} = \left[\left[V_m C_m : (C_{min}^* + C_m)^{-1} + V_i C_i : (C_{min}^* + C_i)^{-1}\right] : \left[(V_m C_{min}^* + C_m)^{-1} + V_i : (C_{min}^* + C_i)^{-1}\right]\right]^{-1} \qquad (1\text{-}4)$$

Upper bound of Hashin-Shtrikman (HS^+)

$$C^{HS^+} = \left[[V_m C_m : (C^*_{max} + C_m)^{-1} + V_i C_i : (C^*_{max} + C_i)^{-1}] : [(V_m C^*_{max} + C_m)^{-1} + V_i : (C^*_{max} + C_i)^{-1}]\right]^{-1} \tag{1-5}$$

Where C_min ^ ∗ and C_max ^ ∗ are defined as:

{■(C_min ^ ∗= E^(−1): C_min − C_min où C_min = min (C_m, C_i) @C_max ^ ∗= E^(−1): C_max − C_max où C_max = max (C_m, C_i))┤ ;

E being the Eshelby tensor.

2.2.5 CHARACTERISTICS OF COMPONENTS

The table below shows the Young's modulus and Poisson's ratio of mortar and rônier fibers. The Young's modulus of Borassus aethipum mart fibers is taken from the work of Gbaguidi [13].

Table 1. Young's modulus and Poisson's ratio of matrix and inclusions

Formulations	Young's modulus (GPa)	Poisson's ratio
MR	24,35	0.15
FR	16,00	0.14

Fiber shape factor: 5;

Volume fraction of fibers: 10%

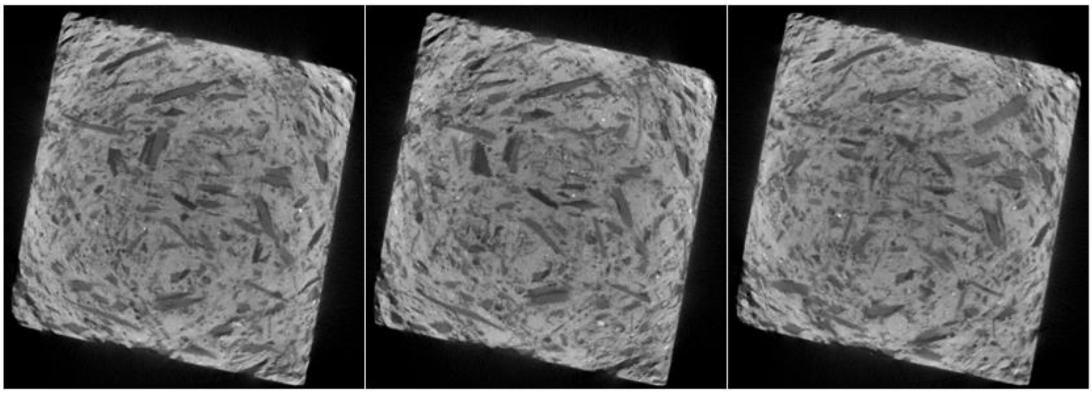

Fig. 1. Distribution of Borassus aethiopum mart fibers in cement mortar

Figure 1 shows that the material can be assimilated to an isotropic material, since the distribution of fibers within it is random.

2.2.6 DETERMINATION OF ELASTIC PARAMETERS

- Determining the Lamé coefficients

  The Lamé coefficients, λ and μ are read from the material stiffness matrices, the results of equations (1-4) and (1-5).

- Determination of elastic characteristics.

  Since the material is isotropic, the Young's modulus and Poisson's ratio can be given by the formulas:

$$E = \frac{\mu \times (3\lambda + 2\mu)}{\lambda + \mu} \tag{1-3}$$

$$\nu = \frac{\lambda}{2 \times (\lambda + \mu)} \tag{1-4}$$

3 RESULTS AND DISCUSSION

3.1 VALUES OBTAINED FROM THE HOMOGENIZATION FORMULA

$E = 23{,}51GPa;\ \nu = 0.149.$

It should be noted that these values are directly functions of the volume fraction of the various constituents of the composite material.

3.2 LOWER BOUNDS OF HASHIN-STRIKEMAN (HS-)

$$\begin{bmatrix}
23.29 & 0.00 & 0.00 & 0.00 & 13.39 & 0.00 & 0.00 & 0.00 & 13.39 \\
0.00 & -3.49 & 0.00 & 13.39 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\
0.00 & 0.00 & -3.49 & 0.00 & 0.00 & 0.00 & 13.39 & 0.00 & 0.00 \\
0.00 & 13.39 & 0.00 & -3.62 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\
13.39 & 0.00 & 0.00 & 0.00 & 23.29 & 0.00 & 0.00 & 0.00 & 13.39 \\
0.00 & 0.00 & 0.00 & 0.00 & 0.00 & -3.49 & 0.00 & 13.39 & 0.00 \\
0.00 & 0.00 & 13.39 & 0.00 & 0.00 & 0.00 & -3.49 & 0.00 & 0.00 \\
0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 13.39 & 0.00 & -3.49 & 0.00 \\
13.39 & 0.00 & 0.00 & 0.00 & 13.39 & 0.00 & 0.00 & 0.00 & 23.29
\end{bmatrix}$$

From this matrix we read the following Lamé coefficients: Lambda $\lambda = -3.49$; Mu $\mu = 13.39$. The elastic characteristics obtained are Young's modulus E and Poisson's ratio v. E=22.06GPa; v=0.15From this matrix we read the following Lamé coefficients: Lambda λ=-3.49; Mu μ=13.39. The elastic characteristics obtained are Young's modulus E and Poisson's ratio v. $E = 22.06GPa$; $\nu = 0.15$

3.3 UPPER BOUNDS OF HASHIN-SHTRIKMAN (HS+)

$$\begin{bmatrix}
22.32 & 0.00 & 0.00 & 0.00 & 13.40 & 0.00 & 0.00 & 0.00 & 13.40 \\
0.00 & -3.47 & 0.00 & 13.40 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\
0.00 & 0.00 & -3.47 & 0.00 & 0.00 & 0.00 & 13.40 & 0.00 & 0.00 \\
0.00 & 13.40 & 0.00 & -3.47 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\
13.40 & 0.00 & 0.00 & 0.00 & 22.32 & 0.00 & 0.00 & 0.00 & 13.40 \\
0.00 & 0.00 & 0.00 & 0.00 & 0.00 & -3.47 & 0.00 & 13.40 & 0.00 \\
0.00 & 0.00 & 13.40 & 0.00 & 0.00 & 0.00 & -3.47 & 0.00 & 0.00 \\
0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 13.40 & 0.00 & -3.47 & 0.00 \\
13.40 & 0.00 & 0.00 & 0.00 & 13.40 & 0.00 & 0.00 & 0.00 & 22.32
\end{bmatrix}$$

From this matrix we read the following Lamé coefficients: Lambda $\lambda = -3.47$; Mu $\mu = 13.40$. The elastic characteristics obtained are Young's modulus E and Poisson's ratio v. $E = 22.11GPa$; $\nu = 0.15$

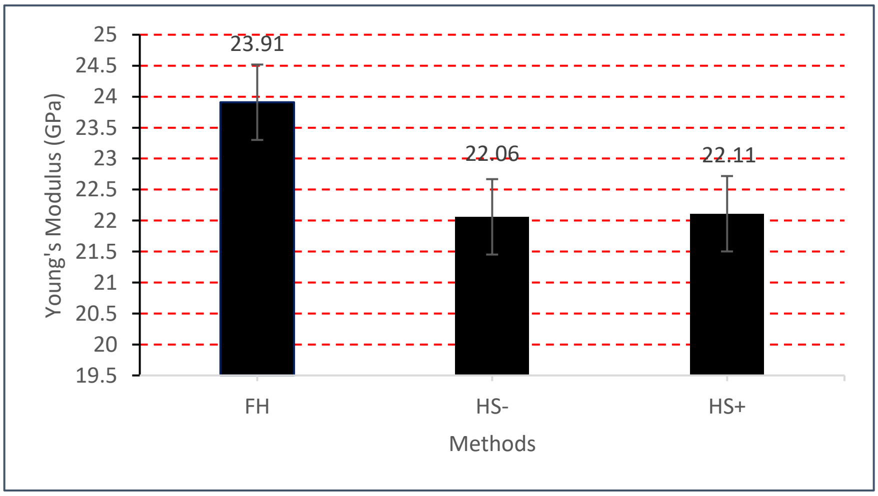

Fig. 2. Young's modulus variation as a function of estimation method

Figure 2 shows the evolution of Young's modulus of elasticity as a function of the method used to estimate its value.

From this figure, we can see that the Young's modulus obtained by the homogenization formula (HF) has a higher value, compared to the values obtained with the lower (HS-) and upper (HS+) bounds of Hashin-Shtrikman. We can also see that HS- has a lower value than HS+. This is quite normal, since the maximum limit of characteristics that the material can have been expressed here by HS+. It's easy to see that there's little difference between the values proposed by the lower and upper bounds of Hashin-Shtrikman. As a result, each of the HS- and HS+ values is potentially a value of the Young's modulus of the Borassus aethiopum mart fibers-reinforced mortar.

From the analysis of this table, we can say that the homogenization formula overestimates the elastic characteristics of our composite [12]. This could be explained by the fact that the homogenization formula does not consider the microstructural data of the various constituents [14], [15].

4 CONCLUSION

This study made it possible to estimate the bounds within which the elastic characteristics of Borassus aethiopum mart fibers-reinforced mortars should lie. The homogenization formula and Hashin-Shtrikman bounds were used to estimate the elastic characteristics of Borassus aethiopum mart fibers-reinforced mortars. The following points can be drawn from this work:

- The homogenization ant is a macroscopic estimate that gives an idea of the expected value but is less precise.
- The homogenization formula increases the actual characteristics of the composite material.
- Hashin-Shtrikman's bounds show small deviations.
- The upper bound of Hashin-Shtrikman gives an intermediate value to the homogenization formula and the lower bound of Hashin-Shtrikman.

The values provided by the Hashin-Shtrikman method are potentially representative of the elastic characteristics of Borassus aethiopum mart fibers-based mortar.

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